

TEMPORAL SYMMETRY OF SOUND AND PROSTHETIC LIMBS DURING TRANSTIBIAL AMPUTEE GAIT WITH VARIOUS PROSTHETIC ALIGNMENT

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Submitted in September, 2007

The term "gait" refers to fundamental locomotion by means of which the individual moves him/herself from one place to another. For people afflicted by some involvement of the lower limbs, this activity is partially or completely reduced. In the course of the biomechanical investigation of gait in subjects with various afflictions, the symmetry of lower limb loading is also the object of research.

A certain number of biomechanical studies are focussed on the kinematic and dynamic variables of the gait cycle in subjects with transtibial amputation (Bateni & Olney, 2002; Thomas et al., 2000; Perry, 2004). An interesting problem is the evaluation of gait symmetry between a transtibial amputee and groups of healthy persons (Winter & Sienko, 1988; Dingwell, Davis, & Frazier, 1996). Miff et al. (2005) compared temporal symmetries in a healthy group with the values in a transtibial amputee group during gait initiation and termination. Nolan et al. (2003) took an interest in changes in gait symmetry influenced by gait speed in transtibial and transfemoral amputees in comparison with a healthy group. The interlimb gait symmetry of transtibial amputees wearing two different prosthetic feet in the early rehabilitation stage was investigated by Marinakis (2004).

Full symmetry in one's gait isn't always desirable. The human system, with its major structural asymmetries in the neuromuscular skeletal system (one limb has been amputated) cannot perform optimally when the gait is symmetrical (Winter & Sienko, 1988). Non symmetrical gait performance, with constraints of its residual system and the mechanics of its prosthesis, is better in this case. For persons who have undergone amputation, asymmetrical gait may be the instrument which protects the stump of the disabled limb. We can say that gait asymmetry would be a relevant measure for investigating the gait characteristics of amputees and establishing their propensity for future joint pain and degeneration (Nolan et al., 2003).

For amputee gait, the choice of a suitable prosthesis is very important. The influence of a prosthetic foot on gait variables in a group of these subjects was observed by Gitter et al. (1991). Efficiency of performance of the gait cycle is also markedly influenced by a prosthesis or prosthetic foot alignment.

Rehabilitation of an amputee can be considered to be successful only when the amputee finds the prosthesis aesthetic and comfortable during walking. Prosthesis alignment has to correspond to the demands of the prosthetist (Fridman, Ona, & Isakov, 2003). When the prosthetic foot isn't aligned optimally, this fact can show up in different levels of gait cycle performance. During gait analysis, the prosthesis is intentionally "not optimally" aligned in order to elicit the implied implications.

Fridman, Ona and Isakov (2003) observed the influence of a prosthetic foot positioned in external rotation. Schmalz, Blumentritt and Jarasch (2002) used sagittal shifting of the foot to both anterior and posterior directions and foot alignment to both plantar and dorsal flexion. Blumentritt et al. (1999) focussed on the effects of sagittal plane prosthetic alignment to the magnitude of knee joint loads on a standing transtibial amputee.

The objectives of prosthetic alignment in persons with lower limb amputation are the enhancement of the remaining limb's comfort and to maximize the individual's walking capabilities. In biomechanical gait analysis, it is important to investigate not only the relationship between prosthetic foot alignment and the prosthetic limb, but also the relationship between this alignment and activity of the contralateral, sound limb (Pinzur et al., 1995). An accent on the sound limb appears in other studies (Nolan & Lees, 2000; Hurley et al., 1990), but there the question of various prosthetic alignments isn't considered. This relationship between the sound and the prosthetic limb can be quantitative, measured by the symmetry or asymmetry of the measured variables.

Keywords: Transtibial amputation, alignment, gait, temporal variables.

OBJECTIVES

The objectives of this study were to evaluate the influence of the prosthesis and prosthetic foot alignment on temporal variables of gait and to observe how these various alignments influence the symmetry of temporal variables between the sound and the prosthetic limb.

