Impact of Bony Geometry on Static Optimization Based Estimations of Muscle Activations and Forces

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1. INTRODUCTION

Musculoskeletal simulations are widely used to increase our insight in healthy and pathological movements (Kainz *et al.*, 2019; Buehler *et al.*, 2021). Typically, a generic musculoskeletal model is scaled to a participant and afterwards employed to calculate joint angles and estimate musculoskeletal loadings (Delp *et al.*, 2007). This approach, however, neglects subject-specific musculoskeletal geometry (Kainz, Wesseling and Jonkers, 2021).

At the femur the neck-shaft angle (NSA) and femoral anteversion angle (AVA) are the most important anatomical features (Bobroff *et al.*, 1999). Recently, two bone-deformation tools have been developed which enable to modify the anatomical features of the femur (Modenese, Barzan and Carty, 2021; Veerkamp *et al.*, 2021). Modifying the NSA and AVA affect hip joint contact forces (Kainz *et al.*, 2020). Furthermore, personalizing the AVA has been shown to increase the accuracy of hip joint contact force calculations (Modenese, Barzan and Carty, 2021).

The impact of personalized femoral geometry on muscle activations and forces has not been assessed yet and therefore was the aim of the current study. We hypothesized that modifying the femoral geometry will alter muscle activations and forces. Furthermore, we assumed that a personalized femoral geometry would improve the agreement between the muscle activations obtained from the simulations and the experimentally measured electromyography (EMG) signals.

2. METHODS

We collected and analysed data of one typically developing boy (age: 8 years; height: 137 cm; weight: 40 kg). Three-dimensional motion capture data (10 cameras, Vicon Motion Systems, Oxford, UK and three force plates, Kistler Instruments AG, Switzerland) and EMG data of lower limb muscles (16-channel, menios GmbH, Ratingen, Germany) were collected during one static trial and several walking trials. Additionally, we collected magnetic resonance images (Siemens, Magnetom Sola, 1,5T) of both femurs using a T1-weighted 3D gradient echo sequence with a resolution of 0.7 x 0.7 x 0.7 mm.

Magnetic resonance images (MRI) of each femur were segmented using 3D Slicer (slicer.org) and used to calculate the subject-specific NSA and AVA based on a previously developed Matlab script (Kainz *et al.*, 2020).

For the musculoskeletal simulations, we first used the torsion tool (Veerkamp *et al.*, 2021) to create the following nine models:

- Ref: Model based on the NSA and AVA obtained from the MRI images
- NSA-20,-10,+10,+20: Ref models with altered NSA from -20 to +20 degrees
- AVA-20,-10,+10,+20: Ref models with altered AVA from -20 to +20 degrees

Afterwards, we scaled each model to the anthropometry of our participant based on the location of surface markers and estimated joint centres (Kainz *et al.*, 2017).

Joint kinematics, joint kinetics, muscle activations, muscle forces and joint contact forces were calculated for each model using OpenSim 4.1 (Delp *et al.*, 2007). Muscle activations and forces were estimated using static optimization, while minimizing the sum of squared muscle activations.

We compared muscle activations and forces of the gastrocnemius medialis, soleus, rectus femoris and gluteus medius muscles between the different models. Furthermore, we compared the EMG data with the activations from the simulations and quantified how much hip, knee and ankle joint contact forces differ between models.

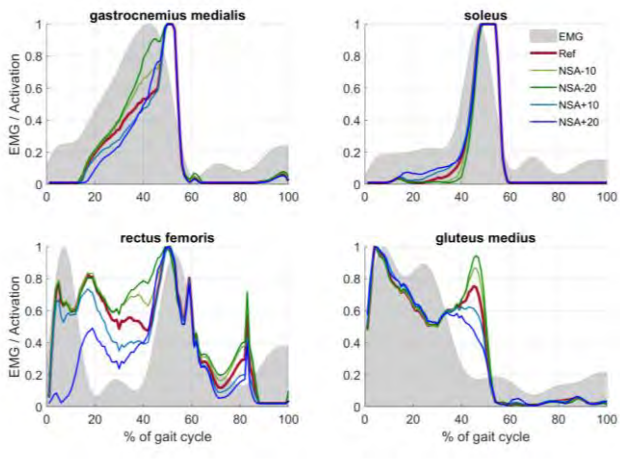

Fig. 1. EMG data and muscle activations from models with altered NSA.

