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# Relationship between ankle function and walking ability for children and young adults with cerebral palsy: a systematic review of deficits and targeted interventions

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## Abstract

**Background:** A primary goal of treatment for children with cerebral palsy is improved walking ability to allow for a more active and independent lifestyle. With the importance of ankle function to walking ability, and the deficits in ankle function associated with cerebral palsy, there is good rationale for targeting this joint in an effort to improve walking ability for this population.

**Research Question:** How do deficits and targeted interventions of the ankle joint influence walking ability in children with cerebral palsy?

**Methods:** A specific search criteria was used to identify articles that either (1) provided information on the relationship between ankle function and walking ability or (2) investigated the effect of a targeted ankle intervention on walking ability in cerebral palsy. PubMed, Embase, CINAHL, and Web of Science databases were searched from 1980–April, 2020. Resulting citations were compared against a prospective set of inclusion and exclusion criteria. Data relevant to the original research question was extracted, and the level of evidence for each intervention study was scored. Interpretation was focused on specific, pre-determined mobility measures.

**Results:** Sixty-one citations (n = 1905) met all criteria for data extraction, six of which were observational, and fifty-five of which were interventional. Level of evidence ranged from 2–4. Self-selected walking speed was the most common measure of walking ability, while physical activity level was the least common.

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**Significance:** Ankle function is an important contributor to the walking ability of children with cerebral palsy, and most interventions targeting the ankle seem to demonstrate a benefit on walking ability, but future higher-powered and/or controlled studies are necessary to confirm these findings.

### Keywords

Cerebral palsy; Ankle joint; Walking ability; Systematic Review

## Introduction

Cerebral palsy (CP) is the most common pediatric physical disability [1]. Characterized by deficits in neuromuscular control, CP results from an injury to the brain before cerebral development is complete [1]. As a childhood-onset movement disorder, this injury to the brain typically leads to a host of secondary effects due to the subsequent limitations in movement during a critical period of activity-dependent plasticity [2]. Therefore, while CP is caused by an injury to the brain early in life, it also associated with a progressive decline in mobility into adulthood [3,4]. In an effort to attenuate this decline in function, interventions for children with CP have sought to address those aspects of the disease that limit mobility, with the ultimate goal of increasing physical activity for improved physical development [5].

The ankle has a clear role in walking ability, accounting for a large portion of the propulsive forces during gait [6] and serving as an important contributor to the pendular motion that allows for efficient movement by minimizing vertical center of mass oscillations [6,7]. Ankle strength [8], range of motion [9], selective control [10], and tone [11] are all negatively impacted by CP, and it is likely that these deficits play a significant role in the reduced walking ability of this population [12,13]. This is supported by the numerous interventions that have specifically targeted the ankle in children and young adults with CP with the goal of improving mobility [14]. Previous systematic reviews have investigated the efficacy of some of these interventions, such as ankle foot orthoses [15–19], functional electrical stimulators [20,21], and botulinum toxin injections [22–24]. However, no systematic review has specifically investigated the role of ankle-specific function and interventions in meaningful measures of walking ability for children and young adults with CP. This is of particular importance given the distal to proximal involvement often observed for individuals with CP, with greater deficits in motor control at the ankle versus more proximal lower extremity joints [25]. Given the important role of the ankle for walking ability, ankle-focused interventions (i.e., ankle foot orthoses) have the potential to impart positive secondary effects at other joints, leading to impactful changes in whole body kinematics and functional mobility for this population.

The goal of this systematic review was to assemble the current understanding of the relationship between ankle function and walking ability in children and young adults with CP, and comprehensively identify interventions that have specifically targeted ankle joint function and quantified the effects on measures of walking ability. By synthesizing prior ankle-focused research findings, we hope to motivate new observational studies, improve

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clinical planning and standard of care, and inform the design of future ankle-specific interventions intended to improve functional mobility. Our specific research question was: how do deficits and targeted interventions of the ankle joint influence walking ability in children with cerebral palsy?

## Methods

The protocol for this systematic review was prospectively registered with PROSPERO (ID #CRD42020184258) and, as closely as possible, followed those steps outlined by PRISMA-P [26].

### Criteria

The goal of this review was to identify any studies that would help elucidate the relationship between ankle function and walking ability for children and young adults with CP. With this goal in mind, we set the following criteria for a paper's inclusion in this review: 1) age of participants between five and 25 years; 2) a primary study objective including at least one measure of ankle function (i.e., strength, range of motion, muscle activity, selective control, etc.) *or* at least one primary intervention of the ankle; 3) a primary objective of at least one measure of walking ability (i.e., self-selected walking speed or physical activity level [27]); 4) Both pre- and post-assessment of mobility if an intervention was investigated; 5) English language; and 6) full-length, original research article. Exclusion criteria included: 1) greater than 30% of participants did not meet the inclusion criteria; 2) inability to access full-text; and 3) case studies or those without a statistical analysis.

### Search methodology

The following search terms were used to broadly identify all relevant studies, searching within both the titles and abstracts: "cerebral palsy" AND "ankle" OR "plantar(−)flexor" OR "plantar(−)flexion" OR "dorsiflexor" OR "dorsiflexion" OR "gastrocnemius" OR "soleus" OR "triceps surae" OR "calf" OR "calves" OR "tibialis anterior" AND "mobility" OR "walk" OR "gait" OR "motor function" OR "motor performance". Searches were completed in the databases PubMed, Embase, CINAHL, and Web of Science, with a date range of 1980 – April 15, 2020.

### Critical appraisal and article selection

Citations from each database were compiled and duplicates between databases were removed. Those citations with titles that were clearly not within the realm of our research question were removed, and the remaining abstracts were reviewed against our inclusion and exclusion criteria by two independent reviewers.

With the primary objective of identifying the relationship between ankle function and walking ability of children with CP, we carefully defined what constituted a measure of "walking ability". For the purposes of this review, self-selected walking speed was considered a direct measure of walking ability [28], while physical activity level (i.e., daily step count) was considered a functional indicator of walking ability [29]. The six-minute walk test (6MWT) and timed up and go (TUG) are objective, clinical and laboratory-based

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measures of walking ability [30,31]. Gillette Gait Index (GGI), Gait Deviation Index (GDI), and Gait Profile Score (GPS) are global, kinematic-based measures of walking ability [32,33]. Metabolic cost and Gross Motor Function Measure (GMFM) – E (walking, running, jumping) are functional measures of walking ability that are significantly correlated to self-selected walking speed and/or physical activity levels for this population [34–37]. Table 1 provides a summary outline of the rationale behind each of these measures. Since the specific goal of this systematic review was to look at the effect of ankle function and targeted ankle interventions on walking ability, we did not include outcome measures that looked specifically at targeted ankle gait parameters. During the review process, those articles that did not include one of these walking ability measures were removed.

The citations that fit within our selection criteria were then fully reviewed by two independent authors. During the review process, articles were critically appraised for validity and study design using the Critical Appraisal Skills Programme (CASP) checklists for each respective article type [38]. If an article did not sufficiently meet the criteria of its respective CASP checklist, it was removed. Finally, if a cited article within a manuscript was relevant to our research question and not already included in our list of citations, it was added for full review. Any disputes between the two reviewers were resolved by discussions with a third, independent reviewer. Figure 1 provides an overview of the article search and selection process.

### Data extraction and level of evidence

Manuscripts were first divided into two categories: observational and interventional. For observational studies, we extracted the study type, participant demographics, the measure(s) of ankle function, the measure(s) of walking ability (according to Table 1), and the study's findings on the relationship between ankle function and walking ability. For interventional studies, in addition to the information extracted for observational studies, we collected details on the targeted ankle intervention in question (i.e., a description of the intervention, length of intervention or time to analysis, and its effect on walking ability).

For interventional studies, level of evidence was evaluated using the Oxford Centre for Evidence-Based Medicine Levels of Evidence using the question row "Does this intervention help?", which ranks studies with the highest level of evidence as Level 1, and the lowest level of evidence as Level 5 [39]. As only systematic reviews of randomized controlled trials constitute a Level 1, only Levels 2 – 5 would be possible for the citations reviewed here. Finally, the ROBIS checklist was used throughout the review process to limit the risk of bias by considering four domains where bias could occur: 1) study eligibility criteria, 2) identification and selection of studies, 3) data collection and study appraisal, and 4) synthesis and findings. Within each domain, the ROBIS checklist provided a list of questions to consider that could introduce bias to the review, ensuring adherence to a methodology that would address any concerns of this bias [40].

## Results

A total of 1,568 unique citations were found using the described search methodology. The initial review of titles and abstracts yielded 82 total citations, and upon full review, 18

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were removed (see Table 2 for rationale behind removal) for a total of 61 papers: [41–101]. During full paper review, no citations were discovered that were not already included and fit within our original research question. Figures 2 and 3 provide a summary overview of the findings from the full review of these citations.

Of the 61 included papers, six reported observational studies (Table 3), 17 investigated the effects of ankle foot orthoses (AFOs) (Table 4), eight investigated the effects of electrical stimulation to the ankle (Table 5), seven investigated the effects of ankle robotic devices (Table 6), ten investigated the effects of botulinum toxin injections to the ankle (Table 7), seven investigated the effects of targeted ankle surgical procedures (Table 8), and six investigated the effect of physiotherapy interventions (Table 9).

The average age of study participants was 9 years 7 months ± 3 years 6 months, and for studies that reported gender, 57% of participants were male. CP type included those with spastic hemiplegia, diplegia, triplegia, and quadriplegia, as well as ataxia, dyskinesia, and mixed. Individuals ranged in functional level from GMFCS level I – IV. To our knowledge, all of the reviewed studies had independent study samples except for [68–69]. Level of evidence ranged from 2 – 4 for interventional studies, with ~16% of these studies at Level 2, and ~74% of these studies at Level 4. Thirty four studies measured walking speed, two studies measured physical activity levels in the form of step counts, six studies measured maximal 6MWT performance, five studies measured maximal TUG performance, 15 studies measured metabolic cost, and 13 studies measured walking gross motor function (GMFM-E).

## Discussion

The purpose of this systematic review was to investigate the current understanding of how ankle function relates to walking ability for individuals with CP, as well as compile findings from intervention studies that specifically targeted the ankle and evaluated potential changes in walking ability. A key qualifier of this review was the primary investigation of the ankle, whereby findings or interventions that did not have a primary target on this single joint level were excluded. We sought to provide succinct information for future studies that are interested in evaluating the ankle as a potential target for improving walking ability. The considerable number of studies that fit within our selection criteria for full review speaks to the significant interest in the ankle as a therapeutic target for improving mobility in this population.

### Observational studies

Given the substantial contribution of the ankle joint to efficient locomotion, it is not surprising that those studies investigating the role of the ankle for walking ability in children with CP found significant relationships. Co-contraction about the ankle was found to be a significant predictor of metabolic cost for children with CP [41]; metabolic cost is inversely related to physical activity levels for this population [35]. Strength of the ankle, both in plantar flexion and dorsiflexion, was a moderate to strong predictor of gross motor function and performance on clinical tests of mobility for children with CP, as demonstrated by multiple studies with relatively large sample sizes (n = 26 – 55) [42,45–46]. Other metrics

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of ankle function, such as range of motion (both static and dynamic) [43,46], also appear to be closely related to walking ability. Muscle architecture, such as muscle thickness, fascicle length, and pennation angle, was found to be significantly related to walking speed [44].

The general consensus of these observational studies seem to support the notion that the ankle joint plays an important role in helping children with CP to be mobile, and should continue to be a target for future interventions. However, in compiling these findings, it became apparent that a significant limitation of some of these studies is the small sample size (n = 6 – 10) with a wide range of functional levels (GMFCS I – V), which makes it difficult to determine the true applicability of results outside of the study participants. For this reason, additional, higher powered studies on ankle function as it relates to walking ability in children with CP are warranted.

## AFO studies

AFO devices were the most commonly studied, targeted ankle intervention for children with CP (~30% of the interventional studies in this review). This is not necessarily surprising, as AFOs are a common prescription for children with CP to place the ankle in a more biomechanically efficient position for walking, with the goal of increasing walking speed, decreasing metabolic cost, and reducing contractures [15–19]. Nearly all studies were cross-sectional, evaluating walking ability with or without an AFO, or comparing between different AFO configurations. The most common measure of mobility for this intervention type was self-selected walking speed, which consistently improved with AFO use for all but one study [61], which found a significant decrease in speed with the use of a spring-hinged ventral shell AFO. The largest cohort studied (n = 378) in the citations reviewed found that AFO use (including hinged AFOs, posterior leaf spring AFOs, and solid AFOs) in children with spastic diplegia resulted in an improvement in non-dimensional walking speed past the minimal clinically important difference [59].

Metabolic cost significantly improved for the eight studies that evaluated the effect of AFOs on this measure. This is in agreement with the findings from Betancourt and colleagues' systematic review of the effect of AFO use on walking efficiency for children with CP [16], where resulting improvements in dorsiflexion angle enable a longer stride length and more efficient gait pattern. Only one study evaluated the effect of AFO use on a gait index, which may be explained by the decreased ability of gait indices to detect differences in gait with AFO use compared to other measures, such as walking speed and metabolic cost [102]. The single study evaluating the effect of AFO use on activity found no effect [62]. Considering the consistent increases in speed and decreases in metabolic cost with AFO use, this is a somewhat surprising finding, but may be explained by the general lack of studies using physical activity level as an outcome measure. Potential negative effects of AFOs on mobility may not have been fully captured in this review because most of the referenced AFO studies did not adequately assess common, but challenging mobility tasks encountered during daily life, such as stair descending.

An important consideration of AFOs is their inherent function as a mobility device, and not a training device. Their positive effects on walking ability are likely limited to when they are worn by a patient, as evidenced by the study design of all of the AFO-related citations

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reviewed here; walking ability was only compared with and without a brace. No studies were identified that evaluated the long-term effects of AFO use for children with CP. This may be a significant area of interest given the reduction in muscle activity that is observed when children with CP walk with AFOs [103].

