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From Stable Standing to Rock and Roll Walking (Part 1) The Importance of Alignment, Proportion and Profiles

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Introduction

Orthoses are one of the most commonly used interventions with children. All interventions should be prescribed optimally if they are to achieve the desired outcomes in the required domains of the International Classification of Function Disability and Health, Children and Youth Version (ICF-CY) (World Health Organisation, 2007; Majnemer 2012). To prescribe orthotic interventions optimally they need to be determined and described in a manner analogous to drug interventions (Morris and Condie 2009). Firstly, by the name of the orthosis, as defined by the International Standards Organisation (ISO 8549-3 1989); secondly, by the dosage, which in the case of orthoses will include the design, alignments, proportions and profiles of the prescription; and finally by the frequency of administration, which is a description of the activities for which the orthosis will be used and for how long it will be worn each day or week.

Many aspects of orthotic provision are defined by the International Standards Organisation. ISO 8549-1:1989 gives the following definitions:

ORTHOTICS is the science and art involved in treating patients by the use of an orthosis.

AN ORTHOSIS OR ORTHOTIC DEVICE is an externally applied device used to modify the structural and functional characteristics of the neuromuscular and skeletal systems.

AN ANKLE FOOT ORTHOSIS (AFO) is one that encompasses the ankle joint and the whole or part of the foot. This definition includes a range of AFO designs including: fixed ankle designs where the ankle joint alignment is set at one angle within the AFO; flexible, hinged or jointed AFO designs which allow full or a limited range of movement into dorsiflexion or plantarflexion; and supramalleolar orthoses. Integral to the function of any AFO is the design of the footwear that is worn with the AFO, so the overall orthosis is now called an AFO Footwear Combination (AFOFC), to give equal emphasis to both parts of the prescription.

Describing the features of orthoses in all three planes is essential but this paper concentrates on some key sagittal plane features of AFOFC prescriptions. These will include principal alignments, principal proportions and principal footwear design features, which are pitch, stiffness and profiles.

There has been much debate in the literature about which AFOFC designs to use. The optimum AFOFC design should be selected according to desired outcomes for the patient. Clinical algorithms can help determine optimal designs and several are available. A clinical algorithm for designing, aligning and tuning AFOFCs based on shank kinematics is published elsewhere (Owen 2005; Owen 2010). An algorithm for determining the optimum Angle of the Ankle in the AFO (AA-AFO) in a fixed ankle AFOFC (Owen 2005; Owen 2010) is reproduced in this paper. An algorithm for determining whether a dorsiflexion free AFOFC is optimal (Owen, 2013) is also presented here. In order to become confident in using the latter two algorithms it is easier to start with determining the alignments of fixed ankle AFOs and then look at the criteria for dorsiflexion- free AFO designs.

Principal Alignments

Definitions of alignments are given in ISO 8551:2003

ALIGNMENT - establishment of the position in space of the components of the prosthesis or orthosis relative to each other and the patient.

ALIGNMENT OF A JOINT - the spatial relationship between the skeletal segments, which comprise the joint.

ALIGNMENT OF A SKELETAL SEGMENT - the spatial relationship between the ends of a segment.

There are many alignments in all three planes within an AFOFC. Two principal sagittal alignments are the Angle of the Ankle in the AFO (AA-AFO) and the Shank to Vertical Angle of the AFOFC (SVA-AFOFC) (Owen, 2002; Owen, 2004; Owen, 2005; Owen, 2010; Bowers and Ross, 2009; Ridgewell, 2010; Eddison and Chockalingam, 2013). Figure 1 illustrates the nine possible configurations of these two alignments (Owen 2004, 2010).

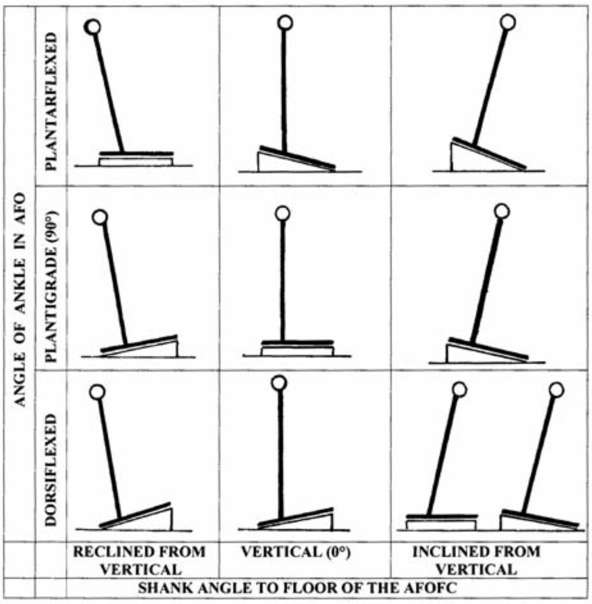


Figure 1 - Nine theoretical configurations of the AA-AFO and SVA-AFOFC (Owen 2004; Owen, 2010)

Until recently these two alignments have been largely confused or ignored in orthotic science (Owen, 2004; Ridgewell et al, 2010). This may be because similar language was used to describe these alignments, the terms dorsiflexion, plantigrade and plantarflexion being applied to both. Reviews of the literature reveal that only a very small proportion of publications from the 1970s to present have differentiated between the two alignments, included information about alignments used and described how those alignments were optimised (Owen, 2004; Bowers and Ross, 2009; Ridgewell et al, 2010; Eddison and Chockalingam, 2013). These reviews acknowledged that differentiating between and stating both alignments, and also how they were optimised, is essential for both clinical practice and future research trials.

