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Effects of hip joint centre mislocation on gait kinematics of children with cerebral palsy calculated using patient-specific direct and inverse kinematic models

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ABSTRACT

Joint kinematics can be calculated by Direct Kinematics (DK), which is used in most clinical gait laboratories, or Inverse Kinematics (IK), which is mainly used for musculoskeletal research. In both approaches, joint centre locations are required to compute joint angles. The hip joint centre (HJC) in DK models can be estimated using predictive or functional methods, while in IK models can be obtained by scaling generic models. The aim of the current study was to systematically investigate the impact of HJC location errors on lower limb joint kinematics of a clinical population using DK and IK approaches. Subject-specific kinematic models of eight children with cerebral palsy were built from magnetic resonance images and used as reference models. HJC was then perturbed in 6 mm steps within a 60 mm cubic grid, and kinematic waveforms were calculated for the reference and perturbed models. HJC perturbations affected only hip and knee joint kinematics in a DK framework, but all joint angles were affected when using IK. In the DK model, joint constraints increased the sensitivity of joint range-of-motion to HJC location errors. Mean joint angle offsets larger than 5° were observed for both approaches (DK and IK), which were larger than previously reported for healthy adults. In the absence of medical images to identify the HJC, predictive or functional methods with small errors in anterior-posterior and medial-lateral directions and scaling procedures minimizing HJC location errors in the anterior-posterior direction should be chosen to minimize the impact on joint kinematics.

1. Introduction

In children with cerebral palsy (CP), three-dimensional gait analysis is used for treatment planning and evaluating the outcome of an intervention [1]. Most clinical gait laboratories use variants of the conventional gait model [2,3], included in most commercially available motion capture systems. Joint kinematics are calculated by the conventional gait model as Cardan angles describing the relative pose of adjacent anatomical segment reference systems, which are defined from the experimental markers' positions and a minimum set of anatomical measurements (Direct Kinematics, DK) [4,5]. Conversely, musculoskeletal software such as AnyBody [6] and OpenSim [7] use an Inverse Kinematics (IK) approach to compute joint angles from marker trajectories. In the IK framework, also known as "global optimization" or "multi-body optimization", joint angles are calculated by adjusting the pose of a scaled musculoskeletal model to best match the model markers' position with the experimental surface markers at each frame of their trajectory [8,9]. Musculoskeletal software may provide valuable additional information on the causes of gait abnormalities and therefore improve clinical-decision making because it allows additional analyses such as musculotendon length estimation [10,11], joint contact force calculations [12,13] and induced acceleration analysis [14].

Kinematic models usually differ between DK and IK approaches. Most currently available lower body IK models use constrained joints,

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