Influence of Longitudinal Prosthetic Stiffness Modification on Ground Reaction Forces during Transtibial Gait

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INTRODUCTION

Lower-limb shock-absorbing prosthetic components, including feet, pylons, and gel liners, are often characterized by reduced longitudinal stiffness, the effects of which are not well understood, particularly during walking. Decreasing the stiffness of a prosthesis should reduce the ground reaction force (GRF) loading peak and increase the time to reach this peak from force onset, commonly used metrics of shock absorption. Previous studies have investigated the effects of reduced-stiffness components in comparison with more traditional components, but have not reported changes in GRFs (Miller & Childress, 1997; Gard & Konz, 2003; Berge, 2005). The purpose of this study was to systematically evaluate the effect of a wide range of longitudinal prosthesis stiffness values on gait biomechanics.

METHOD

Subjects: 12 subjects with unilateral transtibial amputations (mean age: 49 ± 18 years, mean mass: 84.8 ± 21 kg) were recruited to participate in this study. Subjects were required to have at least six months of experience with a prosthesis, be 18-80 years of age, weigh <125 kg, and be able to walk at least 10m without assistance. The Northwestern University Institutional Review Board approved this study and informed consent was obtained from all subjects prior to participation.

Apparatus: Gait data were acquired using a twelve-camera real-time motion capture system (MAC, Santa Rosa, CA) and six force platforms (AMTI, Watertown, MA) embedded within the laboratory floor.

Procedures: Subjects wore their current socket and suspension system, and were provided with an experimental prosthesis consisting of a shock-absorbing pylon (SAP) (Endolite TT Pro, Miamisburg, OH) and a standardized prosthetic foot and shoe. Longitudinal stiffness was varied by swapping out the spring within the SAP. A NORMAL (manufacturer-recommended), a SOFT (50% NORMAL) and a MEDIUM (75% NORMAL) stiffness as well as a RIGID pylon were tested for each subject. Gait analyses were performed for each stiffness condition at both freely-selected and fast self-selected walking speeds.

Data Analysis: Cortex and OrthoTrak software (MAC, Santa Rosa, CA) were used to process data and calculate kinematic and kinetic data. MATLAB (MathWorks, Natick, MA) was used to identify loading peaks, and SPSS was utilized to perform statistical analysis (IBM Corp., Armonk, NY).

RESULTS

Few significant differences were found between stiffness conditions at freely selected walking speeds; a statistically significant difference was found in peak force magnitude between the SOFT and NORMAL conditions during fast walking ($p = 0.021$) (Figure 1). No changes in kinematics or time to loading peak were observed.

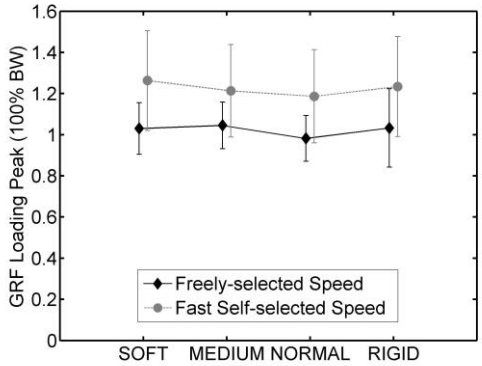

Figure 1. Mean peak GRF loading peak magnitudes for 12 subjects during gait. The error bars denote +/- 1 S.D.

DISCUSSION

No clinically significant changes were found between stiffness conditions at freely selected walking speeds. While some changes were observed at fast speeds, the question of how the prosthetic-side limb system is accommodating the change in prosthetic stiffness remains. Two possibilities exist: (1) that subjects are altering their neuromuscular strategy to change the stiffness of their residual limb/knee joint, or (2) that the experimental stiffness conditions are not sufficient to change the net limb stiffness. In the future, these possibilities may be investigated by incorporation of EMG analysis of the residual limb and analysis of an *in vivo* impact in which active adaptation is minimized.

CONCLUSION

Longitudinal stiffness modification does not influence ground reaction forces at self-selected walking speeds. At fast walking speeds, low stiffness resulted in an unexpected *increase* in loading peaks.

CLINICAL APPLICATIONS

Prosthesis components in which longitudinal stiffness has been reduced *separately from any other factor* are unlikely to enhance prosthetic shock absorption.

REFERENCES

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