

Interlimb symmetry of traumatic unilateral transtibial amputees wearing two different prosthetic feet in the early rehabilitation stage

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Abstract—This study evaluated the SACH and the Greisinger Plus prosthetic feet, in terms of the symmetry provided between the lower limbs, in the case of unilateral transtibial amputees 16.3 weeks from the time of limb fitting and 38.9 weeks from surgery. Sagittal plane gait analysis was carried out for nine right-limb traumatic amputees. In all examined cases, the spatial and temporal parameters measured were significantly improved. When the symmetry indexes of the same parameters calculated with three different methods were considered, significant improvement was observed for the hip and ankle ranges of motion and the stance phase period. However, no significant differences were found for the symmetry indexes of the knee range of motion, cadence, and walking speed. In addition, for most spatial parameters, the statistical significance varied considerably among the three methods used for the analysis of symmetry.

Key words: gait symmetry, prosthetic feet, transtibial amputees, traumatic amputees.

INTRODUCTION

Normal human walking can be defined as “a method of locomotion involving the use of the two legs, alternately, to provide both support and propulsion” [1]. By relying on coordinated muscle action and intact foot and ankle structures, normal individuals control the acceleration and deceleration of the foot and shank, thereby achieving weight-bearing stability while preserving forward progression [2]. On the other hand, amputees

depend on an artificial limb for support of body weight and joint mobility during gait. In many cases, individuals with transtibial prostheses demonstrate walking difficulties, accompanied by asymmetry between the involved and uninvolved limbs. These problems can be partly attributed to the behavior of their prostheses. In a survey of veterans and nonveterans with lower-limb amputation, fit and comfort were reported as two of the most important functional characteristics of their prostheses [3]. The choice of appropriate prosthetic components as part of the prosthetic prescription is critical to user comfort [4].

Prosthetic foot components have a significant impact on several variables that describe lower-limb movement [5]. The solid ankle cushion heel (SACH) foot historically has been the most commonly prescribed conventional prosthetic foot, despite its disadvantages. To overcome the

Abbreviations: PTB = patellar tendon-bearing, ROM = range of motion, SACH = solid ankle cushion heel, SD = standard deviation.

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limitations of the conventional types, developers have introduced new prosthetic feet during the last decade. While the range of prosthetic feet available has broadened, the selection of the most appropriate foot for each patient has become more difficult. The goals of any prosthetic treatment include support of body weight, effective control of the motion of joints, and provision of stability. New prosthetic feet should provide increased range of motion of the joints, better shock absorption, and lower metabolic energy cost.

Several studies have examined the effect of different prosthetic feet by measuring spatial and temporal parameters during gait. When the SACH foot is used in transtibial amputees, its kinematic behavior has been compared with the so-called "dynamic elastic response" foot. The SACH foot exhibits reduced range of motion of the ankle joint, decreased single support time, lower self-selected walking speed, and increased late stance duration asymmetry [6–12]. In addition, the SACH foot is reportedly appropriate for low-activity-level amputees requiring limited dorsiflexion [13], and the walking disability, classified by the patients, was not significantly different between SACH and dynamic elastic response feet users, when indoor walking was considered [14]. Furthermore, several studies have investigated the energy cost of transtibial amputees wearing different types of prosthetic feet [7,13,15–17]. However, to the best of my knowledge, no literature currently exists that compares the behavior of the SACH foot and the Greissinger Plus foot for traumatic unilateral transtibial amputees in the early rehabilitation stage, in terms of the interlimb symmetry provided during gait, by indexes calculated with three different methods.

The present study attempts to provide useful data that will help the professionals involved in the rehabilitation of amputees to choose among different prosthetic feet by fitting the same individuals with two types of feet and analyzing their spatial and temporal gait parameters symmetry via an off-line video analysis system.

METHODS

Design

The independent variable used in this study was the type of prosthetic foot. Two types of prosthetic feet were used, the SACH foot and the Greissinger Plus foot. Both prosthetic feet were manufactured by Otto Bock

Orthopaedic Industry, Inc. (Duderstadt, Germany). The SACH foot was composed of a rigid longitudinal keel, a compressive wedge-shaped heel cushion (to provide energy absorption at impact), and a foot adapter (**Figure 1**). The Greissinger Plus foot was composed of a rigid longitudinal keel and a multiaxial ankle. The keel was longer than that of the SACH foot, due to the extra movement the ankle unit affords. The function of the ankle joint was based on a ring-shaped rubber (rocking rubber) and a cone-shaped bumper (joint retainer) that were compressed to control plantar flexion following heel strike and to provide a dorsiflexion limit in the late stance phase (**Figure 1**). The dependent variables were spatial (hip, knee, and ankle joint range of motion) and temporal (walking speed, cadence, and stance phase period) gait parameters and the correspondent symmetry indexes.

