Sex-Specific Differences in Gluteus Medius Mechanics from MRI-Derived Subject-Specific Models

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INTRODUCTION:
Generic musculoskeletal models are typically based on a small set of male cadavers and uniformly scaled to represent other individuals. This oversimplifies anatomical variation, especially in muscles such as the gluteus medius -- a primary hip stabilizer linked to conditions that disproportionately affect women, including gluteal tendinopathy and patellofemoral pain. This study used MRI-derived subject-specific models to quantify sex-based differences in gluteus medius moment arms and evaluate the accuracy of generic scaling approaches.

METHODS:
Dixon MRI scans from 68 healthy adults (34 female, 34 male) were segmented using a deep learning pipeline (Springbok Analytics, Charlottesville, VA) to generate 3D bone and muscle geometries. Gluteus medius origin points were algorithmically defined along the iliac crest using a k-nearest neighbors approach, and insertion regions were manually placed on the lateral facet of the greater trochanter. Subject-specific muscle paths were constructed for anterior, middle, and posterior compartments. Hip abduction/adduction moment arms (–30° to +30°) were computed in OpenSim for both subject-specific and Rajagopal-scaled models. Linear regressions tested relationships between moment arms and pelvic dimensions (width, depth), and paired *t*-tests compared model types and sexes.

RESULTS SECTION:
Across all compartments, males exhibited longer moment arms than females, while overall curve shapes were preserved, suggesting structural rather than kinematic differences. Significant differences between scaled and subject-specific models were detected in all three compartments for females and in the anterior compartment for males ($p < 0.05$). Pelvic depth moderately predicted moment arms in scaled male models ($R^2 = 0.52$) but showed weaker associations in females and subject-specific models ($R^2 = 0.27$). Boxplot analysis confirmed that scaled models underestimate female moment arm magnitudes across paths.

DISCUSSION:
Findings demonstrate that sex-specific anatomy substantially influences gluteus medius mechanics. While scaled models may capture male morphology adequately, they fail to represent the greater anatomical variability in females. Subject-specific modeling improved alignment with measured geometry and revealed compartment-level differences that may contribute to sex-biased injury patterns.

SIGNIFICANCE/CLINICAL RELEVANCE:
These results emphasize the need for inclusive, anatomy-driven modeling practices to improve predictive accuracy for female musculoskeletal simulations. Incorporating subject-specific geometry can enhance precision in clinical applications such as surgical planning, rehabilitation, and risk assessment for hip-related injuries.

REFERENCES:
[1] Rajagopal et al., 2016. [2] Ladurner, 2021. [3] Ni et al., *J Med Imaging*, 2019. [4] Rowand et al., 2009.

ACKNOWLEDGEMENTS:
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IMAGES AND TABLES:

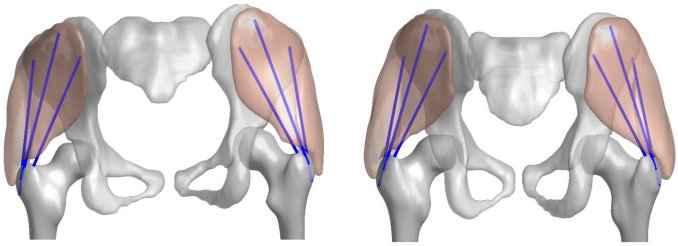

Figure 1. Posterior-view subject-specific muscle paths generated from MRI-derived 3D OBJ files showing individualized gluteus medius compartments (anterior, middle, posterior) in representative female (left) and male (right) models.

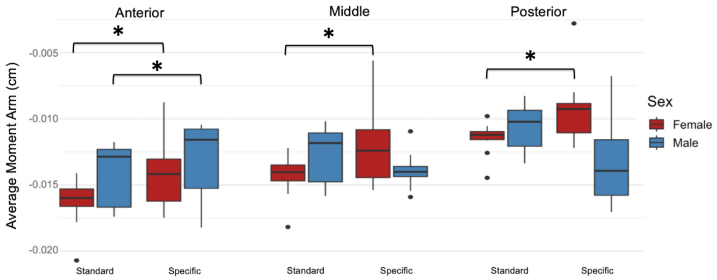

Figure 2. Average gluteus medius moment arms (0–30° abduction) normalized by pelvic width and compared across sex and model type. Boxplots highlight significant differences in anterior, middle, and posterior compartments ($p < 0.05$).