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Short communication

Marker cluster rigidity in a multi-segment foot model

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ABSTRACT

Multi-segment foot models (MSFM) are used in gait analysis for the diagnosis and planning of treatment for patients with foot deformities. Like other biomechanical models, MSFMs represent the leg and foot as a series of linked rigid segments, but such a simplification may not be appropriate, particularly for the flexible forefoot. This study investigated the appropriateness of the rigid body assumption on marker clusters used to define the individual segments (tibia, hindfoot, forefoot) of a widely-used MSFM. Rigidity of the marker clusters was quantified using the rigid body error (σ_{RBE}) calculated for each frame of a representative gait cycle for 64 normal healthy adults who underwent gait analysis. σ_{RBE} is a measure of how well the tracking marker configuration at each frame compares to the arrangement of the same markers in a reference pose. As expected, the patterns of deformation of the three marker clusters differed over the gait cycle. The hindfoot cluster remained relatively undeformed in comparison to the forefoot and tibia clusters. The largest deformations of the forefoot cluster occurred near the beginning and end of the stance phase. The tibia cluster deformed throughout the entire gait cycle, with a pattern similar to that of a typical knee flexion angle graph. The results raise questions about the appropriateness of the rigid-body assumption when applied to MSFMs, particularly in the forefoot region.

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1. Introduction

Multi-segment foot models (MSFM) have become increasingly popular due to the improved accuracy and ease-of-use of motion capture technology, and there is strong evidence supporting their clinical use (Wren et al., 2011). Sub-division of the foot into multiple segments for gait analysis has helped with the diagnosis and planning of treatment for foot deformities, as well as furthering our understanding of foot biomechanics. There are many different MSFMs used in clinical gait laboratories worldwide, including the Oxford Foot Model (OFM) (Carson et al., 2001; Stebbins et al., 2006), the Rizzoli Foot Model (Leardini, Benedetti et al., 2007), the Heidelberg Foot Measurement Method (Simon et al., 2006), and several others (Deschamps et al., 2011; Rankine et al., 2008). These all share some key features, such as a hindfoot segment, but differ in others, notably in how the bones in the rest of the foot are modelled.

Although most lower-limb biomechanical models used in gait analysis represent the leg and foot as a series of linked rigid segments, such a simplification may not be appropriate in a MSFM, even if it makes the related measurements and calculations easier. Whether the midfoot and forefoot in particular should be modelled as rigid bodies is questionable, given the known flexibility of the medial longitudinal arch and the mediolateral spread of the forefoot during the stance phase of gait (Duerinck et al., 2014).

In classical mechanics, a rigid body is characterized by the requirement that the distance between any two points on the body remains fixed. Therefore, the simplest way to quantify deformation is to find the change in Euclidean distance between the points or, alternatively, to calculate the strain. An alternative measure of deformation which uses multiple points at once is the rigid body error (σ_{RBE}) introduced by van den Bogert et al. (1994) for the purpose of quantifying soft-tissue artefact. The σ_{RBE} effectively quantifies violations of the rigid-body assumption. In the present context, it can be thought of as a measure of the difference between the configuration of selected points (identified by clusters of skin-mounted markers) on the surface of a body segment in a reference pose and the configuration of those same points (or markers) after the body has changed position.

This study aimed to quantify the σ_{RBE} of skin-mounted marker clusters on the forefoot, hindfoot, and tibia[a] segments of a multi-

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[a] Note that, in some models, this segment is referred to as the "shank" since it comprises both the tibia and the fibula.

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inter-rater/trial ratio. The rater with more experience in gait analysis achieved a more consistent result, as indicated by their lower intra-rater error for all three clusters. The inter-rater to inter-trial ratio was always greater than one.

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