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.

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 sacroiliac 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.

<table>
<thead>
<tr>
<th>Muscle Attachment Site</th>
<th>Max Force Mag (N)</th>
<th>% Gait Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adductor brevis</td>
<td>54.1</td>
<td>64%</td>
</tr>
</tbody>
</table>
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%

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

REFERENCES

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CONCLUSIONS

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.