MATERIAL AND METHODS

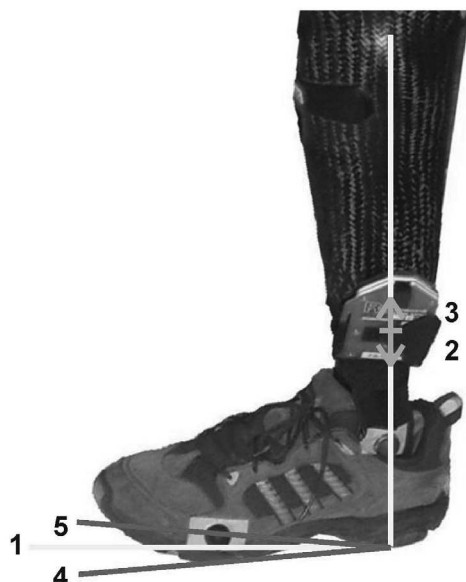
Eleven men (aged 58.9 ± 9.47 years, height 177.3 ± 5.49 cm, weight 87.9 ± 14.85 kg) participated in this study. Each of them used a dynamic prosthetic foot type, which is characterized by a smooth rollover during gait. This foot is intended for second level activity users.

For measurement we used a walkway for time variable analysis. The length of this equipment is 10 m. It makes it possible to do the measurement for each limb individually.

Each of the subjects executes two gait trials with each alignment. There were the following alignments: 1. optimal (assessed by a prosthetist), 2. prosthesis length 1 cm shorter, 3. prosthesis length 1 cm longer, 4. prosthetic foot aligned to plantar flexion ($+5^\circ$), 5. prosthetic foot aligned to dorsal flexion (-5°) (Fig. 1). Two strides were analyzed in each trial.

Fig. 1

Prosthetic alignments used during measurement



Legend

- 1 - optimal alignment
- 2 - prosthesis about 1 cm shorter
- 3 - prosthesis about 1 cm longer
- 4 - prosthetic foot aligned to plantar flexion ($+5^\circ$)
- 5 - prosthetic foot aligned to dorsal flexion (-5°)

In the process of our measurements, we observed the following absolute temporal variables (stance – stance phase duration, swing – swing phase duration), as well as relative temporal variables (% stance – stance phase duration divided by the duration of the gait cycle, % stance = $\text{stance} / (\text{stance} + \text{swing}) \times 100$) and the frequency of the gait cycle. Then we calculated an index of symmetry for each temporal variable according to the following equation (modified from that of Dingwell, Davis, & Frazier, 1996):

$SI = (X_{\text{Sound}} - X_{\text{Prosthetic}}) / (X_{\text{Sound}} + X_{\text{Prosthetic}}) \times 100\%$, where X means an appropriate temporal variable on both the sound and the prosthetic limb. After substitution we obtained three new variables:

SI stance – index of the symmetry of the stance phase's duration,

SI swing – index of the symmetry of the swing phase's duration,

SI % stance – index of the symmetry of the stance phase's duration divided by the duration of the gait cycle.

If the perfect symmetry between the sound and the prosthetic limb (the variable is the same for both limbs), then being equivalent to SI equals zero. A positive number indicates a higher value of the variable on the sound limb; whereas a negative number indicates a higher value of the variable for the prosthetic limb.

For statistical analysis we used the Statistica 6.0 programme. We performed both the ANOVA and Fisher post hoc tests.

RESULTS AND DISCUSSION

The influence of prosthetic alignment to temporal variables of the sound and prosthetic limbs

Values of measured variables and their standard deviations for each alignment are presented in TABLE 1. Statistically significant differences ($p < 0.05$) between variables in various prosthetic alignments for both sound and prosthetic limbs are introduced in TABLE 2. In the frequency of the gait cycle, we didn't find any statistically significant difference.

During the evaluation of absolute variables, we have to take account of the fact that their magnitude can be influenced by gait speed.