The gait data for both the disabled and nondisabled subjects were collected in the Biomedical and Rehabilitation Engineering Unit based at the National Institute for the Rehabilitation of Handicapped in Attica (Greece). The disabled subjects completed two sessions, one with each foot. The first testing session with the SACH foot was completed on the first day in the laboratory. The second testing session with the Greissinger Plus foot was held 1 week later, to ensure acclimation to the prosthetic foot. The reduction and statistical analysis of the data were carried out at the Centre for Biomedical Engineering based at the University of Surrey in Guildford (UK).

Participants

The nine male subjects who participated in this study had unilateral (right) transtibial amputation due to trauma. All amputees were wearing a patellar tendon-bearing (PTB) prosthesis with a soft removable liner. Inclusion criteria were (1) fitted with definitive prosthesis at least 4 months from amputation surgery (early in their

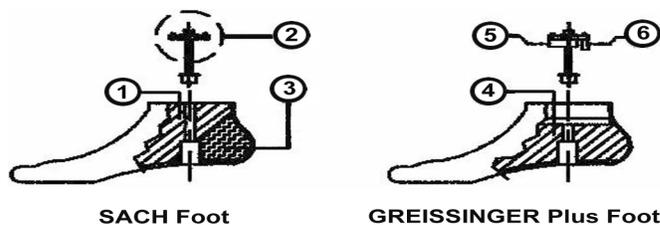


Figure 1. (a) SACH and (b) Greissinger Plus prosthetic feet: schematic view. 1 = keel, 2 = foot adapter, 3 = heel cushion, 4 = keel, 5 = rocking rubber, 6 = joint retainer.

postoperative phase), (2) fitted with and continuously wearing the prosthesis at least 3 months prior to gait analysis, (3) residual limb with no current complications, (4) intact limb with no current complications, (5) independent ambulation prior to accident, (6) ability to walk with the prosthesis independently without any additional technical aid, (7) right-handed and right-footed, (8) absence of any cognitive problems, and (9) absence of any other conditions that could limit walking ability.

The mean age of the amputees group was 54.3 years \pm standard deviation (SD) 2.1 years, their mean weight was 81.3 kg \pm SD 3.5 kg, and their mean height was 1.82 m \pm SD 0.04 m. The mean time from amputation surgery was 38.9 weeks \pm SD 3.1 weeks, and the mean time from limb fitting was 16.3 weeks \pm SD 5.8 weeks. Thirteen nondisabled male subjects also participated in the study. The mean age of the control group was 52.3 years \pm SD 11.3 years, their mean weight was 79.1 kg \pm SD 3.0 kg, and their mean height was 1.79 m \pm SD 0.03 m.

Fabrication and Fitting of Prostheses

The casting, rectification, socket lamination, assembly, alignment, and fitting of the prostheses for all participants were carried out by the same person (the author). The alignment procedures were carried out according to the instructions given by the manufacturer of the prosthetic components, with different designs of the two feet taken into account. After the bench alignment, the subject was asked to try the prosthesis with his own customary footwear of appropriate heel height. Subsequently, the subject underwent a preliminary static and dynamic alignment procedure to assure standing balance and the comfort of the prosthesis. On successful completion of the preliminary alignment, the amputee was trained in the use of the prosthesis and dynamic alignment.

Increased attention was paid during the transfer from the SACH foot to the Greissinger Plus foot, since alignment changes were required to minimize the alterations of the control of stability due to the differences in these two prosthetic feet. When the anteroposterior alignment was considered for both types of prosthetic foot, the middle of the foot was taken as the neutral position in the sagittal plane according to the instructions of the manufacturer (i.e., to increase the forefoot lever, the middle of the foot was positioned anteriorly to the weight-bearing line).

