Stress Shielding in the Distal Femur after Total Knee Arthroplasty

INTRODUCTION:

The mechanical environment due to different implant designs and fixation methods has received relatively little attention despite the fact that femoral component loosening is a major contributor to the need for revision surgery. This study considers the stresses in the distal femur due to two different implant geometry variations: a pegged or cruciate retaining (CR) implant and a box section or posterior stabilizing (PS) implant. Three dimensional finite element (FE) models of the intact femur and femur with the above implants were constructed and computationally subjected to loading representing a walking cycle to evaluate changes in the stress field.

METHODS:

The femur model used for these studies is the third generation composite femur made freely available in the public domain\(^1\). The modification to the intact femur to accommodate the implants was carried out in accordance with surgical protocols. The FE models of the intact femur and femur with implants are shown in Fig. 1.

The forces corresponding to the walking cycle were taken from a previous study that used in vivo telemetric implants\(^2\). The forces comprised of vertical forces (appropriately split over the medial and lateral condyles), anterior-posterior shear force, patellar-femoral force and internal external moment. These were applied to the distal femur over realistic contact areas. This study examined three flexion angles (0º, 22º, and 48º) during a walking cycle.

RESULTS:

Typical von Mises stresses for cancellous bone in a frontal plane section are shown in Fig. 2. It can be seen that there is considerable reduction in stresses post-implantation.

For each region of interest the average von Mises stress was evaluated for the intact and implanted femurs. The average reduction in the entire regional volume of interest is presented in Table 1.

<table>
<thead>
<tr>
<th>Region</th>
<th>% reduction (CR)</th>
<th>% reduction (PS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64</td>
<td>62</td>
</tr>
<tr>
<td>2</td>
<td>65</td>
<td>68</td>
</tr>
<tr>
<td>3</td>
<td>63</td>
<td>61</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>-5</td>
</tr>
</tbody>
</table>

The above results indicate that regions 1-3 experience considerable stress shielding, while region 4 shows a small reduction in the case of CR implanted femur and an actual increase in stress of 5% in the case of the PS implanted femur. These results are found to be in good agreement with the observed patterns of BMD reduction as seen in the clinical situation\(^3,4\).

DISCUSSION:

The study shows that the cancellous bone in the distal femur experiences significantly lower stresses after knee arthroplasty. The stress shielding evident from the results occurs in a similar pattern to reported instances of reduction in BMD in clinical scenarios. Results from these analyses also highlighted stress concentrations for the PS implanted case. These in conjunction with reduction in bone quality due to stress shielding can lead to peri-prosthetic fractures.

The results also indicate that the corners of the femoral box cut are subject to high stress concentration (Fig. 4) that are absent in the intact and CR implanted femurs. These stresses could lead to an increased risk of peri-prosthetic femoral fracture.

REFERENCES:


