APTA Academy of Pediatric Physical Therapy

FACT SHEET

Ankle-Foot Orthoses and Footwear for Children with Cerebral Palsy: Selecting Optimal Designs

INTRODUCTION

An Ankle-Foot Orthosis (AFO) is one that encompasses the ankle joint and the whole or part of the foot.[1,2] Ankle-Foot Orthoses are worn with footwear, which is integral to biomechanical control, so the overall orthosis is now described as an Ankle-Foot Orthosis Footwear Combination (AFOFC). This document provides advice on the selection of AFOs and footwear used for sitting, standing and walking activities.

Orthotic interventions need an interdisciplinary family-centered approach with shared goal setting. Child and family-centered care should include the parents, child, and all professionals involved to share expertise. The key to goal setting and providing optimum interventions is to understand the natural history and prognosis of the condition.

Prognosis is particularly pertinent to orthotic interventions, as the orthosis may provide a preventative role in the natural history of the condition. While the primary insult in cerebral palsy (CP) may be static, secondary skeletal and musculotendinous pathologies develop, as the child grows with the effects of the neurological impairments.[3,4] These may be coupled with the development of pain, an important indicator of quality of life.[5,6] CP is a heterogeneous condition, so additional diagnostic information is required to fully understanding prognosis and set appropriate goals; topography, motor function impairment, degree of impairment.[7-15]

INCORPORATING EVIDENCE INTO CLINICAL DECISION MAKING

Evidence-informed practice is the integration of best research evidence with clinical expertise and patient values.[16,17] Currently, there is limited and low-level research evidence on the effectiveness of ankle-foot orthoses for children with CP.[18-27] Research has focused on limited aspects of the International Classification of Functioning, Disability and Health (ICF),[28] and has been mainly conducted in gait laboratories rather than in daily living activities. Patient values and clinical expertise should be the combined main evidential factors that direct goal setting and clinical decision making. The goals and outcomes for children with CP will span the whole of the ICF.

A summary of outcomes investigated, for the period 1957 to 2019, is presented in Appendix A. Reviews[18-26] and subsequent studies[29-33] report that AFOs can positively influence the arch of the foot (foot posture), gross motor function, spatial temporal measures, kinematics and kinetics, muscle operating lengths and gait efficiency. Ankle power, as calculated by 3D analysis, has been found to be reduced in AFOs that restrict ankle motion. This is inevitable and is often an acceptable compromise in order to optimize other parameters of gait and functional tasks.[20]

Increased internal rotation of the feet may be observed, because the effects of the torsions of the long bones are unmasked once pronation is corrected in the AFO.[33] Previous literature, not included in the reviews, has documented positive facilitation of motor learning with optimally aligned AFOFCs.[34,35] Reviews comment that optimum orthosis and footwear designs and alignments may not have been used in studies.[20,27] Thus, research must be evaluated in light of that finding.

TYPES OF AFOS AND FOOTWEAR

There are many different designs and types of AFOs. There is now agreed international terminology for categorization and description of orthoses.[36] However, many AFO designs were given names previously, and these terms remain in common use.[37]

Table 1 illustrates frequently used designs and common names used in the literature. Terminology mainly relates to the biomechanical control provided at the ankle joint in the sagittal plane, but all AFO and footwear designs will have sagittal, coronal, transverse, and tri-planar design features at ankle and foot joints and all planes need consideration.

DETERMINING OPTIMAL DESIGN, ALIGNMENTS AND DOSAGE

Determine and Set Goals: First determine the short, medium, and long-term goals for the child in collaboration with the family and team. Goals should consider all areas of the ICF (see TABLES 2-5).[38-42] Once goals are identified, it is possible to determine the AFOFC design, alignments and frequency of use to achieve goals.