Measurement Procedure

Subjects were asked to wear dark-colored swimsuits made of elastic, nonreflective material. Six hemispherical retroreflective markers 19 mm in diameter were placed on both sides of each subject's body at specific anatomical points: fifth metatarsal bone, calcaneus, lower third of tibia, knee joint line, greater trochanter, and iliac crest (**Figure 2**). The markers were placed onto the predefined positions with hypoallergenic tape. The placement of the skin-mounted markers was consistent during all tests. The location of the anatomical landmarks was achieved as follows. (1) Fifth metatarsal bone: the marker was placed laterally over the head of the fifth metatarsal bone. (2) Calcaneus: the marker was placed at the heel, laterally of calcaneus, at the same horizontal plane with the fifth metatarsal bone marker. (3) Lower third of tibia: the marker was placed 30 mm proximally of the lateral malleolus along the fibula. (4) Knee joint line: the knee joint line was found via the lateral tubercle of tibia; the width of the lateral aspect of the knee (with the patella excluded) was divided into two equal parts and the marker applied in the middle. (5) Greater trochanter: the hip of the patient was flexed and adducted for the trochanter to become more prominent; the marker was then applied with the hip extended, i.e., without flexion. (6) Iliac crest: the marker was applied one-third of the distance between the anterior superior iliac spine and the posterior superior iliac spine. The above setup of the markers was chosen so that the relevant bony landmarks would be close to the skin with a minimum of flesh in between, in order to minimize skin movement artifacts.

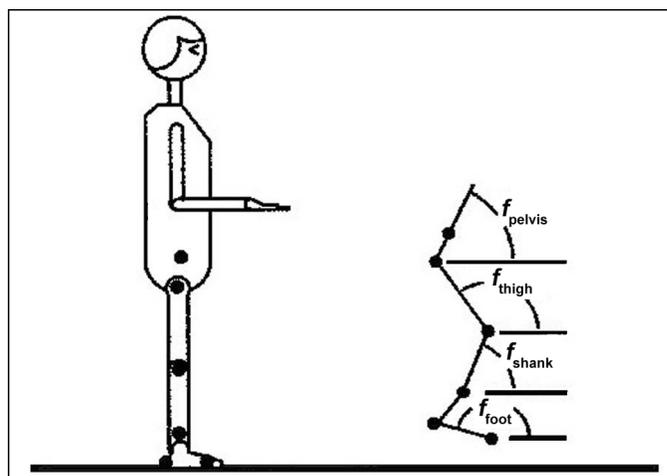


Figure 2. Marker positions and angle definitions.

During each testing session, and prior to actual image capturing, an orientation period was allowed for participants to practice walking under testing conditions; each participant was asked to walk on the 6.50 m × 2.90 m walkway four times at a self-selected speed. Then the participant's performance during two consecutive gait cycles was recorded at the sagittal plane (*X-Y*) with a charge-coupled device (CCD) camera (T-123A, Cohu, Inc.) at a capture rate of 60 Hz. The captured images were simultaneously digitized and analyzed with an image-processing system (VP110 video processor, Motion Analysis Corporation), and then the coordinates of the centroid of all markers at each frame were obtained. The camera was placed 5 m from the middle of the pathway, mounted on a tripod, and leveled to the ground with its optical axis perpendicularly oriented to the longitudinal axis of the pathway. The orientation of the camera lens was kept the same each time it was used. In addition, the image capture was initiated and terminated when predefined positions were crossed by the subject. In some cases, markers were obscured ("winked out" and reappeared) because of arm position and/or body orientation. Hence, the corresponding paths exhibited gaps. These gaps in the trajectories were filled by interpolation with the use of a spline.

Data Reduction

The *x*- and *y*-coordinates for all markers at each frame were smoothed at 8 Hz by a low-pass Butterworth digital filter. Since the filtered coordinates of the markers were known, the angles of the pelvis, thigh, shank, and foot segments could be derived (Figure 2). Then, the angles of the hip, knee, and ankle joints were calculated with the following equations:

$$\theta_{\text{hip}} = f_{\text{thigh}} - f_{\text{pelvis}} ,$$

$$\theta_{\text{knee}} = f_{\text{thigh}} - f_{\text{shank}} ,$$

$$\theta_{\text{ankle}} = f_{\text{foot}} - f_{\text{shank}} + 90^\circ .$$

The range of motion (ROM) of the named joint was calculated (in degrees) by subtraction of the minimum value of a specific joint angle from the maximum one. In addition, the step length (cm) and the step time (s) for each limb were calculated as follows: the step length and the step time of one (uninvolved or involved) limb as the dis-