New terminology has recently emerged and the following terms and definitions are now accepted internationally (Owen, 2004; Meadows et al, 2008; Owen, 2010; Ridgewell et al, 2010; Eddison and Chockalingam, 2013).

ANGLE OF THE ANKLE IN THE ANKLE-FOOT ORTHOSIS (AA-AFO) - the angle between the line of the shank relative to the line of the foot. The line of the foot is defined as the line between the base of the heel and the most inferior point of the foot under the fifth metatarsal head. It is described in degrees of plantarflexion, dorsiflexion or as plantigrade (Owen, 2004).

SHANK TO VERTICAL ANGLE OF THE AFO FOOTWEAR COMBINATION (SVA-AFOFC) - the angle of the line of the shank relative to the vertical when standing in the AFOFC with weight equally distributed between the heel and forefoot. When measured in the sagittal plane the SVA is described as inclined if the shank is leaning forward of the vertical and reclined if it is leaning backwards from the vertical. It is described in degrees from the vertical, 0° describing the vertical (Owen, 2004).

These definitions refer to AFOFCs with fixed ankle designs. The SVA of a flexible or hinged AFOFC can be measured but as the SVA can vary, because of the variability of ankle joint alignment possible in these designs, an additional specification is required in the definition, for the ankle joint alignment when the measure is taken.

Optimising the AA-AFO and SVA-AFOFC is essential to any orthotic prescription (Owen, 2004; Owen, 2010; Bowers and Ross, 2009; Ridgewell et al, 2010; Eddison and Chockalingam, 2013). However optimising these alignments alone will not necessarily produce optimum kinematics and kinetics in standing, stepping or gait. At our centre, which uses a video vector gait laboratory to evaluate the effects of orthoses, we have found that for this to occur all the other alignments, designs, proportions and profiles of the AFOFC in the sagittal plane need to be optimum, as do those in the coronal and transverse plane, and also it is essential to equalise leg lengths in orthotic prescriptions.

Determining the Optimal AA-AFO

The sagittal AA-AFO describes the alignment of the foot segment relative to the shank segment within the AFO. The optimum AA-AFO should be determined for each leg of each patient. To be able to do this we need to be conversant with the factors that might help us best determine this angle, which are the length and stiffness of musculotendinous units (MTU) and the desired triplanar bony alignment of the foot (Owen, 2005). In addition leg lengths come into the consideration and also the activity for which they will be used and whether that activity requires knee extension.

Calf MTU length

AFOFCs are most often used in circumstances when the knee will be extended, in standing or walking, so the length and stiffness of the gastrocnemius should be taken into account. Gastrocnemius is a tri-jointed MTU crossing the knee, ankle and subtalar joints. Setting the AA-AFO without due regard for the available gastrocnemius length will result in insufficient length of gastrocnemius being available to allow knee extension, or pronation/supination of the foot will occur to release gastrocnemius length, or both these scenarios will occur. None of these are desirable as they will compromise gait, prevent optimum development of the bony alignment of the foot and prevent the MTU being used at optimal length. If AFOFCs are only being used with flexed knees, an assessment of soleus length alone is sufficient.

Calf MTU stiffness
MTU stiffness will also determine if knees will extend or bony alignment of the foot will be compromised. (Sanger et al, 2003 ; Lieber, 2010). On clinical examination, MTU length may be available but the stiffness or hypertonia may be such that the AA-AFO has to be adjusted to obtain knee extension and/or maintain bony alignment of the foot. As we know, hypertonia is speed dependant so when AFOs will be used in gait, taking hypertonus into account is very important. Even when walking slowly joint movements and consequent stretch on MTUs can be fast.

Bony alignment of the foot
It is essential that children's feet develop to acquire optimal triplanar bony alignment. All feet, and children's feet in particular, will 'escape' to triplanar pronation or supination, in order to achieve greater degrees of dorsiflexion, if there is insufficient MTU length or excessive MTU stiffness in the calf MTUs. Assessing the length and stiffness of the calf MTUs is therefore essential if the AA-AFO is to be set optimally for maintaining optimal bony alignment of the foot. Neutral alignment of the foot, in regard to triplanar pronation or supination, may only be achieved when the foot is optimally plantarflexed.

Fixed dorsiflexed ankles
Some children with myelomeningocele, and other rare disorders, may have fixed dorsiflexion angles at the ankles. If this is the case then this must be taken into account when determining the AA-AFO.

The algorithm for determining the optimum AA-AFO, (Figure 2) gives consideration to all these factors and any risks associated with using chosen alignments (Owen 2005; Owen, 2010). In addition there are opportunities for interventions if required throughout the algorithm. An optimally designed and aligned AFOFC may be the chosen intervention to increase MTU length, reduce MTU stiffness and develop optimal bony alignment of the foot. To be able to determine whether intervention is needed to increase calf MTU length the normative data of MTU lengths for age are required. Reimers et al (1995) documented the length of the triceps surae MTU, measured as the angle of the lateral border of the foot relative to the axis of the lower leg. They measured 'with the knee extended and the hindfoot in a neutral position and the forefoot sufficiently adducted to bring the talus into a neutral position relative to the calcaneus'. They measured 759 typically developing children aged 3 to 17 years. The proportion of children with one or both triceps surae that could only be brought to plantigrade rose from 24% to 62% between the ages of 3 and 17 years. In 13% of adolescents one or both feet could only achieve 5° plantarflexion. They also found an association between short triceps surae and flat feet in the older group.

