Study of composite elastic elements for transfemoral prostheses: the MyLeg Project
Tabucol, Johnnidel

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CHAPTER 2

BIOMECHANICS OF HUMAN ANKLE-FOOT

Abstract
In order to design an ESR prosthesis made of elastic elements, it is necessary to know the stiffness they must have to make the prosthesis work like a healthy human foot. To know the necessary stiffness, it is necessary to know the rotations that a healthy human foot has during the walk. In addition, it is also necessary to know the loads to which the foot is subjected during the stance phase. In order to determine the abovementioned stiffness and to understand in general the biomechanics of human gait, in this chapter anatomical terms including reference planes, axes and directions of motion, degrees of freedom of the ankle-foot system will be defined. In addition, a brief description of the gait cycle will be given, subdividing it into sub-phases and events. After defining some walking parameters, the values of the foot rotations in all directions of rotations and ground reaction forces exchanged between the foot and the ground during the stance phase will be provided. This latest information will subsequently be reconsidered as biomechanical requirements for prosthetic design.

2.1 Introduction

Human biomechanics is a branch of bioengineering that focuses primarily on the study of human movement involving various types of physical movements. It has a multidisciplinary nature and involves the simultaneous application of knowledge in the medical, biological and engineering fields. The term gait analysis is the biomechanical research area that deals with shedding light on the functioning of human locomotion: walking. Walking can be defined as a method of locomotion that involves the use of two legs, alternatively, to provide both support and propul-
sion [2] and is one of the most natural expressions of motion behavior. Although
the act of walking is a spontaneous gesture in our daily lives, it is a complex
activity and is the result of a synergy involving structures and functions of the
neuro-musculoskeletal system of the human body [3]. The objective of the analysis
of the gait is to study the movements of the body segments participating in the
motion, or how they are performed, to derive the moments and forces acting at
the level of the articulations together with the joint kinematics that they generate.
The final result can be expressed by a set of main parameters that characterize the
gait cycle, useful objective means to discriminate a normal gait from an abnormal
one.

The set of quantitative and qualitative information obtained from the analysis
of the gait are useful in the two main applications of biomechanics: (i) in the
medical field, where clinical evaluations based on quantitative parameters obtained
from an analysis of the path taken on the pathological subject can take decisions
and intervene in the correction of the cycle before the occurrence of potential
injuries, or the worsening of pathology; (ii) in the field of robotics, where the
results obtained from the kinematic and dynamic study of human walking become
useful information for the design of humanoid robots or prosthetic limbs. For the
present work, the interest is on the design, optimization, realization and testing of
prostheses for the lower limb, in particular of the ankle-foot complex.

2.2 Anatomical Terms

A reference to human anatomy is necessary to highlight the spatial distribution
of the constituent parts of the human body. In describing the motion of the body
segments during gait, anatomical terms are used that define their orientation:
position terms are used for the characterization of any part of the body, and in
terms of movement to indicate the type of movement and the direction in which
it occurs. Both terms are defined in reference to a condition whereby the human
body is in the anatomically neutral position, namely: standing upright, with the
upper limbs applied to the sides of the trunk and the lower limbs aligned [4]. From
this anatomical position, the axes and reference planes can be defined.

2.2.1 Reference Planes and Axes of Motion

The position of any part of the human body can be defined by reference to three
orthogonal planes [4,5]: the sagittal, frontal and transverse planes, shown in Figure 2.1. The sagittal plane is considered the most relevant, since it includes the
direction of motion. Taking into consideration the bilateral symmetry of the hu-
man body (it is also called plane of symmetry), the sagittal plane is orthogonal
to the ground and divides the body into the two right and left halves, approxi-
mately symmetrical. The frontal plane is also vertical, orthogonal to the previous
one and divides the body or the body segment into a front and a rear. Finally,
the transverse plane is orthogonal to the two previous planes and parallel to the ground: it divides the body into an upper and a lower part.

In relation to a conventionally established centrality point at the intersection of the three anatomical planes, two useful terms may be defined to describe the position of the body segments in relation to the transverse plane, namely proximity or distance from it [5]: the proximal term and the distal term. Proximal is used to denote a body segment closer to the point of origin, i.e., closer to the center of the body. Distal is used to indicate a body segment located further away from the point of origin, i.e., 'farther away from the centre of the body'.

