

IMPORTANCE OF PROSTHETIC ANKLE RANGE-OF-MOTION FOR ASCENDING AND DESCENDING SLOPES

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INTRODUCTION

Walking on a sloped surface is a common daily activity, but it can be difficult for lower-limb amputees due to the design of prosthetic feet [1]. Prosthetic feet are often flexible, but they generally lack an articulating ankle joint. In contrast, the healthy biological ankle has a range-of-motion of $\sim 70^\circ$ (dorsi-/plantar-flexion), allowing the foot to easily conform to slopes. Without ankle range-of-motion, amputees are forced to alter their gait by compensating with more proximal muscles (e.g., about the hip or knee) and/or with their intact limb. These compensations can increase muscle demands, accelerating fatigue and increasing joint loading (potentially leading to cartilage degradation and osteoarthritis). Several prosthetic feet have been developed to help amputees walk on sloped surfaces by partially restoring ankle range-of-motion. These feet are predicted to benefit amputees when ascending/descending slopes, but there is limited empirical data that characterizes how amputees actually adapt. The purpose of our study was to quantify the effect of ankle range-of-motion on amputee biomechanics when walking on slopes.

METHODS

We performed biomechanical analysis on 4 unilateral transtibial amputees while they walked on 5 different slopes, with vs. without a prosthetic ankle joint. All study participants (male, height 73 ± 5 inches, weight 187 ± 15 lbs) gave informed consent prior to the study. Participants walked on a split-belt force-instrumented treadmill (Bertec) while we recorded ground reaction forces (GRFs) and lower-body kinematics (Vicon). Subjects first walked with their prescribed prosthesis at a self-selected speed (0.83 ± 0.24 m/s) on 5 slopes (0° , $\pm 4.5^\circ$, $\pm 9^\circ$). A certified prosthetist then fit each subject with a

Fillauer Raize foot prosthesis, which has an articulating ankle joint with adjustable dorsi-/plantar-flexion damping. The Raize ankle joint can also be locked, preventing rotation, thus only allowing flexion of its elastic heel and forefoot keels (similar to most other passive energy storage and return prostheses). The prosthetist tuned damping properties of the Raize foot to each subject. We compared amputees walking with an ankle joint vs. without (i.e., while the Raize ankle joint was locked). We computed lower-body kinematics and kinetics via inverse dynamics (Visual3D, C-Motion). Results were stride-averaged prior to reporting. For brevity of this abstract, we focus the results and discussion on two outcome measures: fore-aft GRFs and sagittal knee moments. Fore-aft GRFs provide a useful way to assess gait symmetry (in terms of braking and propulsion forces), which reveals when individuals adopt a limping gait pattern. Knee moments provide an indicator of the muscle demands about the knee, which are pertinent to assessing the difficulty of ascending/descending slopes.

RESULTS AND DISCUSSION

Biomechanical measures suggested that ankle range-of-motion provided benefits for downhill walking, in terms of normalizing limb loading and reducing knee moments. In healthy human gait, each leg contributes to braking (~ 5 - 35% of stride cycle) and propulsion (~ 35 - 65%) GRFs (Fig. 1; Healthy). At constant gait speed, these braking (negative) and propulsion (positive) forces are roughly equal and opposite. When a person begins to limp (favoring one limb over the other), asymmetries increase in fore-aft GRFs. We observed that when walking downhill without an ankle joint, all 4 subjects adopted a highly asymmetrical gait pattern, shown by braking force deficits (which must be compensated for by the intact limb, Fig. 1; Locked). With an ankle joint, however,

we observed a trend towards normalization of the fore-aft GRFs (Fig. 1; Articulating).

