Abstract Introduction:
The mechanism of acetabular labral pathology and its subsequent influence on biomechanics of the hip has recently become an area of intense speculation. Previous biomechanical evaluation of the hip labrum has focused on the acetabular labral seal, which is thought to enhance joint stability. To date, no study has directly evaluated and quantified the acetabular labrum and its role in hip stability under representative in vivo conditions. We have developed a cadaveric robotics model that functions under load-control parameters to recreate in vivo hip mechanics. This study specifically identifies the impingent-free ROM and direction of force vectors required for dislocation in the native hip with and without the labrum. We believe that this may have clinical relevance in the treatment of labral pathology.

Methods:
Five cadaveric hip specimens (male, age 58-79) consisting of a hemipelvis and femur were utilized. Randomly chosen, the left or right hip was disarticulated and the soft tissues were removed preserving the labrum. The hip specimen (femur and hemipelvis) was rigidly secured to a custom testing apparatus and mounted onto a robotic manipulator (Rotopod R2000 Parallel Robotics Systems) which is capable of manipulating in six degrees of freedom (6 DOF). A 6 DOF force-torque sensor (Si-2500-400, ATI Industrial Automation, Apex, NC) was used to evaluate force vectors required for dislocation. A standard joint coordinate system (JCS) was created and defined, with its origin in the joint center and the coordinate axes corresponding to standard clinical definitions. The coordinate transformations between the JCS, robot motion, and force sensor coordinate system were done in real time in the Labview program.

Based on our earlier studies and previous work the hip was positioned in two provocative positions, including (1) full extension with external rotation, and (2) 90° of flexion and 10° of adduction with internal rotation. These lower extremity positions represent a worst case scenario for impingement.

With the load held constant, the femur was externally (position 1) or internally (position 2) rotated until impingement occurred. Impingement was detected as a sudden increase in the reaction moment with respect to the center of the hip. The amount of allowable internal or external rotation was recorded for each condition (i.e., native hip, resected labrum). The reaction moment occurred when the contact force was transmitted via the neck on the acetabular rim or labrum. The rotation was stopped at this point and the joint angles were kept constant.

At this point of impingement, 3D force vectors were applied medially and swept laterally at increasing angles (magnitude held constant) until dislocation was achieved. This was repeated circumferentially in 15 degree increments.

The hemi-pelvis of each specimen was tested in two conditions: (1) native hip with the labrum, (2) native hip without the labrum.

Each dislocation produced one data point for the stability envelope which was subsequently recorded. Stability envelopes are presented for descriptive purposes. A statistical analysis utilizing ANOVA was completed with significance set at a p-value of <0.05 (Table 1) and paired t-test for magnitude (Table 2).

Results Section:
Each specimen was evaluated both with and without its labrum and was tested in two provocative positions. Position 1 data demonstrated significance of 7% between the means of the native hip and absent labrum (p<0.0015). Graphical representations were used to create a stability envelope (figure 2). The envelope magnitude is defined as the percentage of directions a force can be applied and the joint remains stable (Table 2).

Table 1

<table>
<thead>
<tr>
<th>Position</th>
<th>Mean ± SD</th>
<th>Native w/o labrum</th>
<th>Native w/o labrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position 1</td>
<td>-18.8° ± 9.7°</td>
<td>-25.7° ± 8.7°</td>
<td>-18.8° ± 9.7°</td>
</tr>
<tr>
<td>Position 2</td>
<td>-0.2° ± 7.7°</td>
<td>1.1° ± 8.9°</td>
<td>-0.2° ± 7.7°</td>
</tr>
</tbody>
</table>

*p=0.0015*  p=n.s.

Table 2

<table>
<thead>
<tr>
<th>Position</th>
<th>Mean ± SD</th>
<th>Native w/o labrum</th>
<th>Native w/o labrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position 1</td>
<td>52% ± 16%</td>
<td>44% ± 8%</td>
<td>52% ± 16%</td>
</tr>
<tr>
<td>Position 2</td>
<td>53% ± 12%</td>
<td>5% ± 5%</td>
<td>53% ± 12%</td>
</tr>
</tbody>
</table>

*p = 0.287   p = 0.131

Discussion:
This study dynamically evaluates and demonstrates the importance of the labrum in hip stability. Current guidelines often lead to debridement of labral pathology as it has historically been thought to play a minimal role in hip stability. Using the first known application of a 6 DOF Robot, we have developed a reproducible, dynamic, quantifiable testing system for impingement, and subsequent dislocation to better understand the role of the labrum in these processes. Based on our results, the labrum contributes to hip stability significantly in position 1, but not position 2. Moreover, removing the labrum decreased the stability envelope by 8% and 9% in positions 1 and 2, respectively. Despite not reaching statistical significance, this latter finding suggests there may be potential benefit to repairing rather than debriding labral pathology. The clinical consequences of partial labral debridement warrant further investigation to better understanding its role in stability and biomechanics. Future studies utilizing this robotic system will allow us to further elucidate the biomechanics of classic labral pathology and which surgical interventions may provide the best patient outcome.

**Figure 2**

**Figure 3**

3D force vectors were applied medially and swept laterally at increasing angles (magnitude held constant) until dislocation was achieved. This was repeated circumferentially in 15 degree increments.

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