### FES/NMES studies

FES devices typically work by stimulating the common peroneal nerve to induce dorsiflexion during the swing phase of gait, which is especially beneficial for individuals who experience foot drop while walking. The exact mechanism of therapeutic effects from FES devices is still relatively unknown, but has been hypothesized to involve changes in cortical excitability [104]. El-Shamy and colleagues conducted a randomized controlled trial (Level 2 evidence) comparing the effects of FES plus physical therapy versus physical therapy alone for three months for children with spastic hemiplegia, and found that adding FES led to significant improvements in self-selected speed and metabolic cost once the device was taken off [67]. Two additional studies found a significant increase in self-selected walking speed [69,70], while two other studies found no change in speed [65,71]. It should be noted, however, that one of the studies finding no change in speed had a limited sample size (n = 4) and did not report participant GMFCS levels [71]. A single study evaluated the effect of training with a FES device for 12 weeks on daily step counts, and found no change [68]. Similar to the findings from AFO use, it is difficult to draw significant conclusions from this single study on the effect of FES on physical activity, and further work is warranted in this area.

Similar to FES devices, NMES devices can target specific muscles during functional activities. Chan and colleagues found that NMES of the triceps surae plus treadmill training versus treadmill training alone did not have an added effect on GMFM-E, with both groups showing improvement [64]. Comparing the findings between these two studies would seem to indicate that the dorsiflexors are a more efficacious target for NMES. However, this comparison should be taken with caution, as both studies had limited sample sizes (n = 8 – 12) and did not specifically report GMFCS level.

### Robotic device studies

An emerging trend in rehabilitation research is the use of joint-specific robotic devices, as supported by the seven studies to date that have evaluated the effect of robotic ankle devices on mobility in children with CP. Three studies evaluated the effect of training with a seated robotic ankle device that passively stretched and actively trained the ankle [72,73,75]. There was a consistent improvement in 6MWT performance after six weeks of training with a seated device, and two of three studies [73,75] found significant improvement in TUG performance. A single study evaluated a standing, game-based robotic device that actively resisted the ankle through various movements, and observed no change in self-selected walking speed after 10 weeks [74]. The only randomized controlled study of this citation cohort evaluated the effect of assisting and resisting the ankle while walking on a treadmill using a tethered robotic device, finding significant improvements in self-selected walking speed, 6MWT performance, and GMFM-E in the resistance group after six weeks of training [76]. Finally, acting in the capacity of a mobility device, an untethered ankle exoskeleton

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was found to improve metabolic cost and increase self-selected walking speed when children with CP wore the device versus without the device [77–78]. While still an emerging concept, there appears to be significant promise for the use of robotic ankle devices, both as a training intervention and mobility device, for improving walking ability in children with CP.

## Botulinum toxin studies

Botulinum toxin type-A muscle injections (BTX-A) have been rigorously studied and identified as an effective, “green light go intervention” for managing spasticity in children with CP [14]. The specific effect of BTX-A to the calves on mobility has been studied both as an independent intervention and combined with adjuvant therapies for children with CP. Two separate randomized controlled trials investigated the effect of BTX-A, and found significant improvements in GMFM-E [79, 80], but no change in metabolic cost [79] three months post-injection. This is in contrast to a non-randomized study that found a significant decrease in metabolic cost two months post-injection, with no change in speed [81]. It is possible that the difference in follow-up time can explain this contradiction, with the specific effect of BTX-A on metabolic cost only appearing up to two months post-injection.

A common adjuvant therapy alongside BTX-A is casting, whereby a patient’s ankle is held in a slightly stretched position using a cast. A randomized controlled trial that evaluated the effect of BTX-A with and without casting for three weeks post-injection found that casting resulted is a significant improvement in self-selected walking speed and GMFM-E [83]. A separate, prospective cohort study found no difference in these measures with the addition of casting for only two weeks post-injection [85]. Kelly and colleagues compared single versus serial casting after BTX-A treatment, and found no change in speed for either group [87]. In addition, a study evaluating the effect of BTX-A with and without FES for four weeks found no change in self-selected speed for either group [84], while BTX-A with and without NMES to the triceps surae for ten days found a significant improvement in speed and GMFM-E for both groups, with no difference between groups [88]. Finally, a randomized controlled trial evaluating BTX-A with and without resistance training of the plantar flexors and dorsiflexors for 12 weeks post-injection observed no change in GMFM-E for both groups [86]. BTX-A, both independently and with adjuvant therapy, does not appear to have a consistent effect on walking ability, with a nearly even split in findings (improved or no change) for those measures evaluated here. As the effect of BTX-A is influenced by the time from injection, it is possible that the differences in post-injection follow-up time (ranging from 10 days to six months) between studies explains the apparent contradictory findings.

## Surgical studies

Patients who have exhausted non-operative treatments but still have a gastrocnemius, gastrocnemius soleus, and/or Achilles contracture leading to pain, orthotic wear issue, or functional problems are candidates for orthopedic surgery [105]. A unique qualifier of the surgical studies evaluated in this review was the independent operation of the ankle joint only, which would not include those studies that included an operation of the ankle joint as part of a single event multilevel surgery (SEMLS) [105]. This qualifier likely explains the

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relatively low number of studies reviewed here, given the significant role that SEMLS plays in the care of children with CP.

Several procedures, including heel cord advancement (HCA), heel cord lengthening (HCL), Achille's tendon lengthening (TAL), and gastrocsoleus recession (GSR) aim to improve plantar flexor range of motion for children with CP, with the exact type of procedure dependent on the area of calf (i.e., zone) to be operated on [106]. Engsberg and colleagues found that HCA and two forms of HCL procedures (White and Vulpius) were able to significantly increase GMFM-E one year post-op, while HCA alone led to significantly increase self-selected walking speed [89]. TAL procedures were found to have no effect on self-selected walking speed or metabolic cost 1.3 years post-op for children with CP [90]. When TAL was combined with tibialis anterior shortening (TATS), significant improvements in several gait indices (i.e., GPS, GGI, and GDI) were observed both at short-term (1.2 years) [91] and long-term (5.8 years) [94] follow-up, despite there being no change in self-selected walking speed [95]. Finally, GSR was observed to significantly improve GDI and GPS at one to two years post-op [93,95]. Surprisingly, while these independent ankle-joint procedures significantly improve global gait indices, there appears to be limited to no evidence on their specific effects on other measures of functional mobility, such as 6MWT performance, metabolic cost, and physical activity levels.

The citations reviewed here provide medium evidence for independent ankle joint procedures improving walking ability in children with CP. There is an apparent gap, however, in how these procedures affect several measures of walking ability outside of gait indices (i.e., GMFM-E, metabolic cost, 6WMT, and activity), which should be an area of future research.

### Physiotherapy studies

A miscellaneous group of non-surgical, non-pharmacological, and non-device centered ankle-specific interventions were identified with this review. Four of these studies focused on the effect of ankle resistance training. One was a randomized controlled trial that evaluated the effect of plantar flexor, dorsiflexor, and combined plantar flexor and dorsiflexor strength training over six weeks, and observed no change in self-selected speed, but a significant improvement in GMFM-E for all groups [96]. A separate randomized controlled trial found a significant improvement in 6MWT performance with plantar flexor and dorsiflexor resistance training for 12 weeks [101], and two prospective cohort studies found a significant improvement in self-selected walking speed, but no change in GMFM or TUG performance after plantar flexor resistance training (for six [99] and 10 weeks [98]). Strengthening the ankle appears to have variable effects, but those studies with the highest level of evidence (Level 2) [96,101] seem to support this type of intervention for improving mobility in children and young adults with CP. Short-term serial casting (five weeks) was found to have no effect on self-selected walking speed [97], and kinesiotaping of the plantar flexors and dorsiflexors was found to significantly improve TUG performance [100].

