Mechanical characterization of the adaptability of prosthetic feet in the frontal plane.

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Background

- For lower leg amputees an everyday task like standing and walking on uneven ground is challenging due to the limited adaptivity of a conventional prosthetic foot.
- To enhance the frontal plane adaptability (e.g. on cross slopes), prosthetic manufactures have developed prosthetic feet with various design.

Aim

- The aim was to analyze the adaptations of prosthetic feet to cross slopes and to derive a geometric model that describes these adaptations.

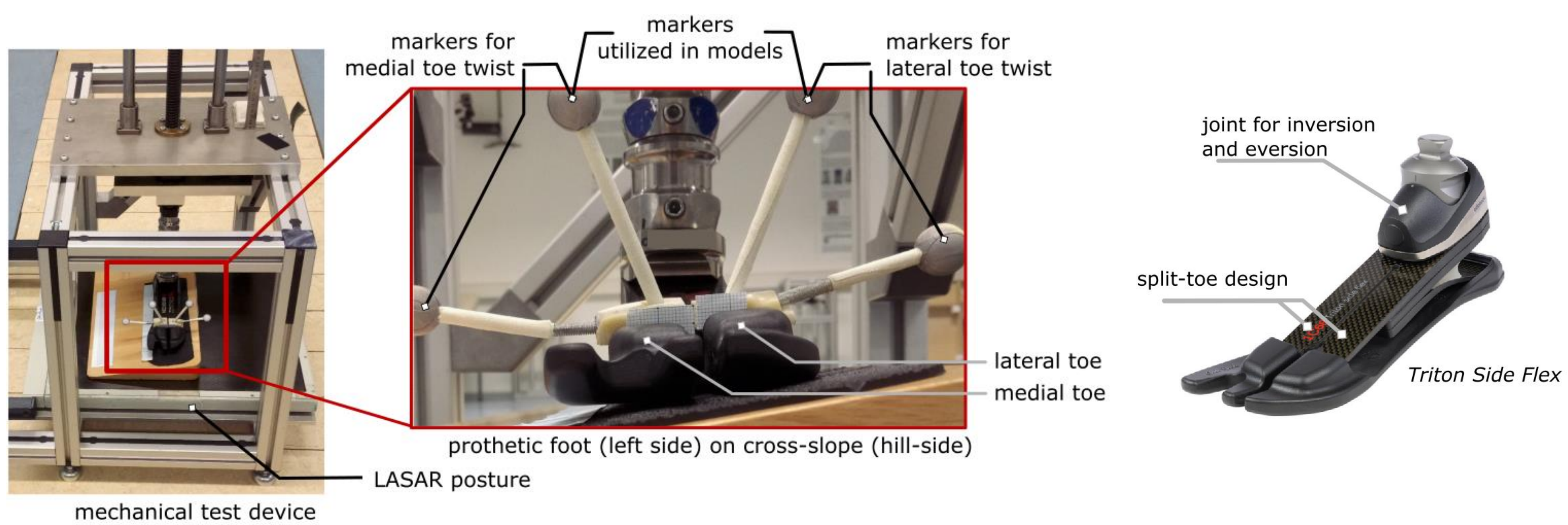

Figure 1. Mechanical test device with a split-toe ESR feet. Reflective markers were used to estimate the adaptations in the frontal plane with a motion capture system. Right - Triton Side Flex with two design features to enhance the adaptability to uneven ground.

Method

- 6 different ESR feet with 5 different designs were considered.
- A mechanical test device was used to apply loads from 0 to 100kg, figure 1.
- Blocks of 0° and 9° were used to simulate level and cross-slope conditions.
- A pair of antenna markers were attached on top of each split toe to estimate the twist in the frontal plane with a motion capture system.

effective adaptation due to shift

$$\varphi = \arctan(h/b) = \arctan(\tan(\beta)\, d/b)$$

effective adaptation due to twist

$$\gamma \approx \gamma\,(\text{hill-side}) + \gamma\,(\text{valley-side}) \approx \frac{1}{2}(\alpha_1 + \alpha_2) = \alpha$$

two-marker adaptation

$$\delta \approx \beta + \gamma \approx \beta + \alpha \approx \arctan(h/d) + \frac{1}{2}(\alpha_1 + \alpha_2)$$

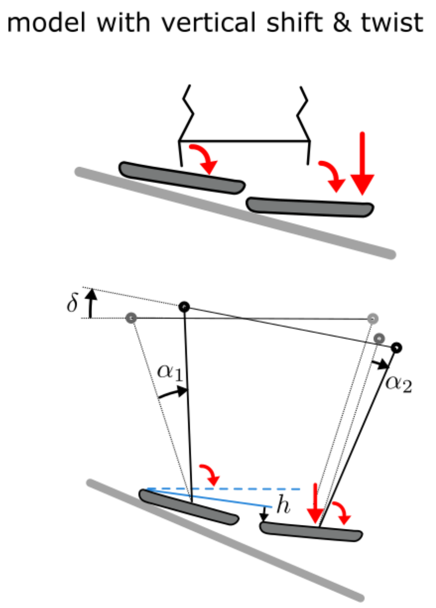

Figure 2. Model used to describe the adaptation of prosthetic split-toe feet on cross slopes. For parameter details and derivation of equations see [1].