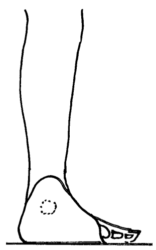
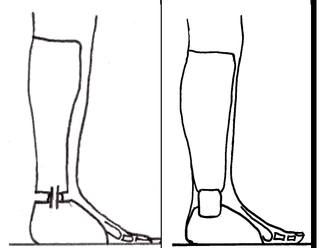
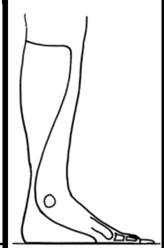
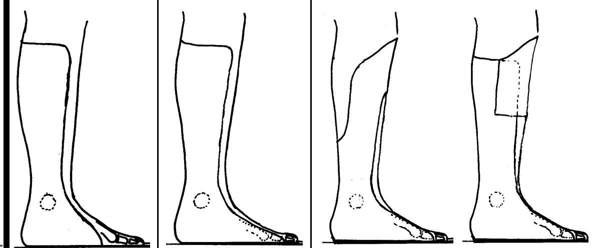
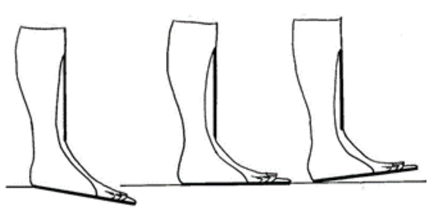
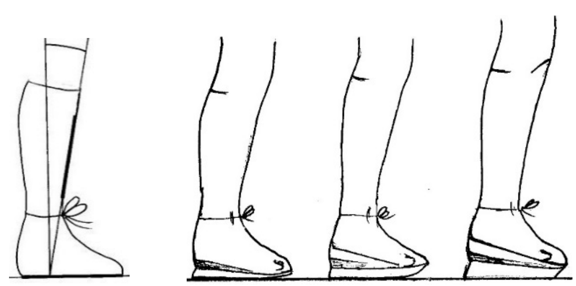
Determine optimum design of AFOFC to Achieve Goals: Tables 2-5 offer design considerations for achieving ICF goals and provide indications and contraindications for commonly used designs of AFOFCs. These tables consider bones and joints, muscles, changing atypical standing and walking patterns, and activities and participation, respectively. Clinical algorithms, based on the indications and contraindications, have been developed, and these may further assist clinical decision making.[27,38,39,43,44]

Determine Optimum Alignment of Joints and Segments in AFOs and AFOFCs: Optimizing joint alignment within an AFO and consideration of the Shank to Vertical Angle (SVA) alignment of the AFOFC is essential. Non-optimal joint and segment alignments will affect sitting, standing, and walking activities, and long-term outcomes.[27,38,44,45] If AFOFCs are used for standing and walking, the design of the heels and soles of the footwear will affect the ability of the AFOFC to change kinematics of segments and joints and kinetics (see TABLE 4).[27,38,43,44,46]

Determine Segment Proportion: Optimizing segment proportion usually includes optimizing the length of the foot for height and equalizing any true leg length discrepancy when wearing AFOFCs or footwear.[38,43]

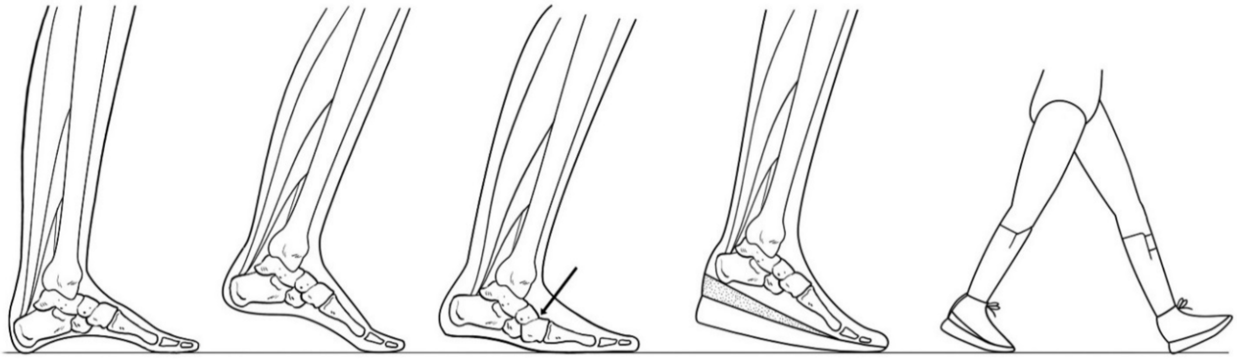
Determine the Dosage Required to Achieve the Goals: Dosage, the percentage of time a child wears the AFOFC to achieve their goals, will need to balance all goals. Some children may need to wear AFOFC for 100% of the week. Other children will have time in the day or week when they do not wear an AFOFC. During these periods, children may still wear footwear with or without a foot orthosis. Design of AFOFCs, of the footwear, and their frequency of use requires regular review.

