FOOTWEAR EFFECTS ON PROSTHETIC FEET
MECHANICAL PROPERTIES WITH IMPLICATIONS FOR GAIT
BIOMECHANICS AND CLINICAL RECOMMENDATIONS

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INTRODUCTION
Studies suggest that the stance-phase mechanical properties of passive prosthetic feet can have considerable effects on mobility outcomes of lower-limb prosthesis users (Major 2014). However, a prosthetic foot is almost always used with a shoe and there remains a lack of understanding of how shoe choices influence the end-user device that has been clinically-optimized based on a patient’s mobility level. Some evidence indicates that footwear nullifies the individual and intended design characteristics of prosthetic feet (Curtze 2009), and so this uncontrolled variable may also result in inconclusive findings of comparative effectiveness studies. This study aimed to evaluate the effects of footwear on the mechanical properties of commonly prescribed prosthetic feet to better understand the implications of footwear on clinical recommendations and gait biomechanics.

METHOD
Samples: Five prostheses recommended for an 80 kg patient (left-side, 27 cm) were tested: Cadence (Trulife, Ireland); Seattle Lightfoot 2 (Trulife); Multiflex foot/ankle (Endolite, Miamisburg, OH); SACH (Willow Wood, Mt. Sterling, OH); and Single-Axis (Otto Bock, Germany). The feet were tested barefoot and under four footwear conditions: trainer (Asics, Japan); hiking boot (Timberland, Greensboro, NC); leather dress (Stafford, Dallas, TX); and flat (Mossimo, NY, NY).

Apparatus: Mechanical tests were conducted using a hydraulic-driven materials test machine (Instron, Norwood, MA) to measure force and displacement.

Procedures: The prostheses were loaded to 1230 N at 200 N/s and unloaded using four loading scenarios: heel (15° sagittal declined surface); midstance (level surface); keel (20° sagittal inclined surface); and inversion (15° coronal inclined surface).

Data Analysis: The loading-unloading hysteresis loop was used to estimate energy return (% Joules), and stiffness (N/mm) was estimated as the average slope of a linear approximation of the loading and unloading curves. These estimations were averaged over four loading cycles for each foot-shoe combination.

RESULTS
For initial contact, hysteresis curves for the barefoot condition and estimated energy return for each foot-shoe combination are presented in Figure 1.

DISCUSSION
The hysteresis curves display how articulated devices rapidly transitioned to foot-flat when loaded, but this behavior was normalized with the addition of shoes to mimic function of non-articulated feet. Shoes seem to impair the desired clinical function of articulated devices to quickly achieve a stable base-of-support for patients of low mobility. Apart from the keel where little effect was observed, shoes normalized and decreased stiffness and energy return across feet. Decreased stiffness would simulate greater range-of-motion, but the greatest reduction was observed at the heel and this may exacerbate user perception of ‘sinking’ into their step. Decreased heel energy return would be beneficial to dissipate loads and protect the residuum, but the reduction in midstance energy return may increase difficulty in energy recovery to aid in transferring weight across the prosthesis and encourage gait compensations. Shoes did not greatly alter keel properties and so prostheses designed to assist late stance push-off may retain this function.

CONCLUSION
Shoes appear to mute the individual design characteristics of some prosthetic feet, thereby forcing a convergence of mechanical behavior.

CLINICAL APPLICATIONS
Clinicians should be aware that shoes may cause an unpredictable change in mechanical function of the prosthetic setup and alter rehabilitation outcomes. Shoes should be controlled in experimental settings.

REFERENCES