An important consideration from this review is the specific metric used to evaluate walking ability and how this varied by intervention type, as displayed in Figure 3. For example, all intervention types had an evaluation of their respective effects on walking speed and

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gross motor function (i.e., GMFM-E), whereas gait indices were used more frequently with surgical interventions, and 6MWT performance was more frequently used to evaluate robotic ankle devices. Of note, only 3.6% (2/55) intervention studies evaluated their effect on physical activity levels. A logical explanation for this is the amount of time and effort that is necessary to reliably and validly measure activity levels. Still, the effects of targeted ankle interventions on physical activity levels is an understudied metric for children and young adults with CP and should be a focus of future studies.

The compiled findings from the studies reviewed here can provide some insight on the most effective ways to improve walking ability in a child or young adult with CP. For example, in a day-to-day setting, if the goal is to increase a child's walking speed and decrease energetic cost, the choice of an ankle-specific intervention with the most evidence is an AFO. If, however, the goal is to improve device-free ankle function for improved mobility in this population, the combined or independent implementation of robotic ankle devices, FES/NMES devices, and/or ankle strengthening protocols have more evidence compared to AFO use and should be considered. Surgery certainly plays a significant role in this equation of interventional choices, improving musculoskeletal alignment and mechanical advantage with moderate evidence for post-operative improvements in gait quality, and likely acts synergistically with any of the non-surgical options. Realistically, the most prudent course of action is a combined prescription of mobility and training interventions, whereby a mobility device such as an AFO enables a more mobile lifestyle in the short-term, with integration of a training device that could improve ankle function in the long-term.

This review has some notable limitations. First, by limiting papers to those that specifically included the measures of walking ability listed in Table 2, it is possible that relevant studies were missed. However, this pre-determined list of measures allowed for an objective selection of papers that would contribute to the original research question. Importantly, the interpretations from this review should be taken with caution, as they are solely based on the outcome measures in Table 2, and there are other important outcome measures that may need to be considered. Second, the ankle procedures reviewed here are likely a small portion of the studies investigating orthopedic procedures for children and young adults with CP, as many will receive multilevel surgery [105]. This limitation was necessary, however, to remain within the original research question of targeted ankle interventions. Third, there was no statistical analysis of the combined results. Fourth, the overall quality of the studies was relatively low, with the majority of studies (~74%) at Level 4, making it difficult to draw strong conclusions with the current evidence. It is recommended that future, randomized controlled trials are utilized for more definitive evidence of the reviewed interventions, as well as large scale observational studies for a more concrete picture of exactly how ankle function influences mobility in this population. Finally, as there was no assessment of publication bias outside of the CASP checklists, it is possible that findings reported from nonrandomized studies were not entirely objective.

## Conclusion

To our knowledge, this is the first systematic review to collectively summarize the findings from studies evaluating the relationship between ankle function and walking ability in

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children with CP, as well as the effect of targeted ankle interventions on walking ability for this population. In compiling these studies, areas with a paucity of data became apparent, such as the effects of ankle-focused interventions on physical activity levels and the long-term effects of AFO use on ankle function in children with CP. Overall, however, evidence indicates that the ankle has an important contribution to walking ability in children with CP, and interventions targeting the ankle joint in children with CP is likely to improve walking ability for this population, making them worthwhile treatment options to continue to develop and explore.

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## Highlights

- Ankle function appears to have an important contribution to walking ability in CP
- Links between ankle function and walking ability in CP require larger samples
- Ankle-specific interventions generally improve walking ability in CP
- Long-term effects of AFOs for children with CP is unknown

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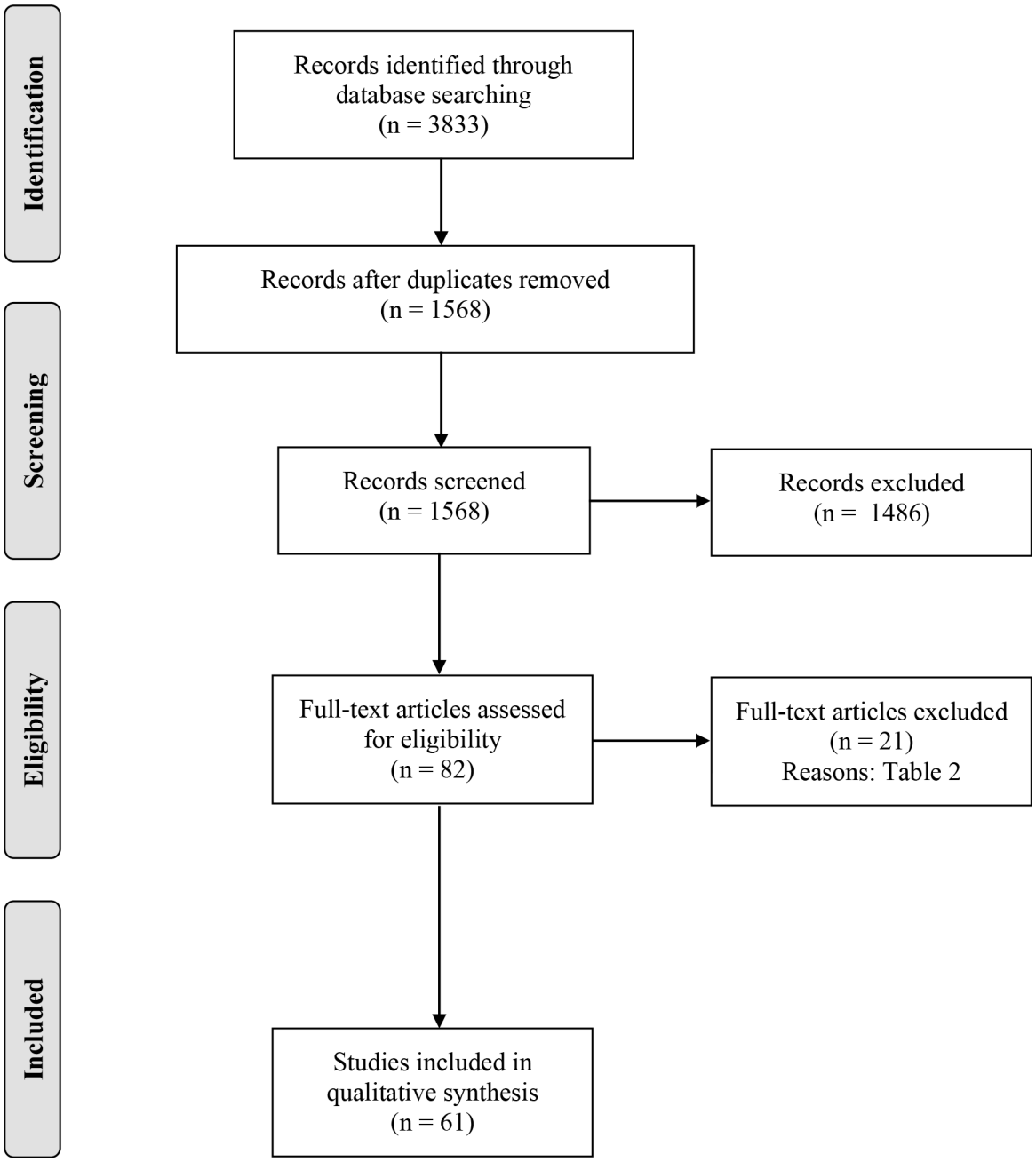


