KINEMATICS AND KINETICS WITH A POWERED LOWER LEG SYSTEM DURING STAIR ASCENT FOLLOWING TRANSTIBIAL AMPUTATION

Jennifer M. Aldridge, Abbie E. Ferris, Jordan T. Sturdy and Jason M. Wilken
Department of Orthopedics and Rehabilitation, Center for the Intrepid, Brooke Army Medical Center
Fort Sam Houston, TX, USA
email: Jennifer.aldridge@us.army.mil

INTRODUCTION

Persons with unilateral transtibial amputation (TTA) commonly demonstrate significant between limb asymmetries and deviations from normal gait when ascending stairs [1]. Deviations include significantly increased involved side hip flexion and joint power, and significantly increased hip joint moments and reduced knee joint powers bilaterally [1]. These deviations are thought to result, in part, from a reduction of ankle motion and power generation on the involved side as compared to intact ankles.

Conventional energy storing and returning (ESR) feet allow motion through deformation of a carbon fiber keel, but are unable to replicate the ankle motion and power provided by the intact ankle. Recently, however, powered prosthetic devices which provide the ability to restore ankle push-off power have been developed. The first of these devices to reach the clinical market uses a series-elastic actuator to provide powered push-off [2]. The effect that such a device will have on stair ascent performance in individuals with TTA is unknown. Therefore, the purpose of the current study was to determine if ankle push-off power improves lower extremity kinematics and kinetics during stair ascent in individuals with TTA.

METHODS

Eleven individuals with unilateral TTA and eleven height and weight matched controls were recruited for the study. Individuals with TTA participated in two biomechanical gait analysis testing sessions: 1) using an ESR foot, and 2) using the powered BiOM device (Powerfoot BiOM, iWalk). Subjects were provided a three week acclimation period to the BiOM device prior to testing. Control subjects (CONT) participated in a similar gait analysis session.

Lower extremity kinematic data were recorded using an optoelectronic motion capture system (Motion Analysis Corp., Santa Rosa, CA) collecting at 120 Hz. Ground reaction force data were collected for four steps (AMTI Inc., Watertown, MA) at 1200 Hz as subjects ascended a 16-step staircase at a cadence of 80 steps per minute. Sagittal plane ankle, knee, and hip angles, moments and powers were calculated for five cycles per side and normalized to 100% gait cycle. Peak values were extracted using a custom MatLab program (Mathworks Incorporated, Natick, MA).

A 2x2 repeated measures ANOVA was used to determine limb (involved and uninvolved) and condition (ESR and BiOM) differences. A one-way ANOVA was used to determine significant differences between the BiOM (involved and uninvolved) and CONT.

RESULTS AND DISCUSSION

Mean peak kinematic and kinetic values at the ankle, knee, and hip joints for the ESR condition (uninvolved and involved limb) were similar to previously published results [1]. The mean values, standard deviation and significance levels of the statistical tests for ankle peak values are presented in Table 1.

Ankle

Condition dependent differences (ESR vs. BiOM) were observed at the ankle (Figure 1). An increase in involved limb peak plantarflexion (PF) angle ($p<0.001$) resulted in a larger ankle range of motion ($p<0.001$) when using the BiOM (17.5 ± 3.7°) as compared to ESR (8.9 ± 2.6°). However, these increases failed to completely normalize ankle kinematics while using the BiOM (ROM: $p<0.001$, Peak PF: $p=0.002$). Participants experienced a 167% increase in involved side peak ankle push-off power ($p<0.001$) from ESR to BiOM. Further, no significant difference between BIOM and CONT were observed, indicating successful normalization of ankle power generation.

Knee and Hip

Limb asymmetries including greater involved side hip flexion throughout the gait cycle, greater involved side hip power during stance, and decreased involved side knee power during stance were observed in both the BIOM and ESR conditions ($p<0.05$). Despite changes in ankle ROM and power no significant kinematic or kinetic changes were observed at the knee or hip between conditions.

CONCLUSIONS

The results of the study indicate that the PowerFoot BiOM device was successful in restoring ankle power during stair ambulation. Further investigation is under way to determine why changes in ankle range of motion and power did not significantly alter function of proximal and contralateral joints. Additional training may be necessary for patients to fully utilize the device during stair ambulation.

REFERENCES

1. Alimusaj, M., et al., *Gait & Posture,* **30**, 2009.
2. Eilenberg, M.F., et al., *IEEE Trans Neural Syst Rehabil Eng*, **18**, 2010.

ACKNOWLEDGEMENTS

Support provided by the U.S. Army Telemedicine & Advanced Technology Research Center (to JMW).

The view(s) expressed herein are those of the author(s) and do not reflect the official policy or position of Brooke Army Medical Center, the U.S. Army Medical Department, the U.S. Army Office of the Surgeon General, the Department of the Army, Department of Defense or the U.S. Government.

Table 1: Mean ± standard deviation for ankle peak kinematic and kinetic values.
⁺p < 0.05 significantly different from controls, *p < 0.05 significantly different from ESR
[1]Positive value = dorsiflexion, Negative value = plantarflexion

Parameter	Controls	Uninvolved Limb		Involved Limb	
		ESR	BIOM	ESR	BIOM
PF max - stance (deg) [1]	-14.7 ± 7.2	-24.2 ± 3.3	-23.9 ± 6.6⁺	5.8 ± 2.7	-4.5 ± 4.4⁺*
DF max - swing (deg) [1]	17.6 ± 4.2	15.8 ± 5.4	14.4 ± 5.2	7.7 ± 2.8	5.1 ± 2.4*
PF moment max1 (Nm/kg)	0.82 ± 0.22	1.03 ± 0.23	1.15 ± 0.19⁺	1.11 ± 0.27	1.05 ± 0.14
PF moment max2 (Nm/kg)	1.22 ± 0.13	1.47 ± 0.19	1.53 ± 0.14⁺	1.04 ± 0.29	1.13 ± 0.17
PF power gen. max (W/kg)	2.12 ± 0.49	4.09 ± 0.99	4.5 ± 0.99⁺	0.59 ± 0.20	1.64 ± 0.51*

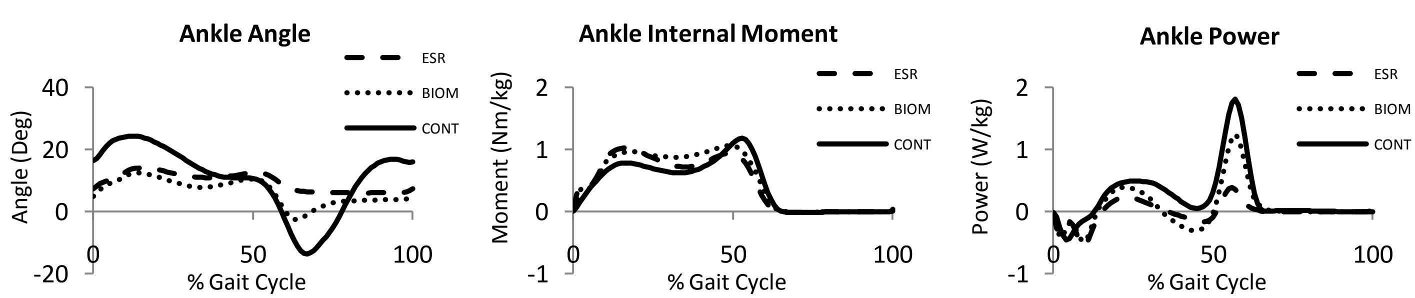

Figure 1: Sagittal plane ankle kinematics and kinetics during stair ascent for controls and patient's involved side while using an ESR device and the BiOM