Introduction

In Part 1, which was published in the May 2014 issue of the APCP Journal (Owen, 2014) definitions were given for many aspects of orthotic prescriptions; two principal sagittal alignments were defined and discussed - the Angle of the Ankle in the Ankle Foot Orthosis (AA-AFO) and the Shank to Vertical Angle of the Ankle-Foot Orthosis Footwear Combination (SVA of AFOFC); two algorithms and the clinical reasoning for them were presented, one for determining if free movement into dorsiflexion is optimal and another for determining the optimal sagittal angle of the ankle in an AFO. The definitions of various aspects of footwear designs were given.

In Part 2 a third algorithm for designing, aligning and tuning AFOFCs will be presented. Standing, stepping, walking with full gait cycles, and the rockers of gait will be defined and discussed. The importance of ‘temporal midstance’ to the gait cycle and rehabilitation strategies will be explored.

Standing, Stepping and Walking with Full Gait Cycles

The International Classification of Disability and Health, Children and Youth Version, (ICF-CY), (WHO, 2007) classifies standing and walking within the component of ‘Activities and Participation’. Standing is categorised within ‘Maintaining a body position’ and walking within ‘Walking and moving’. Walking is defined as ‘moving along a surface on foot, step by step, so that one foot is always on the ground, such as when strolling, sauntering, walking forward, backwards, sideways’.

Walking can be divided into ‘walking with full gait cycles’ and ‘stepping’. This is helpful because when children develop walking skills they first stand, then sway in standing, then start stepping and finally they develop full gait cycles. This developmental sequence is therefore useful for rehabilitation. Also walking with full gait cycles may never be a possibility for some patients, so stepping is a safe and sustainable alternative walking style.

I define ‘stepping’ as ‘walking with an abbreviated gait cycle, single stance finishing at 40% of a full gait cycle and swing phase at 90% (Figure 1).

![Figure 1 - Stepping - walking with an abbreviated gait cycle, single stance finishing at 40% of a full gait cycle and swing at 90%](image)

It is different to strolling, or walking slowly with a full gait cycle and a heel strike. In stepping, initial contact is with a horizontal foot, not the heel, and the shank is vertical not reclined. By the end of single stance the shank and thigh are inclined; there is maximum stance phase knee extension and knee extending moments combined with almost maximum stance phase hip extension and hip extending moments. The stance phase of stepping, as defined, would have some heel rise but in rehabilitation it may be helpful, in some circumstances, to achieve stepping with the stance foot in full contact until contralateral initial contact.

Whether standing and swaying, or stepping or walking with full gait cycles the trunk maintains a vertical alignment and it is translated forwards or backwards. The segments have to be aligned optimally for this to occur (Owen, 2014).

Gait Cycle - Phases, Subdivisions and Temporal Events

The normal gait of children and adults has been described in depth by many authors including Sutherland (1988) and Perry (1992, 2010). Human walking uses a repetitive sequence of lower limb
motions or gait cycles (GC). The complex segment and joint alignments of the lower limbs enable translation of a vertical trunk (Figures 2 & 3).

Figure 2 - SVA 12° inclined (a, b, c) allowing posterior (a) and anterior (c) translation of a vertical trunk. (Owen 2004a, 2010)


Figure 3 - Significant percentages and temporal events of a full gait cycle

Perry divided the segments of the body into a ‘passenger unit’, comprising the head, arms and trunk, and a ‘locomotor unit’ comprising the lower limb segments. A gait cycle is divided into phases and subdivisions and there are also ‘temporal events’ which occur at specific instances. Stance phase is when the foot is in contact with the ground and the lower limb is supporting body weight, and swing phase is when the foot is not in contact with the ground. The subdivisions of the gait cycle described by Perry (1992) have been the most widely recognised over recent decades. They are sometimes referred to as the Rancho Los Amigos (RLA) terms (Table 1). The key temporal events of stance phase are defined in Table 2.