Results

- Distinct adaptations to cross slopes were found for all investigated feet.
- Split-toe ESR feet showed a mixture of twist and shift (between toes) whereas the ratio depends on the foot type tested.
- The foot with the additional ankle joint achieved a full adaptation with the lowest load.
- The model used, figure 2, match the measured data with minor deviations and show high correlations for all feet, figure 3.

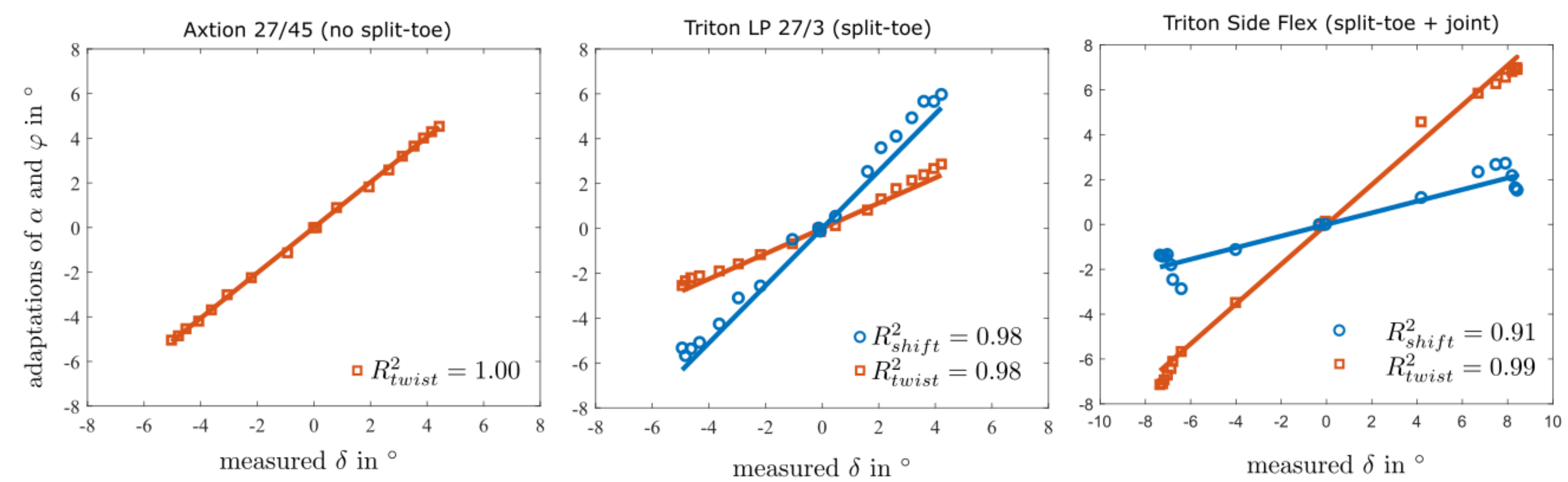

Figure 3. Linear regression of α and φ on δ. The ordinate shows the effective adaptation due to the shift (φ -circles) and twist (α -squares) while the abscissa shows the corresponding value of δ. R^2 coefficients of determination; for asymmetric feet: positive δ for an inversion (valley-side), negative δ for an eversion (hill-side).

Discussion & Conclusion

The ability of prosthetic feet to adapt to cross slopes is design dependent. A split-toe design can adapt better to cross slopes than continuous carbon forefoot feet. An ankle joint allowing for additional inversion and eversion further enhances the adaptability. Furthermore, a theoretical model was successfully derived which described the feet dependent adaptations. The influence of the ESR foot adaptability on biomechanical and clinical parameters of standing and walking on uneven ground should be investigated further [2].

References [1] Ernst et al. Prosthetics and Orthotics International (2020) 44(4): 225-233, [2] Altenburg et al. Canadian Prosthetics & Orthotics Journal (2021) 4(1)

Conflict of interest: All authors are fulltime employees of Ottobock.
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