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**Title**
Lower limb amputee knee mechanics over gradients and the implications for prosthetic design

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**Summary**
Observations of joint kinematics for level and inclined walking indicated that transtibial users were able to adapt swing phase knee flexion during slope ascent, while transfemoral users could not. Reducing prosthetic knee flexion damping on inclines helps to improve ground clearance.

**Introduction/ basics**
The gait mechanics of lower limb prosthesis users have been observed to be affected by environmental conditions, such as slopes [1], as well as the level of amputation [2]. The presence of a residual knee joint allows transtibial amputees (TTA) muscular control for changing surface gradients. The same adaptation is more difficult for transfemoral amputees (TFA), who may rely on the intelligent adaptation of microprocessor devices. This work sought to quantify the differences in gait kinematics between surfaces gradients and amputation level, as well as investigate how these differences can be affected by prosthetic adaptations.

**Material method; implementation/ process**
3D motion capture data was gathered from three TTA and three TFA. Each participant was recorded during level walking and inclined (5°) walking. All trials were performed at the participant’s self-selected walking speed. All wore hydraulic ankles and the TFA all wore microprocessor knees.
Hip, knee and ankle kinematics over a gait cycle were compared between walking gradients and between amputation levels. Virtual markers were defined at the inferior tip of the participant’s feet in order to monitor minimum toe clearance (MTC) during swing phase.

The TFA were all using a prosthesis that allowed microprocessor-controlled adaptation of the knee flexion damping in terminal stance/early swing phase. For the inclined walking, they repeated their trials with two different damping settings:

(1) same knee flexion resistance as they use for level walking (normal)

(2) reduced knee flexion resistance compared to their level walking setting (adapted)

**Results**

On level ground, the differences between amputation levels were observed in early stance phase with TTA presenting stance residual knee flexion (17.1±9.4°) and greater peak prosthetic plantarflexion (TTA=-8.8±1.1°, TFA=-4.8±2.7°, $p<0.05$). On the incline, these same differences remained present, but with the addition increased peak residual hip extension in terminal stance (TTA=-4.2±9.8°, TFA=9.7±10.3°, $p<0.05$) and greater swing phase peak residual/prosthetic knee flexion (TTA=65.0±5.2°, TFA=39.5±5.9°, $p<0.05$).

For TTA, the peak residual hip extension was the only significant difference between level and incline kinematics (level=-4.2±9.8°, incline=6.4±3.6°, $p<0.05$). TFA presented a reduced prosthetic ankle range-of-motion on the incline (level=17.3±1.6°, incline=13.5±1.4°, $p<0.05$) and a significant reduction in swing phase peak prosthetic knee flexion (level=68.1±3.9°, incline=39.5±5.9°, $p<0.05$).

When comparing TFA with normal knee damping to adapted knee damping on the incline, there was a significant 9.4% increase in peak knee flexion during swing phase (normal=39.5±5.9°, adapted=43.2±5.2°, $p<0.05$). Further analysis of MTC [3] showed that the probability of tripping on a 15mm object on the walking surface reduced from 36% to 26% with the adapted damping.

**Discussion/ conclusion; conclusion for the practice**

The findings, as expected, indicated a reduced capacity for TFA to adapt to changing environmental conditions, such as inclines, compared to TTA, who retain knee muscular control. The control of microprocessor knees is essential for TFA to be able to adapt in the same way. Many modern microprocessor knees are designed with a stumble recovery functionality in order to avoid a fall after tripping, but considerations of walking adaptation for slope ascent can increase ground clearance and may provide a solution for reducing the likelihood of a trip occurring in the first place.

## References

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