Biomechanical effects of a carbon fibre foot with a pronounced range of motion on ramps

M. Alimusaj[a*], T. Kaib[a,], J. Block[a], D.W.W. Heitzmann[a], S.I. Wolf[a]

[a]*Heidelberg, Germany; University Hospital, Heidelberg, Germany.*

**Corresponding author: Alimusaj Merkur; merkur.alimusaj@med.uni-heidelberg.de*

Abstract

Walking on inclines is a challenging task for amputees. 3D gait analyses were conducted in 23 unimpaired persons (REF) and 11 patients with transtibial amputation (PTTA) investigating the biomechanical effects of a novel foot with a mechanical pivot unit (ProFlex, Össur, IS) compared to a VariFlex (VA/, Össur, IS) while walking on an instrumented 10° ramp. Additionally the “Soleangle” (angle between foot and ramp) was calculated. Ankle range of motion was in PF significantly greater than in VA. Angular velocity of “Soleangle” was significantly greater in VA compared to PF ramp up and down. In VA condition PTTA showed two different strategies, one with a pronounced knee flexion in stance close to REF (VA1) and one with a significant hyperextension of the knee joint (VA2). PF showed only one pattern, which was close to REF but with a more extended knee joint than VA1 and REF. PEQ ambulation scale for uphill and downhill walking showed significant improvements by 20% using PF.
Results indicated that a rigid lever arm of VA compared to PF might not always be beneficial. However flexibility of the PF did not lead overall to reduced knee moments on the ramp, but the early foot flat and resulting adequate adaptation to the incline indicated a sufficient support during ramp walking. The findings were supported by PEQ results.

Keywords transtibial amputation, prosthesis, walking on ramps, movement analysis, amputation

Introduction

Walking on inclines is a challenging task for amputees using a conventional prosthetic foot, as prosthetic alignment is usually optimized for walking on level ground [1]. Instrumented 3D gait analyses while walking on ramps were conducted in transtibial amputees investigating the biomechanical effects of a novel prosthetic foot with a mechanical pivot unit (ProFlex, Össur, IS) allowing for higher range of motion.

Methods

Data of 23 unimpaired persons (REF) and 11 adult patients with transtibial amputation (PTTA) were included. Kinematics and kinetics were calculated using Plugin Gait Model (Vicon, GB). Additionally the “Soleangle” (angle between foot sole and ramp) was calculated for walking up and down respectively. Participants negotiated an instrumented ramp (2 force plates, AMTI, USA, 8,5m x 0.8m; 10°). PTTA underwent the protocol twice using two different feet (Variflex (VA) and ProFlex (PF), Össur, IS) in a randomized order (cross-over-design). Prior to the measurements they had two weeks to adapt to each prosthetic foot. The prosthetic alignment was done by the same CPO and verified for each patient and each condition by using L.A.S.A.R. Posture (Otto Bock, Germany) [2]. Patients' feedback was determined using the PEQ in both, PF and VA. Parameters where analysed using Wilcoxon signed-rank tests for paired samples ($p<0.05$).

Results

Walking ramp up showed two different strategies with the VA (Figure 1). Five patients showed a pronounced knee flexion comparably to normal when walking with VA (VA1), whereas six patients showed a significant hyperextension in the knee joint (VA2). Walking with PF showed in contrast no strategy changes. All patients showed in PF condition similar behaviour.
Ankle range of motion was in PF significantly greater than in VA. Angular velocity of "soleangle" was significantly greater in VA compared to PF and closer to REF walking down, indicating an early and longer period of "FootFlat" on the ramp surface. Compared to the two strategies walking up the ramp in VA-condition, PF pattern could be recognised in between VA1 and VA2 by a slightly increased knee flexion compared to REF. Correspondingly external extending knee moments in PF and VA2 were higher when walking up the ramp compared to VA1. Walking down the ramp showed significant changes in ankle range of motion, but no significant changes at the knee joint – neither kinematics nor kinetics. PEQ ambulation scale for uphill and downhill walking showed significant improvements using PF.

	Ramp down				Ramp up				
	VA	PF	REF	p-value	VA1	VA2	PF	REF	p-value
Knee kinematics [°]	25.6 ± 7.5	25.4 ± 7.0	27.4 ± 6.4	p<0.001$^{\#}$	7.4 ± 5.0*	-11 ± 0.9^{+}	-3.4 ± 2.1$^{+,*}$	2.2 ± 1.5	P=0.015^{+} P<0.001*
External knee extending moment [Nm/kg]	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	n.s.	0.3 ± 0.1*	0.7 ± 0.1^{+}	0.6 ± 0.1$^{+,*}$	0.7 ± 0.2	p=0.031^{+} P=0.001*
Ankle ROM [°]	13.3 ± 0.8	25.8 ± 1.4	28.6 ± 4.9	n.s.	14.1 ± 1.3*	13.1 ± 0.7^{+}	25.1 ± 2.1$^{+,*}$	42.6 ± 6.6	P<0.001^{+} P<0.001*
Soleangle [°/%GC]	0.9 ± 1.6$^{\#}$	0.6 ± 1.1$^{\#}$	0.5 ± 1.5	p<0.001$^{\#}$	0.4 ± 2.3*	0.4 ± 0.9^{+}	0.2 ± 1.1$^{+,*}$	0.6 ± 1.8	P=0.02^{+} P=0.013

Table 1: Kinematics and kinetics for ramp up and ramp down with both prosthetic feet (p <0.05).
= ramp down VA vs. PF; * = ramp up VA1 vs. PF; + = ramp up VA2 vs. PF

Conclusion and discussion

In contrast to walking down the ramp, participants showed walking up the ramp two different strategies using VA. VA1 showed pronounced knee flexion with corresponding moments during stance phase, accompanied by a late foot flat with early heel rise represented by the sole angle[3]. Indicating reduced stability and a strategy, probably influenced by the foot components, but also by patient's behaviour for reducing external knee extending moments. In contrast, walking with PF lead to homogenous behaviour during stance, similar to VA2. Results indicated that a rigid lever arm in VA might not always be beneficial for individuals.

