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Title
Heel-region properties of prosthetic feet: a comprehensive insight

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Summary
This paper gives insight into the heel-region properties of different prosthetic feet with a new test method and contrasts the results of quasi-static tests as reported in the state of literature with roll-over results generated using a novel machine-based test method.

Introduction/ basics
The heel-region properties of prosthetic feet were investigated with machine-based tests by multiple scientific groups e.g. [1][2][3][4][5][6]. Due to the simplified and supposedly mechanically constrained test methods results have limited outcomes on the actual heel properties of prosthetic feet with implications for everyday tasks such as walking. With the development of more complex test methods [7] simulating a full roll-over under dynamic loads these outcomes are compared herein with previous published results.

Material method; implementation/ process
Different prosthetic feet for a user weight of 70 to 100 kg with sizes of 26 and 27cm but intended for different user populations (low to high active) were simulated in a mechanical test setup and machine according to the protocol described in [7]. Beyond the actual test standard requirements additional loads from 70 up to 100 kg were tested to evaluate potential change in properties such as impact or displacement. Beside the quasi-static loading under a fixed foot platform angle (-15°, 7.5° and 0°), full roll-over tests with a motion from heel-to-toe were performed. The resulting data was post-processed and compared to data found in literature. To further investigate the heel properties during the roll-over tests, a new parameter is found to be useful and is introduced to describe the impact properties during heel strike under these specific test condition, which puts the impact velocity in relation to the acceleration signal measured in the ‘shank’.

Results

As reported in literature quasi-static loading under fixed angles was found to show differences between feet such as total displacement at a fixed maximum load, or total work (hysteresis of force vs. displacement signal). It shall be noted that due to differences in the test setups reported in literature and the test setup describe in [7] resulting values differ (e.g Össur Vari-Flex cat 4 at -15°; 42 N/mm own data vs. 38 N/mm [6]).

The additional data from the acceleration sensor shows limited insight into the impact properties of the heel section of the foot for quasi-static loading as loading and unloading occurs in the same direction.

Adding the dynamic heel-to-toe roll-over test to the outcomes increases the complexity of interpretation as acceleration is dependent on the impact velocity which is a result of the loop control algorithms of the machine. By this, a new parameter is introduced which divides velocity of the foot during impact by the acceleration created. Differences were found both in the magnitude and the impact behavior for a single product and between products (40% less impact for a foot with shock adapter).

The additional parameters, found to be useful, were the force-displacement graphs for the quasi-static loading and the roll-over test as well as the acceleration vs. time and the dynamic impact vs. foot platform angle.

Discussion/ conclusion; conclusion for the practice

As shown in figure 1, both quasi-static and dynamic loading help to understand the heel properties behavior of a prosthetic foot. As quasi-static loading only shows loading - unloading in one direction it provides only limited insight into the rolling behavior of a prosthetic foot.

The heel-to-toe test method [7] allows evaluation of a ‘dynamic stiffness’ which correlates closer with user comments (‘felling a stiff heel’) and describes the loading under a specific impact angle while the foot is rolling further into midstance.

Further parameters are suggested by the authors and will provide insights, such as the first section of the roll-over shape curve from heel strike to midstance, as well as ankle torque vs. ankle angle curve which requires additional sensor equipment such as a camera mounted at the side of the machine.

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