If the algorithm for determining the AA-AFO is followed, a plantarflexed AA-AFO is the only recommendation when patients have a short or excessively stiff gastrocnemius or a foot that will only align in neutral pronation/supination when the ankle is plantarflexed. Any alternative would compromise the triplanar bony alignment of the foot or prevent the knee from extending. Compromising the foot has adverse consequences for the development of normal bony structure of the foot, comfort and skin viability. Also if the bony alignment of the foot is compromised the calf MTUs will not be optimally stretched as the knee extends and foot progression angles may become excessively rotated, leading to reduced toe levers and adverse kinematics and kinetics at the knee and hip.

Despite all these good reasons to use a plantarflexed AA-AFO when it is deemed essential (Owen, 2005; Owen, 2010; Bowers and Ross, 2009), until recently there has been a widely held view that aligning the ankle in plantarflexion in an AFO is not acceptable. This dominant view has prevailed in the literature (Owen, 2004; Bowers and Ross, 2009). There is a notable exception, Nuzzo (1980, 1983, 1986) expounds the use of plantarflexion where required and extols its therapeutic effects.

Exploration of the possible reasons why plantarflexed alignments of the ankle in the AFO has been resisted may help understand why this opinion has been held and why it may now be redundant. Firstly, there has been a fear that using plantarflexed AA-AFO will always lead to MTU shortening. The reality is that if the MTU is short enough to require a plantarflexed AA-AFO there is no alternative, especially if knee extension is required. Knee extension is not only essential to production of normal kinematics and kinetics in standing and walking but it also produces one of the main therapeutic effects on the MTU, which is allowing the MTU to stretch to its optimal length as the knee extends. This may prevent the MTU from shortening or maintain, or increase, its length. Additional strategies may also be used to complement AFOFCs with plantarflexed AA-AFO if the AFOFC intervention is not sufficiently successful in itself. Secondly, the AA-AFO and SVA have not been differentiated well and, coupled with a belief that a vertical alignment of the AFOFC is required for both standing and gait, this has lead to a belief that 90° AA-AFO is the only way to achieve a vertical alignment. It has not been well understood that any SVA alignment can be achieved with any AA-AFO and that inclined alignments of SVAs offer the best chance of achieving optimum standing balance, kinematics and kinetics in standing, stepping and gait, especially if knee and hip extension are goals of interventions (Owen 2004; Owen, 2010).

Leg lengths should be equalised in orthotic prescriptions. Using different AA-AFOs can often be a mechanism to achieve this, wholly or partially. This is because the shorter leg is often the more neurologically affected and the MTUs may be shorter or stiffer or bony alignment considerations may require a different AA-AFO.

The determination of the optimum AA-AFO is largely made from clinical examination, which is not the case for determining the optimal SVA alignment of an AFOFC. This is made by undertaking trials of the activity for which the AFOFC is intended to be used (Owen, 2004; Owen, 2010; Eddisson and Chockalingam, 2013).

