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EFFECT OF MUSCLE ATTACHMENT SITES AND FORCES ON PREDICTED PELVIC BONE STRESS DURING GAIT

Nicholas Dunbar[1], Ata Babazadeh[1], Mohammad Shourijeh[1], Geng Li[1], John Akin and Benjamin Fregly[1]

[1]Department of Mechanical Engineering, Rice University, Houston, TX, United States
Email: nicholas.dunbar@rice.edu, Web: rcnl.rice.edu

INTRODUCTION

Predicting bone stress during walking is a necessary computation during the design of additively manufactured implants which attempt to minimize stress shielding and long-term bone resorption. Sequential modeling is an emerging technique to predict this tissue-level mechanical behavior produced during in-vivo loading. In this technique, a rigid multi-body musculoskeletal (MS) model approximates the muscle forces during an activity which are then applied as boundary conditions to a deformable, finite element (FE) model of the bone. How to best project muscle forces onto the bony surface and choose appropriate boundary conditions remain an open research question.

The first objective of this study was to integrate muscle forces from a musculoskeletal model of gait onto a patient-specific finite element pelvic model using an anatomic and non-anatomic method and to compare the predicted bone stresses. Secondly, the effect of muscle forces at several points during the gait cycle were computed to study the total bone stress distribution that results from walking.

METHODS

A full-body, MS model of human gait was scaled, and calibrated to track motion capture markers during walking on an instrumented treadmill for one male subject [1, 2]. Muscle parameters were calibrated to accurately predict measured knee contact forces from an instrumented knee replacement. Finally, static optimization was used to solve for muscle forces.

The corresponding FE model was constructed from the CT-images of the same subject. Bone and implant geometries were manually segmented and all geometries were meshed with 10-node, quadratic tetrahedral elements. As a result of imaging artifact due to the presence of a total hip prosthesis, the cortical (E = 18 GPa, v = 0.3) and trabecular bone (E = 150 MPa, v = 0.2) were considered isotropic. The acetabular liner (E = 1 GPa, v = 0.3) and cup (E = 210 GPa, v = 0.3) were also considered isotropic. For the anatomic method, muscle attachment regions were manually selected on the pelvic bone surface (Fig. 1 A). For the non-anatomic method, the central node was identified and the connecting mesh faces were selected (Fig. 1 B). Muscle forces were uniformly distributed along these regions along each muscle's effective orientation, respectively. Elastic foundations were defined at the iliosacral and pubic joint boundaries.

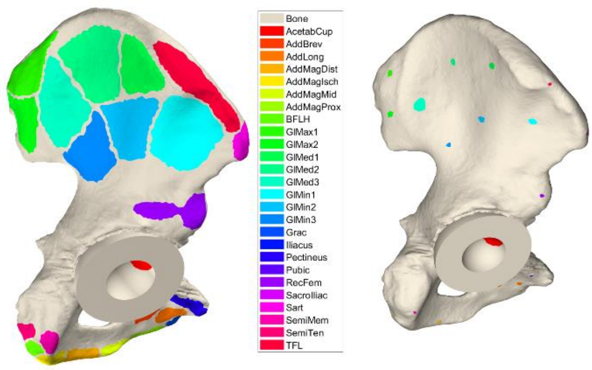


Fig 1: Anatomic (left) and non-anatomic muscle attachment sites.

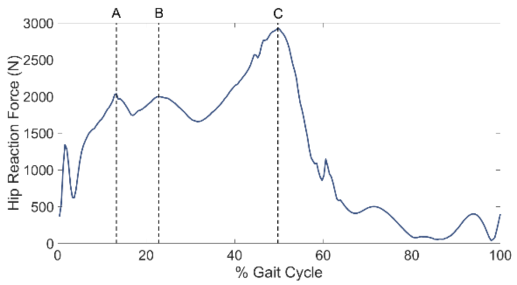
RESULTS AND DISCUSSION

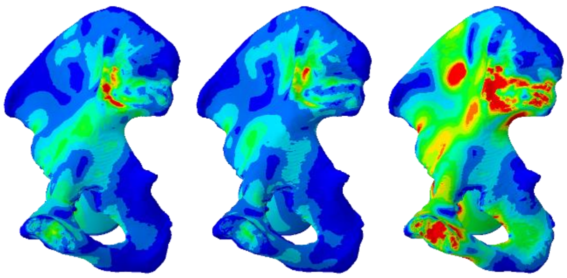
Maximum muscle forces, computed from the MS model, and their location during the gait cycle are presented in Table 1. Muscle attachment site method had a noticeable impact on Von Mises stress distribution (Fig. 2). Choice of attachment method did alter the maximum stress, with non-anatomic attachments resulting in higher values (46% higher for point C in the gait cycle). High stress concentrations near the sacrioilac joint appear more distributed than similar investigations that used a fixed boundary condition [3]. Applying the muscle forces was found to stress regions of the pelvis that otherwise would not be stressed when considering the hip reaction force alone.

Table 1. Magnitude of the maximum muscle loads and timing predicted by the MS model.

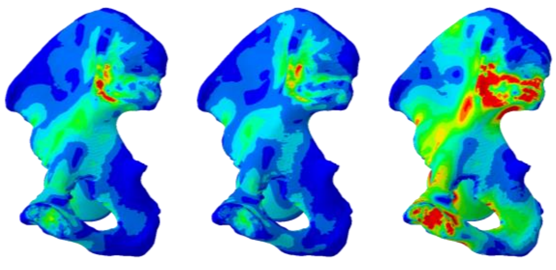
	Max Force Mag (N)	% Gait Cycle
Adductor brevis	54.1	64%

Adductor longus	139.1	62%
Adductor magnus (Distal)	74.0	6%
Adductor magnus (Ischium)	99.6	6%
Adductor magnus (Mid)	41.4	6%
Adductor magnus (Proximal)	66.5	64%
Biceps femoris (Long Head)	160.8	1%
Gluteus maximus (1)	178.2	9%
Gluteus maximus (2)	331.2	8%
Gluteus medius (1)	456.7	25%
Gluteus medius (2)	163.6	13%
Gluteus medius (3)	168.0	10%
Gluteus minimus (1)	70.3	41%
Gluteus minimus (2)	64.2	41%
Ggluteus minimus (3)	58.7	13%
Gracilis	8.4	64%
Iliacus	589.5	48%
Rectus femoris	678.5	54%
Sartorius	23.4	50%
Semimembranosus	297.9	1%
Semitendinosus	45.4	1%
Tensor fasciae latae	118.3	25%





Non-anatomic Muscle Attachements



Anatomic Muscle Attachements

Fig 2: Pelvic bone Von Misses stress (20 MPa upper threshold) at several points in the gait cycle (A, B, and C) where hip reaction force is locally maximum.

CONCLUSIONS

This modeling framework will enable more realistic predictions of pelvic bone stress during walking.

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