Regarding gait performance, there are considerable inter-individual differences. It's perceptible in magnitudes of standard deviations. We found less statistically significant differences between sound and prosthetic limbs than we expected. We used prostheses and prosthetic foot alignments, which appear from experience and correspond with differences, which the prosthetist can make. The changes of prosthetic foot position about $\pm 5^\circ$ or changes of the prosthesis length about

TABLE 1

Mean values of observed variables for whole group in each alignment

Variable	Limb	Alignment 1		Alignment 2		Alignment 3		Alignment 4		Alignment 5	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
% stance	Sound	66.10	4.32	65.40	3.36	65.70	3.71	65.40	3.72	65.70	3.85
	Prosthetic	65.20	3.82	65.60	4.55	65.30	3.30	64.90	4.99	65.80	4.08
Stance (s)	Sound	0.87	0.13	0.85	0.15	0.86	0.13	0.85	0.15	0.83	0.12
	Prosthetic	0.86	0.12	0.85	0.15	0.85	0.12	0.85	0.16	0.84	0.12
Swing (s)	Sound	0.44	0.05	0.45	0.03	0.44	0.04	0.45	0.05	0.43	0.04
	Prosthetic	0.46	0.05	0.44	0.06	0.45	0.04	0.45	0.05	0.43	0.05
Frequency (step/min)		92.18	8.88	94.12	10.60	93.25	9.29	93.53	11.55	95.59	9.55

Legend

SD – standard deviation

± 1 cm can occur during common amputee daily activities, for example by change of footwear (various heights of the heel). If a prosthetic foot was aligned to plantar or dorsal flexion by about 10 and more degrees or the prosthesis was prolonged or shortened by about 2 and more cm, we would probably find more statistically significant differences, but we would get away from realistic conditions. Similar situations occurred in the study of Fridman, Ona and Isakov (2003). These authors found statistically significant differences in stance time and swing time only for the prosthetic foot with 36° external rotation (with 18° statistically significant difference wasn't found).

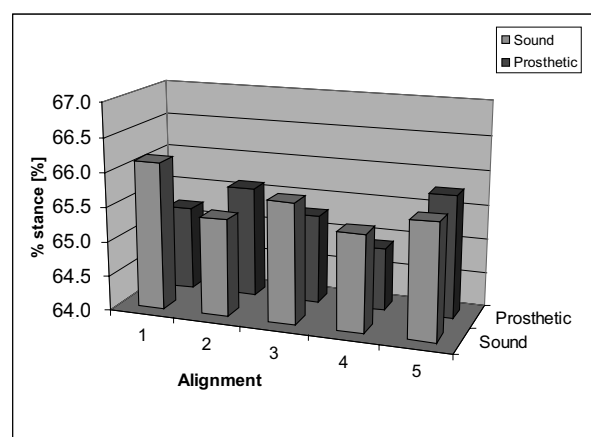
TABLE 2Statistically significant differences between measured variables ($p < 0.05$) in various prosthetic alignments

Variable	Sound	Prosthetic
% stance	4 < 1	4 < 5
Stance	5 < 3, 1	5 < 1
Swing		5 < 3, 4, 1; 2 < 4, 1

On the sound limb, the amputee with a prosthetic foot aligned to plantar flexion, had a smaller relative stance phase duration in comparison with gait performance with optimal alignment (Fig. 2). On the prosthetic foot, the smallest value of this variable was also found in the foot alignment to the plantar flexion. It was probably caused by later initial contact of the gait cycle in this prosthetic foot alignment. The biggest value of relative stance phase duration during gait cycle was observed in the alignment to the dorsal flexion. As we found differences for this variable, especially in the alignment 4 and 5 (plantar and dorsal flexion), we can suppose that the change in alignment of the prosthetic foot (10°) has

Fig. 2

Relative stance phase duration of gait cycle on sound and prosthetic limbs in the various prosthetic alignment positions



Legend

% stance – relative stance phase duration

1 – optimal alignment

2 – prosthesis about 1 cm shorter

3 – prosthesis about 1 cm longer

4 – prosthetic foot aligned to plantar flexion (+5°)

5 – prosthetic foot aligned to dorsal flexion (-5°)

a greater influence on the relative temporal variables of gait than the change in prosthesis length (2 cm).

