

EFFECTS OF A NEW ADAPTIVE ANKLE PROSTHESIS ON LEVEL AND SLOPED WALKING

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INTRODUCTION

Sloped terrains can be challenging for individuals with lower limb amputation to navigate, in part because conventional prosthetic feet are aligned at a fixed angle and lack biological ankle joint articulation. The lack of ankle articulation may cause prosthesis users to adopt compensatory strategies on slopes [1]. To address this issue, various prosthetic feet have been developed to adapt their ankle angle based on the slope, partially restoring ankle articulation. There is evidence that this ankle articulation may help normalize certain gait biomechanics during level [2] and incline walking [3]. However, objective performance data on adaptive ankle prostheses is still limited, and the extent to which these devices benefit users on slopes requires additional investigation.

In this study we investigated a new microprocessor-controlled prosthetic ankle (MPA, Ossur premarket device), which uses a low-power motor to adapt its ankle angle to sloped terrain and to dorsiflex the ankle during swing to enhance toe clearance. We quantified the biomechanical effects of the MPA on unilateral transtibial prosthesis users during level and sloped walking, compared to the MPA with the ankle locked at the neutral position, and also compared to each user's prescribed prosthesis. The first comparison served as a controlled scientific study to isolate effects due specifically to ankle angle adaptation (since all other aspects of the MPA were unaltered). The latter comparison provided a more clinically-relevant assessment of the MPA against prostheses that users wear each day.

METHODS

Eight individuals with unilateral transtibial amputation participated in this study of level, incline and decline walking. These individuals (7 male, 1 female, height 1.78 ± 0.1 m, weight 92 ± 15 kg, age 45 ± 14 years) were all K3-K4 level ambulators, at least 6 months post amputation surgery. Six healthy controls (4 female, 2 male, height 1.78 ± 0.1 m, weight 69 ± 10.6 kg, age 21 ± 1.8 years) also performed identical walking conditions, to assist with results interpretation. All participants provided informed consent, according to Vanderbilt Institutional Review Board procedures.

Prosthesis users were fitted with the MPA by a certified prosthetist, and then users were educated on the functions of the device. After the fitting, prosthesis users wore the MPA for 2-3 weeks of at-home acclimation before returning for formal gait analysis testing.

Prosthesis users (and healthy controls) performed level (0°) and sloped ($\pm 7.5^\circ$ incline/decline) walking on a treadmill at a fixed speed (either 0.8 or 0.9 m/s). Prosthesis users walked on: (i) the MPA, (ii) the MPA with the ankle locked at the neutral position (hereafter referred to as the MPA-locked condition), and (iii) their prescribed prosthesis (primarily higher profile energy storage and return prostheses). Ground reaction force data were collected under each foot at 1000 Hz using a split-belt force-instrumented treadmill (Bertec), and lower-body kinematics were recorded at 200 Hz via a synchronized motion capture system (Vicon). Joint level kinematics and kinetics, as well as center-of-mass power, were calculated using common gait analysis methods. Prosthesis power was estimated using a previously published method that computes power due to all structures distal to the prosthetic socket [4]. Statistical significance was evaluated via repeated measures ANOVA, $\alpha=0.05$.

RESULTS AND DISCUSSION

This study resulted in a comprehensive biomechanical characterization of lower-limb kinematics and kinetics, and center-of-mass power. Various changes were only observed in prosthetic-side biomechanical outcomes. However, in many cases, these changes were observed within a subset of users. Changes in sound limb kinematics and kinetics across the prosthesis conditions were generally small in magnitude, and inconsistent across participants. For brevity, the focus of this abstract is limited to (i) reporting key trends that were observed to be consistent among multiple, or a majority of participants, and (ii) reporting on a subset of outcome metrics of interest based on previously published prosthetics studies. Additional/extended results and discussion will be presented at the conference itself.

MPA vs. MPA-locked Results

The MPA adapted its ankle angle by the programmed amount on slopes ($6.0 \pm 1.5^\circ$ dorsiflexion for 7.5° incline, $2 \pm 0.4^\circ$ plantarflexion for 7.5° decline) and provided more toe clearance (minimum height of toe above ground between 75% and 85% of gait cycle) than the MPA-locked condition during level (1.39 ± 0.44 cm, $p < 0.001$), incline (1.99 ± 0.40 cm, $p < 0.001$) and decline walking (0.81 ± 0.46 cm, $p = 0.005$).

MPA vs. Prescribed Results

The MPA provided more toe-clearance than prescribed prostheses during level (1.46 ± 0.7 cm, $p < 0.001$), incline (1.84 ± 1.0 cm, $p = 0.001$) and decline walking (1.17 ± 1.06 cm, $p = 0.012$). During incline walking, four users switched from a toe-landing gait pattern on their prescribed prosthesis to a heel-to-toe gait pattern on the MPA, which was more consistent with the gait pattern of the controls. The MPA stored and returned less elastic energy for 6 of 8 subjects during level walking, and for 5 of 8 subjects during both incline and decline walking.

Discussion

The MPA may provide benefits by reducing trip risk due to increased toe-clearance. This was anecdotally supported by one user who reported less “toe-catching” during the at-home acclimation period with the MPA compared to his prescribed prosthesis. For half the prosthesis users, the MPA also appeared to promote a more typical heel-to-toe gait pattern for incline walking (i.e., more similar in appearance to the controls); however, a trade-off was that elastic energy return was generally reduced relative to prescribed prostheses. One limitation of this study was that K2 users (limited community ambulators) were not tested, a group for whom large elastic energy storage/return may be less important, and for whom ankle articulation has been shown to benefit walking performance [2].

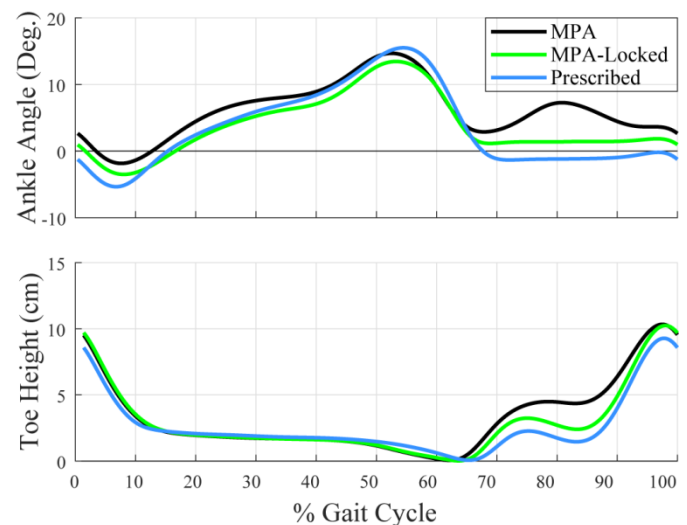


Figure 1: The MPA dorsiflexes the ankle during swing (~80% gait cycle) (top) to provide increased toe clearance (bottom), which may reduce trip risk. Representative subject depicted.

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