The axes of motion (or anatomical axes) are identified by the intersection of the planes previously considered and constitute an orthogonal tern of axes that originates in the center of body mass. The sagittal axis is defined by the intersection of the sagittal and transverse planes. The longitudinal axis is formed by the intersection of the frontal and sagittal planes. And finally, the transverse axis is situated at the intersection of the frontal and transverse planes.

### 2.2.2 Ankle-Foot Degrees of Freedom

The relative motion between the body segments in the sagittal plane is characterized by the following terms [5]: (i) flexion and (ii) extension. Flexion and extension correspond to the decrease and increase of the inner angle formed by two adjacent segments, respectively. In the case of the rotation of the ankle-foot system in the sagittal plane, the flexion is called dorsiflexion, while the extension is called plantarflexion. The two rotations are shown in Figure 2.2a. The ankle-foot system rotates also in the frontal and transverse planes, and these motions are also key movements [6]. The inward rotation of the foot in the frontal plane is called inversion, while the outward motion is called eversion (Figure 2.2b). Concerning the transverse plane, the inward rotation of the foot is called adduction, while the motion in the opposite direction is called abduction (Figure 2.2c). Considering the axes of motion shown in Figure 2.1, if the foot is approximated as a single
rigid segment, the dorsiflexion-plantarflexion rotations occur around the $y$-axis, while the inversion-eversion and adduction-abduction occur respectively around the $x$-axis and $z$-axis.

2.3 Gait Cycle

Having defined reference planes, axes and directions of movement, the gait cycle can be described. The gait cycle represents the functional unit of reference in the analysis of the walk. The basic requirements for walking are two [7]: (i) Periodic movement of each foot from one supporting position to the next. (ii) Sufficient ground reaction forces applied through the feet to support the body.

For a healthy subject, the periodicity of the walk is considered a valid initial hypothesis from which to start. It can therefore be traced back to the study within a single cycle of walking since it is assumed that these characteristics are repeated cycle after cycle. In reality this is not exactly accurate, they are expected to differ slightly in previous and subsequent cycles. With this hypothesis, the contralateral limb will assume half-cycle offset values from the homolateral limb [7].

The gait cycle is defined as the time interval confined between two successive initial contacts of the same foot, and represents the temporal reference in which all other mechanical events and muscle activity are described. For the study of a normal walk it is usual to first identify the temporal event of beginning of the cycle of the step, conventionally taken as the instant of initial contact (heel-strike) of the heel of the right foot.

2.3.1 Main Phases of the Gait Cycle

The stance phase indicates the time interval in which the foot shares at least one point of contact with the ground. It goes from the initial contact of the heel to the detachment of the toe from the ground. This stage usually represents about 60%
of the walking cycle, as average. The swing phase indicates the interval of time that elapses between two successive steps of stance, that is during the oscillation that is making the limb raised from the ground in the direction of walking, that ends in the instant of support to the ground, coincident with the beginning of the next phase of stance. This phase usually occupies the remaining 40% of the gait cycle.

**Subdivision of the Stance Phase in Initial Double Support, Single Support and Final Double Support**

The limb in contact with the ground performs the function of supporting the weight of the body, while the counter-lateral limb advances in the direction of motion swinging up to the support. This motion alternately follows between the two limbs to compose what it is called ‘walk’ [8]. The gait cycle starts with an initial double support (*initial double support*) where both limbs are in contact with the ground; the reference limb (black leg in Figure 2.3) is starting the stance phase while the opposite limb (grey leg in Figure 2.3) is preparing for the start of the swing phase (*Figure 2.3a* and *Figure 2.3b*). This phase is important because there is an exchange of support roles from one foot to another while they are both in contact with the ground. Usually this interval covers the initial 10% of the cycle. The single support phase (*single support*) begins with the detachment from the ground of the counter-lateral limb (*Figure 2.3c*), ready to swing to allow to carry forward the center of gravity of the body. Normally this interval covers 40% of the cycle. Finally, there follows a phase of double terminal support (*final double support*) in which the limb taken as a reference is in the final stage of the stance phase (*Figure 2.3f* and *Figure 2.3g*) while the opposite limb is in its initial stage of the stance phase.