tance and time by which the named limb moved forward in front of the other one, or the distance and time between the heel strike of the backward foot to the heel strike of the named foot. The stride time (s) was calculated by addition of the step times of the involved and uninvolved limb. The stance phase time (s) for each limb was calculated as the time between the first heel strike to toe-off. The walking speed (cm/s) for each limb was obtained by the distance covered in a given unit of time or by division of the step length of the named limb over the step time of the same limb. The cadence (steps/min) was calculated by division of the walking velocity over the step length and multiplication by 60. The stance phase period (% stride time) was obtained by division of the stance phase time by the stride time and multiplication by 100.

RELIABILITY OF DATA

For an evaluation of the accuracy of the measurement setup and method of analysis, a procedure similar to the one suggested by Richards [18] was followed.

The ability to measure the distance between two constantly visible markers moving on the sagittal plane was evaluated by recording of the motion of two 19 mm markers affixed to a rigid rod such that their centers were 400 mm apart; the rod was located on a calibrated plane and rotated about its center. During all reliability tests, the SD was less than 0.6 percent and the range difference less than 1.2 percent.

Symmetry

Several methods have been used to quantify symmetry [19–21]. Each gives different results, which might lead to varied conclusions; thus, it might be useful to present symmetry index values obtained with different methods. The symmetry indexes of the measured spatial and temporal parameters between the involved and the uninvolved limb were calculated with the use of the following methods.

Method I

The gait parameter measured for one limb (exhibiting the smaller value) was divided by the same parameter for the contralateral limb. The obtained result was then multiplied by 100:

$$\text{S.I.} = 100 * \min(P_R, P_L) / \max(P_R, P_L) ,$$

where S.I. stands for the symmetry index and P_R , P_L stand for the values of the gait parameter measured for the involved and uninvolved limb, respectively.

Method II

The absolute difference between the gait parameters measured for the right and left limbs was divided by 0.5 and multiplied by the sum of the values of the same parameter for the right and the left limb. The obtained result was then multiplied by 100 and subtracted from 100:

$$S.I. = 100 - [100 * |P_R - P_L| / (0.5 * |P_R + P_L|)] .$$

Method III

The absolute difference between the gait parameters measured for the right and left limbs was multiplied by 50 and divided by the difference between the maximum and minimum values of the same parameter measured in the control group. The obtained result was then subtracted from 100 (a method used by Motion the Analysis Corporation):

$$S.I. = 100 - [|P_R - P_L| (*50 / N_{\max(R,L)} - N_{\min(R,L)})] ,$$

where $N_{\max(R,L)}$ and $N_{\min(R,L)}$ stand for the maximum and minimum values of the correspondent gait parameter measured in nondisabled subjects.

Statistical Analysis

The unpaired *t*-test was used to characterize the difference of the temporal and the spatial parameters and their symmetry indexes observed between the amputees wearing a prosthesis with a SACH foot and those wearing a prosthesis with a Greissinger Plus foot. A two-tailed *p*-value of 0.05 or less was chosen to reflect statistical significance. When the *p*-value was between 0.01 and 0.05, the difference among the tested parameters was characterized as "significant." For *p*-values between 0.001 and 0.01, it was characterized as "very significant," and for *p*-values less than 0.001, "extremely significant." An improvement meant that the values came closer to the ones observed in the nondisabled group.

RESULTS

Typical graphs of the variation of the hip, knee, and ankle joint angles during a gait cycle for one of the examined amputees are shown in **Figures 3, 4, and 5**. The two

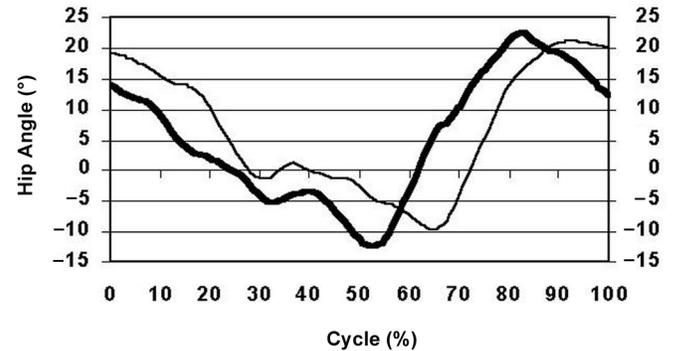


Figure 3.

