# The importance of prosthetic ankle range-of-motion for ascending and descending slopes

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## Summary

Several prosthetic feet have been developed to restore ankle plantar-/dorsi-flexion motion to amputees. These feet are predicted to be beneficial when ascending and descending slopes, but there is limited empirical data evaluating these predictions. Thus, the purpose of our study was to quantify the effect of ankle range-of-motion on amputee biomechanics when ascending and descending slopes. Biomechanical analyses of 4 unilateral transtibial amputees revealed potential benefits for downhill walking when using a prosthetic foot with an ankle joint (vs. walking on the same foot with the ankle joint locked/non-rotational). All subjects exhibited improved prosthetic limb ground reaction forces (fore-aft) and reduced knee moments when walking with an articulating ankle. Consistent benefits or detriments were not observed across subjects during level and uphill walking, which require further study.

## Introduction

Walking on sloped surfaces can be difficult for lower-limb amputees due to the design of prosthetic feet (Vrieling et al., 2008). Most prosthetic feet are flexible, but they commonly lack an articulating ankle. In contrast, the biological ankle has a range-of-motion of ~70º (plantar-/dorsi-flexion) allowing the foot to easily conform to different slopes. Amputees can partially regain this ankle motion by using prosthetic feet that incorporate an articulating ankle. However, there is little data on how amputees adapt to this ankle motion or to what degree it improves gait biomechanics (Struchkov and Buckley, 2016).

## 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°, ±4.5°, ±9°). A certified prosthetist then fit each subject with a Fillauer Raize foot prosthesis, which has an articulating ankle joint with adjustable plantar-/dorsi-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). We computed lower-body kinematics and kinetics via inverse dynamics (Visual3D, C-Motion), but for the brevity of this abstract we focus on fore-aft GRFs. 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.

## Results & Discussion

Biomechanical measures suggested that ankle range-of-motion provided benefits for downhill walking, in terms of normalizing limb loading. 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). Concomitant reductions in prosthetic side knee moments were also observed (Fig. 2). Biomechanical changes were evident in level and uphill walking with vs. without an ankle joint; however, trends were subject-specific and there was substantial inter-subject variability.

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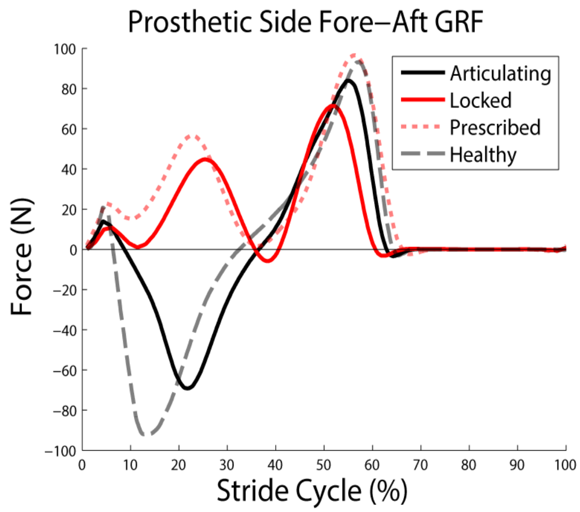


**Figure 1**: Prosthetic side fore-aft GRFs during downhill gait (-9°), for an example subject. Braking GRFs were absent (or greatly diminished for other subjects) when walking without an ankle joint (Locked ankle and Prescribed foot conditions). Walking with an Articulating ankle joint generally led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

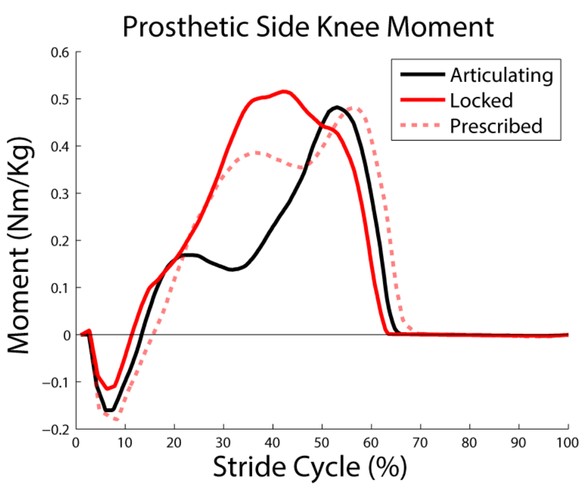


**Figure 2**: Prosthetic side sagittal knee moment during downhill gait (-9°), for an example transtibial amputee. Having an Articulating ankle led to reduced knee moments vs. Locked ankle and Prescribed foot conditions.

**References**

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