![Figure 2.3: Subdivision of the Stance Phase.](image)

**Sub-Phases of the Gait Cycle**

A further subdivision of the two main phases of the cycle is made taking as discriminating the main events of the step. The purpose of this subdivision is to identify
the functional meaning of events within the cycle of walking. It is essential to analyze in detail the mechanics of movements between the various rigid limb members at the level of the main joints, such as the hip, knee and ankle joint. In fact, a correct gait requires a correct correlation between the relative movements and the functionality that the locomotor apparatus intends to pursue in each sub-phase (synergic movement of participants in the motion). The acceptance of the load, the single support and the advancement of the limb are the necessary conditions for the cycle to occur [8].

The subphases with which the cycle of walking can be divided can be obtained by adopting one of the following two terminologies: the traditional terminology and the Rancho Los Amigos (RLA) system [9].

Traditional terminology has developed as an interest in the rehabilitation of gait developed after World War II in an effort to improve the quality of lower limb prosthetics. It describes walking in terms of discrete and momentary events, such as heel contact (heel strike) and toe detachment from the ground (toe-off). It has been shown to be valid also for cases of transfemoral amputees, while it is not applicable for some pathological subjects, where for example the contact with the heel may not occur in the initial contact. The RLA terminology that describes the walk more in terms of processes and features, such as loading response or initial contact. Its use is becoming more and more a standard due to the fact that being more generic allows a better understanding of the common characteristics of the normal and abnormal gait and favors the comparison. It is valid and applicable to any type of gait.

**Sub-Phases of the Gait Cycle according to RLA**

![Figure 2.4: Sub-Phases of the Stance Phase according to RLA.](image)

The sub-phases of the stance phase, according to RLA are:

- **Initial Contact**: the limb is positioned so as to begin the support with the rolling of the heel. It includes the first moments when the foot comes into contact with the ground, marking the beginning of the support phase (Figure 2.4a). The relative position that the body segments assume at the
impact promotes initial stability and determines the mode of response to the load, which during the double support is shared with the counter-lateral limb. The hip is flexed, the knee is extended and the segment of the foot is neutral, ready to facilitate the rolling of the heel.

- **Loading Response**: impact absorption, stability under load and preservation of progression. From the initial contact (Figure 2.4a) until the end of the double support (Figure 2.4b), the complete transfer of the weight on the homolateral limb happens thanks to the bending of the knee, necessary for the absorption of the energy procured by the impact, together with a foot plantarflexion, accompanied by the rolling of the heel, which is interrupted by the complete support of the surface of the foot on the ground (flat foot condition).

- **Mid Stance**: progression on the foot in support and stability of the trunk and limb. The phase of single support begins Figure 2.4b), the opposite limb (grey leg in Figure 2.4) advances in its swing phase (Figure 2.4c) while the extension of the knee and hip of the homolateral limb allow the progression of the body on the support foot.

- **Terminal Stance**: progression of the body over the foot in support. The final stage of the single support includes the final swing of the opposite limb (Figure 2.4c) and the heel lifting (called also heel-off) of the considered limb (Figure 2.4d). The knee continues the extension and then flexes slightly. The simultaneous extension of the hip, together with the rolling of the forefoot allow to bring the center of gravity of the body forward beyond the foot in support.

- **Pre-Swing**: positioning of the limb for the swing. It goes from the initial contact of the contralateral limb (Figure 2.4d) to the detachment of the toe of the considered foot (Figure 2.4e). It begins the transfer of the load on the opposite limb, while the reference limb prepares to the oscillation increasing the bending of the knee and the plantarflexion of the foot, configuration adopted to generate a thrust necessary to the forward thrust of the limb that takes place in the next step.

The sub-phases of the swing phase, according to RLA are:

- **Initial Swing**: advancement of the limb and lifting of the foot from the ground. It starts with the lifting of the foot from the ground (Figure 2.5a) and includes the initial progression of the limb characteristic of the swing phase. At the same time as this progress, the hip is flexed and the knee is flexed. This phase ends approximately when the limb in progression is parallel to the foot in support (Figure 2.5b).
• **Mid Swing**: advancement of the limb and lifting of the foot from the ground. In this phase the progression movement continues, where the swinging limb is carried beyond the line of gravity of the body thanks to the flexion of the hip. It ends with a movement of extension of the knee that allows to bring the tibia in an approximately vertical position (Figure 2.5c).