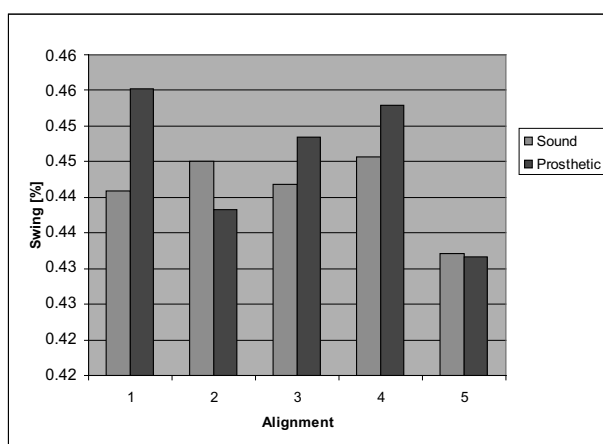
Stance phase and swing phase duration were the smallest in the foot alignment to dorsal flexion on both sound and prosthetic limbs. In this case, the frequency of the gait cycle was the biggest, but the difference wasn't statistically significant. The prosthetic foot, which was aligned to dorsal flexion, hurries the subject forward during the late stance phase, thereby the gait speed is bigger.

Comparison of sound and prosthetic limbs

A statistically significant difference between the sound and prosthetic limbs was found only for the swing phase duration when there was optimal alignment (Fig. 3). On the prosthetic limb, the swing phase lasts longer. It corresponds with the longer duration of the stance phase on the sound limb (Pinzur et al., 1995). However in this case, we didn't find any statistically significant difference.

Fig. 3

Swing phase duration of gait cycle on sound and prosthetic limbs in the various degrees of prosthetic alignment



Legend

Swing – swing phase duration

1 – optimal alignment

2 – prosthesis about 1 cm shorter

3 – prosthesis 0.1 cm longer

4 – prosthetic foot aligned to plantar flexion (+5°)

5 – prosthetic foot aligned to dorsal flexion (-5°)

There is the question of why we found a difference between the sound and prosthetic limbs only in the case of optimal alignment. We can suppose that a certain degree of asymmetry was natural for the amputee in the case of optimal prosthetic alignment. Better symmetry of temporal variables of the gait cycle between the sound and prosthetic limbs when aligned differently isn't necessarily positive. It's caused by the fact that the sound limb can't fully execute its compensational function during gait.

Temporal symmetry of the sound and prosthetic limbs

In the observed group, there are large inter individual differences in the values of symmetry indexes again (Fig. 4). The biggest difference was found for SI swing variables between alignments 1 a 2. The value of this variable is less for more subjects (9 from 11) in optimal alignment (1) than in alignment 2. The lower value of the SI swing variable indicates a longer swing phase duration of the gait cycle on the prosthetic limb

in optimal alignment. It appears that the shortening of a prosthesis (alignment 2) causes longer loading of prosthetic limbs during gait. Apparently, the prosthetic limb isn't relieved during gait and compensation mechanism can't be fully applied.

Temporal symmetry is different for an amputee as opposed to healthy persons. In the study of Dingwell, Davis and Frazier (1996), symmetry indexes weren't significantly different from zero value for healthy subjects. These authors found significantly larger asymmetry in relative stance phase duration (% stance) and in single support phase duration (swing) for the amputee group than for the healthy group.

The asymmetry of the gait cycle can't be always considered to be undesirable. The central neural system of an amputee has recognized new asymmetries (caused by amputation) and has compensated for lost motor function and altered anthropometric indicators (Winter & Sienko, 1988).

While asymmetries of certain variables might be related to each other, other variables aren't interrelated and in general can't refer to each other. An amputee can alter gait cycle to decrease one form of asymmetry by increasing other forms of asymmetry. It's necessary to dedicate more effort to identifying those variables for which attaining a more symmetrical gait pattern are most beneficial (Dingwell, Davis, & Frazier, 1996).

Asymmetry of the temporal variables of the gait cycle, as a side effect of gait modification after amputation, also appear in transfemoral amputees. Nolan et al. (2003) found considerably larger temporal asymmetry for groups of transfemoral amputees than for group of transtibial amputees.

