

Amputee Gait Adaptation: Adjusting Residual Limb Compliance In Bouncing Gaits

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Introduction

Amputee musculoskeletal adaptation to mechanical changes in prosthetic componentry is not well understood, but may be similar to an adaptive strategy used for able-bodied individuals. An efficient expenditure of energy is obtained through a controlled excursion of the center-of-mass (COM) of the body during gait, even when affected by external parameter such as ground compliance. A simple, but remarkably accurate model that is used to evaluate this body motion in able-bodied individuals is the Linear Spring Model. This describes the motion of the body in bouncing gait as a point mass on a linear spring^{1,2}. This model has also been successfully applied in the evaluation of overall limb stiffness on compliant surfaces in bouncing gaits^{3,4,5}. Such research demonstrates that able-bodied runners adapt their overall limb stiffness to maintain constant center-of-mass motion in response to changes in ground compliance. This is accomplished primarily by altering the ankle joint stiffness and knee angle during the ground contact phase of gait. The objective of this study was to use a similar model to determine if the residual limb compliance of transtibial amputees adapts in a similar manner to mechanical changes made in an energy storage and return (ESAR) prosthetic limb during bouncing gaits (gait that involves both a single-limb stance period and an aerial period). Understanding this adaptive process may further improvements in prosthetic design and promote biomechanical matching of the mechanical properties of an ESAR prosthesis to the remnant musculoskeletal structures of an amputee. These results might suggest optimum prosthetic configurations and clinical prescriptions for active prosthesis users.

Methodology

A single male transtibial amputee (age 33, height 1.79m, weight 75.5kg) was fit and clinically aligned for running and walking with three stiffness categories of the Flex-Foot® Vari-Flex ESAR prosthesis. The as-prescribed (AP) limb was selected according to manufacturer guidelines and prosthetist recommendation. The remaining limbs were selected as one stiffness category higher (high-stiffness, HS) and lower (low-stiffness, LS) than the AP prosthesis. Kinetic data obtained from hopping, jogging in place, and jogging forward were collected at 240Hz from a surface mounted force platform. The vertical ground reaction force (VGRF) from ten trials per limb condition were collected and averaged for comparison. The motion of the center-of-mass (COM) was obtained from double-integration of the acceleration data⁶. The overall limb stiffness was approximated from a least-squares residual fit of the resultant VGRF vs. COM displacement data. Similarly, the prosthesis stiffness was calculated using a least-squares residual fit of the load-displacement data obtained during mechanical testing of the prostheses. The stiffness of the residual limb was then computed from a one-dimensional, two-element linear spring model for single-limb amputee hopping.

Results

The overall limb compliance was calculated as the slope of a least squares linear fit of the VGRF vs. COM displacement data for each limb condition. Overall leg stiffness of 24.1 (AP), 23.6 (LS), and 26.1 (HS) kN/m were obtained during single-limb hopping. Mechanical testing of the ESAR prostheses resulted in stiffness values of 53.0 (AP), 47.5 (LS), and 69.1 (HS) kN/m, consistent with previously published values⁷. The residual limb adjusted stiffness by -14.3% and 33.3% to accommodate the changes to the mechanical stiffness of the prosthesis. The constituent compliance (stiffness⁻¹) values for a hopping amputee are shown (Fig. 1).

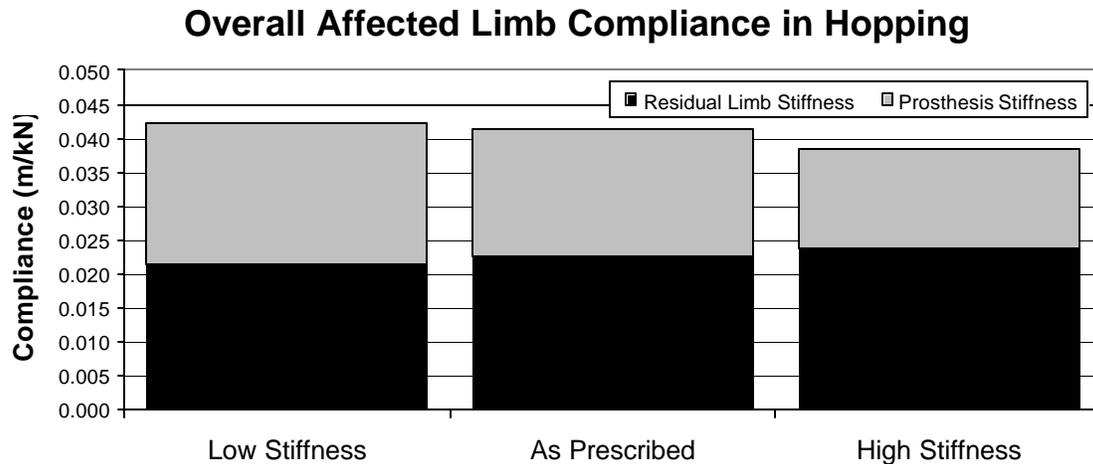


Figure 1 – Overall, prosthetic, and residual limb compliance of a transtibial amputee in single-limb hopping gait. The residual limb compliance (black) increases as the prosthesis compliance (gray) decreases, but not sufficiently to maintain a constant overall limb compliance (summed residual limb and prosthesis compliance values).

Discussion

The initial data suggests that the residual limb is adapting and potentially compensating for the mechanical stiffness changes made to the prosthesis. However, the adaptation provided by the residual limb is insufficient to maintain a constant overall limb stiffness. One reason for this may be the lack of musculoskeletal structures capable of compensating for the differences in the prosthesis stiffness categories. Modulation of ankle stiffness has been reported as the primary mechanism of leg stiffness adaptation in able-bodied individuals³. It is quite possible that the limb is unable to fully adapt to changes in overall compliance without the intact ankle. Further research and additional subjects are required to quantify and determine the mechanism of residual limb adaptation.

References

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