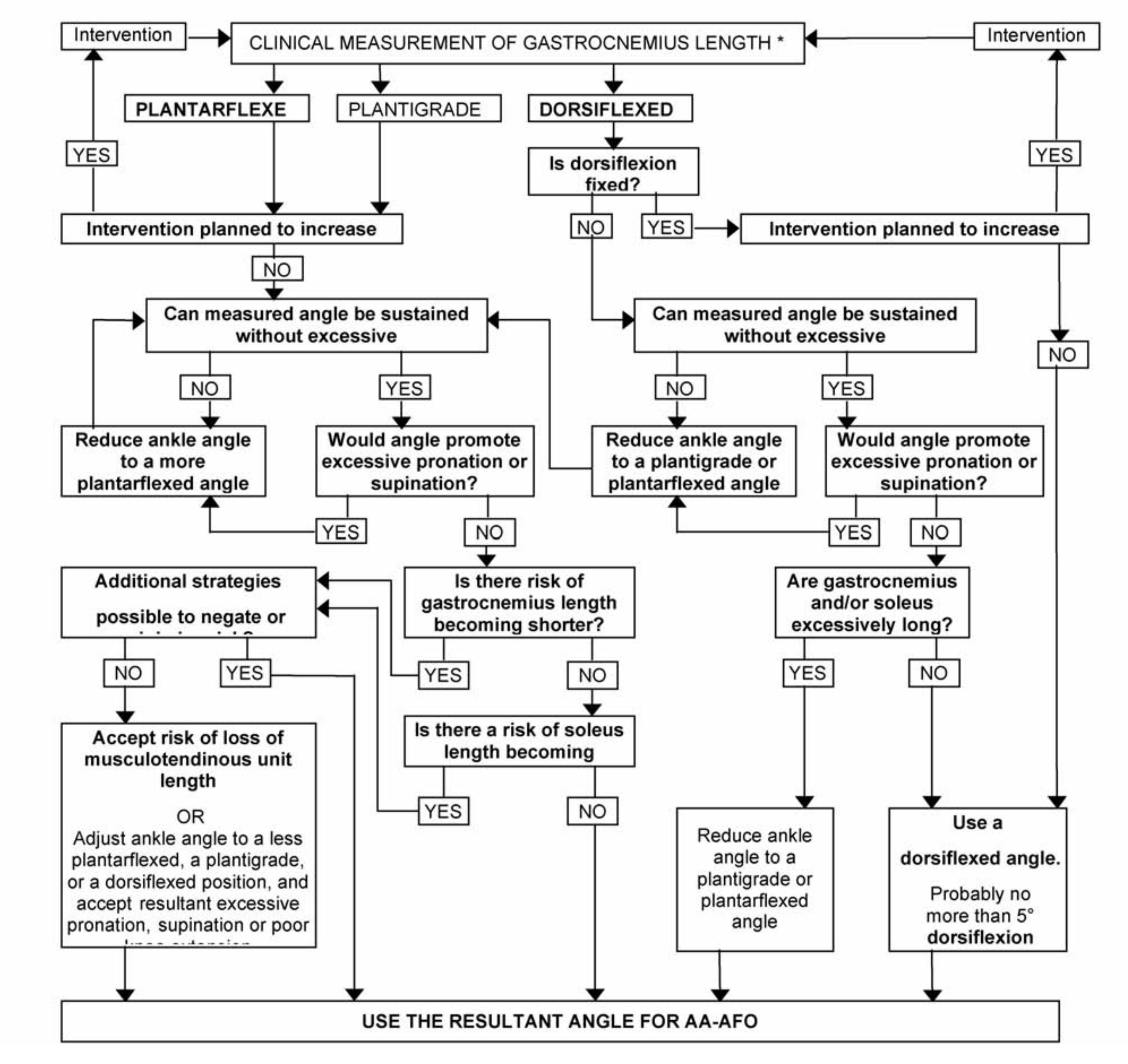


Figure 2 - Clinical algorithm for determining the sagittal angle of the ankle in an ankle-foot orthosis footwear combination (Owen 2005; Owen, 2010)

Determining the Optimal SVA-AFOFC

The optimal SVA-AFOFC should be determined for each leg and the activities for which the AFOFC will be used. The SVA-AFOFC used for weight bearing activities has been defined. Determining the optimal SVA is done by trials of the required activities. A number of terms have been used in the literature in regard to optimising, tuning and aligning orthoses. To establish clarity definitions are required.

TUNING - the dictionary definition of the word 'tuning' is 'to adjust for optimum performance', such as tuning a car engine or a musical instrument. A definition of tuning an AFOFC can be derived from this.

TUNING AN AFOFC - the process whereby fine adjustments are made to the design and alignment of the AFOFC in order to optimise its performance during a particular activity such as sitting, standing, transferring, stepping, walking, running, climbing stairs (Owen, 2010; Eddison and Chockalingam, 2013).

BIOMECHANICAL OPTIMISATION - the process of designing, aligning and tuning an AFOFC in order to optimise its performance (Owen, 2010; Eddison and Chockalingam, 2013).

ISO 8549-1(1989) gives definitions of three terms commonly used in prosthetic science but, until recently less used in orthotic science.

BENCH ASSEMBLY AND ALIGNMENT - assembly and alignment of the components of a prosthesis or orthosis in accordance with the characteristics and with previously acquired data regarding the patient.

STATIC ALIGNMENT - process whereby the bench alignment is refined while the prosthesis or orthosis is being worn by the stationary patient.

DYNAMIC ALIGNMENT - process whereby the alignment of the prosthesis or orthosis is optimised by using observations of the movement pattern of the patient.

Static alignment is therefore the process of setting or resetting the SVA of the AFOFC while the patient is static in standing, and dynamic alignment is the process of assessing whether the set SVA alignment has produced the optimal results. The terms 'tuning' and 'biomechanical optimisation' also apply to the process of setting and determining the optimal SVA alignment, but they have a wider context. Biomechanical optimisation has the broadest context as it covers designing, aligning and tuning in all three planes. Tuning has the next broadest context as it involves fine adjustment of any part of the design or any alignment during activities and it also refers to any adjustment in any plane. Static and dynamic alignment usually only refer to optimally aligning the sagittal SVA.

It is essential to optimise the SVA-AFOFC because SVA alignment affects more proximal segment alignments, in both standing and walking. Figure 3 shows nine standing conditions, all with accurate human segment proportions and the foot horizontal on the floor (Owen, 2004; Owen, 2010).

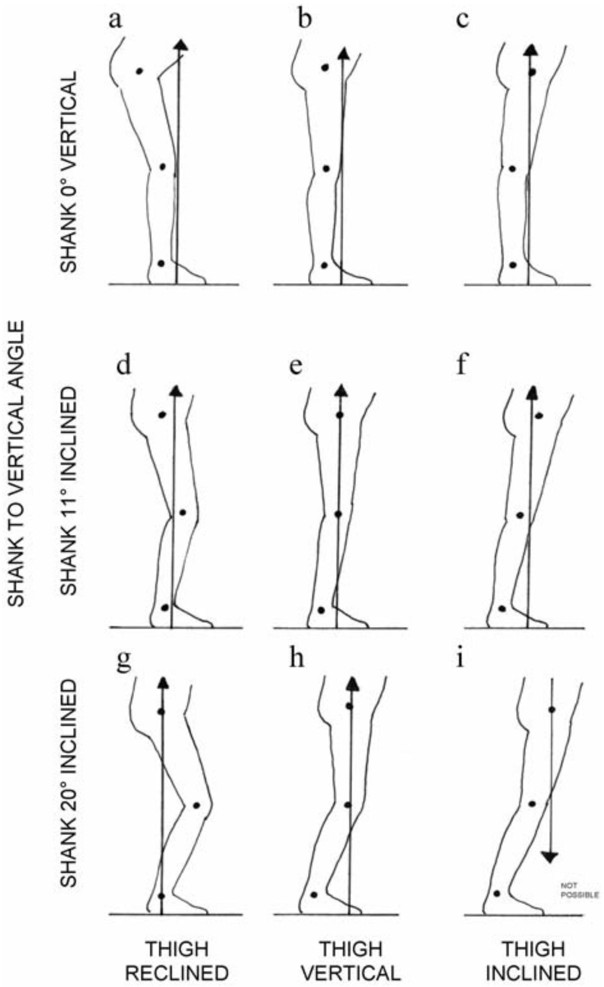


Figure 3 - Shank kinematics dictate proximal segment kinematics and GRF alignment (Owen, 2004; Owen, 2010)

