Effects of Acetabular Shell Deformation and Liner Thickness on Frictional Torque in Polyethylene Acetabular Bearings

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Introduction: Studies have shown that frictional forces in an acetabular component during the gait cycle may be a contributing factor to acetabular shell loosening. Recent publications have indicated that metal shell deformation can cause secondary forces attributed to insertion technique of press-fit components.

In addition, it is also recognized that larger diameter femoral heads offer the advantages of an enhanced range of motion (ROM) and increased stability. Therefore, larger head diameters can effectively reduce dislocation, which is a major complication after total hip arthroplasty. The effect of frictional torque produced with a deformed metal shell with a larger head diameter or a thinner polyethylene insert is unknown. The purpose of this study was to evaluate how changes in polyethylene insert thickness and polyethylene insert inner diameter affect frictional torque within the acetabulum.

Materials and Methods: Polyurethane synthetic bone model (Pacific Research Laboratories, Vashon, WA) was designed to represent a worst-case scenario for acetabular shell deformation as defined by Jin et al.1 To create the test model, a 30lb/ft³ density polyurethane foam block was machined to be 2mm ± 0.1mm less than the diameter of the acetabular shell. A second cavity was then formed to remove supporting material from the superior and inferior acetabular rim that to create a deformed shell. Highly polished cobalt chrome femoral heads and matched femoral stem neck angle of 130° were used. The acetabulum was mounted onto a multi-axis test frame (MTS Corp, Eden Prairie, MN) with a multi-planer moveable table at an angle to simulate 45° acetabular anteversion. The following measurements were taken to determine deformation of the acetabular shell and polyethylene insert using a caliper (±0.01 mm): diameter before insertion and diameter after insertion.

A femoral head (sizes 36 mm/40mm/44mm) was mounted onto a rotating actuator at an angle of 50° from the superior direction to simulate an average femoral stem neck angle of 130°. The foam block and fixture, that simulate the acetabulum, was mounted onto a multi-axis test frame (MTS Corp, Eden Prairie, MN) with a multi-planer moveable table at an angle to simulate 45° of shell abduction, which is the targeted inclination profile. The insert and head maintained in a bath containing bovine calf serum (Hyclone Labs, Logan, Utah) at room temperature that was diluted to 50% with 40% deionized water and 10% of 7 pH 20mMole ethylenediaminetetraacetic acid. A 890 N load was applied superiorly to the model while the rotating actuator was oscillated 20 cycles to ±20° at 0.5 Hertz. In order to determine the thickness of the polyethylene insert and its effect on the frictional torque, two different sized polyethylene thickness inserts were tested. In addition, two different sized femoral heads were tested to determine the effect of the diameter on frictional torque. All statistical analysis was performed using a student's paired t-test with a two-tailed distribution.

Results: The average amount of shell deformation measured in the 36E (5.9mm poly) group was 0.60 ± 0.04 mm compared to 0.81 ± 0.02 mm in the 36D group (3.9mm poly). This difference was statistically significant (p=0.0021). The average amount of polyethylene deformation measured in 36E (5.9mm poly) was 0.85± 0.05 mm compared to 0.97±0.06 mm in the 36D (3.9mm poly). This difference was also statistically significant (p=0.035).

Table 1. The Effect of Polyethylene Thickness on Frictional Torque

<table>
<thead>
<tr>
<th>Insert</th>
<th>Polyethylene Thickness (mm)</th>
<th>Frictional Torque (N mm) (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36E (5.9)</td>
<td>5.9</td>
<td>13.2 ± 4.1</td>
</tr>
<tr>
<td>36D (3.9)</td>
<td>3.9</td>
<td>11.4 ± 4.6</td>
</tr>
</tbody>
</table>
| p=0.0165

To assess the effects of head size on the model, the polyethylene thickness was maintained at 3.8 mm for both groups and the head size altered (Table 2).

Table 2. The Effect of Diameter on Frictional Torque

<table>
<thead>
<tr>
<th>Insert</th>
<th>Diameter (mm)</th>
<th>Polyethylene Thickness (mm)</th>
<th>Frictional Torque (N mm) (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>44E (3.9)</td>
<td>44E (3.9)</td>
<td>5.9</td>
<td>13.2 ± 4.1</td>
</tr>
<tr>
<td>44D (4.0)</td>
<td>44D (4.0)</td>
<td>5.9</td>
<td>11.4 ± 4.6</td>
</tr>
</tbody>
</table>
| p=0.063

The shell size differed in order to accommodate similar polyethylene thickness with different femoral head sizes. The average amount of shell deformation measured in the 40E group was 0.62 ± 0.04 mm compared to 0.78±0.09 mm in the 44F group. This was statistically significant (p=0.023). The polyethylene deformation measured in 40E was 0.91±0.05 mm compared to 1.02±0.10 mm in the 44F group. This finding was not statistically significant (p=0.0602).

Discussion: Previous studies found that frictional torque would diminish as polyethylene thickness increased.2 We found the opposite to be true. In our model, the thinnest polyethylene thickness (36D-3.9mm) led to less frictional torque than the thicker polyethylene (36E-5.9mm). The differences in the torque measurements were statistically significant. One explanation for this finding may be the ability of the thinner polyethylene to more readily conform around the femoral head. The increased compliance of the insert may have produced less contact stress and possibly reduced torque.

Thinner polyethylene allows for greater ROM by permitting use of a larger femoral head size and increased head-to-neck ratio for the same shell ID. In turn, this may increase hip stability and reduce the incidence of dislocation. Unfortunately, it was also concluded that larger femoral head size (44F) produced greater frictional torque compared to a smaller femoral head size (40F). In addition, when similar polyethylene thicknesses were used with an increasing femoral head size (44F) it produced statistically significantly greater frictional torque than the smaller 36E (p=0.0001). It is unknown whether the additional torque would have clinical significance. In addition, the laboratory model uses polyurethane foam and does not provide the stress relaxation seen in cadaveric and presumably living bone. In vivo, shell deformation may decrease with time thereby reducing the torque values. In conclusion, the highest frictional torque was seen in a larger diameter femoral head and thicker polyethylene insert.


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