Suitability of Scaled Generic Musculoskeletal Models in Predicting Longitudinal Changes in Joint Contact Forces in Children with Juvenile Idiopathic Arthritis.

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1. Introduction

Traditional gait analysis has found utility and has proven beneficial in the analysis and understanding of human movement. Despite this utility, traditional gait analysis approaches are limited in the amount and kind of information that can be derived. This limitation has led to the development of musculoskeletal modelling approaches that utilize mathematical representations of the human body to estimate and measure quantities of interest in human movement such as muscle forces and joint loads. The development of these models also permits for the investigation of "what if" scenarios and providing a means for clinically meaningful insights.

Image-based subject-specific (SS) musculoskeletal models are currently considered the preferred solution in the estimation of biomechanical parameters due to their high accuracy and reliability compared to scaled generic models (GS) (Lenaerts et al., 2009). The high accuracy and reliability however come at the extra burden of obtaining medical images and time to build the models from these images (Valente et al 2014). The use of subject-specific models also becomes a challenge when analysis must be performed based on data for which imaging data is not available such as in a retrospective study and in most of standard clinical scenarios.

Several studies have looked at the influence of including different levels of subject-specific detail in the modelling process and compared their outputs to those from the generic modelling approach. Scheys et al., (2008) investigated moment arm and muscle-tendon length differences between rescaled generic and personalised musculoskeletal models and found differences in estimates between the two models, however the magnitude of change in estimates between two conditions (normal and pathologic) was found to be similar for most muscles for the two models. Similarly, it was shown that predictions of muscle function from generic models are consistent with those from personalised ones despite significant differences in moment arms calculated for muscles between the two (Correa et al, 2011).

It can be argued then that quantitative differences exist in estimates calculated from GS models compared to those from MR-based personalised models, however direction of changes in magnitude of measures might remain consistent between the two modelling approaches. This study hypothesises that joint contact force estimates between scaled generic and personalised models are different but the direction of changes in magnitude remains consistent and thus propose the practicability of using scaled generic models to infer similar meaning from gait analysis data as would be obtained using a subject-specific modelling approach despite the

expected differences in estimates between models developed using the two modelling approaches.

2. Methods

Data from two of three observations (12 months apart) of 11 participants, part of a larger cohort from an earlier study in Juvenile Idiopathic Arthritis, was utilised in this analysis (age: 11.45±3.24, mass:46.48±18.0, 51.43±20.53). Gait data was collected across two laboratories, one using a 6-camera setup (BTS, SmartDX, 100Hz) with two force plates (Kistler, 1 kHz) and the other, an 8-camera system (Vicon, MX, 200Hz) with two force plates (AMTI, OR6, 1 kHz). The Vicon Plug in gait protocol augmented with the modified Oxford Foot Model formed the set of forty-four markers used. MRI was used to acquire entire lower limb images for each participant at a single timepoint using a 3D T1-weighted fat-suppression sequence. In-plane resolution was 1 mm with a slice thickness of 1 mm. SS models were obtained by segmenting MRI images. Joint axes were defined by morphologic fitting of articular surfaces. Details of experimental protocol and subject-specific modelling approach are further provided in Modenese et al, 2018. The scaled generic models were created based on the cadaver-based generic gait2392 model. The generic model was scaled by participant mass and anthropometry based on experimental markers placed on anatomical landmarks in a standing trial to create the scaled generic models. Maximum isometric force for each muscle was also scaled by the ratio of subject mass to mass of the gait2392 model. Optimal fibre length was scaled to maintain the muscle-tendon ratio in the gait2392 model. Scaled-generic models were reduced to a single lower limb model (12 DOF) for consistency with the subject-specific models which were unilateral. Simulations of walking were subsequently performed in OpenSim 3.3 with a minimum of three trials for each participant. Simulation included inverse kinematics, inverse dynamics, static optimization and joint reaction analysis. Static posture joint angles were considered as zero in comparing kinematic outputs between the two models. Muscle dynamics (force-length-velocity relationship) were ignored for both models during the estimation of muscle activation and force during static optimization. Joint contact forces (JCFs) and differences in JCFs (ΔJCF) at the hip, knee and ankle between the two groups were compared using one sample paired t-tests ($\alpha = 0.05$) from the SPM1D statistical parametric mapping package in MATLAB (v9.5.0, R2018b, Mathworks, USA).

