Effect of Acetabular Cup Orientation and Design on the Contact Mechanics and Range of Motion of Metal-on-Metal Hip Resurfacing Prostheses

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INTRODUCTION

Metal-on-metal (MoM) hip resurfacings have been extensively used in the past decade, due to the perceived advantages in terms of biomechanics and biotribology that these devices can theoretically offer over conventional total hip arthroplasty. However, a number of problems have been identified recently from clinical retrievals, including significant elevation of wear when the implant is mal-positioned [1-4]. This can cause edge loading and deterioration of lubrication, which causes increased wear in MoM bearings. The occurrence of edge loading will also be dependent on cup coverage; a high profile cup design decreases the likelihood of edge loading. However, the Australian registry data has not shown an advantage with high profile cups compared to lower profile cup designs. Our hypothesis is that implant mal-position as well as cup coverage can affect the contact mechanics as well as the range of motion of the resurfacing hip implant, and therefore a design compromise is required. The aim of this study was to investigate the effect of acetabular cup orientation and cup coverage profile on the contact mechanics and the range of motion of MoM hip resurfacing prostheses.

METHODOLOGY AND FINITE ELEMENT MODELS

Three generic metal-on-metal hip resurfacing prostheses were modeled using a finite element (FE) method. The variable considered in these designs was the effective coverage angle of the acetabular cup; low, 152º; medium, 164º; high, 178º. The acetabular component had a nominal inner bearing diameter of 54.6 mm (60.5 mm outside diameter) and the diametrical clearance between the femoral head and the acetabular cup was 0.11 mm. The resurfacing components were implanted into a hemi-pelvic hip joint bone model [5]. All the materials in the FE model were assumed to be homogenous, isotropic and linear elastic [6]. The anteversion angle of the acetabular cup was varied from 0º to 30º, the inclination angle varied from 35º to an upper limit dependent on the coverage profile, (e.g. 65º for low profile and 80º for high profile). Contact at the bearing surface between the cup and femoral head was modeled as frictionless, it is generally accepted that even a large friction coefficient of 0.1 would not have large effect on the predicted contact area and pressure [5]. For this study, the femoral component was fixed into the femur (except the guide pin) using PMMA cement (approximately 1mm thick) with an inclination angle of 45º and an anteversion angle of 10º. The other contact interfaces in the FE model (cup/acetabulum, cement/bone and cement/femoral component) were all assumed to be rigidly bonded. The hip joint model was loaded through a fixed resultant hip joint contact force of 3200N, and was applied through medial, anterior muscle forces and subtrochanteric forces to simulate the fixed resultant hip joint contact force of 3200N, and was applied through medial, anterior muscle forces and subtrochanteric forces to simulate the fixed resultant hip joint contact force of 3200N, and was applied through medial, anterior muscle forces and subtrochanteric forces to simulate the fixed resultant hip joint contact force of 3200N, and was applied through medial, anterior muscle forces and subtrochanteric forces to simulate the fixed resultant hip joint contact force of 3200N, and was applied through medial, anterior muscle forces and subtrochanteric forces to simulate the fixed resultant hip joint contact force of 3200N, and was applied through medial, anterior muscle forces and subtrochanteric forces to simulate the fixed resultant hip joint contact force of 3200N, and was applied 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RESULTS AND DISCUSSION

The effect of the cup implant position on the contact area and contact pressure at the bearing surfaces was predicted for each cup design (Table 1). Edge contact was detected once the inclination angle became greater than 65º and 80º for the low and high coverage cup profiles respectively. Increasing the anteversion angle resulted in a further shift of the contact area towards the edge of the cup. Edge loading elevated the contact stress at the rim of the cup, however, more importantly, this can block the lubricant entry into the contact and therefore cause lubricant starvation. Under these adverse lubrication conditions, wear of MoM bearings can be markedly increased. The finding from the current study on the adverse effect of the high cup angles is consistent with both experimental [10] and clinical studies reported recently [11]. The contact mechanics study reveals that increasing the cup coverage may be one option to minimize the occurrence of edge loading, however, such an approach may compromise the range of motion. This was demonstrated from the range of motion studies of three cup design for varying cup implant orientations as shown in Fig. 2. Although the range of motion was found to be dependent on cup orientation, the low profile cup offered the best range of motion, particularly at high implantation angles (Fig. 2). This is consistent with the Australian Registry where high profile cups have not been shown to perform better clinically.

Table 1: Contour plots of the contact distribution at the bearing surface, showing the effect of acetabular cup orientation & cup coverage.

<table>
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<tr>
<th></th>
<th>Low coverage</th>
<th>Medium coverage</th>
<th>High coverage</th>
</tr>
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<tbody>
<tr>
<td>45º inclination</td>
<td>16.16 MPa</td>
<td>15.91 MPa</td>
<td>15.66 MPa</td>
</tr>
<tr>
<td>65º inclination</td>
<td>25.22 MPa</td>
<td>14.61 MPa</td>
<td>14.57 MPa</td>
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</table>

This study highlights the importance of surgical technique as well as cup designs on the contact mechanics/tribology and biomechanics of MoM hip resurfacing and the potential outcome of these devices. Optimisation in terms of both tribology of the bearing surfaces and biomechanics is required.

ACKNOWLEDGEMENTS:
DePuy International, NIHR, LMBRU, WELMEC

REFERENCES: