

CENTER OF ROTATION POSITION IN NON-ARTICULATED PROSTHETIC FEET: IMPLICATIONS FOR PROSTHETIC FOOT KINETICS

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INTRODUCTION

Joint kinetics have been estimated via inverse dynamics with link-segment models to analyze the performance of non-articulated energy storage and return (NA-ESR) prosthetic feet [1] and to examine the motor control strategies and compensations adopted by lower limb amputees [2]. A central assumption of the link-segment model commonly used in this application is that the ankle's axis of rotation acts as a fixed hinge; yet in NA-ESR prosthetic feet, no true ankle articulation exists, and the extent to which any axis remains fixed is unknown. Despite these concerns, this computational approach has been used to assess differences within and between amputees, and in comparison to non-amputees [1,3]; thus reports of estimated kinetics in NA-ESR prosthetic feet, and proximal joints may be in question [4]. Two groups have attempted to address this concern [4,5], yet neither reported the actual axis location. Additionally, the feet tested previously are not commonly prescribed in clinical use today. The overall objectives of our work are to discern the magnitude of ankle joint axis mis-location required to induce meaningful alterations in joint kinetics, evaluate the center of rotation position in a series of NA-ESR prosthetic feet, and quantify the effect of any differences in center of rotation position on prosthetic foot and proximal joint kinetics of a unilateral transtibial amputee. The primary focus of this paper is the quantification of the center of rotation position in NA-ESR prosthetic feet.

METHODS

To determine the magnitude of ankle joint axis mis-location required to induce meaningful alterations in joint kinetics, systematic error simulations were performed using previously collected gait data from one healthy non-amputee. Incremental adjustments

of 10mm were made to the location of the ankle joint axis in the anterior-posterior direction (in the tibial coordinate system) by modifying a link-segment model in BodyBuilder™ (Vicon; Lake Forest, CA). Differences in kinetic output were examined at the ankle, knee and hip. Next, the position of the center of rotation for eight commonly prescribed NA-ESR prosthetic feet was estimated from kinematic gait data collected at 120 Hz from one unilateral transtibial amputee walking at self-selected walking speed. Using KineMat [6], a MATLAB™ (MathWorks, Natick, MA) software package, the sagittal plane position of the helical axis of motion [7] was estimated. Differences between the assumed fixed ankle axis and helical axis position were examined over stance phase.

RESULTS AND DISCUSSION

The systematic error simulations of ankle joint axis position resulted in substantial changes to knee and ankle kinematics, as well as ankle kinetics. Ankle powers are presented for an entire gait cycle in Figure 1.

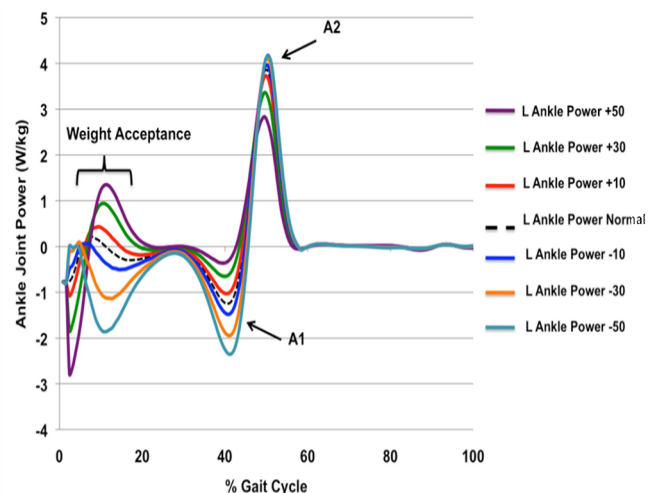


Figure 1: Changes in ankle joint power with alterations to A-P ankle joint axis position.

A posterior shift of the ankle joint axis resulted in greater power absorption during the A1 power burst, while anterior shifts generated a decrease in power absorption. During the A2 power burst shifting the axis posteriorly resulted in increased power generation, whereas power generation was reduced with an anterior shift. These results indicate that from weight acceptance to toe-off, a posterior shift in the ankle joint axis location from its traditionally assumed position near the lateral malleoli would induce an overestimation of power absorption and generation, while an anterior shift would result in an underestimation of power absorption and generation.

Using a helical axis of motion to estimate the center of rotation position across a series of NA-ESR prosthetic feet resulted in notable differences in the anterior, posterior, superior and inferior directions from the traditionally assumed fixed axis position. Tibial angle at the point of peak displacement (difference between fixed and helical axis positions) differed across directions and in some cases between feet within a direction. Peak anterior displacement of the helical axis compared to the assumed fixed axis position for eight NA-ESR prosthetic feet and the tibial angle at peak displacement are shown in Figure 2. Displacements ranged from slightly over 10 mm up to nearly 80 mm, occurring between mid-stance (4° tibial angle) and toe-off.

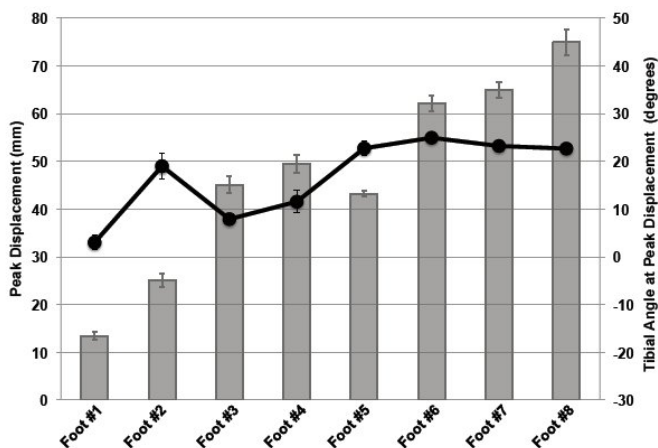


Figure 2. Peak anterior displacement of the helical axis from the fixed axis position for eight commonly prescribed prosthetic feet and the tibial angle at peak displacement; columns represent peak displacement, line represents tibial angle at peak displacement.

Based upon the results from the systematic error simulation, displacements of 10 mm in the anterior direction occurring near mid-stance (foot #1), would likely have little effect on estimates of power at the ankle, while a displacement of 80 mm occurring later in stance (foot #8), would grossly misrepresent power at the ankle. Our group is currently working on comparisons between joint kinetics estimated using the assumed fixed axis and helical axis positions respectively.

CONCLUSIONS

This paper represents the first effort to estimate the actual center of rotation position in NA-ESR prosthetic feet. Based on these results, the validity of calculating joint kinetics for NA-ESR prosthetic feet and the proximal joints may be in question if the ankle axis is assumed to act as a fixed hinge that mirrors the position of the intact contralateral ankle. The helical axis position may be utilized to more precisely account for the kinetics within prosthetic foot-ankle prostheses. Additionally, the differences in peak displacement of helical axis position between different prosthetic feet may have implications for how unilateral transtibial amputees utilize the energy storing capacity of these feet and subsequently how they should be trained during rehabilitation. The results from our first two aims validate the need to re-examine techniques commonly employed to estimate foot and ankle kinetics among individuals with lower limb loss.

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