Quantifying asymmetry in amputee gait in relation to healthy subjects is the first step in trying to define what degree of asymmetry is acceptable or desirable in amputee gait during rehabilitation (Dingwell, Davis, & Frazier, 1996).

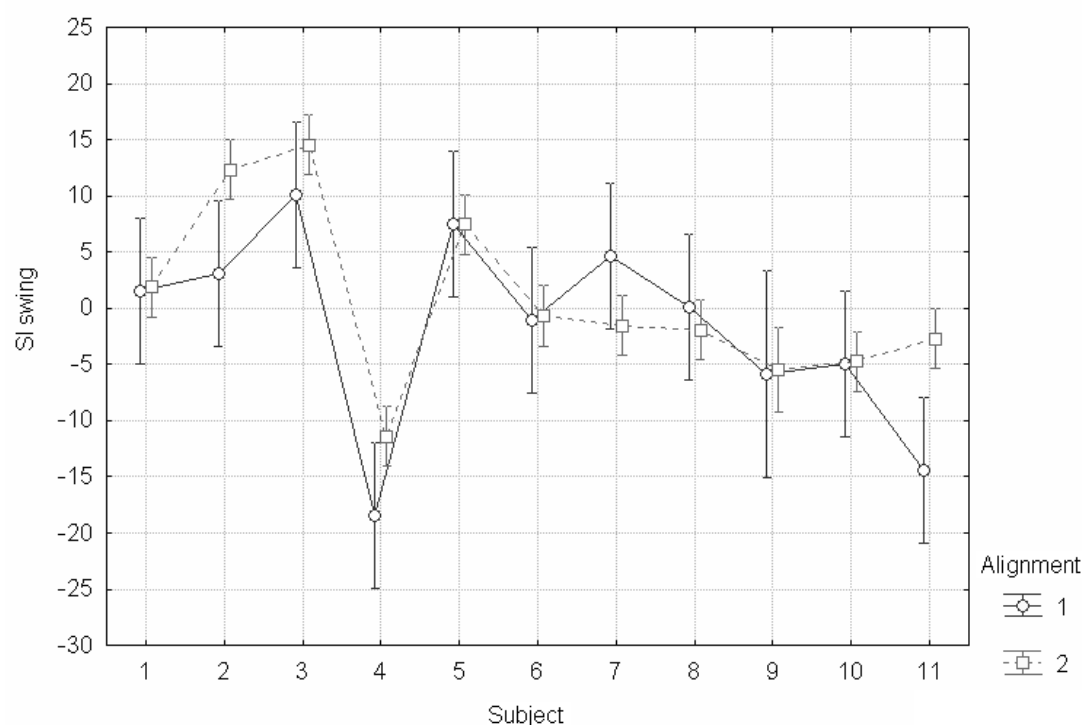
CONCLUSIONS

Alignment of the prosthesis to dorsal and plantar flexion influences the relative stance phase duration of the gait cycle more than any change in prosthesis length. In the foot alignment to the plantar flexion this variable is smaller on both the sound and prosthetic feet.

When optimal alignment is present, the difference between the swing phase duration on the sound and prosthetic limb is the biggest. On the sound limb, the stance phase is longer and the swing phase is shorter than in other forms of alignment. This asymmetry during the gait cycle compensates for limb loss and is desirable to a certain extent. In other forms of alignment, the asymmetry between the sound and prosthetic limb are less, which means that the compensational function of the sound limb is limited.

Fig. 4

Symmetry indexes of swing phase duration for each observed subject

**Acknowledgments**

This study was carried out within the research project granted by the Ministry of Education, Youth and Sports "Physical activity and inactivity of inhabitants of the Czech Republic, no: 6198959221".