Hip joint angular position of involved limb through complete gait cycle. Thick line = Greissinger Plus foot; thin line = SACH foot.

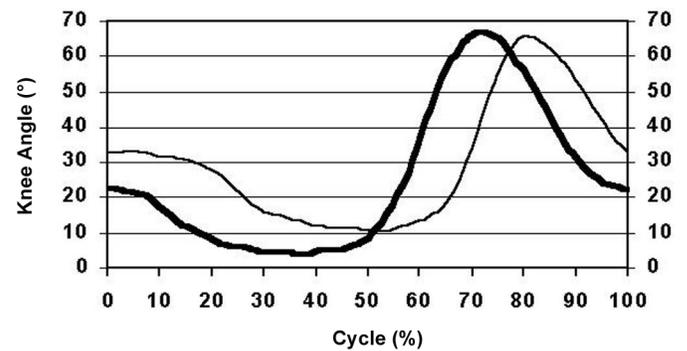


Figure 4.

Knee joint angular position of involved limb through complete gait cycle. Thick line = Greissinger Plus foot; thin line = SACH foot.

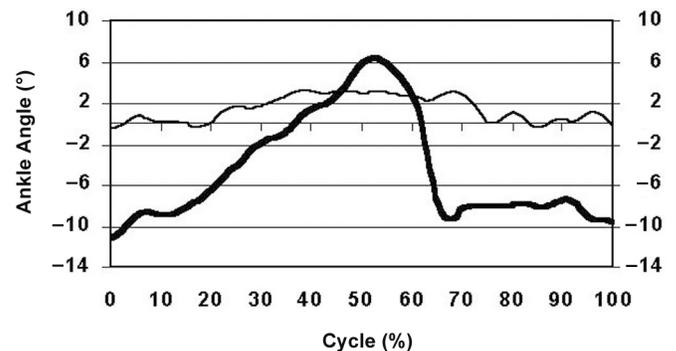


Figure 5.

Ankle joint angular position of involved limb through complete gait cycle. Thick line = Greissinger Plus foot; thin line = SACH foot.

curves in each graph correspond to the data obtained with the subject wearing a Greissinger Plus foot (thick line) and a SACH foot (thin line). In both cases, the knee was

flexed at heel strike (**Figure 4**). Therefore the hip was forced into increased flexion (**Figure 3**). This behavior was more prominent in the case of the SACH foot, where the hip was flexed almost 20° at heel strike. As expected, the ankle joint behavior improved when the Greissinger Plus foot was used (**Figure 5**). With the SACH foot, the ankle joint was continuously at a low-angle dorsiflexion, reaching a maximum of 3.0°. With the Greissinger Plus foot, the maximum dorsiflexion was 6.5°, and the maximum plantar flexion 11°, resulting in an ROM within the lower limits of the range of values observed during measurements with the nondisabled subjects.

The values of the calculated spatial and temporal parameters are presented in **Tables 1** and **2**. For the spatial parameters, the mean values of the hip, knee, and ankle joint ROMs of the involved limb were increased by 18.6, 9.7, and 128.1 percent when the Greissinger Plus foot was used. The observed differences were significant for the knee joint and extremely significant for the hip and ankle joints, as shown by the statistical analysis in **Table 1**.

In addition, the minimum (among the three methods used) increment observed for the symmetry index of the ROM of the hip, knee, and ankle joints was 1.9, 6.6, and 21.5 percent, respectively. However, a significant difference was found for the symmetry indexes of the hip and the ankle ROMs and not for the symmetry index of the knee ROM.

Furthermore, the symmetry index values varied considerably among the three different methods used to calculate them. When the symmetry of the hip ROM was considered, the resulting *p*-values for methods I, II, and III were 0.0460 (significant), 0.0532 (not significant),

and 0.3525 (not significant). This variation was more prominent in the symmetry indexes calculated for the ROM of the ankle joint, where the obtained *p*-values were 0.0322 (significant), below 0.0001 (extremely significant), and 0.1326 (not significant).