A new interpretation of the gait cycle
Perry divided the gait cycle into very meaningful subdivisions as she was mindful of both joint and segment kinematics. The stance phase subdivisions primarily arise from foot kinematics. Loading Response (LR) is from initial contact to foot flat. Midstance (MST) is from foot flat to heel rise, which occurs just after temporal midstance, the foot remaining in full contact with the floor during midstance. The start of Terminal Stance (TST) coincides with heel rise and the end of TST with contralateral initial contact. Pre Swing (PSW) ends with toe off. Swing phase is divided by changes of shank and thigh kinematics.

These subdivisions remain helpful, especially if the segment kinematics and temporal events that create the subdivisions are given greater emphasis. It is also helpful to develop the current established interpretations of the gait cycle so that we have one that is most meaningful for the rehabilitation of standing, swaying, stepping and full gait cycles.

Temporal midstance is a key event in the gait cycle and it occurs exactly in the middle of stance phase, at 30% GC (Gibson et al, 2006). At this instant the head and trunk are positioned directly over the foot and the relevance and importance of temporal midstance is described in Owen (2010). Temporal midstance is very akin to standing, a position in which we can sway and from which we take our first steps in childhood and in rehabilitation (Figure 2). Naming the gait cycle around temporal midstance is more intuitive for the development of rehabilitation strategies (Table 3).

The proportion of stance phase prior to temporal midstance can be described as the ‘entrance to midstance’ and the proportion after temporal midstance, the ‘exit from midstance’ (Owen 2004a, 2004c, 2005b, 2010). The new terminology sits well within Perry’s subdivisions of stance phase of the gait cycle, but creates a new emphasis for the significance of temporal midstance, placing it centre stage.
### Table 1 - RLA phases and subdivisions of the gait cycle

<table>
<thead>
<tr>
<th>%GC</th>
<th>0-10%</th>
<th>10-30%</th>
<th>30-50%</th>
<th>50-60%</th>
<th>60-73%</th>
<th>73-86%</th>
<th>86-100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE</td>
<td>STANCE</td>
<td>SWING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUBD</td>
<td>LOADING RESPONSE</td>
<td>MID STANCE</td>
<td>TERMINAL STANCE</td>
<td>PRE SWING</td>
<td>INITIAL SWING</td>
<td>MID SWING</td>
<td>TERMINAL SWING</td>
</tr>
</tbody>
</table>

### Table 2 – Key temporal events of stance phase

<table>
<thead>
<tr>
<th>EVENT</th>
<th>DEFINITION</th>
<th>% GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Contact</td>
<td>The instant when the foot makes first contact with the ground</td>
<td>0%</td>
</tr>
<tr>
<td>Foot Flat</td>
<td>The first instance when the whole foot is flat on the ground</td>
<td>10%</td>
</tr>
<tr>
<td>Temporal Midstance</td>
<td>The instant when the head, trunk and pelvis are directly over the supporting foot which is at 50% of the time interval from initial contact to toe off</td>
<td>30%</td>
</tr>
<tr>
<td>Heel Off/ Heel Rise</td>
<td>The instant when the heel leaves the ground</td>
<td>Just after 30%</td>
</tr>
<tr>
<td>Contralateral Initial Contact</td>
<td>The instant when the contra-lateral foot makes contact with the ground</td>
<td>50%</td>
</tr>
<tr>
<td>Toe Off</td>
<td>The instant when the toe leaves the ground</td>
<td>60%</td>
</tr>
<tr>
<td>Maximum knee extension</td>
<td>The instant in stance phase when maximum knee extension occurs.</td>
<td>40%</td>
</tr>
<tr>
<td>Maximum hip extension</td>
<td>The instant when maximum hip extension occurs.</td>
<td>50%</td>
</tr>
</tbody>
</table>

### Table 3 - RLA and additional terminologies for gait cycle

<table>
<thead>
<tr>
<th>RLA Terminology</th>
</tr>
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<tbody>
<tr>
<td>Perry 1992</td>
</tr>
<tr>
<td>Loading Response</td>
</tr>
<tr>
<td>Entrance into Midstance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional Terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owen 2004</td>
</tr>
</tbody>
</table>
The Rockers of Gait

The term ‘rocker’ is commonly used in descriptions of gait. There has been increasing confusion about the rockers and a clear understanding is required for analysis of gait and creation of optimal rehabilitation strategies and orthotic designs (Owen, 2009).

