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A new method for estimating joint parameters from motion data

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Abstract

Joint centers and axes of rotation (joint parameters) are central to all branches of movement analysis. In gait analysis, the standard protocol used to determine hip and knee joint parameters is prone to errors arising from palpation, anthropometric regression equations, and misplaced alignment devices. Several alternative methods have been proposed, but to date none have been shown to be accurate and reliable enough for use in the clinical setting. This article describes a new method for joint parameter estimation. The new method can be summarized as follows: (i) the motions of two adjacent segments spanning a single joint are tracked, (ii) the axis of rotation between every pair of observed segment configurations is computed, (iii) the most likely intersection of all axes (effective joint center) and most likely orientation of the axes (effective joint axis) is found. Initial validation of the method was conducted on a hinged mechanical analog and a single healthy adult subject. For the analog, the center was found to be within 3.8 mm of the geometric center and 2.0° of the geometric axis (standard deviation). For the adult subject, hip centers varied on the order of 1–3 mm, knee centers by 3–9 mm, and knee axes by 2.0°. The results suggest that the new method is an objective, precise, and practical alternative to the standard clinical approach.

Keywords: Center of rotation; Axis of rotation; Joint center; Gait analysis; Precision

1. Introduction

The center of rotation (CoR) and axis of rotation (AoR) of a joint, collectively referred to here as joint parameters, are fundamental elements of clinical movement analysis. Joint parameters allow a coordinate system defined by surface mounted markers (technical coordinate systems) to be aligned with a coordinate system defined by the underlying anatomy (anatomical coordinate system). The absolute and relative motions of the anatomical coordinate system comprise the primary data used in scientific and clinical applications of movement analysis. It is therefore clear that the transformation between the technical and anatomical coordinate systems is a crucial step in the movement analysis protocol.

Clinical gait analysis is one of the most prominent specialities within the scope of movement analysis. The protocol proposed by Davis (Davis et al., 1991), is used by a vast majority of clinical laboratories. This approach, referred to here as the *standard protocol*, considers the lower extremity to be a chain of seven rigid segments: one pelvis, two thighs, two shanks and two feet. The joint parameters necessary to define these segments are hip center, knee center, average knee flexion axis, ankle (talo-crural joint) center, and average ankle flexion axis. These joint parameters are estimated using a variety of ad hoc means that introduce numerous sources of error. Errors in hip centers stem from three distinct sources: marker location, regression uncertainty, and anthropometric measurements. An offset vector from the marker-based pelvic origin locates the hip centers. This vector is computed from an anthropometric regression equation that is scaled by manually measured distances on the subject's body. For the knee, errors arise primarily from the visual identification of the mean knee flexion axis. These errors

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