Different levels of Rotational and Translational Surgical Mal-Positioning Affects the Occurrence and Severity of Edge Loading and Wear in Total Hip Replacements

Mazen Al-Hajjar¹, Oscar O'Dwyer Lancaster-Jones¹, Sophie Williams¹, Louise M. Jennings¹, Jonathan Thompson², Graham H. Isaac¹,², Eileen Ingham¹, John Fisher¹.

¹Institute of Medical and Biological Engineering, School of Mechanical Engineering, University of Leeds, Leeds, United Kingdom, ²DePuy Synthes Joint Reconstruction, Leeds, United Kingdom.


Introduction: Increased wear rates [1, 2] and acetabular rim fracture [3] of hip replacement bearings reported clinically have been associated with edge loading. Edge loading could occur due to rotational and/or translational surgical mal-positioning [4]. Translational surgical mal-positioning can lead to dynamic microseparation mechanisms resulting in edge loading conditions. The wear of different bearing materials under edge loading conditions is well documented. Steep cup inclination angle alone did not reproduce stripe wear in ceramic-on-ceramic bearings in vitro, however, microseparation, a result of translational mal-positioning, has replicated stripe wear and the bi-modal wear particle size distribution observed clinically [5, 6]. The wear of metal-on-metal bearings increased due to both rotational and translational mal-positioning [7-9]. The wear of hard-on-polyethylene did not increase under edge loading conditions, however; excessive deformation of the acetabular liner rim was reported [10].

The aim of this study was to determine the influence of different levels of translational and rotational surgical mal-positioning conditions on the magnitude of dynamic microseparation, severity of edge loading, and the resulting wear rate of ceramic-on-ceramic bearings, in a hip joint simulator.

Methods: The six-station Leeds Mark II physiological anatomical hip joint simulator was used in this study. Ceramic-on-ceramic bearings (BIOLOX® delta) in which the ceramic liner was inserted into a titanium alloy shell (Pinnacle®, DePuy Synthes, UK) were tested under conditions of rotational and translational mal-positioning. A standard gait cycle with a twin-peak loading (3kN peak load and approximately 70N swing phase load), extension/flexion -15°/+30° and internal/external ±10° rotations was applied. A fixed surgical translational mal-positioning between the centres of rotations of the head and the cup in the medial/lateral axis was applied on all stations (Figure 1). Four different studies were completed for a total of three million cycles each (Table 1). The lubricant used was 25% (v/v) new-born calf serum supplemented with 0.03% (w/v) sodium azide to retard bacterial growth. The magnitude of dynamic microseparation was measured using a LVDT. Wear was assessed every one million cycles gravimetrically using a microbalance (XP205, Mettler Toledo, UK) and geometrically using a coordinate measuring machine (CMM, Legex 322, Mitutoyo, UK). Statistical analysis was performed using one way ANOVA with significance taken at p<0.05.

Results: Both rotational and translational mal-positioning affected the magnitude of dynamic microseparation displacement (Figure 2). For the same level of translational mal-positioning, steeper
inclination angle resulted in higher level of dynamic microseparation and higher wear rates. For the 2mm translational malpositioning condition, the wear rate was significantly (p=0.02) higher with the steep cup inclination angle condition (65°, mean wear rate ± 95% confidence limit: 0.14±0.05mm³/million cycles) compared to a cup inclination angle of 45° (0.07±0.04mm³/million cycles). This observation was more prevalent with the 4mm translational mal-positioning condition compared to the 2mm translational mal-positioning condition (Figure 2). For the 4mm translational malpositioning condition, the wear rate was significantly (p<0.01) higher with the steep cup inclination angle condition (65°, 1.01±0.17mm³/million cycles) compared to a cup inclination angle of 45° (0.32±0.04mm³/million cycles). The penetration on the femoral heads was significantly higher for the steep cup inclination angle group with a mean (±95% confidence limit) penetration of 8±3 and 33±6µm (for 2mm and 4mm translational malpositioning respectively) under the 65° cup inclination angle condition and 3±1 and 15±3µm (for 2mm and 4mm translational malpositioning respectively) under the 45° cup inclination angle condition. Stripe wear was present on the femoral heads under all conditions.

**Discussion:** An in vitro model has been developed, not only to determine the wear under edge loading conditions, but also to predict the occurrence of edge loading condition and its severity due to rotational and translational mal-positioning. Larger magnitudes of surgical translational mal-positioning resulted in greater level of dynamic microseparation conditions and hence a more severe edge loading condition. This study also showed that cup inclination angle affects the magnitude of dynamic microseparation for a given surgical translational mal-position, thus leading to severe edge loading and increased wear rates with increased cup inclination angles. The occurrence and severity of the resulting edge loading causing increased wear in hip bearings will depend on the combinations of surgical variations, such as steep inclination angle, excessive version angle, medialised cups, head offset deficiencies, stem subsidence, and joint laxity and future work will include investigating these variables.

**Significance:** An advanced physiological in vitro simulator method, that can predict the occurrence and severity of edge loading and the wear of different hip bearings materials and designs due to surgical mal-positioning, developed in this study, can be used as a preclinical testing technique to better predict the efficacy and reliability of new hip replacement bearings.

**Table 1: Study variables in terms of translational mal-positioning and cup inclination angle.**

<table>
<thead>
<tr>
<th>Study</th>
<th>Translational mal-positioning</th>
<th>Cup inclination angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study 1</td>
<td>4mm</td>
<td>45°</td>
</tr>
<tr>
<td>Study 2</td>
<td>4mm</td>
<td>65° (rotational mal-positioning)</td>
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<tr>
<td>Study 3</td>
<td>2mm</td>
<td>45°</td>
</tr>
<tr>
<td>Study 4</td>
<td>2mm</td>
<td>65° (rotational mal-positioning)</td>
</tr>
</tbody>
</table>
Figure 1: Schematic illustrating translational mal-positioning condition with two cup inclination angle conditions leading to dynamic microseparation conditions.
- 2mm translational malpositioning with 45° cup inclination angle
- 2mm translational malpositioning with 65° cup inclination angle
- 4mm translational malpositioning with 45° cup inclination angle
- 4mm translational malpositioning with 65° cup inclination angle

Figure 2: Wear rate of ceramic-on-ceramic bearings versus dynamic microseparation displacement under the four different testing conditions.

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