The rockers of gait were originally described by Perry in 1974. She attributed their purpose to be production of ‘tibial advancement’ during stance, an essential element in forward progression of the body during the gait cycle. The rockers Perry described involved both joints and segments, so her description included shank and foot segments, ankle and foot joints, and also muscle actions.

When she first described the rockers of gait she allocated them to loading response, midstance and terminal stance subdivisions, no rocker being allocated to pre-swing. Perry later named the rockers according to the pivot of each rocker: ‘heel rocker’ during loading response, ‘ankle rocker’ during midstance and ‘forefoot rocker’ during terminal stance. She also extended the description of the forefoot rocker to include pre-swing. However, including TST and PSW subdivisions in one rocker can be confusing as there are important differences in the kinematics and muscle actions occurring in TST and PSW, especially at the ankle joint. During TST the ankle is virtually locked, ‘quasi-stiff’, in dorsiflexion. In PSW the ankle joint moves very fast from a position of dorsiflexion to plantarflexion.

Recently, the rocker in pre-swing has been termed fourth or ‘toe-rocker’ and a four-event model has been proposed (Owen, 2009; Perry, 2008, 2010) (Figure 4a). A definition of the rockers is ‘mechanisms of the ankle and foot that produce shank kinematics during the stance phase of the gait cycle’ (Owen, 2009). First rocker uses a heel lever to move the foot to the floor, the angular velocity of the movement being controlled by the anterior tibial muscle actions which also pull the shank forward to a less reclined or near vertical alignment by foot flat at 10% GC. In second rocker, the foot is in full contact with the floor and tibial advancement occurs through dorsiflexion at the ankle joint, the calf muscles restraining the forward movement of the shank once it has passed vertical, and shank alignment becomes 10-12° inclined and relatively stationary by temporal midstance at 30% GC. Tibial advancement continues in third rocker by heel rise and metatarsophalangeal joint (MTPJ) extension, the ankle joint being virtually locked in approximately 10° dorsiflexion by calf muscle activity, quasi-stiffness of the ankle joint. In fourth rocker, tibial advancement occurs by a combination of ankle joint motion, from dorsiflexion to plantarflexion, and MTPJ extension increasing heel rise. There is ongoing debate about the muscle actions occurring and whether the muscle is actively shortening or whether it is acting as a spring (Fukunaga, 2000).

An importance of the rockers is that the distal segment alignments and kinematics dictate proximal kinematics and kinetics (Owen, 2004a, 2010; Meadows et al, 2008). ‘Normal distal produces normal proximal’ and ‘abnormal distal
produces abnormal proximal’. Understanding each of the rockers of gait and incorporating normal segment alignment strategies into all rehabilitation and orthotic interventions for standing, stepping and walking is essential. The rockers of barefoot gait are dependent on movement at both the ankle and MTPJs. If these joints are not able to move it is still possible to produce normal shank kinematics if the correct footwear or orthosis design is used, because joint kinematics and segment kinematics are independent of each other (Figure 5).

Figure 5. Segment kinematics are independent of ankle kinematics (Owen 2004a, 2010)

When walking in footwear with no heel sole differential the segment and joint kinematics will be the same as barefoot gait as long as the sole is flexible to allow full MTPJ extension. Footwear with a stiff sole requires a rocker sole profile, to enable use of a simulated third and fourth rocker. When using footwear with a heel sole differential the base of the footwear becomes the effective foot and undertakes the normal foot kinematics while shank kinematics remain normal, the ankle joint making the adjustment required to produce normal shank kinematics while shank kinematics remain normal, the ankle joint making the adjustment required to produce normal shank kinematics (Figure 5) (Owen, 2004, 2010; Hansen and Childress, 2004; Murray, 1967).

When walking in AFOFCs the design of the AFOFC needs to create normal foot and shank kinematics and subsequent normal thigh kinematics, and knee and hip kinematics and kinetics (Figures 4 & 6) (Owen 2004, 2010; Meadows et al, 2008).

For a number of reasons we often have to fix the ankle joint or MTPJs in orthotic designs. This prevents use of anatomical rockers, so normal shank kinematics must be replicated by the use of simulated rockers created by the design of the footwear that is combined with the ankle-foot orthosis. Normal shank kinematics can be created by determining the optimal SVA alignment of the AFOFC and by optimising the designs of the heels and soles of the footwear to facilitate the foot and shank kinematics required for entry to and exit from temporal midstance (Figure 4). When using AFOFCs the base of the footwear becomes the ‘effective foot’. Designs of soles vary the timing and rate of heel rise and shank kinematics. Designs of heels vary the rate of foot kinematics from heel strike to foot flat and shank kinematics. For children with disabilities it is sometimes helpful to exaggerate the slowing of the angular velocity of the forward progression of the shank into temporal midstance and maintain the shank in a still position at temporal midstance for longer than normal in order to facilitate the ballistic movement of the thigh to an inclined position and moment switching to external extending moments at the hip and knee (Figure 2).

Shank Kinematics as a Basis for Gait Categorisation and Clinical Algorithms for Orthotic Designs

It is possible to define and classify the characteristics of pathological gait in a number of ways (Dobson et al, 2006). This has most often been by joint kinematics and kinetics. Four knee kinematic categories are commonly used: in stance phase, genu recurvatum or hyperextending knee, crouch knee and jump knee and, in swing phase, stiff knee (Sutherland and Davids, 1993). In ‘hyperextending knee gait’, the knee hyperextends; in ‘crouch knee gait’, the knee is excessively flexed through MST and TST; in ‘jump knee gait’, the knee is excessively flexed in MST but recovers extension in TST. However, when trying to determine optimum orthotic prescriptions, a more helpful categorisation is by kinematics of the shank in the sagittal plane (Owen, 2004a, 2004c, 2005b, 2010). This is because, while all segment and joint abnormalities are important, correction of abnormal sagittal shank kinematics is the key to normalising more proximal segment and joint kinematics and kinetics (Figure 6). Once foot and shank kinematics are normalised, it is possible to determine whether more proximal segment and joint deviations observed are of primary origin or whether they are secondary to distal segment deviations.

This paper reviews a categorisation of gait and an algorithm for designing, aligning and tuning AFOFCs, based on shank kinematics (Owen, 2004a, 2004c, 2005b, 2010). The algorithm is primarily for patients with abnormal shank kinematics but can also be helpful when designing AFOFCs for children who present with normal shank kinematics, but abnormal foot kinematics, as it will facilitate design choices that normalise foot kinematics and other segment and joint kinematics and kinetics, while maintaining normal shank kinematics.

Categories of Abnormal Shank Kinematics

The normal shank kinematics produced by the ‘rockers of gait’, have been described. Children with disability most often have abnormal shank kinematics during the GC. The shank may be either
insufficiently or excessively inclined during MST and possibly TST.

There are two subgroups within both of these categories and some children have a combination of shank kinematic abnormality within a GC. The abnormal shank kinematics are often combined with abnormal foot kinematics, but categorisation is largely by shank segment abnormality alone. Identification of segment kinematics abnormality in some children may be obvious by visual observation of gait but it is far preferable to observe kinematics with slow motion video playback or by video vector analysis.

**Group 1 - Insufficiently Inclined Shank Kinematics**

Group 1B presents with ‘shank reversal’ or ‘retrograde movement of the shank’, Group 1A does not (Figure 6).

**Group 2 - Excessively Inclined Shank Kinematics**

Group 2B presents with the foot in full contact with the floor, in Group 2A there is only toe contact (Figure 6).

Group 1 is largely analogous to the category of hyperextending knee gait; Group 2 largely with crouch gait. Jump knee gait is also analogous with Group 2 in MST but there is recovery in TST.

Some children will present with normal shank kinematics but abnormal foot kinematics. The algorithms will be helpful when designing AFOFCs for these children. They can be used to facilitate designs that normalise foot kinematics while maintaining the normal shank kinematics and other segment and joint kinematics and kinetics.

**Algorithm for Designing, Aligning and Tuning AFOFCs**

Clinical algorithms simplify the process of clinical decision making in order to select optimum prescriptions. At least thirty sagittal, coronal and transverse design variables may be included in an optimum prescription and prescriptions may be different for each leg. Sagittal design variables include details of which joints are fixed or free, the alignments of all the joints within the AFO, the overall SVA of the AFOFC, the stiffness of the AFO, the depth of the heel and sole of the footwear, the heel sole differential of the footware, the length of heel and toe lever, the stiffness or flexibility of the sole and heel and the design profile of the heel and sole of the footwear particularly the type and position of rocker soles.

Three algorithms have been developed for the sagittal plane designs of an AFOFC (Owen, 2005a, 2005b, 2010, 2013) with an understanding that consideration of the design in the coronal and transverse plane is equally important. Two of these algorithms have been detailed in Part 1 (Owen, 2014), one for determining whether an orthosis that allows free movement into dorsiflexion may be suitable and one for determining the optimal angle of the ankle in an AFO.

The third algorithm, (Figure 7), is based on identification of abnormal shank kinematics in gait. An assumption is made that the user understands that normal gait requires normal foot segment kinematics and that it is the combination of normalised foot and shank kinematics that will allow normalisation of more proximal joint and segment kinematics and kinetics.

The algorithm is primarily intended for tuning whole gait cycles but can also be used to determine optimal AFOFC designs for standing, swaying, stepping and partial gait cycles. Guidelines for optimal designs for standing, stepping and walking with full gait cycles are included in the ‘step by step’ process outlined below. If any aspect of standing, stepping or full gait cycles can’t be achieved then all aspects of design, alignment and proportion need to be revisited. If success is still not possible the child’s physical condition may preclude complete normalisation.

**Step 1 - Identify Patients Who Require Fixed Ankle AFOFCs**

The algorithm has a simple approach to determining whether a fixed ankle AFO is the optimum design. It states that if shank kinematics in stance phase are abnormal a fixed ankle AFO design is recommended. This pathway came from many years of clinical experience biomechanically optimising AFOFC designs using a video vector gait laboratory. An extended algorithm for this decision gives a more complete picture (Owen, 2013, 2014).

**Step 2 - Determine the Optimal Ankle Angle Alignment**

One principal prerequisite for successful tuning is to have the optimal Angle of the Ankle in the AFO. This decision has its own algorithm (Owen 2005a, 2010, 2014).

**Step 3 - Identify the Abnormality of Shank Kinematics in Stance Phase**

The algorithm has two main pathways based on the presenting abnormality of stance phase shank kinematics observed in barefoot gait (Figure 6).
1a and 1b. Shank insufficiently inclined in MST. Vector excessively anteriorly aligned at foot, knee and hip in MST. Vector vertical (a) or forward leaning combined with shank reversal (b).

1c. AFOFC producing normal shank kinematics at MST and TST by increasing the inclination of the shank with resulting improvement of GRF alignment at foot, knee and hip.

2a and 2b. Shank excessively inclined in MST. Vector aligned posterior in MST and TST. Variable alignment at hip and foot.

2c. AFOFC producing normal shank kinematics at MST and TST by reducing shank inclination and resultant improvement of GRF alignment at foot, knee and hip.

Figure 6 - Abnormalities of shank kinematics in pathological gait (Owen 2004a, 2010)
Figure 7 – Clinical algorithm for designing, aligning and tuning AFOFCs (Owen, 2005b, 2010)
Children who present with insufficiently inclined shanks follow the pathway on the left hand side of the algorithm and those with excessively inclined shanks follow that on the right.

**Step 4 - Identify the Design of AFO Required for Control of the Ankle and Shank in Stance Phase**

Following the categorisation of gait, the algorithm determines the sagittal design of the AFO. On the left hand side of the algorithm an AFO design that controls plantarflexion and insufficient incline is selected, A or B (the difference between them is the design at the MTPJs, a decision made at the next step). On the right hand side of the algorithm an AFO design that controls dorsiflexion and excessive incline is selected, design B or C, C having more biomechanical control.

**Step 5 - Identify the Design of AFO Required for Control of the MTPJs in Stance Phase**

The pathway in the algorithm is based on designs needed to optimise gait but there are additional reasons for selecting free or fixed designs at the MTPJs, which must also be considered.

‘Metatarsal phalangeal joint fixed’ designs are chosen when:
- The MTPJs do not have full extension or there are toe abnormalities requiring MTPJ fixation;
- The foot is significantly short and an optimum foot length has to be created by a stiff sole with a rocker profile;
- there are problems of forefoot adduction or abduction in the transverse plane which need control from a distal trimline on the medial or lateral wall of the AFO at the foot;
- the patient cannot obtain good kinematics and kinetics in terminal stance once the ankle joint is fixed and the AA-AFO and SVA of the AFOFC are optimised.

Patients who require an AFO design which allows the MTPJs to extend, an ‘MTPJ free’ design, need to have the AFO combined with footwear with a flexible sole to enable use of anatomical third rocker. If a fixed MTPJ design is chosen the shoe must then have sufficient rocker profile to create a simulated third rocker. The alignment of the MTPJs also needs to be selected in MTPJ fixed designs.

The selected optimum orthosis design at the ankle and MTPJs will only become effective once coupled with the optimum footwear design in the AFOFC.

**Step 6 - Tuning AFOFCs for Stance Phase**

The current consensus is that AFOFCs should be ‘tuned’ (Bowers and Ross, 2009; Eddison and Chockalingam, 2013; Ridgwell et al, 2010). Tuning has been defined in Part 1 (Owen, 2014). It is the process whereby fine adjustments are made to the design of the AFOFC in order to optimise its performance; it can include adjustments to both design and alignments of the AFOFC. The essence of tuning is that it is done by the use of practice trials of activities. Pre-requisites for successful tuning are that all the steps in the algorithm prior to tuning have been optimised.

When tuning full gait cycles the process has a sequence of three stages. Initially, temporal midstance is tuned by ascertaining the optimal SVA alignment of the AFOFC. This is followed by tuning the exit from MST, by optimising the design of the AFO at the MTPJs and sole of the footwear, and then by tuning the entrance to MST by optimising the design of the heels (Figures 4, 7 & 8), (Owen, 2004c, 2010). Adjusting the design of the AFOFC during the tuning process manipulates foot and shank kinematics and consequently more proximal segment and joint kinematics and kinetics. If tuning of midstance cannot be achieved by simple adjustment of the SVA then tuning the design of the soles and heels of the footwear is required. Entrances and exits then need to be reviewed.

Tuning for standing and swaying involves only ‘midstance tuning’, optimising SVAs and heel and toe levers.

When tuning for stepping; midstance, entrance and exit tuning is performed but for an abbreviated GC. Stance will terminate at the equivalent to 40% full GC, swing phase will terminate at the equivalent to 90% (Figure 1).

**Step 6a - Tuning the SVA of the AFOFC for Temporal Midstance**

The terms ‘SVA alignment of an AFOFC’, ‘Static alignment’ and ‘Dynamic Alignment’ have been defined in Part 1 (Owen, 2014). Tuning the SVA influences not only temporal midstance but also entrance and exit. When tuning midstance the SVA of the AFOFC is adjusted until optimum kinematics and kinetics are produced in the required activity. This process is called ‘dynamic alignment’. Measurement of the SVA of the AFOFC is done in standing and aligning the SVA in standing is called ‘static alignment’.

Prerequisites for successful tuning of SVA alignments are optimal alignment of the ankle joint within the AFO, optimal AFO design and optimal segment proportions and heel and toe levers. If midstance tuning is not achieved with simple adjustment of the SVA all the prerequisites need review including the decision whether to leave free
or fix the MTPJs and the design of the soles or heels of the footwear, in particular sole design and toe lever length.

The SVA must be optimised by tuning (Bowers and Ross, 2009; Eddison and Chockalingam, 2013; Owen 2004a, 2010; Ridgwell et al, 2010). There is limited research, however, that provides guidelines for optimal SVA alignments for children and adults. Appendix 1 of Part 1 (Owen, 2014) details the evidence to date.

The following guidelines derive from an original study (Owen, 2002, 2004a, 2010) and clinical experience over 15 years of tuning AFOFCs on a video vector gait laboratory. The study included a group of children who walked independently without walking aids, Gross Motor Function Classification System (GMFCS) 1 and 2 equivalents, but these guidelines apply to all walkers including those who use assistive devices, GMFCS 3 equivalent. Gait category Group 1A, SVA 10-12° incline; Group 1B, SVA 12-15° incline; Group 2A and 2B children with no excessive stiffness at hips and knees, SVA 10-12° incline; Group 2A and 2B children with significant stiffness at knees or hips, SVA 15-19° incline. Pre-requisites for successful SVA optimization are optimum AFO design, optimum Angle of Ankle in AFO, optimum leg and foot segment lengths, optimum heel lever lengths and optimum toe lever lengths with optimum sole design, the latter being particularly important for high SVAs. The use of high SVAs for children with stiffness seems counterintuitive but the increased incline of alignment of the SVA facilitates the ability of the thigh to become vertical and inclined. This in turn facilitates the creation of knee and hip extending moments and knee and hip extension. It is imperative when using high SVAs that children are also given optimum heel and toe levers and sole designs. Children who require SVA alignments above 15° incline usually walk with assistive devices.

Part 1 (Owen, 2014) Appendix 1 details the publications that have recommended or optimised SVAs. Those that used kinematic or kinetic analysis to optimise SVAs had findings that concur with these guidelines. Indeed the first paper published on polypropylene AFOs recommended 10° incline, based on a theoretical justification (Jebsen et al, 1970). Also, Pratt et al (2011) undertook a study to investigate normative shank kinematics data for 11 typically developing children aged 5-16 years.

Figure 8. Examples of tuning AFOFC’s (Owen 2004c)
They demonstrated that at midstance, at 30% GC, the mean SVA for the group was 11.4° inclined. The authors concluded that this data provided supportive evidence for the results of Owen (2002, 2004a).

**Step 6 B - Tuning Exit from Temporal Midstance**

The kinematics and kinetics of exit are optimised by the choice of stiffness and profile of the sole of the footwear.

The principal designs that are being manipulated are:
- the length of the toe lever;
- the flexibility or stiffness of the AFO and footwear at the MTPJs;
- the design profile of the sole of the footwear.

The various designs manipulate the length of the toe lever and foot kinematics, in particular the timing of heel rise. This, in turn, manipulates the position of the centre of pressure (CoP) of the ground reaction force (GRF) and shank kinematics, which, in turn, can manipulate more proximal segment and joint kinematics and kinetics.