TABLE 1: Designs & Terminology for AFOs, Footwear, and AFOFC

AFO DESIGN or TYPE & TERMINOLOGY				
Commonly Used AFO Designs *Straps and pads are not illustrated, for clarity*				
Common Name	[a] Supra-Malleollar AFO	Articulated or Hinged AFO *Articulated AFO with anterior shell not illustrated*	Flexible or Spring AFO	[b] Solid or Fixed or Rigid AFO [c] AFO with an anterior shell is often called a Ground Reaction or Floor Reaction Orthosis (GRO/ FRO/GRAFO)
Available Motions within Orthosis	Ankle: full or partial movement; free, limit, stop, assist or resist designs. [d] Metatarsal phalangeal joints (MTPJs): typically free but may have MTPJs fixed.			Ankle: no movement at ankle. MTPJs: free or fixed, GROs -usually MTPJs fixed design.
FOOTWEAR DESIGNS & TERMINOLOGY - SAGITTAL PLANE				
Heel Sole Pitch	[e] Heel Sole Differential (HSD)			
Sole Design	[f] Stiffness = Flexible or Stiff [g] Profile = Flat or Rounded [h] Length of Toe Lever			Stiffness = Flexible or Stiff Profile = Flat or Rounded or Point Loading Length of Toe Lever
Heel Design	Stiffness = Flexible or stiff Profile = Flat or Rocker Length of Heel Lever			Stiffness = Flexible or Stiff Profile = Flat or Rocker Length of Heel Lever
FOOTWEAR DESIGNS & TERMINOLOGY – CORONAL PLANE				
Sole & Heel Designs	[i] Medial and Lateral Flares Stiffness, profile and length			
AFO & AFOFC ALIGNMENTS - SAGITTAL PLANE				
	[j] Ankle Angle alignment AFO 		[k] Shank to Vertical Angle alignment AFOFC 	

a. The terms ‘Supramalleollar Orthosis’ (SMO) and ‘Dynamic AFO’ (DAFO) emerged in the 1980s. DAFO was usually used to describe an SMO with a neurophysiological footplate, but Dynamic AFO is also used to describe any type of AFO with this design feature.
b. Fixed Ankle AFO, Rigid Ankle AFO, and Solid Ankle AFO are designs intended to prevent movement at the ankle joint.
c. Ground Reaction Orthosis (GRO) is an AFO designed to manipulate the Ground Reaction Force (GRF) at the knee. All AFOs have the potential to manipulate the GRF, but ‘GRO’ is usually linked to an AFO with an anterior shell.
d. If MTPJs are fixed in an AFO or Footwear and walking requires some ‘heel rise’, a rocker profile is essential. Design and position of the rocker need to be determined.[38]
e. The Heel Sole Differential (HSD) is the difference between the height of the heel of the footwear (rear foot height) and the thickness of the sole at the MTPJs. It is a measure that reflects the pitch of the footwear.[38]
f. Stiffness, resistance to bending. MTPJ free designs require a flexible sole; MTPJ fixed require a stiff sole with a rocker profile, rounded or point loading.[38]
g. The profile is the shape of the distal surface of the footwear. If sole is stiff, the profile is described as a rocker.[38]
h. Heel and Toe Levers (Sagittal Plane); Heel Lever = length of heel of footwear from ankle joint. Toe Lever= length of sole of footwear to MTPJs if flexible and to the rocker position if stiff. The length of heel and toe levers will be determined individually. If the heel lever is long but not stiff the effectiveness as a ‘heel lever’ is minimal.[38]
i. Medial and Lateral Flares (Coronal Plane). The medial and lateral walls of the lowers of the footwear can be extended to produce medial and lateral levers, at the heel or forefoot. They will be of optimum length for the individual and to be effective will be stiff with a flat profile
j. Ankle Angle alignment of the AFO (AA AFO); determined by length and tone of gastrocnemius, and foot posture.[38]
k. Shank to Vertical Angle alignment of the AFOFC (SVA AFOFC) is a measure of the static alignment of the AFOFC when standing still and weight-bearing equally between heel and sole. Optimal SVA AFOFC for an individual child is determined by; gait pattern, degree of hip and knee flexion contractures. Optimal SVAs for standing and walking are usually inclined, most by 10-12° incline, many by 12-15° incline and some by 15-19° incline.[38]