PF lead in principle to a significantly higher range of motion in the ankle joint, as previously shown for level ground walking [4], leading to an increased angular velocity in "soleangle" and leading in both, ramp up and down, to an early foot flat with a late heel rise going along with a higher flexibility of the PF. However this increased flexibility did not lead to reduced knee extending moments while descending the ramp. The early foot flat and the adequate adaptation to the incline indicated a sufficient support during ramp walking. Underlined by the PEQ in both, ramp up and down. These findings need to be addressed in further analysis.

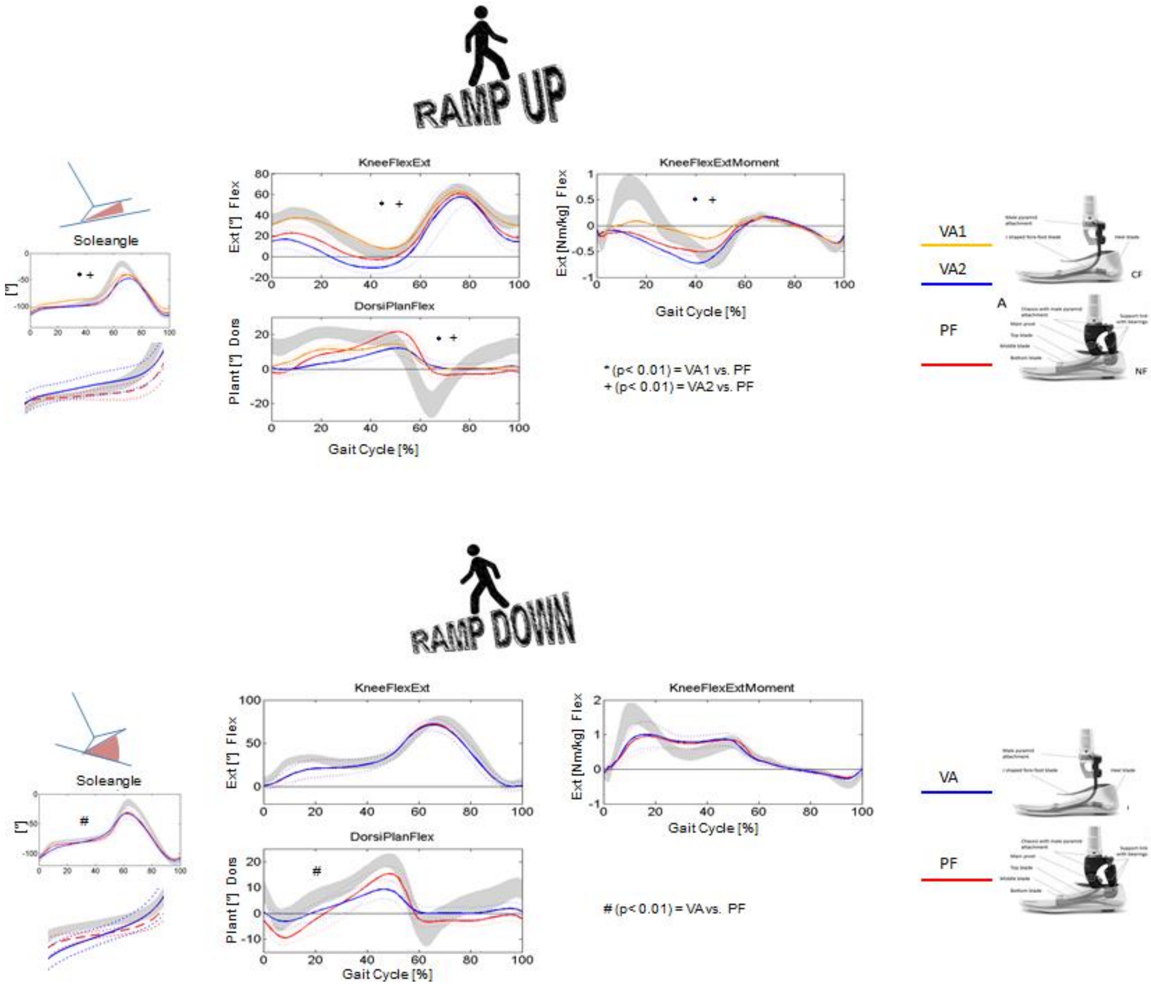

Figure 1. Kinematics, Kinetics and soleanlge data of the two prosthetic feet for walking up and down ramps.

References

[1] Fradet et al. - Gait&Posture 2010

[2] Blumentritt et al. Prosthet Orthot Int. 1999

[3] Alimusaj et al. – Abstract OTWolrd 2016

[4] Heitzmann et al. - Gait&Posture 2018