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DOČASNÁ SYMETRIE ZDRAVÝCH A PROTETICKÝCH KONČETIN BĚHEM CHŮZE OSOBY S TRANSTIBIÁLNÍ AMPUTACÍ S RŮZNÝM PROTETICKÝM ZAŘAZENÍM

(Souhrn anglického text)

Termín „chůze“ označuje základní pohyb, jehož pomocí se jednotlivec pohybuje z jednoho místa na druhé. U osob s postižením dolních končetin je tato aktivita částečně či zcela redukována. Během biomechanického šetření chůze u osob s různým postižením se také zkoumala symetrie zatížení dolních končetin.

Určité množství biomechanických studií se zaměřuje na kinematické a dynamické proměnné cyklu chůze u osob s transtibiální amputací (Bateni & Olney, 2002; Thomas et al., 2000; Perry, 2004). Zajímavým problémem je hodnocení symetrie chůze mezi osobami s transtibiální amputací a skupinami zdravých jedinců (Winter & Sienko, 1988; Dingwell, Davis, & Frazier, 1996). Miff et al. (2005) srovnává dočasnou symetrii u zdravé skupiny s hodnotami u skupiny osob s transtibiální amputací během počáteční a konečné fáze chůze. Nolan et al. (2003) se zajímal o změny v symetrii chůze ovlivněné rychlostí chůze u osob s transtibiální a transfemorální amputací ve srovnání se zdravou skupinou. Symetrii chůze u osob s transtibiální amputací, které na počátku rehabilitace nosily dvě různé protetické nohy, zkoumal Marinakis (2004).

Úplná symetrie chůze není vždy žádoucí. Lidský systém s velkou strukturální asymetrií v neuromuskulární kosterní soustavě (jedna končetina byla amputována) nemůže optimálně fungovat, když je chůze symetric-

ká (Winter & Sienko, 1988). V tomto případě je lepší nesymetrická chůze s omezením reziduálního systému a mechaniky protézy. U osob, které podstoupily amputaci, může asymetrická chůze být nástrojem, jenž chrání pahýl postižené nohy. Lze říci, že asymetrie chůze je relevantním měřítkem pro zkoumání charakteristiky chůze osob s amputací a stanovení jejich sklonu k budoucí společné bolesti a degeneraci (Nolan et al., 2003).

Pro chůzi osob s amputací je velmi důležitý výběr vhodné protézy. Vliv protetické nohy na proměnné chůze ve skupině těchto probandů zkoumal Gitter et al. (1991). Efektivnost chůze je také významně ovlivněna nastavením protézy nebo protetické nohy.

Rehabilitaci osoby s amputací lze považovat za úspěšnou pouze tehdy, pokud tato osoba považuje protézu během chůze za estetickou a pohodlnou. Nastavení protézy musí vyhovovat potřebám postiženého (Fridman, Ona, & Isakov, 2003). Když protetická noha není optimálně vyladěna, může se tento fakt projevit v různých cyklech chůze. Během analýzy chůze je protéza úmyslně „neoptimálně“ nastavena, aby se vyvolaly skryté následky.

Fridman, Ona a Isakov (2003) pozorovali vliv protetické nohy umístěné ve vnější rotaci. Schmalz, Blumentritt a Jarasch (2002) použili sagitální posun nohy vpřed a vzad a nastavení nohy do plantární a dorzální flexe. Blumentritt et al. (1999) se zaměřil na účinky nastavení protézy v sagitální rovině na velikost zatížení kolenního kloubu u stojící osoby s transtibiální amputací.

Nastavení protézy u osob s amputací dolní končetiny má pomoci zvýšit pohodlí zdravé nohy a maximalizovat možnosti chůze těchto osob. V rámci biomechanické analýzy chůze je důležité prošetřit nejen vztah mezi nastavením protetické nohy a protetické končetiny, ale také vztah mezi tímto nastavením a aktivitou druhé, zdravé končetiny (Pinzur et al., 1995). V jiných studiích se objevuje důraz na zdravou končetinu (Nolan & Lees, 2000; Hurley et al., 1990), ale v nich není řešena otázka různých nastavení protéz. Tento vztah mezi zdravou a protetickou končetinou může být kvantitativní, měřený dle symetrie nebo asymetrie měřených proměnných.

Klíčová slova: transtibiální amputace, nastavení, chůze, dočasné proměnné.

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