• **Terminal Swing**: complete advancement of the limb and preparation of the limb for support. The last subphase of swing phase begins with the vertical tibia and ends with the beginning of a new cycle, that is with the support of the heel on the ground (Figure 2.5d). The further extension of the knee prepares the limb for support.

**Sub-Phases of the Gait Cycle according to Traditional Terminology**

• **Heel Strike**: moment during which the heel of the foot projected forward is in contact with the ground at a single point. It gives rise to the beginning of the cycle.

• **Flat Foot**: instant when the entire sole of the foot is in contact with the ground, and is identified by the support of the Metatarsal and Toe Strike, that for simplification can be assumed contemporary.

• **Mid Stance**: the moment when the swinging counter-lateral limb exceeds the supporting foot.

• **Heel Off**: the moment when the heel terminates contact with the ground.

• **Toe Off**: the moment when the contact of the toes from the ground ends.

• **Early Swing**: interval that is placed in the initial phase of swing, confined between the Toe Off and the Mid Swing. The limb is lifted from the ground and accelerated forward.

• **Mid Swing**: the moment when the homolateral limb in swing passes the body;
• *Late Swing:* interval that is placed in the final phase of swing, confined between the Mid Swing and the initial contact of the new cycle. The limb is decelerated in the forward direction in preparation for impact.

**Events and Sub-Phases of the Stance Phase defined by the Author**

![Figure 2.6: Events and Sub-Phases of the Stance Phase defined by the Author.](image)

In this Section, the author provides the terminology for the stance phase that will be used to explain in the following Chapters the working principle of prosthetic feet. The terminology used by the author is very similar to traditional terminology. Only the stance phase is taken into consideration as the swing phase is not interesting for the design of the foot prosthesis and for the optimization of its stiffness.

Before defining the sub-phases of the stance phase, events are first defined. To better understand, both events and sub-phases are shown in **Figure 2.6:**

- **Heel Strike:** shown in **Figure 2.6a,** is the moment during which the heel of the foot projected forward is in contact with the ground at a single point. It is basically the first contact (through the heel) between the foot and the ground, therefore it is considered the beginning of the gait cycle.

- **Toe Strike:** shown in **Figure 2.6b,** is the moment when the toe of the foot comes in contact with the ground. For simplicity, metatarsal strike and toe strike are assumed as a contemporary event. From here on, only toe strike will be mentioned.

- **Heel Off:** shown in **Figure 2.6c,** is the moment when the heel comes off the ground.

- **Toe Off:** shown in **Figure 2.6d,** is the moment when the toe comes off the ground. As for the metatarsal strike and toe strike, also in this case, the metatarsal off and toe off are considered by the author as two events that
take place simultaneously. Therefore, from here on, only the toe off will be mentioned.

Defined the events, then also the sub-phases of the stance phase can be defined:

- **Early Stance**: it’s the sub-phase that goes from the heel-strike (Figure 2.6a) to the toe-strike (Figure 2.6b). As can be seen later, presenting the rotation of the foot around the ankle in the sagittal plane, during this sub-phase, the foot rotates in plantarflexion (extension).

- **Mid Stance**: is the sub-phase that begins when the toe-strike (Figure 2.6b) occurs and ends when the heel comes off the ground (heel-off – Figure 2.6c). During this sub-phase, you have the so-called flat foot, i.e., the foot is entirely resting on the ground, from the toe to the heel. During this sub-phase, the foot changes from being in plantarflexion to being in dorsiflexion, performing a flexion movement (the frontal angle between the tibia and the foot is reduced).

- **Late Stance**: this sub-phase starts from the moment the heel-off (Figure 2.6c) takes place and ends when the toe-off also takes place (Figure 2.6d). During this sub-phase, the healthy leg muscles inject energy to accomplish the plantarflexion that serves to complete the stance phase of the current gait cycle and facilitate the continuation of the gait cycle of the other foot. In literature and biomechanics in general, this sub-phase is also called push-off.

### 2.3.2 Gait Cycle Parameters

#### Time Parameters

<table>
<thead>
<tr>
<th>Stride Time Reference Leg</th>
<th>Step Time Reference Leg</th>
<th>Step Time Opposite Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Support Time</td>
<td>Single Support Time</td>
<td>Double Support Time</td>
</tr>
<tr>
<td>(Initial)</td>
<td>Reference Leg</td>
<td>(Final)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Opposite Leg</td>
</tr>
</tbody>
</table>

Figure 2.7: Gait Cycle Time Parameters.

