THE CENTER FOR **ORTHOTICS AND PROSTHETICS**
LEARNING AND OUTCOMES/EVIDENCE-BASED PRACTICE

# Estimation of the Axis of Rotation Position in Non-articulated Energy Storage and Return Prosthetic Foot-Ankle Mechanisms; Implications for Prosthetic Foot-ankle Mechanism Efficiency and Motor Control Strategies in Unilateral Transtibial Amputees

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# Final Report

Project Title: Estimation of the axis of rotation position in non-articulated energy storage and return prosthetic foot-ankle mechanisms: Implications for prosthetic foot-ankle mechanism efficiency and motor control strategies in unilateral transtibial amputees.

## Project Background, Goal and Aims

This project set out to examine a major limitation of traditional biomechanical methods used in the assessment of non-articulated energy storage and return (NA-ESR) prosthetic feet during instrumented gait analysis; that their axis of rotation can be accurately modeled as a fixed hinge joint over the course of stance phase.

During typical instrumented gait analyses the anatomical ankle joint is commonly modeled as a fixed hinge joint. This allows for all kinetic values to be summed about an unchanging point, greatly simplifying the required calculations to determine ankle joint moment, power and work or energy. However, designs of NA-ESR foot-ankle mechanisms do not consist of hinge joints, nor can their axis of rotation truly be considered to be fixed. Despite this contradiction, during instrumented gait analysis NA-ESR prosthetic feet are currently assigned a fixed axis of rotation whose position matches that of the contralateral intact ankle joint. Under these conditions two assumptions are being made; 1) the axis of rotation in NA-ESR prosthetic feet remains in a fixed location during stance phase, and 2) the axis of rotation is fixed in a position that matches the intact contralateral ankle joint.

While this issue has received some attention in the literature, no previous work had clearly demonstrated to what extent the axis of rotation is or is not fixed in NA-ESR prosthetic feet and what impact a changing axis of rotation position may have on commonly reported kinetic values. Therefore, the main goal of this project was to determine if the axis of rotation in a series of NA-ESR prosthetic feet displaces over the course of stance phase and if so what impact this displacement may have on prosthetic foot and proximal joint kinetics (moments, power, energy absorption/generation) as calculated through inverse dynamics. Specifically we sought to examine this question by first identifying the amount of ankle joint axis displacement required to alter joint kinetics in healthy non-amputees, followed by a quantification of the axis of rotation position in a series of NA-ESR prosthetic feet and the subsequent impact any change in the axis of rotation position may have on joint kinetics.

## Overview of Methods Used

Using previously collected gait data from one healthy non-amputee subject, we performed a systematic error simulation, making incremental adjustments of 10mm to the location of the ankle joint axis in the anterior-posterior direction (10, 20, 30, 40 and 50 mm). Errors in kinetic output for the ankle, knee and hip were examined. The position of the center of rotation for five NA-ESR prosthetic feet was estimated from kinematic gait data collected on one unilateral transtibial amputee. Using an established software package, the sagittal plane position of the axis of rotation was estimated for each foot. Differences between the assumed fixed calculated axis positions were examined over stance phase. While preliminary plans were to use this axis of rotation for joint kinetic analysis, we found that current models and commercially available software were not suitable to incorporate a moving axis of rotation. As such, the calculated axis of rotation position was used to infer likely changes in joint kinetics.

Findings

Our systematic error simulations of ankle joint axis position resulted in substantial changes to knee and ankle kinematics, as well as ankle kinetics. Regarding ankle kinetics, from weight acceptance to toe-off, a posterior shift in the ankle joint axis location from its traditionally assumed position induced an overestimation of power absorption and generation, while an anterior shift resulted in an underestimation of power absorption and generation. The positions of the axes of rotation in a series of five prosthetic feet were found to display notable divergence from the traditionally assumed fixed axis position (Figure 1). This displacement was typically anterior to the assumed fixed axis position and was most apparent at the beginning (45 to 74 mm), and again at the end (27-56 mm) of stance phase.