**Figure 1.**
PRISMA flow diagram of search and article selection process

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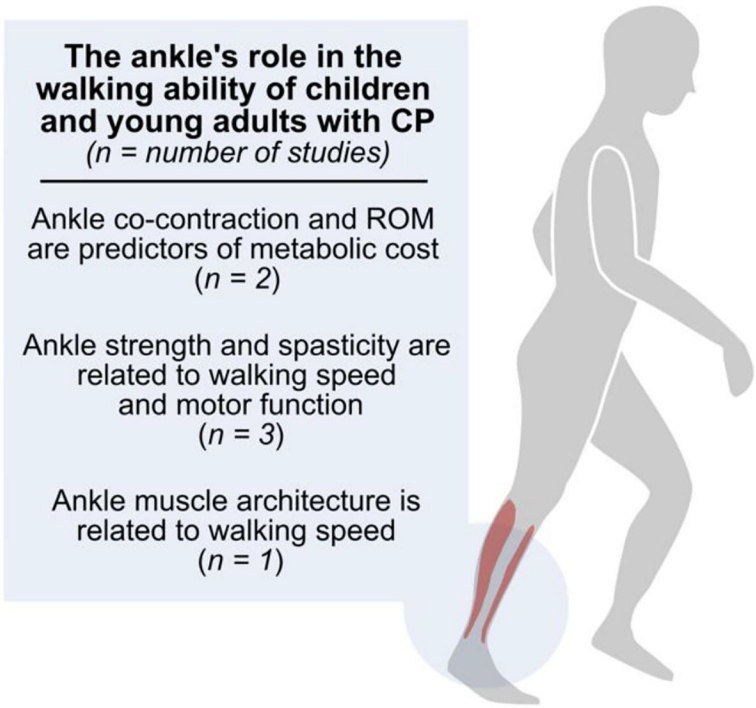


**Figure 2.**
Summary findings from the reviewed observational studies on the role of the ankle in walking ability for children and young adults with cerebral palsy.

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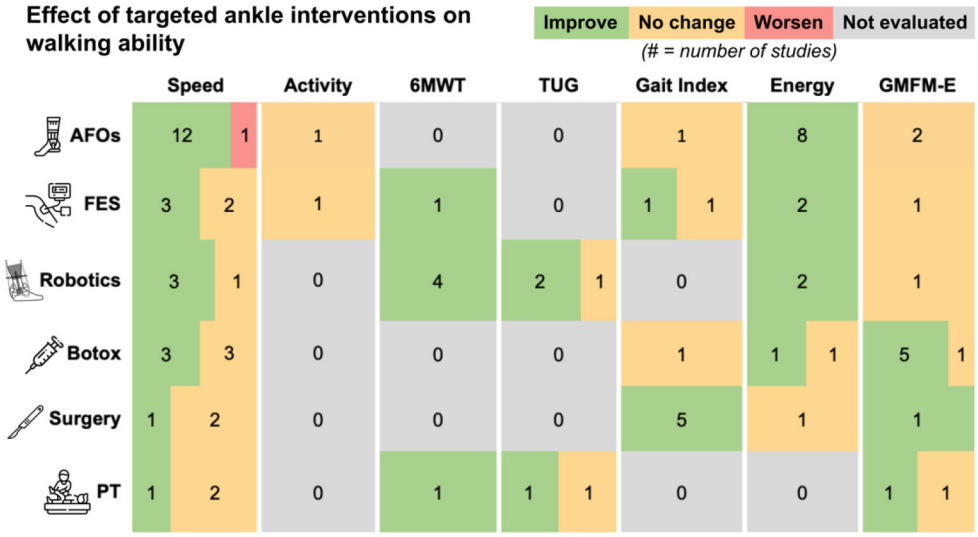


**Figure 3.**

Summary findings from the reviewed interventional studies on the effect of targeted interventions of the ankle on walking ability in children and young adults with cerebral palsy. Improve, No change, and Worsen are based on the respective studies' statistical outcomes. AFOs: Ankle Foot Orthoses; FES: Functional Electrical Stimulation; Botox: Botulinum toxin A; PT: Physical Therapy.

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**Table 1.**

Rationale behind selected measures of walking ability.

| Measure | Rationale |
|---|---|
| Self-selected speed | Considered a direct measure of walking ability [28] |
| Physical activity level | Considered a functional indicator of walking ability [29] |
| 6MWT/TUG | Clinical measures of walking ability [30,31] |
| GGI/GDI/GPS | Kinematic-based measures of walking ability [32,33] |
| GMFM-E, Metabolic cost | Functional measures of walking ability that are significantly related to self-selected walking speed and/or physical activity levels [34–37] |

Six-minute walk test (6MWT)/timed up and go (TUG)

Gillette Gait Index (GGI)/Gait Deviation Index (GDI)/Gait Profile Score (GPS)

Gross Motor Function Measure (GMFM) – E (walking, running, jumping)

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**Table 2.**

Rationale behind removal of citations during full paper review

| Citations | Reason for removal |
|---|---|
| 107 – 117 | Did not assess walking ability using a measure from Table 1 |
| 118 – 119 | Did not meet all components of the respective study type CASP checklist |
| 120 – 123 | Did not include a formal statistical analysis |
| 124 – 127 | Study design, intervention, and/or analysis did not have a *primary* target of the ankle joint |

Critical Appraisal Skills Programme (CASP)

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**Table 3.**

Observational study results

| Study | Participants | | | | | Ankle measure(s) | Mobility measure(s) | Significant relationships |
|---|---|---|---|---|---|---|---|---|
| | n | Age (y:m) | M:F | GMFCS | CP type | | | |
| 41 | 9 | 12:8 ± 2:10 | 7:2 | NR | SH, SD, SQ | Co-contraction between soleus and tibialis anterior | Metabolic cost ($VO_2$) | Co-contraction explained 42.8% of variance in oxygen consumption |
| 42 | 55 | 10:8 ± 2:7 | 35:20 | I - III | SD | PF and DF isometric strength | GMFM-E | PF strength and GMFM-E (R = 0.75), and DF strength and GMFM-E (R = 0.67) |
| 43 | 10 | 17:4 ± 2:5 | NR | I - III | SH, SD, SQ | Ankle ROM at self-selected walking speed | Metabolic cost (EEI) | Ankle ROM and EEI (R = -0.82), max PF angle and EEI (R = 0.74); ankle ROM was largest predictor of EEI (explained 66% of variance) |
| 44 | 20 | 13:1 ± 3:6 | 10:10 | I - II | SH, SD | Muscle thickness (MT), pennation angle (PA), fascicle length (FL), and cross-sectional area (CSA) of tibialis anterior via ultrasound | Fast walking speed | Fast walking velocity correlated to MT (R = 0.67), PA (R = -0.47), FL (R = 0.58), and CSA (R = 0.51) |
| 45 | 50 | 10:7 ± 2:10 | 27:33 | I - II | SH, SD, SQ, AT | DF isometric strength, PF concentric strength (# of heel raises) | 6MWT | DF and PF strength correlated to 6MWT; 47.8% of variance in 6MWT explained by hip flexor and PF strength |
| 46 | 26 | 6:11 ± 2 | 14:12 | NR | SH | PF and DF isometric strength, passive ankle ROM, ankle spasticity (Modified Tardieu Scale), muscle stiffness, and hysteresis | Self-selected walking speed | Muscle stiffness, DF strength, Tardieu catch angle, and DF ROM explained 59% of variance in walking speed |