For the temporal parameters, the mean values of the walking speed and cadence of the involved limb were increased by 19.5 percent and 10.9 percent when the Greissinger Plus foot was used, whereas the stance phase period was decreased by 22.2 percent. The observed differences were significant for the cadence, very significant for the walking speed, and extremely significant for the stance phase period, as shown by the statistical analysis in **Table 2**.

In addition, the minimum increment observed for the symmetry indexes of the walking speed, cadence, and stance phase period was 0.89 percent, 1.3 percent, and 19.5 percent, respectively. However, significant difference was found for the symmetry index of the stance phase period only and not for the symmetry indexes of the walking speed and the cadence.

DISCUSSION

In most cases, the amputees' walking deviated from the so-called "normal" pattern. However, normal patterns vary from individual to individual and change with walking speed, age, weight, height, and other factors. Therefore, it is important to keep in mind one of the most outstanding characteristic of normal locomotion—that is, symmetry.

Table 1.

Spatial parameters (mean value ± standard deviation).

Parameter	SACH	Greissinger Plus	<i>p</i> -Value
Hip ROM (°)—R	28.0 ± 2.6	33.2 ± 2.5	0.0005 (ES)
Hip ROM S.I. (%)—I	86.7 ± 3.3	89.6 ± 2.3	0.0460 (S)
Hip ROM S.I. (%)—II	85.7 ± 3.9	89.0 ± 2.7	0.0532 (NS)
Hip ROM S.I. (%)—III	85.5 ± 4.4	87.2 ± 3.0	0.3525 (NS)
Knee ROM (°)—R	54.7 ± 5.3	60.0 ± 5.3	0.0499 (S)
Knee ROM S.I. (%)—I	86.2 ± 7.5	91.9 ± 4.9	0.0744 (NS)
Knee ROM S.I. (%)—II	84.9 ± 8.7	91.4 ± 5.2	0.0723 (NS)
Knee ROM S.I. (%)—III	80.6 ± 12.2	88.5 ± 7.0	0.1114 (NS)
Ankle ROM (°)—R	5.7 ± 1.3	13.0 ± 3.6	<0.0001 (ES)
Ankle ROM S.I. (%)—I	37.6 ± 10.7	52.2 ± 15.3	0.0322 (S)
Ankle ROM S.I. (%)—II	23.7 ± 3.1	63.5 ± 22.6	<0.0001 (ES)
Ankle ROM S.I. (%)—III	53.0 ± 12.2	64.4 ± 17.8	0.1326 (NS)
R = right (involved) limb	I, II, or III = method used to calculate S.I.	S = significant	ES = extremely significant
S.I. = symmetry index	NS = not significant	VS = very significant	

Table 2.Temporal parameters (mean value \pm standard deviation).

Parameter	SACH	Greissinger Plus	<i>p</i> -Value
Walking speed (cm/s)—R	47.6 \pm 6.8	56.9 \pm 5.1	0.0047 (VS)
Walking speed S.I. (%)—I	89.6 \pm 4.4	90.4 \pm 5.7	0.7432 (NS)
Walking speed S.I. (%)—II	88.9 \pm 5.0	89.7 \pm 6.3	0.7692 (NS)
Walking speed S.I. (%)—III	95.4 \pm 1.7	96.4 \pm 1.9	0.2565 (NS)
Cadence (steps/min)—R	88.6 \pm 8.9	98.3 \pm 10.2	0.0472 (S)
Cadence S.I. (%)—I	95.9 \pm 3.9	97.2 \pm 1.3	0.3569 (NS)
Cadence S.I. (%)—II	95.7 \pm 4.1	97.1 \pm 1.4	0.3468 (NS)
Cadence S.I. (%)—III	87.7 \pm 12.1	93.2 \pm 2.9	0.2034 (NS)
Stance phase period (%)—R	74.9 \pm 3.2	61.3 \pm 1.8	<0.0001 (ES)
Stance phase period S.I. (%)—I	81.1 \pm 6.2	96.9 \pm 1.8	<0.0001 (ES)
Stance phase period S.I. (%)—II	78.9 \pm 7.6	97.0 \pm 1.9	<0.0001 (ES)
Stance phase period S.I. (%)—III	59.3 \pm 9.1	92.8 \pm 5.0	<0.0001 (ES)
R = right (involved) limb S.I. = symmetry index	I, II, or III = method used to calculate S.I. NS = not significant	S = significant VS = very significant	ES = extremely significant

For most rehabilitation professionals, the achievement of symmetry of the lower limbs during walking has been an unquestioned goal of gait reeducation.