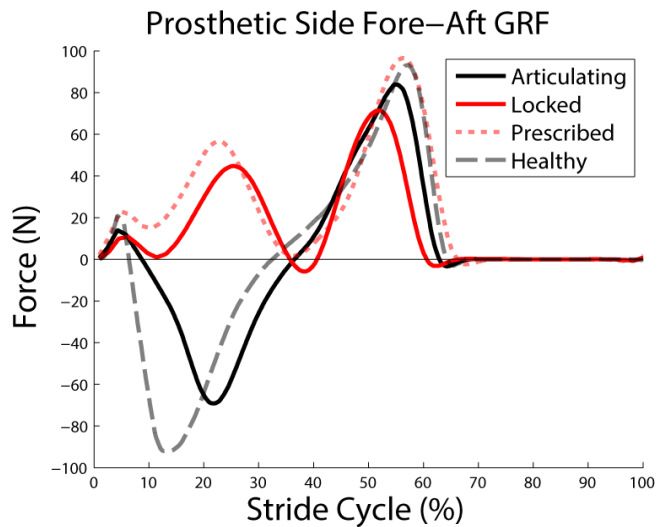


Figure 1: Prosthetic side fore-aft GRFs during downhill gait (-9°), for an example subject. Braking GRFs were absent (or greatly diminished for other subjects) when walking without an ankle joint (Locked ankle and Prescribed foot conditions). Walking with an Articulating ankle joint generally led to more normal GRFs.

We also observed concomitant reductions in the prosthetic side knee moment when walking downhill with an ankle joint, as compared to walking without an ankle joint (Fig. 2). Similar knee moment reductions were also seen in the intact limb. Since joint moments are largely due to muscle contractions, larger knee moments indicate increased muscle (and presumably metabolic) demands. Thus, these results suggest that an articulating ankle may play an important role in reducing muscle demands during downhill gait. These results are consistent with another recent study which reported minor reductions in prosthetic side knee work during ramp descent using a similar type of prosthesis with an articulating ankle ($N=9$) [2].

Biomechanical changes were also observed in level and uphill walking with vs. without an ankle joint; however, trends were subject-specific and there was substantial inter-subject variability. Fore-aft GRFs and prosthetic side knee moment, which were illuminating for downhill walking, did not exhibit consistent trends for level or uphill walking. The

importance/effect of ankle range-of-motion for these activities warrants further study. A larger sample size may be needed, and some amputees may benefit from longer habituation time to the prosthesis. Alternatively, given that amputees may adapt differently to the same prosthetic foot, it may be advantageous to use more individualized testing protocols (e.g., single-subject study design).

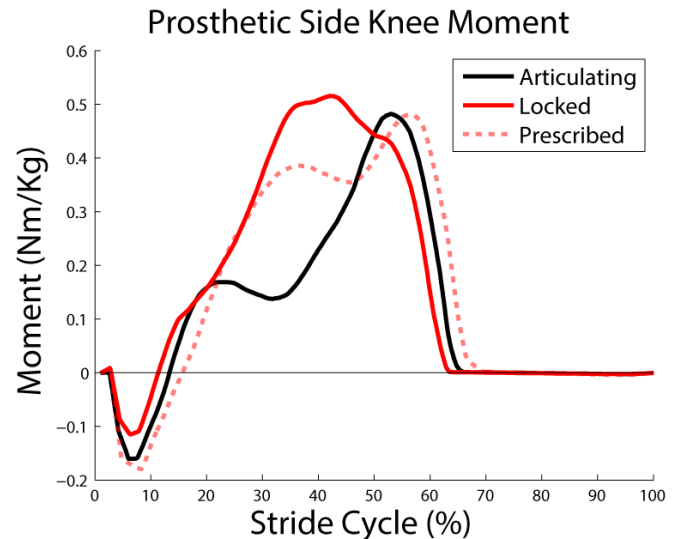


Figure 2: Prosthetic side sagittal knee moment during downhill gait (-9°), for an example transtibial amputee. Having an Articulating ankle led to reduced knee moments vs. Locked ankle and Prescribed foot conditions.

CONCLUSIONS

Prosthetic feet with articulating ankle dorsi-/plantarflexion may be beneficial for downhill walking, based on observed improvements in limb loading and reductions in knee moments. Benefits and/or detriments were less clear during level and uphill walking, which require further study.

REFERENCES

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2. Struchkov V et al. *Clin Biomech*, 2015.

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