The longer the toe lever the later the heel will rise. The MTPJs on a normal foot are at 72% the length of the foot. If the anatomical foot is not able to provide the optimum length of toe lever, in that it is short or it is aligned in plantarflexion or both, then a longer effective foot needs to be created by the use of stiff rocker soles and a toe lever that is appropriate for the height of the patient. Sometimes it is helpful to have a longer than normal foot length for patients with stiffness at the knees and hips.

The guidelines for criteria for a flexible MTPJ free design outlined in Step 5 apply for determining whether a stiff or flexible sole will be optimum. If stiff rockers are used the type of rocker design will need to be determined (stiff rounded or stiff point loading) and all stiff rockers will need their position optimised.

For standing a 100% or greater rocker position can be used. When stepping, a 100% rocker could be used if only very short steps are required. If full or near full step lengths are required then the heel has to be allowed to rise and at the optimum percentage of the GC. For walking with full gait cycles a guideline follows, it is based on an early study (Owen, 2004d) and many years experience of tuning AFOFCs on a video vector gait laboratory.

If Group 1 patients need a stiff rocker, a position of 70-75% is usually sufficient to normalise foot and shank kinematics, prevent knee hyperextension and excessive knee extending moments. If rockers of less that 70% are needed to control gait they may make standing unstable, so a compromise may be needed.

If Group 2 patients need a stiff rocker, which they often do, a position of 75-95% will usually normalise foot and shank kinematics. The position of rockers depends on the stiffness at hips and knees and step length. If the patient has no or a little stiffness at the knees and hips and small step lengths, up to a 95% rocker can be used but longer step lengths require a 75-85% rocker. If the patient has stiffness at the knees and hips, from joint stiffness or increased tone, a rocker at 85-95% is needed, the position depending on the degree of stiffness and the step length. Patients with considerable stiffness and short step lengths require a 90-95% rocker. Patients with stiffness but normal or near normal step lengths require an 85-90% rocker.

‘Point loading rocker’ profiles (PLR) have additional biomechanical controls for TST compared to rounded rocker profiles (RR), (Figure 7), (Owen 2004b, 2014). Firstly, once heel rise occurs the CoP is harnessed at the PLR unlike a RR design when the GRF moves forward along the rocker. The harnessing of the GRF at the floor facilitates GRF alignment posterior to the hip and improved hip extending moments. Secondly, PLRs maintain their optimised position better than RRs, so control of standing, stepping and gait is maintained over time. Rockers need to be angled if the foot progression angle is significantly internally or externally rotated, to bring the line of the rocker 90° to the line of progression.

The sole must be deep enough to ensure sufficient ‘toe spring angle’ (TSA). For full gait cycle step lengths a TSA of 30° is required, shorter steps require less. A small study found that the mean TSA was 33°, range 18-50° (Owen, 2004b). TSAs in excess of 30° occurred by virtue of the position of a long rocker on a deep sole.

**Step 6 C - Tuning Entrance to Temporal Midstance**

The kinematics and kinetics of entrance are optimised by the choice of stiffness and profile of the heel of the footwear.

The principal designs that are being manipulated are the:
- length of the heel lever;
- flexibility or stiffness of the heel;
- design profile of the heel.

Patients may require negative, cushion, plain or positive heels to normalise foot and shank kinematics (Figure 7; Owen 2014). These design variables manipulate the length of the heel lever and
consequently the position of the point of application of the GRF and the moment arms created at the ankle, knee and hip. These, in turn, influence the angular velocity of the foot and shank segments during entrance. Positive heels create faster and negative heels slower, foot and shank segment kinematics (Owen, 2004c).

Conclusion

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 ICF-CY. 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 type 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, stiffness and profiles of the prescription - the algorithms and the clinical reasoning for the algorithms presented in Part 1 and Part 2 of this paper help achieve optimisation of dosage; 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, which will depend on the intended outcomes in all domains of the ICF (Brehm, 2011; Harlaar et al 2010).

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