n = Indicates number of participants with CP only; GMFCS = Gross Motor Function Classification System; NR = not reported; CP type = spastic hemiplegic (SH), spastic diplegic (SD), spastic triplegic (ST), spastic quadriplegic (SQ), ataxic (AT), mixed (MX); Ankle measure(s) = plantar flexion/plantar flexors (PF), dorsiflexion/dorsiflexors (DF), range of motion ROM); Mobility measure(s) = Gross Motor Function Measure (GMFM)-E (walking, running, jumping), Energy Expenditure Index (EEI), heart rate (HR)

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**Table 4.**

AFOs and mobility study results

| Study | Study type | Level of evidence | Participants | | | | | Targeted ankle intervention | Time | Mobility measure(s) | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | n | Age (y:m) | M:F | GMFCS | CP type | | | | |
| 47 | CS | 4 | 18 | 8:4 ± 2:10 | 10:8 | NR | SD | SAFO | - | Metabolic cost (PCI) | Metabolic cost significantly reduced with vs. without AFOs |
| 48 | CS | 4 | 35 | 2:6 – 19 | NR | NR | SD | SAFO | - | Self-selected walking speed | Significant increase in speed vs. barefoot walking |
| 49 | CS | 4 | 10 | 9 ± 2:1 | 8:2 | I – II | SD | HAFO | - | Metabolic cost ($VO_2$), GMFM-E | Significant reduction in O2 cost at 90% fastest speed only, no change in GMFM-E |
| 50 | CS | 4 | 30 | 5:2 – 15:2 | 21:9 | NR | SH | HAFO vs. PLS vs. SAFO | - | Self-selected walking speed, metabolic cost ($VO_2$) | Significant improvement in all mobility measures with all configurations |
| 51 | CS | 4 | 115 | 5 – 15 | 52:63 | I – III | SD, SH | AFO (hinged and solid) | - | Self-selected walking speed | Significant increase in speed |
| 52 | CS | 4 | 24 | 6:8 ± 0:8 | 10:14 | NR | SD, SH | AFO (type not specified) | - | Self-selected walking speed | Significant improvement in speed |
| 53 | CS | 4 | 11 | 7:2 ± 1:2 | 7:4 | NR | SH | HAFO | - | Self-selected walking speed, metabolic cost ($VO_2$) | Significant improvement in speed and metabolic cost |
| 54 | CS | 4 | 56 | 8:11 ± 3:6 | 32:24 | I – II | SD, SH | AFO (hinged and solid) | - | Self-selected walking speed | Significant improvement in speed for SD but not SH group |
| 55 | CS | 4 | 181 | 9 ± 3 | 110:71 | NR | SD, SH, SQ | AFO (PLS and solid) | - | Self-selected walking speed, metabolic cost ($VO_2$) | Significant improvement in speed; improvement in metabolic cost for SQ group only |
| 56 | CS | 4 | 15 | 7:6 ± 2:11 | NR | I | SD | AFO (hinged and dynamic) | - | Self-selected walking speed, GMFM-E | Significant improvement in speed for both AFO types, no change in GMFM-E |
| 57 | CS | 4 | 21 | 9:7 ± 4:1 | 16:5 | NR | SD | AFO (hinged and solid) | - | Self-selected walking speed | Significant increase in speed for both AFO types |

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| Study | Study type | Level of evidence | Participants | | | | | Targeted ankle intervention | Time | Mobility measure(s) | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | n | Age (y:m) | M:F | GMFCS | CP type | | | | |
| 58 | CS | 4 | 48 | 7:5 ± 2:4 | 27:21 | II – III | SD, MX, DY | Solid PAFO, hinged PAFO, GRAFO, KAFO, metallic AFO | - | Metabolic cost (EEI) | Significant decrease in metabolic cost for solid PAFO and GRAFO group; significant increase with KAFO and metallic AFO |
| 59 | CS | 4 | 378 | 9:10 ± 3:10 | 215:163 | NR | SD | HAFO, PLS, SAFO | - | Self-selected walking speed (non-dimensional), GDI | Improvement in speed past minimal clinically important difference (MCID), change in GDI not past this MCID |
| 60 | PC | 4 | 10 | 4 – 12 | 4:6 | I and II | SD, SH | Dynamic and adjustable dynamic response AFO | 4 wks/AFO | Self-selected walking speed | Significant increase in speed with dynamic AFO only |
| 61 | PC | 4 | 15 | 10 ± 2 | 11:4 | I – III | SD, SH | Springhinged ventral shell AFO at 3 stiffness levels: 1) rigid, 2) stiff, 3) flexible | 4 wks/ stiffness level | Self-selected walking speed, metabolic cost ($VO_2$) | Significant decrease in speed and metabolic cost; no difference between stiffness levels |
| 62 | PC | 4 | 11 | 3 – 6 | NR | I – III | SD | AFO (variable types) | 2 wks with vs. without AFO | Activity (daily step count) | No change in daily step count with AFO use |
| 63 | CS | 4 | 4 | 8:6 ± 1:4 | 2:2 | II | SD, SH | Tuned vs. non-tuned SAFO | - | Self-selected walking speed, metabolic cost ($VO_2$ and EEI) | 3/4 participants had improvements in metabolic cost and speed with tuned vs. non-tuned AFO |

Study type = cross-sectional (CS), prospective cohort (PC); n = number of participants with CP only; GMFCS = Gross Motor Function Classification System; NR = not reported; CP type = spastic hemiplegic (SH), spastic diplegic (SD), spastic quadriplegic (SQ), dyskinesia (DY), mixed (MX); Targeted ankle intervention = solid ankle foot orthosis (SAFO), hinged ankle foot orthosis (HAFO), posterior leaf spring ankle foot orthosis (PLS), ground reaction force ankle foot orthosis (GRAFO), knee ankle foot orthosis (KAFO); Mobility measure(s) = physiological cost index (PCI), Gross Motor Function Measure (GMFM)-E (walking, running, jumping), Energy Expenditure Index (EEI), gait deviation index (GDI), six-minute walk test (6MWT)

