INTRODUCTION

Most traditional tibial baseplates used with posterior stabilized (PS) articular components employ a long central stem, but are not well suited for use in minimally invasive surgical (MIS) procedures because the stem is difficult to insert through a small incision. Conversely, plate designs with short cemented pegs are ideally suited for insertion through small surgical windows, but are generally not used with PS tibial inserts because the fixation integrity of short cemented pegs is unknown. Some clinical studies have questioned whether a cemented central stem because the fixation integrity of short cemented pegs is unknown. Some studies suggest that proper cement fixation has a greater effect on tibial plate stability than stem length.

The objective of the current study was to compare the fixation provided by a new tibial baseplate design utilizing a short, wide stem (NexGen® MIS™ Tibial Component; Zimmer, Inc., Warsaw, IN) to that provided by a clinicially successful baseplate with a long, narrow central stem (NexGen® Steamed Tibial Plate) during various activities of daily living. To predict how the shorter stem design will perform in PS applications relative to the traditional stem design, finite element analysis (FEA) was performed on both designs to calculate the stresses at the implant-cement interface caused by loading scenarios which might promote lift-off of the tibial baseplate.

METHODS

Three PS-specific loading scenarios were considered: (1) heelstrike loading of the anterior tibial spine eminence which is observed to occur in some patients² and may promote anterior lift-off, (2) rising from a one-legged kneel in which the anteriorly directed force on the tibial insert spine from the femoral can exceed the tibiofemoral compression force and cause a tendency for posterior lift-off, and (3) deep flexion activity such as rising from a chair or squatting, which causes the potential for anterior lift-off due to the extreme posterior position of the femur relative to the tibia. For each loading condition, both baseplate designs were analyzed with the thickest available tibial insert (20 mm) and in the size which is expected to be most susceptible to lift-off due to plate dimensions (either size 1 or 5). Table 1 summarizes the model inputs for the analyzed load cases.

Since it was not feasible to explicitly model the anatomy of a proximal tibia or a thin mantle of bone cement on the underside of each plate, plates were modeled as if embedded in a dual-density foam “bone analog.” This construct, consisting of a high density polyurethane foam block with a 25mm diameter lower density core (Fig. 1), has been used in previous physical experiments in our lab to simulate the reported non-uniform compressive modulus and strength properties of a resected proximal human tibia.

Table 1. FEA model inputs for each PS-specific load case

<table>
<thead>
<tr>
<th>Loading Scenario</th>
<th>Heelstrike</th>
<th>Kneeling</th>
<th>Deep Flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyzed Plate Size</td>
<td>1068 N</td>
<td>886 N</td>
<td>1375 N</td>
</tr>
<tr>
<td>Flexion Angle</td>
<td>155°</td>
<td>88°</td>
<td>155°</td>
</tr>
<tr>
<td>Compressive Force</td>
<td>2669 N</td>
<td>498 N</td>
<td>394 N</td>
</tr>
<tr>
<td>Anterior Force</td>
<td>894 N</td>
<td>894 N</td>
<td>894 N</td>
</tr>
</tbody>
</table>

Displacements on the bottom face of the bone analog construct were constrained in all directions. Insert-baseplate and baseplate-foam interfaces were assumed to be perfectly bonded, allowing no relative motion between components. In both models, similar components were meshed using identical element sizing controls to eliminate differences in stress magnitudes which might result from inconsistent mesh density. Solids were assigned linear elastic properties for their respective materials. Linear static FEA analyses were performed using ANSYS Workbench (v8.1; ANSYS, Inc., Canonsburg, PA). The value of the maximum normal stress in the foam at the baseplate-foam interface was used as the primary predictor for tensile failure of the in vivo cement-baseplate interface.

RESULTS

For both stem lengths and all loading scenarios considered, peak stress magnitudes were predicted along the anterior and posterior edges of the baseplate, while the stresses occurring along the faces of the stem were generally much lower. Rising from a one-legged kneel produced the highest normal stress at the baseplate-foam interface for both plate designs (Fig. 2). In this loading case, the difference between the shorter-stemmed plate (3.96 MPa) and the longer-stemmed plate (3.94 MPa) was only 0.5%. Relative to the kneeling load case, the heelstrike loading case generated slightly lower stress for the shorter-stemmed baseplate (3.92 MPa) and significantly lower stress for the longer-stemmed baseplate (2.79 MPa). The deep flexion loading scenario produced much lower stress values for both baseplate designs.

DISCUSSION

These results indicate that the fixation provided by the short, broad stem of the MIS-specific baseplate design in the worst case loading condition is virtually equivalent to the fixation provided by the long central stem of the clinically successful traditional baseplate. Despite the fact that the heelstrike loading case was defined with an extremely large spine force, stresses are predicted to be no worse than during kneeling.

Figure 1. Exploded view of the short-stemmed (left) and long-stemmed (right) component assemblies used for the analysis of heelstrike (red), rising from a 1-legged kneel (green), and deep flexion (blue).

Figure 2. Interfacial stress results for all three load scenarios.

REFERENCES

4. Johnson, TS, et al., 7th World Biomats Congress, 1126, 2004