DETERMINATION OF CONTACT STRESS DISTRIBUTIONS ON EMU FEMORAL HEADS

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INTRODUCTION Successful orthopaedic management of femoral head osteonecrosis remains problematic. Availability of an animal model, reliably mimicking the human disorder in terms of collapse, could provide valuable insight. Recently, the emu has been established as such a model, in that cryo-induced osteonecrosis consistently progresses to femoral head collapse. Besides merely collapsing, however, another prerequisite to serving as a meaningful model for human osteonecrosis is that the patterns of load transmission through the emu hip be reasonably consistent with those in humans. Since forestalling juxta-articular collapse is such a major consideration in treating osteonecrosis, one aspect of load transmission of particular importance is the distribution of intra-articular contact stress. Contact stress mapping in the emu hip is here reported, using a cadaveric Fuji-film preparation.

METHODS Recent contact stress measurement work for human hips5 has highlighted the importance of maintaining physiologically realistic peri-acetabular deformations. Key considerations in that regard are to simulate (muscle) traction loads on the pelvis, and to avoid artifactual reinforcement retro-acetabularly (i.e., no PMMA potting of the acetabulum). We have developed an “emu version” of the Olson/Bay loading apparatus6, augmented to include the capability for capturing contact stress data for various joint configurations spanning the stance phase of the emu gait cycle (Figure 1).

In the case of the emu, based upon exploratory dissections, plus existing literature which describes the leg musculature5 and gait characteristics7, two principal muscle groups needed to be included: hip abductors and hip extensors. The hip abductors were modeled with attachment points from distal to the greater trochanter, to three locations on the pelvis: anterior and superior to the acetabulum, directly superior to the acetabulum, and posterior and superior to the acetabulum.

Due to the high degree of femoral flexion seen throughout the gait cycle in emus (early in stance phase the femur approaches 90° from vertical), the other muscle group modeled was the hip extensors, which attach the distal femur to the caudal end of the pelvis. Force plate recordings, combined with kinematic data obtained from published literature8 were used to estimate the ground reaction forces at five-degree femoral flexion intervals during the stance phase of a gait cycle. The distal femur was PMMA-potted, and loaded with the calculated ground reaction force, while the pelvis was allowed translational freedom transversely, and rotational freedom in the sagittal and coronal planes. A load cell was positioned in series with the hip extensor muscle group to monitor muscle tension; to maintain balance, the abductors were counter-weighted as the hip was loaded. Both Super Low and Fuji-films were used to record static joint contact stresses. Duplicate films were recorded at five-degree increments of flexion across the entire range of motion seen during stance phase.

RESULTS It is apparent from these data that although emus load their hips with a high degree of flexion, the contact stress is superiorly concentrated, as in humans (Figure 2). This is due to the large flexion moments (loading at the knee) that the hip extensors must overcome to maintain stability, thereby axially compressing the femur into the acetabulum. At increased flexion angles, regions of light contact were detected on the (cartilage-covered) greater trochanter surface, although these stresses generally accounted for only 5-20% of the resultant hip load.

Figure 1. Schematic (a) and photograph (b) of emu hip loading fixture. The pelvis attachment fixture (aluminum struts, plus two PMMA pots) freely moves in A-P and M-L translation, and in rotation about A-P and M-L axes; S-I translation, and rotation about the S-I and M-L axes, are constrained. The distal femur potting block is subjected to S-I force from M-L axes; S-I translation, and rotation about the S-I and M-L axes, are constrained.  The distal femur potting block is subjected to S-I force from M-L axes; S-I translation, and rotation about the S-I and M-L axes, are constrained.  The distal femur potting block is subjected to S-I force from M-L axes; S-I translation, and rotation about the S-I and M-L axes, are constrained.

Figure 2. Femoral head contact stress distributions for 55° (left) and 85° (right) flexion (measured from vertical). Two pins on the greater trochanter serve as fiducial markers for Fuji film.

For each loading case, peak stress and articular contact area were also calculated. Three cases which span the range of motion simulated are summarized in Table 1.

Table 1. Head contact stress and area (emu B.W.=400N)

<table>
<thead>
<tr>
<th>Flex. Angle</th>
<th>Recov. Cntct F</th>
<th>Pk Stress</th>
<th>Head Cntct. A</th>
<th>% Fem. Head</th>
</tr>
</thead>
<tbody>
<tr>
<td>55°</td>
<td>470 N</td>
<td>2.5 MPa</td>
<td>205 mm²</td>
<td>24%</td>
</tr>
<tr>
<td>70°</td>
<td>1250 N</td>
<td>8 MPa</td>
<td>253 mm²</td>
<td>30%</td>
</tr>
<tr>
<td>85°</td>
<td>537 N</td>
<td>3 MPa</td>
<td>182 mm²</td>
<td>22%</td>
</tr>
</tbody>
</table>

DISCUSSION The stress distributions recorded for emu femoral heads are generally similar to those seen in human femoral heads, in terms of anatomic engagement sites and contact stress magnitudes. The loading apparatus setup provides consistent results, verified by the similar magnitudes and articular contact distributions seen in duplicate films.

The super-low Fuji films tended to overestimate the hip reaction forces. Due to the sensitivity of the super-low film, forces generated during specimen seating may have increased the staining intensity, resulting in an overestimation of recovered hip load.

SUMMARY Emu proximal femur articular stress distributions were mapped using a cadaveric fuji-film preparation. The fixturing and loading procedure mimicked in vivo loading seen during a typical gait stance phase. Emu femoral head contact stress distributions are generally similar to those in humans, in terms of stress magnitudes and contact patch locations.

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