TABLE 2: Design Considerations for Bone & Joint Goals



2a 2b 2c 2d 2e

Considerations:

- Abnormal forces imposed on a developing skeleton can lead to abnormal bone growth and joint deformity, predisposing the child to pain.[4]
- Arches of the foot, foot posture, develop during the first 7 years.[47,48] During this time, feet are susceptible to deformation.
- Within AFOFCs, foot joints and arches need to be in a stable alignment (2a, 2b, 2d) and not deformed (2c). If it is not possible to achieve normal foot posture alignments, optimal alignments of the foot joints are required. In fixed ankle AFOFCs, ankle joint alignment needs to be appropriate for calf muscle length, stiffness, and foot posture;[27,38,43] in articulated AFOFCs, dorsiflexion should occur at the ankle (2a, 2b), not by foot pronation/supination or deformation of foot joints (2c).[38,44,49]
- Walking patterns may influence development of bones and joints proximal to the foot and ankle (2e).[38,50]
- Standing and walking activities require optimum length of foot for height. Children with CP may have a shorter foot for their height and may need the effective foot length optimised in AFOFC prescriptions.[38] Leg length discrepancies from short shank or thigh segments usually need to be equalised to prevent abnormal compensatory foot postures and gait patterns from developing.[38]

AFOFC DESIGN	INDICATIONS	CONTRAINDICATIONS
Ankle: Solid/ Fixed/Rigid	• Poor or unstable tri-planar alignment of foot. • Dorsiflexion occurs at foot joints, not ankle joint. • Required range of ankle motion (ROM) not available.	
Ankle Dorsiflexion: Free, Limit, Assist, Resist, Stop	• Required ankle joint ROM available. • Stable tri-planar alignment of the foot. • Dorsiflexion occurs at ankle joint, not foot joints.	• Required ankle joint ROM not available. • Unstable tri-planar alignment of the foot. • Dorsiflexion occurs at foot joints, not ankle joint.
Ankle Plantarflexion: Free, Limit, Assist, Resist, Stop	• Required ankle joint ROM available.	• Required ankle joint ROM not available.
MTPJs: Free	• Required MTPJ joint ROM available.	• Required MTPJ joint ROM not available.
MTPJs: Fixed	• MTPJ joint ROM not available. • Control of correctable Hallux Valgus. • Short foot for height.	