Three SVA alignments are illustrated; vertical, 10-12° incline, 20° incline. The three SVA conditions are combined with three possible alignments of the thigh; reclined, vertical and inclined. In standing, swaying, stepping and walking translation of a vertical trunk is required. The optimal SVA alignment that allows forward and backward trunk translation is 10-12° incline. With this alignment it is possible to move the thigh from a reclined to an inclined position, and vice versa, and translate a vertical trunk. It is not possible to achieve this with the other 2 SVA alignments. With a vertical SVA the thigh cannot incline without knee hyperextension and with SVA 20° incline the thigh cannot become inclined as this would bring the centre of mass outside the base of support. Of course it would be possible to incline a thigh if the base of support were longer, so manipulating the length of a foot, or 'effective foot', can be helpful in rehabilitation. In both standing and walking, moving the thigh to an inclined position while maintaining an inclined shank and vertical trunk creates hip and knee extension and stabilising hip and knee external extending moments. In standing, stepping and walking demonstrated by an able bodied person a 10-12° inclined shank is the optimal SVA to achieve this, for a number of reasons (Owen, 2010). However, when optimising SVA alignments of AFOFCs, an SVA of more than 12° incline may be needed if the patient hyper-extends the knees or if they have excessive stiffness at the hip and knee joints. In the latter case this is because a more inclined position of the SVA enables the thigh to become vertical or inclined. All SVA alignments, and especially those that are more inclined than 12°, need to be coupled with the optimum length of toe lever to have a positive effect.

SVA Guidelines

There is limited research that provides guidelines for optimal SVA alignments for children and adults (Appendix 1). Early guidelines were justified by a theoretical perspective or observational gait analysis rather than from actual kinematic and kinetic tuning, and usually just one SVA alignment was suggested. Only recently is there an emerging evidence for optimal SVA alignments obtained from gait laboratories. There is also an increasing understanding that the SVA needs to be determined for each leg of each patient as it will be dependant on the clinical condition and the type of gait pathology, and that the optimum footwear designs are also required (Owen, 2004; Owen et al, 2004; Meadows et al, 2008; Bowers and Ross, 2009; Ridgwell et al, 2010; Eddison and Chockalingam, 2013).

Principal Proportions

Homo sapiens evolved from early hominids who were the first non feathered bi-pedals. Early hominids had long trunks, short legs, walked with a flexed gait, had an unstable mid-foot and no valgus alignment at the knees. All these elements meant that walking on two limbs required a lot of energy. Homo sapiens evolved a more efficient gait, which enabled walking over longer distances and carrying of objects. We evolved longer legs and shorter trunks, a gait that has extension at both knees and hips or 'strider gait', a stable mid-foot, a toe lever and valgus at the knees.

The proportion of the segments of the lower limb and the trunk dictate the kinematics and kinetics of normal human gait. The lengths of all the body segments at all ages are documented (Tilley, 2002). It is interesting to note that the segment proportions do not remain the same at all ages. The foot length of a 2-3 year old is 38% of overall leg length but by adulthood it is 31%. So when young children are at the stages of balance and gait maturation they have a longer foot in proportion to the leg length, and overall height, which gives them an increased base of support.

Short heel and toe levers can have an adverse effect on the quality of gait. The reduction of heel lever affects first rocker and the reduction of toe lever affects third rocker, in particular the ability of the ground reaction force to align itself anterior to the knee to create knee extending moments. Short heel and toe levers are not only the resultant of a short anatomical foot, they are also created when an anatomically correct length foot has an excessive externally or internally rotated 'foot progression angle'. Many children have a combination of a short foot and abnormal foot progression angles compromising their length of toe lever. When normalising gait in AFOFCs an essential task is to normalise segment lengths, which includes normalising the length of the overall 'effective leg', equalising leg lengths and normalising the 'effective heel and toe levers' of the foot. In some circumstances it may be helpful to increase heel and toe levers beyond those of normative data to create additional stability. Optimising heel and toe lever lengths in AFOFCs is part of the tuning process when tuning for standing, stepping and whole gait cycle. To do this the optimum stiffness and profile of the heel and sole of the footwear should be determined (Owen, 2004; Owen, 2008; Owen, 2010).

Principal Footwear Designs – Pitch, Stiffness and Profiles

Pitch or heel sole differential

This paper concentrates on the sagittal plane designs of AFOFCs and has previously distinguished, defined and discussed two of the principal sagittal alignments in any AFOFC, the AA-AFO and the SVA-AFOFC. The optimal AA-AFO for each leg is determined by a clinical algorithm and then the optimal SVA is determined by trials of the activity for which the AFOFC is required. When using a fixed ankle AFOFC or one with a plantarflexion stop function, the desired SVA is set by adjusting the 'pitch' or more specifically the 'heel sole differential' (HSD) of the footwear and any accompanying internal wedges (Figure 1) (Cook and Cozzens, 1976; Owen, 2004; Owen, 2010). The HSD describes the difference in height between the heel and sole of the footwear. Heel height alone does not describe pitch.