3. Results and Discussion

Models output were similar in terms of range of motion and general trend of the joint angle profiles and joint moments. JCFs and differences in JCF recorded at two time points, T1 and T2, at the hip, knee and ankle are presented in Figure 1. JCFs scaled by body weight (BW) were found to be different and varied significantly for the first peak of hip in stance at T1 and T2 between the GS and personalised models. The GS model tended to underestimate this first peak. Nevertheless, estimates were consistently in the same direction of change (positive) when

comparing the two time points. When comparing the differences in JCF estimates between the two time points for each of the models, the generic tended to report higher differences than the subject-specific although no statistical significance was found at the group level. Although

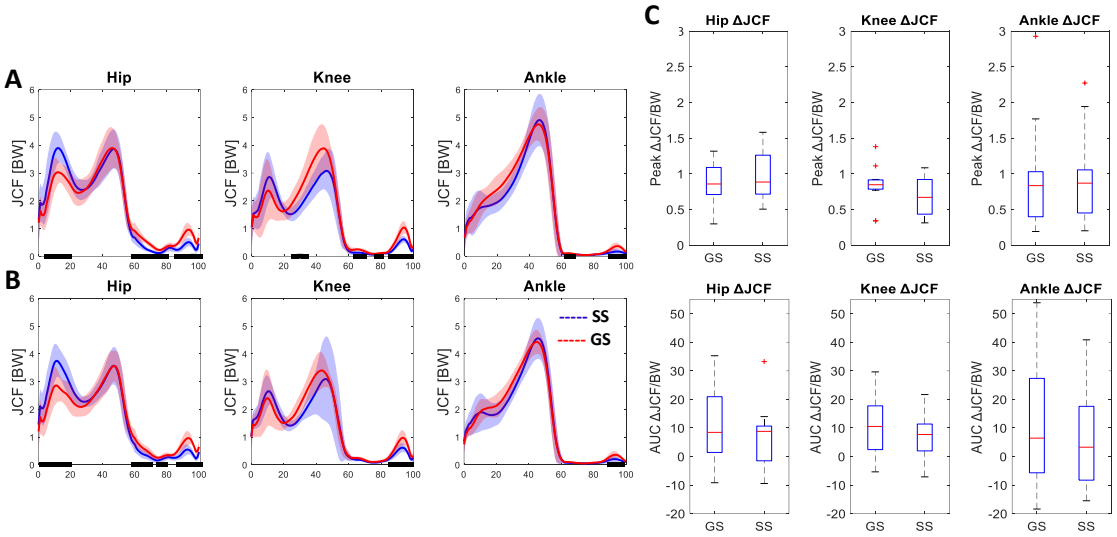

***Figure 1**. Comparison JCF profiles from scaled generic models and subject-specific models of 11 juvenile subjects during normal walking and at two time points. GS vs SS at T1 (A) and T2 (B). Peak and AUC of ΔJCF (T2-T1) between GS and SS (C). Black bars indicate significance at p<0.01*

maximum isometric force was determined using different methods in the two models ($\frac{mass_S}{mass_g}$ vs $\frac{masslimb_S}{masslimb_g}$), where S and g refer to the subject and gait2392 model respectively, it has been suggested that this has no significant influence on estimates of joint contact forces (Modenese et al, 2018). Differences in muscle lengths and moment arms during the motion may account for the differences observed as muscle origins, insertions and paths were modified in the SS models based on the MRI images. Both models also showed an overall increase from T1 to T2 when comparing JCF mean peak values of changes in JCF for all joints (hip: 0.9±0.3, 1.0±0.3; knee: 0.8±0.3, 0.7±0.3; ankle: 1.0±0.8, 0.9±0.6 for GS and SS).

These results are in consonance with the earlier studies which reported differences in estimates of muscle moment lengths and forces but similarities in the trends and function reported between subject specific models and scaled generic ones.

4. Conclusion

As expected, estimates of joint contact forces differed between scaled generic models and image-based subject specific models. Nevertheless, there is consistency in the direction of deviation of estimates by the scaled generic models compared to the subject specific. This suggests the feasibility of using scaled generic models to analyse gait analysis data for which there is no imaging data such as in a retrospective study and also in instances where interest is in trends rather than in specific estimates.

References

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