TABLE 3. Design Considerations for Muscle & Tendon Goals

Muscle actions lower leg — 0-10%GC, 10-30% GC, 30-50% GC, 50-60% GC

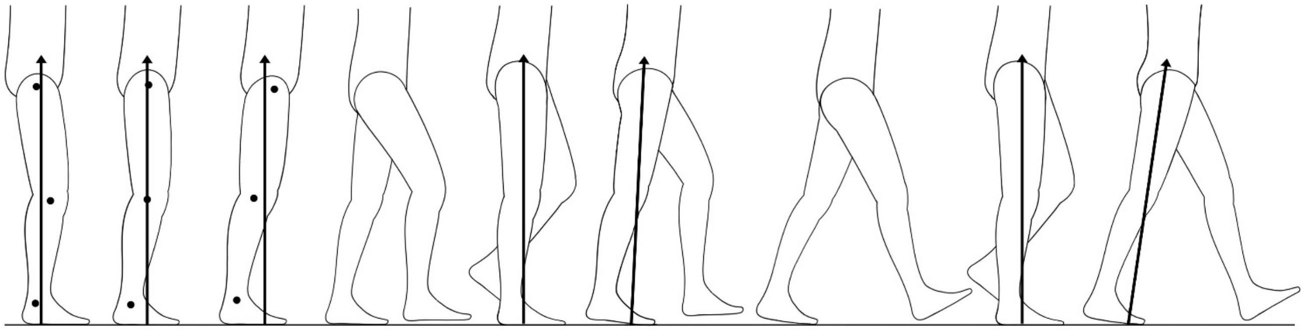
Muscle lengthening — 40%GC, 50% & 100% GC

Considerations:

- Goals for muscles within and more proximal to the AFOFC will include muscle length, strength, tone, selective control and timing.[38,39]
- Pay attention to tri-articular gastrocnemius, if knee extension is required in standing and walking, as non-optimum ankle angle, may leave insufficient muscle length available for knee extension.[38,43,44]
- AFOFCs will need to compensate for weak muscles, have optimal alignments for short and stiff muscles, and induce optimum muscle actions and lengthening when standing and walking.[38,43,44]

AFOFC DESIGN	INDICATIONS	
Ankle: Solid/ Fixed/ Rigid	• Weak plantarflexors or dorsiflexors. • Stiffness/high tone in plantar or dorsiflexors. • Short plantarflexors or dorsiflexors. • Turn tri-jointed gastrocnemius into uni-jointed muscle to achieve control of lengthening and actions during the gait cycle.	
Articulated, Hinged Flexible, or Spring	• Indications and contraindications for muscles using these designs are highly complex, so selection requires advanced knowledge of kinematics, kinetics, and muscle actions.	
	INDICATIONS	**CONTRAINDICATIONS**
Ankle: Plantarflexion Stop at 90° Dorsiflexion Free	• Weak dorsiflexors. • Plantarflexor length: at least 10° dorsiflexion in knee extension. • Plantarflexor tone: not marked or considerably increased. • Plantarflexor strength: sufficient strength to control shank kinematics & ankle joint dorsiflexion.	• Plantarflexor length: short, less than 10° dorsiflexion with knee extended. • Plantarflexor tone: marked or considerably increased. • Plantarflexor strength: weak, unable to control shank kinematics and ankle joint dorsiflexion.
Ankle: Plantarflexion Free Dorsiflexion Free	• Dorsiflexor strength: Strong in swing phase & 0-10% stance phase. • Plantarflexor length: at least 10° dorsiflexion with knee extension. • Plantarflexor tone: not marked or considerable increase. • Plantarflexor strength: sufficiently strong to control shank kinematics & ankle joint dorsiflexion.	• Dorsiflexor strength: Weak, insufficient to control swing phase & 0-10% stance phase. • Plantarflexor length: short, less than 10° dorsiflexion with knee extension. • Plantarflexor tone: ‘marked or considerable increase. • Plantarflexor strength: weak, unable to control shank kinematics and ankle joint dorsiflexion.
MTPJs: Free	• Muscle length available.	• Muscle length not available.
MTPJs: Fixed	• Muscle length not available.	

