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Trajectory of the center of rotation in non-articulated energy storage and return prosthetic feet

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ABSTRACT

Non-articulated energy storage and return prosthetic feet lack any true articulation or obvious point of rotation. This makes it difficult to select a joint center about which to estimate their kinetics. Despite this absence of any clear point of rotation, methods for estimating the kinetic performance of this class of prosthetic feet typically assume that they possess a fixed center of rotation and that its location is well approximated by the position of the contralateral lateral malleolus. To evaluate the validity of this assumption we used a finite helical axis approach to determine the position of the center of rotation in the sagittal plane for a series of non-articulated energy storage and return prosthetic feet. We found that over the course of stance phase, the sagittal finite helical axis position diverged markedly from the typically assumed fixed axis location. These results suggest that researchers may need to review center of rotation assumptions when assessing prosthetic foot kinetics, while clinicians may need to reconsider the criteria by which they prescribe these prosthetic feet.

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1. Introduction

In the study of lower limb prosthetics, joint kinetics are used to analyze the performance of prosthetic components and motor control strategies adopted by individuals with lower limb loss (Winter and Sienko, 1988; Gitter et al., 1991; Underwood et al., 2004). These kinetic descriptions of movement are calculated using pre-defined joint axes (Winter, 2009), whose positions require accurate approximation for estimating hip (Delp and Maloney, 1993; Stagni et al., 2000), and knee joint moments (Holden and Stanhope, 1998). Analyses have rarely been performed on joint axis localization (Rusaw and Ramstrand, 2010) and its importance for estimating kinetic parameters in prosthetic componentry (Prince et al., 1994; Geil et al., 2000; Miller and Childress, 2005).

Non-articulated energy storage and return (NA-ESR) prosthetic feet are typically constructed from carbon fiber composite, have a "J" shape design and lack a clearly-defined axis of rotation. To facilitate comparison with the natural foot–ankle complex and simplify the required calculations, typical assessments of NA-ESR prosthetic foot performance have used constrained link-segment models which assume that the ankle axis of rotation is approximated by the lateral malleolus position (Gitter et al., 1991; Barr et al., 1992; Powers et al., 1998; Underwood et al., 2004; Su et al., 2008; Supan et al., 2010) and behaves as a fixed hinge. In NA-ESR prosthetic feet this assumption is problematic as no true "ankle" articulation exists, the extent to which the joint center remains fixed is unknown, and its approximation by the lateral malleolus has been questioned (Rusaw and Ramstrand, 2010).

To account for any uncertainty in joint power and energy estimates caused by the movement or mis-location of the axis of rotation in NA-ESR prosthetic feet, several groups have incorporated translational power terms into their inverse dynamic analyses (Prince et al., 1994; Geil et al., 2000) on the basis of work in the anatomical foot–ankle (Buczek et al., 1994). However, the extent to which the inclusion of translational power terms can account for joint center mis-location and/or true joint translations in NA-ESR prosthetic feet has not been established.

In light of the limited information regarding the position of the axis of rotation among NA-ESR prosthetic feet, the objective for the current study was to identify the sagittal plane center of rotation position among a series of NA-ESR prosthetic feet in order to assess the appropriateness of continued use of a fixed joint center in the kinetic analysis of NA-ESR prosthetic feet.

2. Methods

Five NA-ESR prosthetic feet (Table 1) were assessed on one unilateral transtibial amputee (Table 2). Each foot was chosen specifically for the participant

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