Is sex a relevant factor in the application of musculoskeletal models?

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Summary

Currently available musculoskeletal models are primarily based on male bone geometry and mixed-sex parameters, introducing a potential bias that may compromise their accuracy, particularly for females. This study compares personalized and linearly scaled musculoskeletal models to assess sex-related differences in landmark and joint center errors. Preliminary results based on morphometric scaling show that a better fit to individual's bone morphology is needed.

Introduction

Musculoskeletal (MSK) models and simulations are powerful non-invasive tools to understand MSK pathologies. The MSK system exhibits differences based on sex, from bone geometry to muscle mass distribution [1,2]. It is therefore important that sex differences are reflected in MSK models to improve our understanding and treatment of MSK health and sports performance. The field of biomechanics often relies on linear scaling of generic MSK models that are based on male bone geometry and mixed-sex musculotendon parameters. It is unclear how the differences in bone geometry impact the reliability of the MSK simulations for a diverse population. Especially, how well models based on male anatomy serve female individuals. The goals of this project are 1) to determine the error introduced by scaling a generic model to a broad population; 2) to investigate new scaling techniques to generate models that account for sex/individual specific differences in the MSK system.

Methods

We acquired a dataset of full body MRI, 3D body scans, motion capture, electromyography, strength measurements, and demographics of 43 healthy adult participants (18-90 years, 21F, 22M). We segmented the MRI scans of 14 young adult participants (20-39 years, 8F, 6M) for the lower body bones using a combined approach of manual and automatic segmentation by leveraging an nn-UNet model. From this segmentation, we generated 14 personalized MSK models of the right and left hip using the STAPLE automatic pipeline [3]. We linearly scaled a widely-used generic MSK model using the landmarks detected with STAPLE. We determined the Euclidean distance between marker pairs and hip joint center pairs (HJC) between the personalized (STAPLE) and linearly scaled model. To assess sex differences in landmark error, we performed an unpaired t-test. Additionally, we performed a morphometric scaling for the participant with the largest marker discrepancy using a workflow in OpenSim Creator based on morphometric transformations to transform existing musculoskeletal models to specimen-specific anatomy. We compared the differences in moment arms a selection of muscles.

Results and Discussion

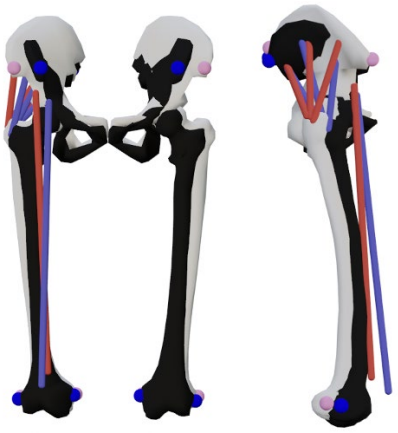

Figure 1: Front and side view of linear (white, pink markers, red muscles) vs. morphometric (black, blue markers, purple muscles) scaled models.

Results show that the difference between linearly scaled versus personalized models for the HJC is 1.4 ± 0.4 cm and 1.9 ± 0.7 cm for the other landmarks. Maximum differences were 2.4 cm (HJC, M participant) and 3.9 cm (left ASIS, F participant). These differences are above what is considered acceptable errors in MSK model fit to experimental marker data. The error in HJC was not statistically higher in females (1.4 ± 0.2 cm) compared to males (1.6 ± 0.5 cm) ($p = 0.16$). The maximum difference in muscle moment arms between linearly scaled and warped models (Figure 1) was 1.6 cm for the GMED1, 0.4 cm for the GMED2, 0.2 cm for the GMED3,and 0.3 cm for the RFEM. The full dataset is currently being processed. Our dataset reveals large variability in pelvis and femur shapes, highlighting that sex is not the sole determining factor in MSK system variability. Genetic variation also plays a crucial role. Therefore, we are working towards a morphometric scaling technique that combines demographic information as well as full-body shape data, to generate more specific models.

Conclusions

A better fit to individual's bone morphology is needed, as shown by preliminary results based on morphometric scaling.

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References

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