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**Table 5.**

FES/NMES and mobility study results

| Study | Study type | Level of evidence | Participants | | | | | Targeted ankle intervention | Time | Mobility measure(s) | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | n | Age (y:m) | M:F | GMFCS | CP type | | | | |
| 64 | CC | 3 | 12 | 4 – 11 | 9:3 | NR | SD, SH | NMES of triceps surae + treadmill training vs. treadmill only | 4 wks (3x/ week, 15 mins/ session) | GMFM-E | No observed difference between groups (both improved) |
| 65 | PC | 4 | 19 | 7:6 – 20 | 10:9 | I - II | NR | FES of DF during swing phase of gait | 3 months (using FES at least 6 hrs/day) | Walking speed (self-selected and fast) | No change in walking speed |
| 66 | CS | 4 | 4 | 18:6 ± 7:1 | 2:2 | I | SH | FES of DF during swing phase of gait | | GPS, GDI, GGI | Significant improvement GPS and GDI, but not GGI |
| 67 | RCT | 2 | 34 (17 per group) | 8 – 12 | 21:13 | I - II | SH | FES of DF during swing phase of gait | 3 months (3 days/wk, 2 hrs/day) | Self-selected walking speed, metabolic cost ($VO_2$) without device | Significant improvement in speed and metabolic cost with FES compared to control group |
| 68,69 | PC | 4 | 11 | 6 – 16 | 8:3 | I - II | SH | FES of DF during swing phase of gait | 12 wks (daily use, 6 hrs/day) | Self-selected walking speed, GDI, 6MWT, and activity (step count) | Significant improvement in speed and 6MWT with device on; no significant change with device off; no change in GDI or activity |
| 70 | NRCT | 3 | 26 (15 in FES group) | 7 – 14 | 15:11 | I - III | SD, SH | FES of DF during swing phase of gait + physical therapy vs. physical therapy only | 12 wks (5 days/wk, 30 mins/ session) | Self-selected walking speed, metabolic cost (PCI) | Significant improvement in speed and metabolic cost compared to physical therapy only |
| 71 | PC | 4 | 4 | 10:6 ± 3:11 | 2:2 | NR | SH | FES of DF during swing phase of gait | 3 months (daily use, time/day not specified) | Self-selected walking speed | No change in speed |

Study type = case control (CC), cross-sectional (CS), prospective cohort (PC), randomized controlled trial (RCT), non-randomized controlled trial (NRCT); n = number of participants with CP only; GMFCS = Gross Motor Function Classification System; NR = not reported; CP type = spastic hemiplegic (SH), spastic diplegic (SD); Targeted ankle intervention = neuromuscular electrical stimulation (NMES), functional electrical stimulation (FES), dorsiflexion (DF); Mobility measure(s) = physiological cost index (PCI), Gross Motor Function Measure (GMFM; D: standing; E: walking, running, jumping; 66: combined D and E), Energy Expenditure Index (EEI), gait profile score (GPS), Gillette gait index (GGI), gait deviation index (GDI), six-minute walk test (6MWT)

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**Table 6.**

Robotic ankle devices and mobility study results

| Study | Study type | Level of evidence | Participants | | | | | Targeted ankle intervention | Time | Mobility measure(s) | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | n | Age (y:m) | M:F | GMFCS | CP type | | | | |
| 72 | PC | 4 | 12 | 8:6 ± 3:7 | 6:6 | I - III | SD, SH | Seated, passive stretching and active movement training of ankle via robotic device | 6 wks, 3x/wk, 1 hr/ session | 6MWT, TUG | Significant improvement in 6MWT; no change in TUG |
| 73 | PC | 4 | 28 | 8:2 ± 3:7 | 19:9 | I - III | SD, SH, ST | Seated, passive stretching and active movement training of ankle via robotic device | 6 wks, 2x/wk, 75 mins/ session | Self-selected walking speed, 6MWT, TUG | Significant improvement in speed, 6MWT, TUG |
| 74 | PC | 4 | 6 | 9:4 ± 2:5 | 2:4 | I - III | SD, SH, DY | Standing, game-based robotic ankle resistance training | 10 wks, 5x/wk, 30 mins/ session | Self-selected walking speed | No change in speed |
| 75 | PC | 4 | 41 (23 home-based) | 7 – 18 | 31:10 | I - III | SD, SH | Seated, passive stretching and active movement training of ankle via robotic device (home vs. lab-based) | 6 wks, 3x/wk, 40 mins/ session | 6MWT, TUG | Significant improvement in 6MWT and TUG for both groups (home and lab-based training) |
| 76 | RCT | 2 | 23 (12 in resist group) | 6 – 14 | 11:12 | I - IV | SD | Assistance or resistance to legs during swing phase while treadmill walking via tethered robotic device | 6 wks, 3x/wk, 40 mins/ session | Self-selected walking speed, 6MWT, GMFM-E | Significant improvement in 6MWT (resist group compared to baseline and assist group), but no change in speed or GMFM-E for either group |
| 77 | CS | 4 | 5 | 15:2 ± 10:7 | 4:1 | I - III | NR | PF assistance while treadmill walking via untethered ankle exoskeleton | | Metabolic cost ($VO_2$) | Significant decrease in metabolic cost while walking on treadmill with device |
| 78 | CS | 4 | 6 | 15:10 ± 9:1 | 5:1 | I - III | NR | PF assistance while overground walking via untethered ankle exoskeleton | | Self-selected walking speed, metabolic cost ($VO_2$) | Significant improvement in metabolic cost and speed while walking overground with device |

Study type = case control (CC), cross-sectional (CS), prospective cohort (PC), randomized controlled trial (RCT); n = number of participants with CP only; GMFCS = Gross Motor Function Classification System; NR = not reported; CP type = spastic hemiplegic (SH), spastic diplegic (SD), spastic triplegia (ST), dyskinesia (DY); Targeted ankle intervention = plantar flexion (PF); Mobility measure(s) = Gross Motor Function Measure (GMFM)-E (walking, running, jumping), six-minute walk test (6MWT), timed up and go (TUG)

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**Table 7.**

Botox and mobility study results

| Study | Study type | Level of evidence | Participants | | | | | Targeted ankle intervention | Time | Mobility measure(s) | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | n | Age (y:m) | M:F | GMFCS | CP type | | | | |
| 79 | RCT | 2 | 40 (22 in BTX-A group) | 2:10 – 16:5 | 17:23 | I - II | SH, SD | BTX-A to triceps surae | 12 wks post-injection | Metabolic cost (PCI), GMFM-E | Significant improvement in GMFM-E, no change in PCI compared to control group |
| 80 | RCT | 2 | 24 | 3 – 13 | NR | I | SH | BTX-A to triceps surae | 3 and 6 mos post-injection | GMFM-E | Significant improvement in GMFM-E at 3 and 6 mos compared to control group |
| 81 | NRCT | 3 | 16 | 11:1 ± 1:7 | 13:3 | I - II | SH, SD | BTX-A to gastrocs | 8 wks post-injection | Metabolic cost ($VO_2$), self-selected walking speed | Significant decrease in metabolic cost with no change in speed |
| 82 | PC | 4 | 39 | | 22:17 | I - III | SH, SD | BTX-A to triceps surae | 4 wks post-injection | GPS | No change in GPS |
| 83 | RCT | 2 | 10 (5 in casting group) | 4 – 11 | 7:3 | NR | SD | BTX-A to triceps surae, with and without casting | Casting: for 3 wks post-injection, with 4 mo follow-up | Self-selected walking speed, GMFM-E | Significant improvement in speed and GMFM-E for casting vs. non-casting group |
| 84 | PC | 4 | 5 (3 in FES group) | 4 – 6 | 3:2 | I | SH | BTX-A to gastrocs with and without FES of DF and PF while walking | FES: following injection for 4 wks (5 days/wk, 30 mins/ session) | Self-selected walking speed | No change in speed after BTX-A with or without FES |
| 85 | PC | 4 | 20 (11 in casting group) | 3 – 5 | 9:11 | NR | SD, SH | BTX-A to gastrocs (2 injections, 4 months apart) with and without casting | Casting: for 2 wks post-first injection, follow-up at 4 mos post-final injection | Self-selected walking speed, GMFM-E | Significant increase in speed and GMFM-E for both groups, with no difference between groups |
| 86 | RCT | 2 | 14 | 5 – 14 | NR | I | SH | BTX-A to triceps surae with and without resistance training of PF and DF | Resistance training: 12 wks post-injection (2 days/wk, 45 mins/ session) | GMFM-E | No change in GMFM-E in either group |
| 87 | RCT | 2 | 20 (10 per group) | 2 – 7 | 9:11 | I -II | SH, SD, ST | BTX-A to triceps surae with single vs. serial casting | Single cast: single cast for 3 wks post-injection; serial cast: new cast each wk for | Self-selected walking speed | No change in speed |

