DO SHORT-STEMMED HIP IMPLANTS PROVIDE PHYSIOLOGICAL LOAD TRANSFER IN THE PROXIMAL FEMUR?

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INTRODUCTION

Short-stemmed hip implants have been introduced in order to conserve proximal bone mass and could facilitate the use of minimally invasive surgery (MIS), in which smaller incisions limit access to the hip joint. MIS techniques have been associated with faster rehabilitation, reduced peri-operative blood loss and less post-operative pain [1]. The limited access during MIS may increase the risk of surgical mal-placement, the influence of which on the internal loading of the proximal femur is unknown. While conventional stems have been extensively studied in terms of the influence of design, surgical and patient parameters on femoral loading, little is known about the influence of such parameters in the case of short-stemmed implants. Changes to the internal loading of the proximal femur have been associated with bone resorption [2], which may lead to implant loosening [3]. The goal of this study was to examine the influence of surgical implantation, as measured by effective offset and anteversion, of a short-stemmed implant on the strain energy density within the proximal femur.

METHODS

A model of a short-stemmed implant (Nanos, size 4, Endoplant GmbH, Germany) was implanted virtually into the Standardized Femur such that the normal hip centre was maintained, and was considered the reference model. The implant was then repositioned, resulting in a hip centre that was shifted 5.9mm medially, 3.7mm superiorly and 2.0mm posteriorly. This was the first case of mal-position studied, and was termed the “offset” model. The second case of mal-position studied was simulated by rotating the implant of the reference model about the femoral shaft axis to increase the anteversion from 4° to 11°, and was termed the “anteverted” model. In all cases the femur was resected at the shoulder of the prosthesis. The models were meshed using approximately 4mm 10-node tetrahedral elements to which linearly-elastic material properties were assigned (Table 1). The distal third of the implant is polished so Coulomb friction was assumed with a coefficient of 0.01; the remainder of the implant and bone mesh surfaces were tied together to simulate full osseointegration. The intact model was created by assigning cancellous bone properties to the implant region and adding the femoral head.

Muscle and joint contact forces were calculated for walking and stair climbing using a previously-validated musculoskeletal model [4] and each force was applied at a single node corresponding to the centre of the muscle attachment site or joint contact area. All analyses were performed using the Abaqus finite element solver (v 6.5 Abaqus Inc., Pawtucket, RI). The effect of implantation on proximal femoral loading was analysed by comparing the average cortical strain in every Gruen zone (Figure 1). In every Gruen zone the offset model produced the highest strain energy density, followed by the anteverted model. The largest difference from the reference model was seen in zone 5, where the increased offset increased the strain energy by 7.9 kJ/m³ (34%). In contrast, increased anteversion produced strain energy 2.2 kJ/m³ (10%) higher than the reference model, also in zone 5.

The largest difference from the reference model was seen in zone 3, 4 and 5. Strain energy densities in the proximal-medial region (zone 7) were reduced to approximately one third of the intact value for all implanted models. Increased strain energy was seen in the distal region of the offset model, especially in zone 5, where the difference was 3.7 kJ/m³ (14%). Although the strain energy density magnitudes differed under stair climbing, the patterns were unchanged.

DISCUSSION

For the first time, the internal loading of the proximal femur has been determined for a short-stemmed hip implant. This study found that, while strain energy density was relatively insensitive to implant placement, large decreases were seen in the proximal regions relative to the intact femur. Increased offset increased the strain energy density in the cortex adjacent to the distal region of the implant relative to the reference model. Increased anteversion also increased the strain energy density, however differences from the reference model were smaller. In the most proximal regions of the femur, differences between implanted models were small when compared to the decrease in strain energy from the intact situation.

Bone resorption has been previously explained by a decrease in strain energy density due to the presence of a hip implant [2]. The large decrease in proximal-medial strain energy density relative to the intact model seen in this study corresponds to a region of bone resorption reported with a short-stemmed implant [6]. A small region of elevated strain energy was seen in zone 3 of the implanted models due to high contact stresses between the implant and bone, which may result in the increased density that has also been reported in this region with a short-stemmed implant [6]. In conclusion, proximal femoral loading was found to be relatively insensitive to ‘mal-placement’ in this study, within the range considered. Thus use of a short-stemmed implant in combination with MIS is expected to give reproducible results. However, stress shielding of the proximal femur was seen, which may lead to bone resorption seen clinically [6]. Long-term prospective clinical trials would be required to determine what influence this bone loss may have on the survival of this implant.

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REFERENCES


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Table 1: Material properties applied to the various regions of the models.

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic Modulus</th>
<th>Poisson’s Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cancellous bone</td>
<td>1.0 GPa</td>
<td>0.3</td>
</tr>
<tr>
<td>Cortical bone</td>
<td>17.0 GPa</td>
<td>0.33</td>
</tr>
<tr>
<td>Implant (titanium)</td>
<td>110 GPa</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Figure 1: Strain energy density (kJ/m³) varied by Gruen zone. "Ref”=reference implant model; “AV”=anteverted implant model.

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