The selection of the appropriate type of technical aid and, more specifically, of lower-limb prostheses, especially while amputees are still in the early stage of rehabilitation, is of critical importance in the achievement of this goal. Gait analysis provides useful data for both rehabilitation professionals and patient feedback, contributing to the selection of the most effective and efficient prosthetic treatment. In addition, quantitative measurement of function is sometimes desirable to allow documentation of changes in the patient's condition.

All methods used to calculate the symmetry index of the measured spatial and temporal parameters exhibited advantages and disadvantages. An advantage of methods I and II is that "normal" data are not required, and thus measurement time is saved and calculations are simplified. The main disadvantage of method I is the relatively small asymmetry observed in most of the tested parameters. The main disadvantage of method II is that differences are reported against their average values; i.e., if a large asymmetry is present, the average value does not correctly reflect the performance of either limb [21]. Method III requires data from "normal" subjects, leading to a longer measurement procedure. However, asymmetrical behavior of the lower limbs during able-bodied ambulation has been addressed by many investigations [21–23]; therefore, it could be useful to incorporate it in the calculation of the symmetry indexes. A disadvantage

of method III is that there is a possibility (although quite small) that calculations will result in a denominator with a zero value (i.e., no difference between the minimum and maximum parameters in the control subjects), leading to a meaningless result.

All the measured spatial and temporal parameters were significantly improved when the SACH foot was replaced by the Greissinger Plus foot, as expected. However, when the symmetry indexes were considered, the observed differences were not significant for all the measured parameters. And this seems to be more important when the symmetry of the walking speed and cadence is considered, since these two parameters are commonly used to evaluate the functional outcome of the prosthetic treatment.

Although the increment of the symmetry indexes of some parameters such as the knee range of motion, walking speed, and cadence was relatively small, it may be clinically important, given the high energy cost of trans-tibial amputee walking. In addition—especially in the case of the knee range of motion—although the difference observed could not be characterized as significant, the *p*-values, when calculated with methods I and II, were very close to the set limit of 0.05 (0.0744 and 0.0723). In any case, one must keep in mind that each of the three methods used to calculate the symmetry indexes gave different results, and in some cases, these led to varied conclusions. This was particularly true in the case of the spatial parameters, as reported earlier.

Another point that caught my attention during this study was that 16.3 weeks after prosthesis fitting, most patients still wanted to use the conventional SACH foot, even though a better outcome in terms of their gait profile could be achieved if they were to use the Greissinger Plus Foot. Only four of them agreed to change their prosthesis. The final decision to use one or the other type of prosthetic foot is not subjected only to the judgment of the rehabilitation professionals but also to factors that the patients consider important, such as feeling of stability, feeling of safety, and cost. One factor related to cost is that since all the tested amputees were prescribed a SACH foot, their insurance companies would not cover any expenses connected to a different type of prosthetic foot. The subject's decisions could also reflect the finding that the symmetry indexes of the walking velocity and cadence were not significantly improved. Patient decisions may be based, in the early rehabilitation phase, on many issues and not gait profile alone. However, this study did not include structured interviews with questions that cover major aspects of life that might be affected while living with a prosthesis (e.g., physical, physiological, and social) and why patients chose the foot they did. Therefore, a more justified explanation cannot be given.

This study will continue with more subjects wearing various types of prostheses (including more modern ones) and following different treatment strategies, since the fitting of a prosthesis is an integral part of the treatment program. In addition, patient outcomes, such as stability and safety, combined with data obtained via structured interviews, will be included, since selecting a prosthesis solely on the basis of gait analysis data is unwise.

CONCLUSION

For the examined group of traumatic right-limb trans-tibial amputees fitted with a PTB prosthesis and tested in the early rehabilitation stage, the spatial and temporal parameters were significantly improved when the SACH foot was replaced by the Greissinger Plus foot. Significant improvement was also observed for the symmetry indexes of the hip and ankle ROMs and the stance phase period. However, no significant difference was found for the symmetry indexes of the knee ROM, cadence, and walking speed. In addition, for most of the spatial parameters, the statistical significance varied considerably among the three methods used for the analysis of symmetry.

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