The gait cycle is characterized by several temporal parameters, where the main ones are [10]:

• **Step Period or Step Time:** is the time interval, expressed in seconds, between the heel-strike (Figure 2.7a) of the reference foot and the analogous opposite limb event (Figure 2.7c).

• **Stride Period or Stride Time:** is the time interval, expressed in seconds, between two consecutive heel-strike events of the same foot, which means the time from the event shown in Figure 2.7a to the event shown in Figure 2.7e.

• **Single Support Time:** is the time interval in seconds during which only a single foot touches the ground. It is confined between toe-off (Figure 2.7b) and the heel-strike (Figure 2.7c) of the counter-lateral limb.

• **Double Support Time:** is the time interval in seconds during which both feet are in contact with the ground. The initial double support interval is limited by the events: heel-strike of the reference limb (Figure 2.7a) and the toe-off of the opposite limb (Figure 2.7b). With the periodicity hypothesis it will be equal to the final double support interval (From Figure 2.7c to Figure 2.7d)).

**Space Parameters**

![Gait Cycle Space Parameters](image)

Figure 2.8: Gait Cycle Space Parameters.

The gait cycle is also characterized by spatial parameters, where the main ones are:

• **Step Length:** it’s the distance covered in the progression direction during a step period, which means the distance covered from the heel-strike of the reference leg (Figure 2.8a) to the heel-strike of the opposite leg (Figure 2.8b).

• **Stride Length:** it’s the distance covered in the progression direction during a stride period, which means the distance covered from the heel-strike of the
reference leg (Figure 2.8a) to the next heel-strike of the same leg (Figure 2.8e).

With the hypothesis of the periodicity of the walk, if the person is walking in a straight line it can be said that the length of the stride corresponds to twice the length of the step and will be equal for both limbs.

2.4 The Ankle-Foot Rotation

2.4.1 The Ankle-Foot Range of Motion

In Section 2.2.2, the rotations of the foot around the ankle were briefly presented. In a simplified representation, the ankle is taken as a spherical joint with a single rotation center. Actually, the foot is not just a segment attached to the shank through the ankle joint. It is composed in total of 26 bones, if also the two bones of the lower leg are considered, i.e. tibia and fibula, for a total of 33 joints (Figure 2.9). Each with its own range of motion, but in theory the foot undergoes rotations around these joints, when the foot is resting on the ground and is loaded by the weight force and inertia force.

In [11], Brockett reported that many authors consider the tibiotalar joint as a hinge with axis parallel to the transverse axis, and thus a joint around which the foot rotates only in the sagittal plane. According to Brockett, other authors have suggested that the tibiotalar joint is multi-axial, as in their studies they found that the foot rotates inwards during dorsal rotation, while it rotates outwards during plantarflexion. However, according to [12] and [13] these rotations occurring during dorsiflexion and plantarflexion are simply due to the (single) tibiotalar axis not parallel to the transverse axis (Figure 2.10).

According to one study, the range of motion of the ankle varies significantly between individuals due to the different activities of daily living [14]. The predominant degree of freedom of the ankle occurs in the sagittal plane, with the dorsiflexion/plantarflexion occurring mainly around the tibiotalar joint. Several studies have shown that in the sagittal plane, the foot rotates around the ankle for a total of 65-75 degrees [14, 15]. In the frontal plane, the total range of inversion/eversion is about 35 degrees. However these values are not achieved in
the various activities of the daily living, and especially in the regular gait on a horizontal surface. In the next section, the ankle ranges of motion during normal gaiting on a horizontal plane are reported.

Figure 2.10: The Tibiotalar Joint [11].

2.4.2 The Ankle-Foot Rotation in a Gait Cycle

2.4.3 Dorsiflexion and Plantarflexion

Many studies of normal walking have been reported in the literature. Several conditions have been studied to see their influences on ankle rotation. Most of these studies concerned almost only the sagittal plane. From these studies, it has been shown that the ankle range of motion while walking on normal ground is significantly influenced by several factors, such as walking velocity, age and gender [16–23] - Figure 2.11. However, the curves that describe the behavior of the ankle rotations for different conditions follow the similar path. Thus, the healthy human ankle rotation has an initial plantarflexion during early stance (from 8% to 12% of the gait cycle) that goes from $-1^\circ$ to $-8^\circ$. The maximum dorsiflexion before heel-off occurs from 60% to 70% of the gait cycle and goes from $6^\circ$ to $16^\circ$ of ankle rotation.

