Impact of subject-specific musculoskeletal geometry on estimated joint kinematics, joint kinetics and muscle forces in typically developing children

Hans Kainz, Mariska Wesseling, Lorenzo Pitto, Antoine Falisse, Sam Van Rossom, Anja Van Campenhout, Friedl De Groote, Kaat Desloovere, Chris Carty, Ilse Jonkers

Introduction

Gait analysis together with musculoskeletal modeling can be used to calculate muscle forces and assess pathological gait [1]. No generic, pediatric musculoskeletal models are available and, therefore, linear scaling methods are commonly used to personalize a generic, adult musculoskeletal model to the child's anthropometry.

Research question

How different are joint kinematics, joint kinetics and muscle force estimates of generic scaled models compared to medical-imaging based models in typically developing (TD) children?

Methods

3D motion capture data and magnetic resonance images (MRI) of a TD boy (age: 8 years; height: 1.23m; weight: 20.4kg) were collected. Two musculoskeletal OpenSim models were created: (1) a scaled generic model (M_gen), and (2) a MRI-based model, which included subject-specific musculoskeletal geometry (M_mri) [2]. Joint kinematics, joint kinetics and muscle forces were calculated for each model using OpenSim 3.3 [3]. Joint kinematics, joint kinetics, muscle force waveforms, as well as femoral anteversion angle, neck-shaft angle and hip joint centre location were compared between both models.

Results

Joint kinematics and joint kinetics were surprisingly similar between the M_gen and M_mri with root-mean-square-differences below 2.8° and 0.05Nm/kg for joint angles and moments, respectively (Figure 1 and 2). Depending on the analyzed muscle, differences in muscle forces varied substantially (up to 230 % difference) between the M_gen and M_mri (Figure 3).

Femoral anteversion and neck-shaft angles differed between M_gen and M_mri by 12 and 5 degrees, respectively. The hip joint centre position differed between both models by 5, 15 and 6 mm in the anterior/posterior, superior/inferior and medial/lateral direction, respectively.

Discussion

Joint kinematics and kinetics were similar between the M_gen and M_mri but some muscle forces showed a large discrepancy between both analyzed models. This was probably caused by the different joint centre locations as well as different bony geometry, e.g. femoral anteversion and neck-shaft angle, having a major effect on the muscle moment arms.

Previous research showed that hip joint centre perturbation in the superior/inferior direction have a minor impact on joint kinematics [4], which was confirmed by our results. However, depending on the muscle, a difference of joint centre location of 15 mm in the superior/inferior direction can have a large impact on the moment arm and, therefore, significantly changing the magnitude of the muscle force.

Considering femoral anteversion angle changes around 15 degrees and the neck-shaft angle around 6 degrees during growth [5] and our observed differences between the M_gen and M_mri, pediatric musculoskeletal models, which include age-specific femoral geometry, are needed to improve muscle force estimations in the absence of medical-imaging based models.

References

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Figure 1. Joint kinematics

Figure 2. Joint kinetics

Figure 3. Muscle forces during gait