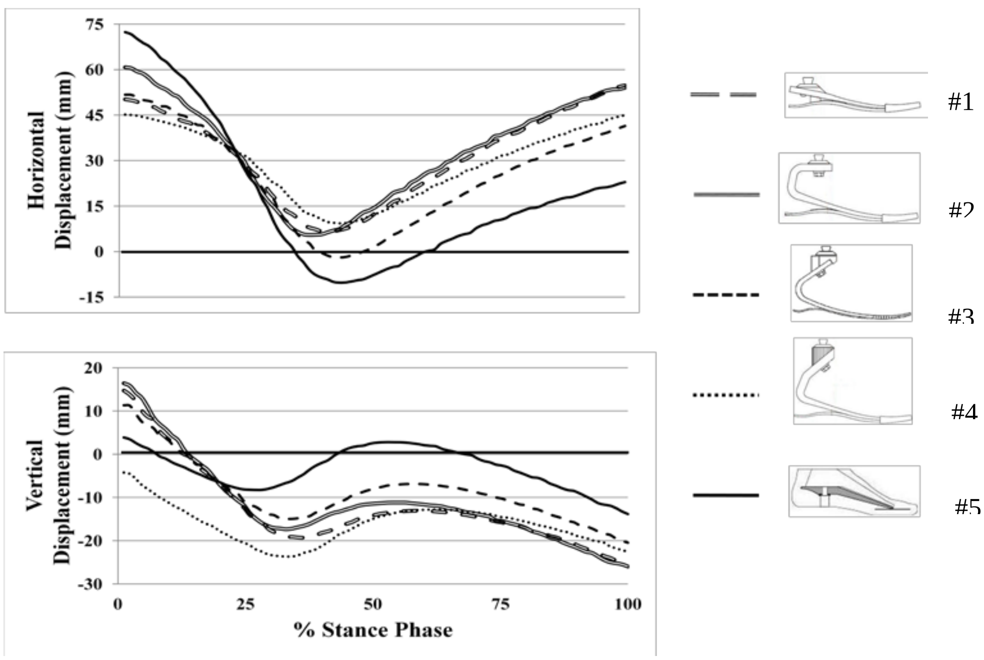


**Figure 1**: Position of the calculated axis of rotation in five NA-ESR prosthetic feet relative to the assumed fixed axis position (denoted by the black zero line) over stance phase. Positive values on the vertical axis represent anterior or superior positions, while negative values represent posterior or inferior positions. Each foot is represented by an ensemble average of five trials.

While not directly calculated for reason explained above, prosthetic foot kinetics (joint moments and powers) estimated using the calculated axis position would likely be markedly lower than those estimated with the assumed fixed axis position given the notable anterior position of the calculated axis of rotation vs. its traditionally assumed position (Figure 1).

Given the likely decrease in joint power, there would also be a corresponding decrease in the amount of energy returned by these prosthetic feet during push-off. These findings indicate that NA-ESR prosthetic feet may contribute far less to forward progression than would be reported if the assumed fixed center of rotation position were used.

To date the findings of this project have been presented at the American Society of Biomechanics annual conference and are scheduled to be presented at the American Academy of Orthotists and Prosthetists annual meeting this coming March. Additionally, a manuscript based upon this work has been written, submitted and is currently under review with the *Journal of Biomechanics*.

## Implications of Findings

These results contradict a commonly held clinical belief that NA-ESR prosthetic feet should be prescribed on the basis of their ability to return energy during terminal stance. The rationale for NA-ESR foot prescription and use may require re-examination to include additional features and characteristics (shock absorption and comfort, biomimetic roll-over shape etc.) of these feet. Additionally, prosthetists interpreting research studies evaluating the biomechanical characteristics of prosthetic feet should do so with caution when a fixed axis of rotation is assumed.

Additional research will be required to confirm the findings of this study. Nonetheless, given the sizable displacement demonstrated by the calculated axis and its likely influence on the estimation of prosthetic foot kinetics, it would appear unwise for researchers to continue using a fixed center of rotation that mimics the position of the lateral malleolus when evaluating NA-ESR prosthetic feet during instrumented gait analysis.

## Problems and Challenges

Simplification of the methods used in this study to determine the axis of rotation position would be required to integrate the chosen methods into standard practice in addition to the development of a model and/or software package capable of integrating a moving joint center. Additionally, given the single subject design of our study, these results are far from conclusive and require additional research to confirm.

## Future Work

We are continuing to pursue improved methods with which to evaluate prosthetic feet. We are in the process of using commercially available hardware to instrument a series of prosthetic feet to obtain direct measures of their kinetic function and thus provide a gold standard to which all other methods could be compared, including the one reported on here. Additionally, the creation of an appropriate model to account for differences in segment anthropometrics (mass, center of mass position etc.), and changes in segment length during stance phase (shock absorbing pylons) is underway. The creation of such a model would serve to greatly improve the accuracy with which lower limb amputee locomotion is assessed.