Figure 2.11: Dorsiflexion-Plantarflexion during Normal Gait for several walking conditions.
2.4.4 Inversion and Eversion

![Graph showing Inversion and Eversion during Normal Gait.](image)

For rotation in the frontal plane of the foot, during a gait cycle on horizontal and regular plane, the maximum values of eversion and inversion of the foot change, as the points with respect to the gait cycle in which these maximum values are reached change. However, as seen in the graph of Figure 2.12, as it happens for the dorsiflexion and plantarflexion, these values have a similar course both during the stance phase and the swing phase. Unlike the dorsiflexion and plantarflexion, the design of MyFlex feet do not aim to achieve these objectives of rotation in the frontal plane. However, as will be seen in the following chapters of this thesis, the prostheses have been designed with the aim of not having torsional stiffness in the frontal plane and in the transverse plane tending to infinity.

Plotted values in Figure 2.12 were taken from the public dataset published by Fukuchi et al. in [20]. The lightest grey curve, S01 in the legend, represents the progression of the rotation of the foot in the frontal plane at the lowest walking velocity, while the darkest grey curve, S08 in the legend, represents the highest walking velocity. The other curves represent intermediate walking velocities.

2.4.5 Abduction and Adduction

The same concept explained for the foot inversion/subversion also applies for the abduction/adduction.

Plotted values in Figure 2.13 were taken from the public dataset published in Fukuchi et al.’s article [20]. The lightest grey curve, S01 in the legend, represents the progression of the rotation of the foot in the transverse plane at the lowest walking velocity, while the darkest grey curve, S08 in the legend, represents the highest walking velocity. The other curves represent intermediate walking velocities.
2.5 Vertical Ground Reaction Force

Like kinematics, the ground reaction force is influenced by several factors. Normalizing with respect to weight, it has been seen how the ground reaction force is strongly influenced by the walking speed [20], as also shown in Figure 2.14. The lightest grey curve, S01 in the legend, represents the progression of the vertical ground reaction force at the lowest walking velocity, while the darkest grey curve, S08 in the legend, represents the highest walking velocity. The other curves represent intermediate walking velocities. The behaviour of the ground reaction force curves remains the same, even if the maximum and minimum values change and when these values are reached during the gait cycle. And again, as we have seen, the ground reaction force has an M-shape. The first peak occurs during early stance, while the second peak occurs at the end of mid stance. The first peak,
according to the data considered, is between 95% and 130% of the body weight of the person walking, while the second peak measures between 95% and 105% of body weight. The question that could arise spontaneously could be how the ground reaction force is lower than the body weight: this happens when the peak is reached when the other foot is still (first peak) or already in contact (second peak) which means the condition of walking is in double support.

2.6 Conclusion

In this chapter, anatomical terms including reference planes, axes and directions of motion, degrees of freedom of the ankle-foot system were defined. In addition, a brief description of the gait cycle was given, subdividing it into sub-phases and events to make the explanations clearer about the working principle of prosthetic feet, explanations given in the following chapters. After defining some walking parameters, the values of the foot rotations in all directions of rotations and ground reaction forces exchanged between the foot and the ground during the stance phase were provided. This latest information will subsequently be reconsidered as biomechanical requirements for prosthetic design.

In short, and to respond also to RQ1 (Section 1.3.1), the rotations that a prosthetic foot must have and the loads to which it is subjected during a gait cycle are the following:

- **Plantarflexion at Toe-Strike**: between 1 degree and 8 degrees.
- **Dorsiflexion at Heel-Off**: between 6 degree and 16 degrees.
- **Ground Reaction Force first peak**: between 95% and 130% of the body weight of the user.
- **Ground Reaction Force second peak**: between 95% and 105% of the body weight of the user.

The values of dorsiflexion and plantarflexion and of the loads corresponding to them vary according to the final user; therefore, the biomechanical objectives in the design of prosthetic feet can vary. However, they must be included in these values of rotations and ground reaction forces if the aim is to replicate the healthy human foot behavior during stance phase.