INTRODUCTION

Limb trauma requiring reconstructive surgery commonly results in decreased performance of key functional activities such as walking and running. Ankle-foot orthoses (AFOs) are frequently prescribed to restore limb function by providing mechanical support. To address the desire of patients with injuries requiring lower limb reconstruction to return to running and other high-energy activities, a custom carbon-fiber, passive-dynamic orthosis, the Intrepid Dynamic Exoskeletal Orthosis (IDEO), was developed to improve upon previous AFO designs [1] and facilitate the return to high-energy, performance-based tasks [2]. The customizable nature of the IDEO allows certain features, such as its stiffness, to be tailored to meet the needs of the individual. This mechanical stiffness may also influence the stiffness or compliance of the lower extremity joints [3]. The purpose of this study was to determine the effect of AFO stiffness on lower extremity running biomechanics in individuals with lower limb reconstructions.

METHODS

Ten male subjects with traumatic, unilateral lower limb reconstruction underwent gait analysis (marker data: 120 Hz, Motion Analysis Corp, ground reaction force data: 1200 Hz, AMTI, Inc.) of the lower extremity during overground running at a self-selected speed. All patients were regular users of a custom IDEO (Fig. 1) whose stiffness characteristics were clinically prescribed by the prosthetist/orthotist based on the patient’s available range of motion, activity level, body mass and load carriage requirements. Three struts were fabricated using a selective laser sintering technique [4]: 1. Nominal (clinically prescribed stiffness, mean: 832 ± 182 Nmm), 2. Compliant (20% less stiff), and 3. Stiff (20% stiffer).

RESULTS AND DISCUSSION

There was a significant interaction (p=0.011) such that the stiffness of the sound ankle remained unchanged across conditions while the affected ankle was, on average, 152.5% stiffer than the unaffected (p<0.001) and increased joint stiffness with increasing strut stiffness (p=0.019). Specifically, the stiffest strut resulted in an 18% increase in ankle joint stiffness compared to the compliant strut (p=0.001) (Fig 2). Strut stiffness did
not affect temporal spatial measures, preferred running speeds, kinematics or any other kinetics.

![Graph showing Ankle and Knee Joint Stiffness](image)

**Fig 2.** Ankle and knee joint stiffness during the braking phase of stance for the affected (solid bars) and unaffected (dashed bars) limb. † indicates significance between strut stiffness conditions and * indicates significance between groups.

Although the affected ankle was stiffer than the unaffected side, the knee of the affected limb was, on average, 123.2% more compliant (p=0.007), potentially in an effort to preserve total limb stiffness [3]. Positive and negative mechanical work were 212.0% and 64.2% greater, respectively, on the unaffected limb for the ankle (pos: p<0.001, neg: p=0.013) and 62.3% and 124.3% greater for the knee (pos: p=0.008, neg: p=0.003), respectively.

Limb stiffness is a fundamental component needed for optimal performance [5] and dynamic AFO stiffness can influence the amount of energy storage and return an individual experiences during gait. However, a 40% range in strut stiffness did not influence kinematic and most kinetic mechanics of running. Subjects either readily adapted to the different stiffness conditions or the 40% range of stiffnesses evaluated in this study was not broad enough to elicit significant changes in mechanics. The only exception was that the stiffer strut did increase the stiffness of the affected biological ankle joint compared to the compliant strut. However, the increase in ankle stiffness did not affect mechanical work or decrease the knee stiffness, which would be expected if total leg stiffness were maintained [3].

**CONCLUSIONS**

Strut stiffness did not influence joint angles, moments, powers, or mechanical work during running in individuals with unilateral lower limb salvage. However, a stiffer AFO results in a stiffer ankle joint structure which may be particularly useful for patients with limited pain free ankle range of motion. The changes in joint stiffness were not associated with significant changes in mechanical work. It is unknown how these results translate to populations with other injuries and pathologies, but is likely that some adaptation occurs to different stiffnesses. Therefore, a range of stiffness may be clinically appropriate when prescribing ankle-foot orthoses for running activities, while a stiffer AFO may reduce the risk of mechanical failure during high-energy activities other than running.

**REFERENCES**


**ACKNOWLEDGEMENTS**

Nicole Harper and Dr. Richard Neptune at the Univ. of Texas designed, fabricated and tested all struts. Support for this study was provided by the Center for Rehabilitation Sciences Research, Dept. of Physical Medicine and Rehabilitation, Uniformed Services Univ. of Health Sciences, Bethesda, MD.

The views expressed herein are those of the authors and do not reflect the policy or position of Brooke Army Medical Center, the US Army Medical Department, US Army Office of the Surgeon General, Department of the Army, Department of Defense or US Government.