3. RESULTS

Altering the NSA and AVA had an impact on the activations and forces of all our analysed muscles (Fig. 1 and 2). Activations from our simulations showed a reasonable agreement with the EMG data (Fig. 1). Both, altering the NSA and AVA had a big impact on hip and knee joint contact forces and a minor impact on ankle joint contact forces (Fig. 3). The AVA had a larger impact on joint contact forces compared to the NSA. Due to the page limit, only figures for the altered NSA are shown in this abstract.

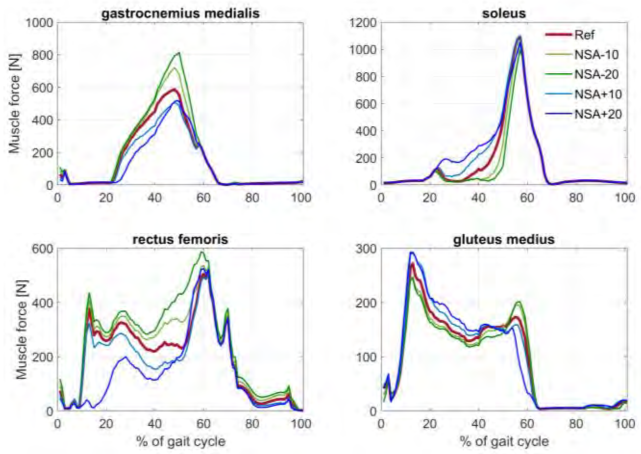

Fig. 2. Muscle forces from models with altered NSA.

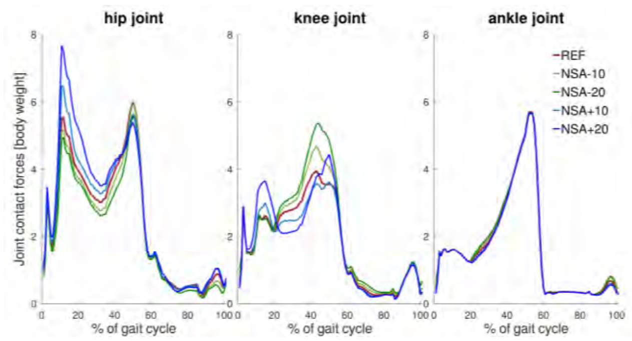

Fig. 3. Joint contact forces from models with altered NSA.

4. DISCUSSION

In agreement with our hypothesis, we showed that altering the femoral geometry affects muscle activations and forces from all analysed muscles. Although modifying the NSA and AVA did not change the moment arms of the gastrocnemius and soleus muscles, it had an impact on these muscles due to the global optimization used to estimate muscle forces. This also explains why altering the femoral geometry influences the knee and ankle joint contact forces, additionally to the hip joint contact forces.

We assumed that the personalized geometry will improve the agreement between EMG and muscle activation from the simulations. From our primary results based on one participant (Fig. 1), we cannot confirm this assumption. Several factors influence the estimation of muscle forces additionally to the bony geometry. Our models included generic muscle properties (e.g. maximum isometric muscle forces), which might not present the muscles of our participant and influences our results (Kainz *et al.*, 2018). Furthermore, different optimization approaches will likely lead to a different distribution of muscle forces (Wesseling *et al.*, 2015).

In conclusion, this is the first study, which showed that the femoral geometry affects muscle and joint contact forces at all joints. More comprehensive studies are needed to evaluate if the personalized femoral geometry can improve the accuracy of muscle force calculations in musculoskeletal simulations.

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