Can sexual dimorphism in bone geometry explain sex-related differences in proportional muscle masses?

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Summary

Currently available musculoskeletal models are based on male bone geometry and mixed-sex parameters. We have shown that this might affect the validity of the models for females ('biasmechanics'). The goal of this study was to investigate whether sexual dimorphism in the pelvis and femur bones explains differences in the proportional masses of the Gluteus Maximus (GMAX) and Rectus Femoris (RFEM) between sexes. The full-body MRI scans of sixteen healthy young adults were segmented. Pelvic and femoral geometrical metrics were analyzed using stepwise regression to predict GMAX and RFEM proportional masses.

Introduction

Research in biomechanics continues to exhibit bias, often positioning males as the default in human studies—a phenomenon we refer to as biasmechanics [1]. Open-source musculoskeletal (MSK) models also reflect this bias, as they are predominantly based on male bone geometry and mixed-sex musculotendon parameters [2]. Current MSK models do not accurately represent muscle mass distribution for specific age or sex groups, and none of them accurately reflect female muscle mass distribution [2]. This highlights the need for a deeper understanding of sex differences and their impact on musculoskeletal model estimations. Additionally, there is a critical need to develop methodologies for creating accurate, musculoskeletal models that account for sex-specific variations based on known relationships. This study investigates whether sexual dimorphism in the pelvis and femur bones explains differences in the proportional masses of the Gluteus Maximus (GMAX) and Rectus Femoris (RFEM) between the sexes.

Methods

Sixteen healthy young adults (9F (28±3 yrs old), 7M (30±4yrs old)), underwent full-body MRI scans. The skeleton and muscles (GMAX and RFEM) of 4 subjects were manually segmented using 3D Slicer. Two deep-learning models, one for muscles (BODIES_muscles021) and one for the lower extremity skeleton (BODIES_skeletonLL047), were trained using nn-UNet in an iterative approach. The final models were evaluated using DICE similarity scores (DSC) and Hausdorff distance (HD), showing an accuracy of DSC: 92.6-95.4% and HD: 15.7-19.1mm. Pelvic and femoral geometrical measurements were extracted via STAPLE [3]. Muscle volumes were converted to mass using the specific muscle mass (1.056 g/cm^3) and normalised by the fat-free body weight. To assess similarity in bone variables and muscle mass between both legs, a paired t-test was performed. Likewise, a Student's t-test was used to analyze sex-related differences in muscle mass and bone metrics. Eventually, relationships between proportional muscle mass (%RFEM, %GMAX) and bone geometry measurements were analyzed using a Step-wise regression, which converged based on Akaike Information Criterion (AIC) and p-values to minimize overfitting.

Results and Discussion

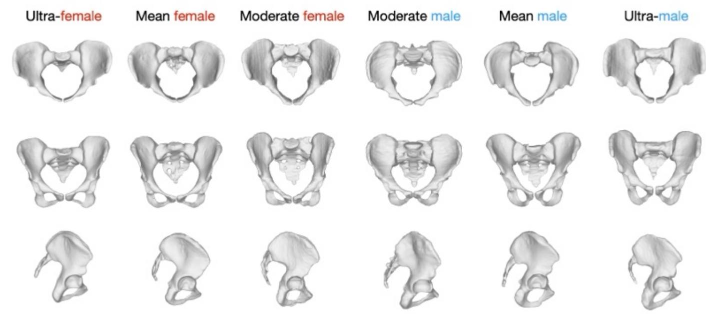

Figure 1: Comparison of different pelvic morphologies extracted from 16 participants, similar to analysis in [4].

Our data could not confirm [2] that females had statistical higher %GMAX (F:1.77%,M:1.70%) and males in %RFEM (F:0.46%, M:0.49%), but showed a similar trend. This may be since these muscles account for only a small proportion of the total fat-free body mass compared to the lower-extremity muscle mass considered in [2]. Stepwise regression identified ASIS-to-knee joint distance (β=-0.051, p=0.004) and femoral offset divided by knee width (β=2.198,p=0.039) as the strongest predictors of %GMAX (R^2=0.259). For %RFEM, femur length (β=-0.03,p<0.001), and femoral offset (β=0.108,p<0.001), were most predictive (R^2=0.511). Interestingly, femoral offset showed significant sex differences (p = 0.002), suggesting important biomechanical implications, explaining its predictive behavior for both muscles. Notably, all predictors were femur-related or based on pelvis-to-femur metrics, with no metrics solely reflecting the pelvis.

Conclusions

Our results show that the proportional and absolute muscle mass differences in GMAX and RF can partly be explained by sexual dimorphism in the pelvis and femur bones.

Acknowledgments

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