Heel Sole Differential
The measured difference between the depth of the heel at mid-heel and the depth of the sole at the metatarsal heads. The term 'Final heel sole differential' can be used to describe the overall HSD when it includes the HSD of the footwear and HSD of any internal wedges. The HSD is generally measured in centimetres in clinical practice. Degrees of pitch may be used in research or when explaining the linkage between AA-AFO and SVA alignments.

Adjusting the HSD of the footwear to adjust the SVA is a key element in static and dynamic alignment and tuning AFOFCs. Optimising the SVA is essential to optimise standing balance, swaying, and stepping and 'temporal mid-stance' of the gait cycle (Owen, 2010).

Heel and Sole Designs – Stiffness and Profile
The design of heels and soles of footwear also affects standing balance, swaying, stepping and the three rehabilitative subdivisions of the gait cycle, 'entrance to midstance', 'temporal midstance' and 'exit from temporal midstance' (Figures 4 & 5) (Owen, 2004; Owen, 2005; Owen, 2010). Stepping is different to walking with full gait cycles. Stepping has a 'temporal midstance', as does a full gait cycle but it has an abbreviated 'entrance' and 'exit'. The first 10% of stance and the last 10% of single stance are not present. Young children start walking with abbreviated gait cycles and then develop full gait cycles and, as we get older, we often regress to 'stepping'.

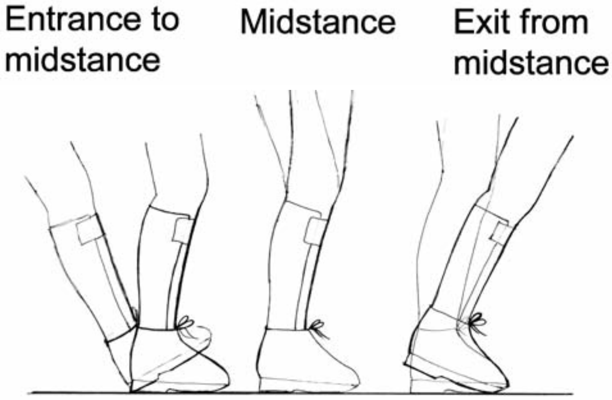


Figure 4 - Producing normal foot, shank and thigh kinematics with an AFOFC (Owen, 2004; Owen, 2010)

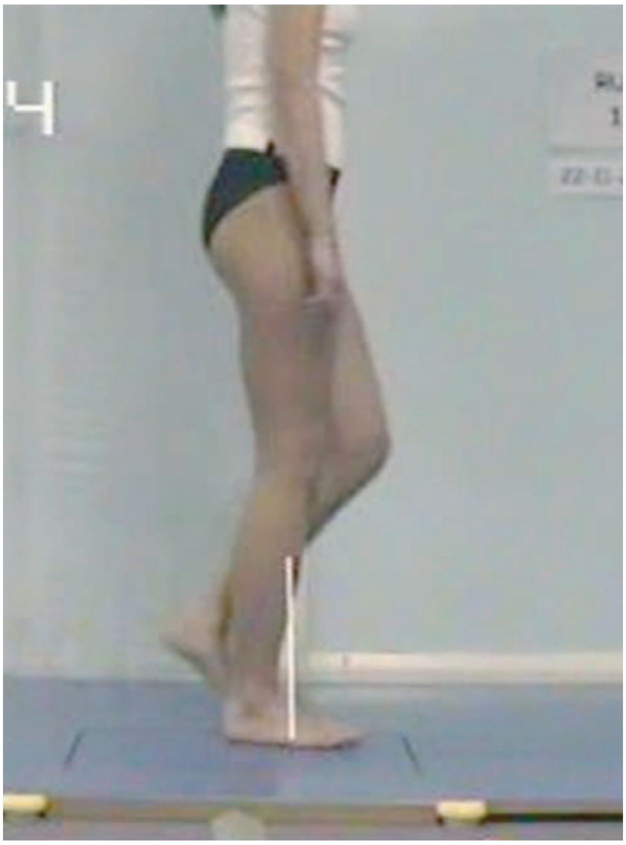


Figure 5 - Temporal midstance 30% gait cycle (Owen, 2010)

STIFFNESS refers to the ability of the material and design to resist bending.

PROFILE is the shape of the sagittal view of the distal surface of the footwear.

Both the stiffness and profile of heels and soles of footwear can be designed and optimised for the required activity (Figure 6) (Owen, 2004; Owen, 2005; Owen, 2010). The optimised sole design may be flexible or stiff. If it is stiff it should have a rocker sole profile. Whether the optimum design is a rounded rocker or point-loading rocker the optimum position of the rocker for the desired activity needs to be determined. The position of the rocker dictates the length of the 'toe lever' and an optimum toe lever is required for standing, stepping and in full gait cycles for both 'temporal midstance' and the 'exit from temporal midstance'. If a patient has a short foot it may be necessary to optimise foot proportion by use of a stiff rocker sole to create a false longer toe lever. Optimising heel design has effects on the 'heel lever' for the 'entrance to midstance'.

