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Title
The influence of hydraulic range-of-motion on prosthetic ankle performance

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Summary
The effects of an increased hydraulic range of ankle motion were investigated using gait analysis and subjective user feedback. Increased range allowed greater ground adaptation and toe clearance in swing phase without significantly diminishing ankle power generation or user stability.

Introduction
Falls are a major issue for lower limb amputees [1]. Research of falls in non-amputee elderly populations have shown tripping to cause 28.5% of falls and “a loss of balance” to cause 30.5% of falls [2]. The loss of one or more functional joints can only exacerbate these problems so prosthetic technology must seek to mitigate these risks as much as possible.
Compared to conventional energy-storing-and-return (ESR) feet, hydraulic ankles have been shown to improve gait symmetry [3], reduce socket pressure [4] and increase minimum toe clearance [5]. Increasing the hydraulic range-of-motion may further these benefits but there is also a chance that it may lead to reduced stability. This study sought to investigate these hypotheses through biomechanical analysis and user feedback.

Methods
A mixed cohort of transtibial and transfemoral participated in the analysis. Gait analysis was performed for level walking using a motion capture system and ground force plates.
Two prosthetic conditions were tested; a hydraulic ankle prosthesis with 9° range-of-motion (standard) and a hydraulic ankle with 25° range-of-motion (extended range – ER). Each user’s prostheses were aligned and set up to their individual preferences by a senior prosthetist. The prosthetic conditions were tested in a randomised order.

Participants were allowed to take the ER ankle away for a trial period of three months. Subsequently, bespoke questionnaires were provided to participants to give feedback on the device and rate different aspects of the design including stability, energy return, noise and bulk.

Results

The gait analysis highlighted the effects that the range-of-motion had on the prosthetic ankle behaviour. In terminal stance phase (40-60% gait cycle), as predicted, the ER ankle had an increased dorsiflexion angle and remained at a higher angle during swing phase, compared to the standard ankle (Figure 1, top left). This meant that there was a greater plantarflexion movement required to reach a foot-flat position, but this was achieved by approximately 15-20% of the gait cycle.

Some of the subjective feedback suggested that a few users perceived less ‘energy return’ with the ER ankle compared to the standard ankle, but the gait analysis showed there was no significant change in the peak ankle power generation in terminal stance.

A benefit of the ER ankle being in a greater level of dorsiflexion during swing phase was that the minimum toe clearance of the prosthetic limb was increased by approximately 27%.

The questionnaire used Likert scales from 1 (poor) to 7 (excellent) to ask participants about their perception of stability with the ER ankle. The mean ratings indicated that participants felt stable during level walking (5.7), sloped walking (6.3), stair ascent/descent (5.5) and quiet standing (5.4).

Conclusion

The increased range of hydraulic motion of the ER ankle appears to be beneficial to users. While it may have been feared that too much hydraulic range could lead to instability, the participant feedback in this study contradicts that hypothesis. Maintaining good stance phase balance and surface adaptation, while also increasing prosthetic toe clearance during swing phase, could be beneficial in reducing the frequency of falling and, as a consequence, decreasing the number of falls-related injuries for users.

One of the other outcomes of the subjective feedback was that many patients perceived reduced pressure and shear on their residual limb when using the ER ankle. This is an area that warrants further quantitative investigation in the future as it may be indicative of improving residual limb health.

References

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