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| Study | Study type | Level of evidence | Participants | | | | | Targeted ankle intervention | Time | Mobility measure(s) | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | n | Age (y:m) | M:F | GMFCS | CP type | | | | |
| | | | | | | | | | 3 wks post-injection; follow-up 6 mos post-injection | | |
| 88 | PC | 4 | 38 (19 in NMES group) | 4 – 10 | 19:19 | I - III | SD | BTX-A to triceps surae with and without NMES of PF | NMES: 10 days post-injection (20 mins/day), follow-ups at 2 wks and 3 mos post-injection | Self-selected walking speed, GMFM-E | Significant improvement in speed and GMFM-E for both groups, with no difference between groups |

Study type = prospective cohort (PC), non-randomized controlled trial (NRCT), randomized controlled trial (RCT); n = number of participants with CP only; GMFCS = Gross Motor Function Classification System; NR = not reported; CP type = spastic hemiplegic (SH), spastic diplegic (SD), spastic triplegic (ST); Targeted ankle intervention = Botulinum toxin type-A injection (BTX-A), functional electrical stimulation (FES), neuromuscular electrical stimulation (NMES), plantar flexion (PF), dorsiflexion (DF); Mobility measure(s) = Physiologic Cost Index (PCI), Gait Profile Score (GPS), Gross Motor Function Measure (GMFM)-E (walking, running, jumping)

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**Table 8.**

Surgical interventions and mobility study results

| Study | Study type | Level of evidence | Participants | | | | | Targeted ankle intervention | Time | Mobility measure(s) | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | n | Age (y:m) | M:F | GMFCS | CP type | | | | |
| 89 | PC | 4 | 32 | 4 – 11 | 19:13 | I | SD | HCA vs. HCL-V vs. HCL-W procedures | 1 yr post-op | Self-selected walking speed, GMFM-E | Significant increase in speed for HCA group, significant improvement in GMFM-E for all groups; no clear difference between surgeries |
| 90 | RA | 4 | 27 | 11:5 ± 3:2 | NR | I - III | SD, SH | TAL procedure | 1.3 yrs post-op | Self-selected walking speed, metabolic cost ($VO_2$) | No change |
| 91 | RA | 4 | 29 | 15:1 ± 6:4 | 19:10 | I - II | SH, SD, SQ | TATS + TAL procedure | 1.2 yrs post-op | Self-selected walking speed, GPS, GGI, GDI | No change in speed; significant improvement in GPS, GGI, and GDI |
| 92 | PC | 4 | 19 | 8 ± 3:5 | 13:6 | NR | SD, SH | Gastrocnemius fascia lengthening via modified Vulpius technique | 1 yr post-op | GPS | Significant improvement in GPS |
| 93 | RA | 4 | 26 | 5 – 17 | 20:6 | I - III | SD, SH | Transverse Vulpius GSR | 2.4 yrs post-op | GPS | Significant improvement in GPS |
| 94 | RA | 4 | 23 | 14:11 ± 4 | 13:7 | I - II | SH, SD | TATS + TAL procedure | 5.8 yrs post-op | GPS | Significant improvement in GPS |
| 95 | RA | 4 | 14 (7 per group) | 6 – 10 | 9:5 | II - IV | SH, SD | Endoscopic vs. open transverse Vulpius GSR | ~2 yrs post-op | GDI, GPS | Significant improvement in GDI and GPS, with no difference between groups |

Study type = prospective cohort (PC), retrospective analysis (RA); n = number of participants with CP only; GMFCS = Gross Motor Function Classification System; NR = not reported; CP type = spastic hemiplegic (SH), spastic diplegic (SD), spastic quadriplegic (SQ); Targeted ankle intervention = heel cord advancement (HCA), heel cord lengthening according to Vulpius (HCL-V), heel cord lengthening according to White (HCL-W), Achilles tendon lengthening (TAL), tibialis anterior shortening (TATS), gastrocsoleus recession (GSR); Mobility measure(s) = Gross Motor Function Measure (GMFM)-E (walking, running, jumping), Gait Profile Score (GPS), Gillette Gait Index (GGI), Gait Deviation Index (GDI).

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**Table 9.**

Physiotherapy/non-surgical interventions and mobility study results

| Study | Study type | Level of evidence | Participants | | | | | Targeted ankle intervention | Time | Mobility measure(s) | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | n | Age (y:m) | M:F | GMFCS | CP type | | | | |
| 96 | RCT | 2 | 12 | 9:11 ± 3:6 | 3:9 | I - III | SD | DF, PF, or DF + PF strength training | 12 wks, 3x/wk | Self-selected walking speed, GMFM-E | No change in speed, significant improvement in GMFM-E for all training groups |
| 97 | PC (CD) | 3 | 9 | 6 – 10 | 4:5 | I - III | SH, SD | Short term serial casting vs. no casting | 5 wks (2 – 3 changes in casts) | Self-selected walking speed | No change |
| 98 | PC | 4 | 13 | 6 – 11 | 7:6 | I - II | SH, SD | PF strength training | 10 wks, 4x/wk, | TUG | No change |
| 99 | PC | 4 | 6 | 5:10 ± 2:6 | 1:5 | I | NR | PF strength training | 6 wks, 3x/wk, 30 mins/ session | Self-selected walking speed, GMFM-E | Significant increase in speed, no change in GMFM-E |
| 100 | PC | 4 | 19 | 11:7 ± 3:7 | 8:11 | I - II | SH | Kinesiotaping of PF and DF | 2 days | TUG | Significant improvement in TUG |
| 101 | RCT | 2 | 17 (8 in strength group) | 21 ± 4 | 9:8 | I - II | SH, SD | PF and DF strength training | 12 wks, 3x/wk, | 6MWT | Significant improvement in 6MWT compared to control group |

Study type = randomized controlled trial (RCT), prospective cohort (PC) – crossover design (CD); n = number of participants with CP only; GMFCS = Gross Motor Function Classification System; NR = not reported; CP type = spastic hemiplegic (SH), spastic diplegic (SD); Targeted ankle intervention = dorsiflexion (DF), plantar flexion (PF); Mobility measure(s) = Gross Motor Function Measure (GMFM)-E (walking, running, jumping), timed up and go (TUG), 6-minute walk test (6MWT).