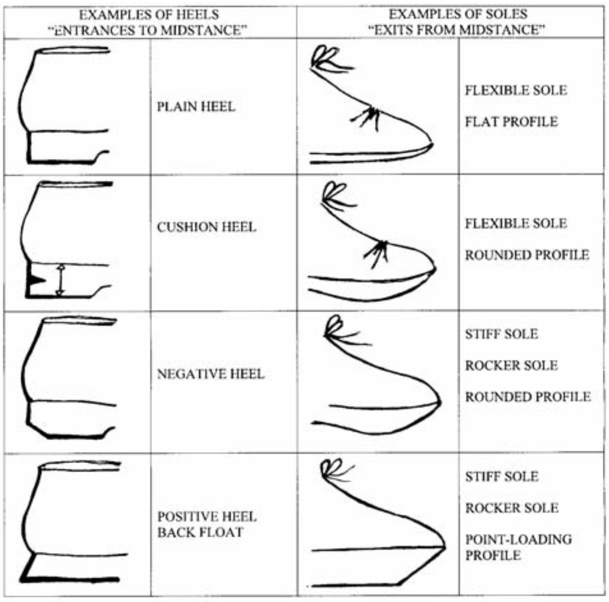


Figure 6 - Heel and sole designs for standing, stepping and 'entrances to' and 'exits from' temporal midstance (Owen, 2004; Owen, 2005; Owen, 2010)

An Algorithm for Determining Whether a Dorsiflexion Free AFOFC is Appropriate

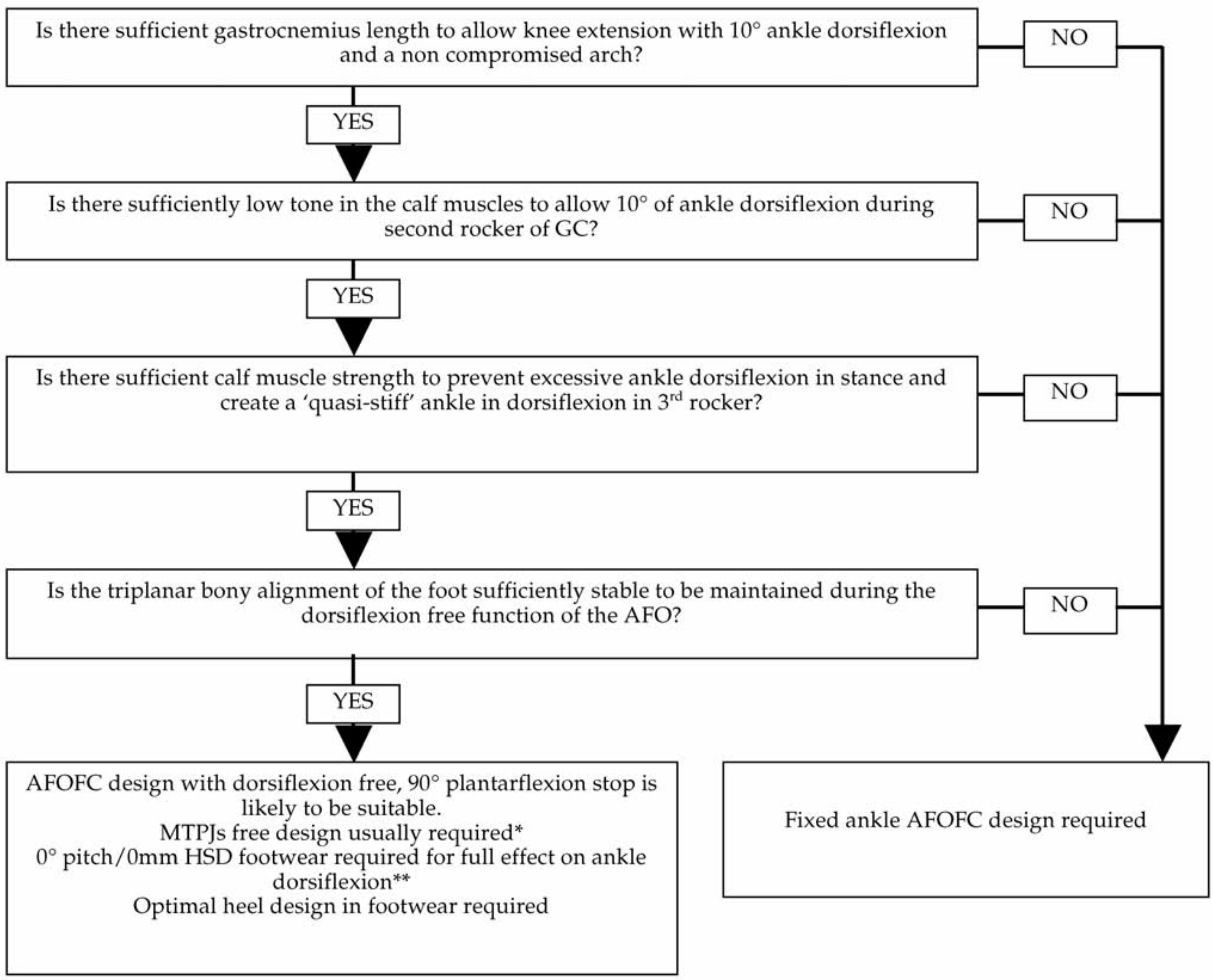
Like the decision about the optimal AA-AFO alignment in a fixed ankle AFO, the decision as to whether it is appropriate to use an dorsiflexion free function in an AFO design is based on calf MTU length and stiffness and triplanar bony alignment of the foot, and an additional consideration is also required, which is the strength of the calf MTU. An AFOFC with a dorsiflexion free function, often combined with a 90° plantarflexion stop function, has been a commonly investigated orthosis. The research to date has a number of problems, particularly when related to gait (Owen, 2013; Bowers and Ross, 2009):

- research often seeks to determine whether a fixed ankle or hinged/dorsiflexion free AFO design is optimum for diagnostic groups or categories, which is inappropriate;
- dorsiflexion free AFOs have been investigated with study subjects who have contraindications to their use;
- AFOFCs with dorsiflexion free functions have been coupled with fixed metatarsal phalangeal joints (MTPJs) which may adversely affect ankle joint kinematics;
- some literature states that movement at the ankle joint is essential for gait which is incorrect (Owen, 2013).