TABLE 4: Design Consideration for Motor Control of Standing & Walking and Changing Atypical Gait Pattern Goals

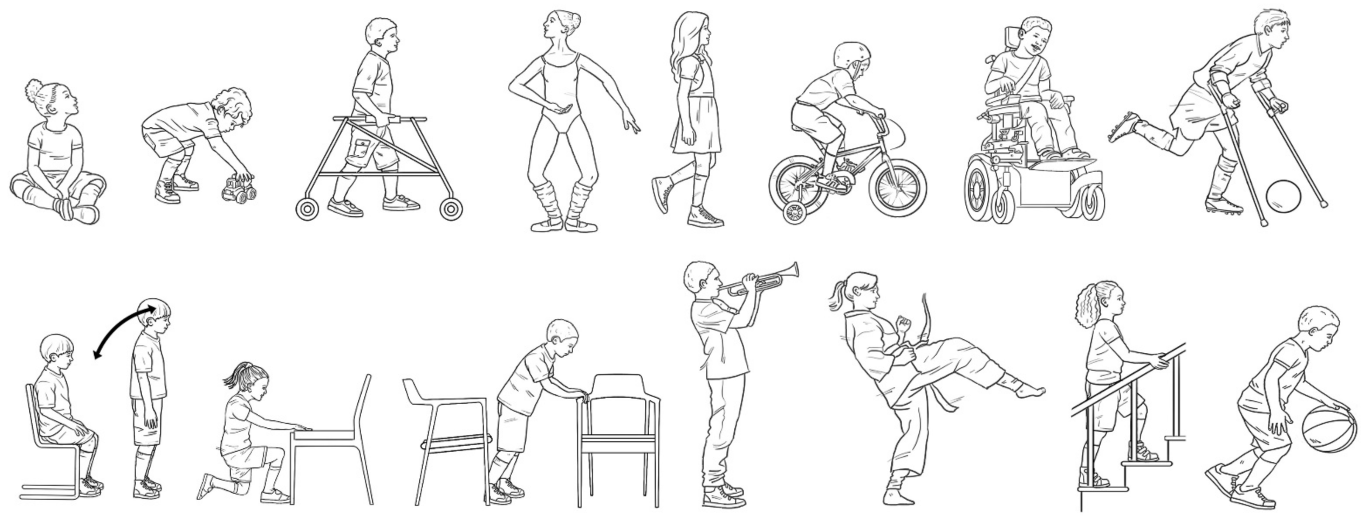


Considerations:

- Children with CP walk with atypical gait patterns for various reasons, including muscle and joint deformity and poor motor control.[4,27,38] Goals are often set for improving motor control of standing and walking to achieve optimal standing and walking patterns: standing and swaying; stepping, walking with an abbreviated gait cycle, or walking with full gait cycles.[38,43,44] These patterns may first be achieved when wearing the AFOFC, but later may be achieved using footwear or when barefoot.
- Motor learning of more typical kinematics and kinetics requires repetitive practice of the activity. Reducing the 'degrees of freedom' in the lower limb, by reducing the number of joints that move, may help motor learning. Therefore, fixing the ankle joint in an AFO to learn control of knee and hip may be helpful.[27,34,35,38]
- When prescribing AFOFCs for standing and walking activities, consideration of alignment of body segments is as important as the alignment of joints. Normalizing distal segment alignments will often normalise proximal segment and joint alignments, kinematics and kinetics.[27,38,43,44]

AFOFC DESIGN	INDICATIONS	CONTRAINDICATIONS
Ankle: Solid/ Fixed/ Rigid	• Inability to produce normal kinematics and kinetics of trunk, hip, thigh, knee, shank, foot, if ankle free to move. • Reduction of 'degrees of freedom' from 3 to 2 by fixation of ankle joint; knee and hip joints free to move.	
Ankle Dorsiflexion: Free, Limit, Assist, Resist, Stop **Ankle Plantarflexion:** Free, Limit, Assist, Resist, Stop	• Able to walk with normal segment and joint kinematics and kinetics with movement of ankle joint in selected AFO design. • Normal foot, shank, knee, thigh, hip, pelvis, and trunk kinematics in selected AFOFC,	• AFOFC does not correct gait pattern sufficiently.
MTPJs: Free	• Able to normalise walking pattern with MTPJs free. • Foot correct length for height.	• AFOFC does not correct gait pattern sufficiently.
MTPJs: Fixed	• Foot is short for height; optimal length of foot for height required to achieve normal kinematics and kinetics. • Unable to normalise walking pattern with MTPJs free.	

TABLE 5. Design Considerations for Activities & Participation Goals



Considerations:

- A variety of footwear and orthosis for various activities are needed.
- For recreational activities, a general rule, use the orthosis or footwear that allows the best performance of the activity, as long as other ICF goals are not compromised or harm done.
- For ambulant children, there may be complex considerations to balance when deciding the percentage of time an AFOFC is worn.[38,39]
  - Walking is a common activity and goals for bones, joints, muscles, and development of an optimum walking pattern may depend on the hours of walking in the AFOFC.
  - However, the child will also be undertaking other functional activities in their day, and for many children, there will be periods in the day when they would not use the AFOFC for walking.
  - Often a compromise needs to be made as to when the AFOFC is worn and when not.
- Considerations will be different for differing ages.

AFOFC DESIGN	INDICATIONS	CONTRAINDICATIONS
Ankle: Fixed/ Solid/ Rigid **MTPJs:** Free, Fixed	• Activity is not possible or performed less well with less support. • Goals in other domains of ICF will be compromised in an AFO with less biomechanical control.	
Ankle Dorsiflexion: Free, Limit, Assist, Resist, Stop. **Ankle Plantarflexion:** Free, Limit, Assist, Resist, Stop	• Activity is performed better. • Goals in other domains of ICF will not be compromised.	• Forces on the muscles and joints would cause harm to developing structures for duration of use in the activity.

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APPENDIX A: Topics Covered in Published Literature 1957-2019

BONES & JOINTS	MUSCLES	FUNCTIONING, STANDING & WALKING
Foot alignment (foot posture)[19,20]	• Prevent or correct deformity[18,19] • Muscle length[18-20,29] • Muscle activity[19-21,30] • Ankle power[19,20,26,30,31]	• Function and ability,[20] gross motor function,[23,24,26] GMFM,[19,23,24] GMFCS,[23] PEDI[24] • Sitting balance,[20] sit to stand,[19-21] standing balance,[16,17,19] base of support,[18] standing posture,[18] balance,[24] stairs,[19-21] activities of daily living[24] • Upper limb,[20] perceptions[20] • Training of standing and walking[18,34,35] • Walking kinematics and kinetics,[19-21,30-32,34,35] pelvis kinematics,[20,23] hip kinematics,[20,23] hip kinetics,[20] knee kinematics,[19,20,23,30-32,34,35] knee kinetics,[20,30,31,34,35] shank kinematics,[31] ankle kinematics,[19-21] ankle kinetics,[20] ankle power,[20,26,30,31] foot kinematics,[18-20] foot progression angle,[33] gait symmetry,[23] stability in stance[19] • Spatiotemporal,[19-21,23,31] velocity,[19,20,22-24,26,30,31] cadence,[20,22,24,26,31,32] stride length and step length[19,20,22-26,31] single support,[19,20,31] double support,[20] centre of pressure,[31] gait indices: GDI,[23] GGI[23] • Efficiency of gait,[18,19] metabolism & cardiopulmonary cost,[20] energy expenditure,[21] energy consumption,[23,30,32] EEI,[23] oxygen consumption[20,23]

References 18-26 are reviews of literature. Papers published subsequent to the latest review are cited separately, ie, references 29-33, as are significant papers that are not included in the reviews ie, references 34 & 35

KEY:

GMFM	Gross Motor Function Measure
GMFCS	Gross Motor Function Classification System
PEDI	Pediatric Evaluation of Disability Inventory
GDI	Gait Deviation Index
GGI	Gillette Gait Index
EEI	Energy Expenditure Index

Modified from Owen E. When to use lower limb orthoses in cerebral palsy. *Paediatrics and Child Health*. 2020;30(8):275-282.