An algorithm to determine whether an AFOFC with a dorsiflexion free function is likely to be the optimal prescription for gait can be created (Figure 8) if a few key requirements for normal barefoot gait are considered (Owen, 2013):

- at 40% gait cycle maximum stance phase knee extension occurs and at this time the ankle is dorsiflexed 10-12° (Figure 7) - there must be sufficient gastrocnemius length available to allow both these kinematics;
- the ankle dorsiflexes to 10-12° during mid-stance - there must be sufficient length and sufficiently low tone in soleus and gastrocnemius to allow this movement;
- the ankle is prevented from excessively dorsiflexing in mid-stance and is maintained in a quasi-stiff position of dorsiflexion in terminal stance by the actions of the calf muscles - there must be sufficient strength of the calf muscles to achieve this;
- ankle dorsiflexion in gait is coupled with stable bony alignment of the foot.

Figure 7 - 40% gait cycle - maximum knee extension, ankle dorsiflexion, maximum gastrocnemius length (Owen, 2005; Owen, 2010)



* An AFOFC with an MTPJ free design is required to allow MTPJ extension during third rocker for two reasons. Firstly, restriction in MTPJ extension may produce excessive ankle dorsiflexion. This compensatory response is required to enable normal shank kinematics if MTPJs are fixed and not compensated for by a rocker sole profile. Secondly, patients who meet the criteria for a dorsiflexion free AFO should also meet the criteria for an MTPJ free design AFOFC. If they do not then a rocker sole profile is required on the footwear.

** To obtain 10-12° of ankle joint dorsiflexion in gait the dorsiflexion free AFO needs to be combined with footwear that has a 0mm Heel Sole Differential (HSD) or 0 degree pitch. For each degree of pitch in the footwear there will be a reduction of one degree of ankle dorsiflexion. This is because gait requires normal shank kinematics and ankle joint kinematics adjust to the pitch of the footwear to achieve this. In normal gait the shank is 10-12° inclined by the end of MST and a 10-12° pitch in the footwear negates the need for ankle joint movement to achieve this.

Figure 8 - Proposed algorithm for determining whether a dorsiflexion free AFO is an appropriate prescription (Owen 2013)

Conclusion

Research about biomechanical optimisation of AFOFCs is still at any early stage of development (Owen, 2004; Owen, 2010; Meadows et al, 2008; Bowers and Ross, 2009; Ridgewell, 2010, Eddison and Chockalingam, 2013). One of the problems with the emerging evidence is that only the SVA seems to have been manipulated in some trials with lack of detail about the AA-AFO and whether it was optimised prior to tuning trials. The designs at the metatarsal phalangeal joints and the heels and soles of the footwear are also not stated as being optimised. The pre-requisites for determining the optimal SVA alignment for each leg of each patient are that all the other design features of the AFOFC are optimal, which includes optimisation of AA-AFO, designs of the AFO, heel and toe levers, design of the footwear heel and sole stiffness and profile and having leg lengths equalised in prescriptions (Owen, 2010). The process of optimising prescriptions is therefore multi-faceted. In future research it would preferable if AFOFC prescriptions were optimised in all parameters and then just one parameter varied, rather than vary one parameter while other parameters may not be optimum. A recent editorial (Fatone, 2010) has suggested that there are many challenges in lower limb orthotic research because of the heterogeneity of: the mechanics of the device; the individual and each leg of the individual; the interaction of the device with the individual; and the required outcomes for the individual. She comments that customisation produces confounding variables, standardisation limits the population for the study and single subject research and case studies are perhaps the most readily understood by practitioners and transferred into clinical practice.

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Appendix 1

Publications detailing a recommended or optimised SVA for fixed ankle AFOFCs.

Children included in all except one (*). Adapted from Owen E (2004) MSc Thesis

YEAR	AUTHOR	SVA	COMMENT
1970	Jebsen, Corcoran, Simon	10° Incline	• Theoretical justification
1972	Glancy & Lindseth	3-5° Incline	• Visual gait analysis
1978	Fulford & Cairns	Slight Incline	• Theoretical justification
1978	Simon et al	10-15° Incline	• SVA deducible from other data given in Rosenthal et al 1975 • SVAs optimised on an inclined walkway • Kinematic and kinetic gait analysis
1983	Nuzzo	Knee cap over MTPJs	• Theoretical justification from kinematic gait analysis
1984	Meadows	4-17° Incline	• SVAs deducible from other data given • SVAs are best of selected SVA trails and may not be fully optimised • Kinematic and kinetic gait analysis
1986	Nuzzo	7-10° Incline	• Theoretical justification and kinematic gait analysis
1990	Cusick	5° Incline	• Theoretical justification
1992	Hullin, Robb, Loudon	0° with a rocker sole or 10° incline without a rocker sole	• SVAs deducible • Two conditions trialled, SVA 0° with rocker sole and SVA 10° Incline with no rocker sole • Kinematic and kinetic gait analysis.
2002	Owen E	7-15° Incline Mean 11.4° Inc	• SVAs tuned to optimum • Kinematic and kinetic gait analysis
2009	Jagadamma et al	10.8° Inc (SD 1.8)	• SVAs are best of selected SVA trails and may not be fully optimised • Kinematic and kinetic gait analysis
2010	Jagadamma et al *	14° Inc	• SVA and sole design tuned to optimum • Kinematic and kinetic gait analysis • Single case study, adult with CVA