THE INFLUENCE OF IMPINGEMENT ON THE WEAR OF A METAL-ON-METAL ARTICULATION: A HIP SIMULATOR STUDY

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ABSTRACT

Wear magnitude and location for a metal-on-metal bearing couple were studied on a hip simulator with and without the occurrence of impingement. The steady-state wear increased by a factor thirty due to the impingement and the shape and location of the impingement zone closely resembled clinical observations. Metal-on-metal bearings have the advantage of combining low wear with a high toughness. The low wear is only guaranteed if impingement phenomena are excluded, thus showing the importance of proper implant designs and surgical techniques.

INTRODUCTION

Hard-on-hard bearing couples are an established alternative for hard-soft bearings in total hip replacements. Advantages are their reduced wear volumes compared to a metal-on-polyethylene articulation, the inertness of the wear particles and enhanced scratch resistance (for ceramic-on-ceramic) or their high toughness (for metal-on-metal). The wear of these bearing systems has been studied extensively using simulators. Wear is measured under controlled conditions and factors like stop-and-go walking, jogging [1] or microseperation [2] have been introduced to generate clinically relevant wear volumes. However, the influence of impingement on wear for a metal-on-metal articulation was studied to a lesser extent, despite its clinical relevance since not all cups are positioned within the safe-zone [3]. Cups positioned outside this safe-zone are suspected to have a higher impingement potential. Therefore, the influence of neck-rim impingement on the wear magnitude and wear pattern is studied here for a metal-on-metal hip system and compared with an impingement-free articulation.

MATERIALS AND METHODS

Six EPF inlays (PLUS Endoprothetik) with a metal-polyethylene sandwich design were paired with 28 mm CoCr low carbon ball heads (XXL, PLUSMET ISO 5832-12). An AMTI hip simulator was used and the kinematics and force input data were taken from literature [4]. Three inlays were embedded horizontally and three inlays under an angle of 45° to ensure impingement between the skirt of the XXL ball head and the rim of the metal insert. The simulator test was done using diluted calf serum (30gr/l) as a lubricant and lasted 5 millions cycles. The weight changes of the ball heads were measured each 0.5-millions cycles and the geometric changes on the surface of the ball were determined using a Mitutoyo 3D coordinate measuring machine. The impingement areas were analyzed using scanning electron microscopy (SEM).

RESULTS

The gravimetric weight losses of the metal ball heads as a function of the number of wear cycles are shown in Figure 1.

Figure 1: Gravimetric weight losses of CoCr balls versus the number of gait cycles in the simulator with (●) and without (○) impingement between ball and cup.

For the metal balls without impingement, the steady-state wear after the run-in phase (0-0.5 millions cycles) is low and amounts 0.24 mg/millions cycles. For the ball heads with head-neck impingment, the weight losses increase almost linearly and no bedding-in wear region can be observed. The steady-state wear rate amounts 8.15 mg/millions, i.e., a thirtyfold increase in wear compared to the couples without impingement. Also the standard deviation is higher for the bearings with...
impingement showing that minor changes in the cup positioning have a larger effect on the wear magnitude compared to the ideal situation.

A photograph of a ball head after 5 million gait cycles is presented in Figure 2. An ellipsoidal impingement zone could be detected on the skirt of the heads with an averaged depth of 0.36mm and a length of 10 mm. The location of the impingement zone corresponds well with clinical retrievals (Figure 2, Right). The scanning electron micrographs pictures (SEM) show also a comparable surface texture and therefore it seems that the simulator impingement closely replicates clinical impingement patterns.

Figure 2: Left: Photograph of the ball head after 5 millions gait cycles; Right: Revised ball head after 3.5 years in-vivo. Impingement area on the neck is indicated by the rectangle.

Top views of the 3D-coordinate measurements of the simulator ball heads are depicted below (Figure 4). The shape of the wear zones is different. The ball heads without impingement have a circular wear zone at the top of the ball head (left). For the ball head with impingement a stripe wear pattern is found on the surface (right), opposite to the impingement area on the neck. The stripe wear pattern is the result of rim loading of the cup which has often been associated with microseparation phenomena in hard-hard bearing couples [5], i.e., it might be that next to head-neck impingement also microseparation occurs during the gait cycle. The maximum linear wear values and the calculated wear from the integrated wear volumes from the 3D analysis are plotted in the table below. The measured cumulative gravimetric wear after 5 million cycles (Figure 1) is shown as well.

Table 1: Wear data from 3D-coordinate and gravimetric measurements

<table>
<thead>
<tr>
<th></th>
<th>Max. Linear wear at surface of ball [µm]</th>
<th>Calculated wear from the surface [mg]</th>
<th>Measured wear from surface and neck [mg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Imp.</td>
<td>5</td>
<td>6.5</td>
<td>4.9</td>
</tr>
<tr>
<td>Imp.</td>
<td>16</td>
<td>16.7</td>
<td>40.8</td>
</tr>
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The maximum linear wear and calculated wear of the surface is higher for the impinging balls showing that the microseparation increases the wear between the articulating surfaces. The differences between the measured cumulative wear of the balls and the calculated wear volume at the surface represents an estimate for the material loss at the neck in the impingement zone (Figure 2). Therefore, for the impinging balls, approximately 60% of the wear is generated at the neck and 40% at the surface of the ball.

Figure 4: 3-D coordinate plots of metal balls after 5 millions gait cycles. Shown are the differences between maximum and minimum radius values. Blue represents no wear; red represents maximum wear. Left side: no neck-rim impingement maximum radius difference is 5 micrometer; Right side: with neck-rim impingement, maximum radius difference is 16 micrometer.

CONCLUSIONS

The steady state wear rate of a metal-on-metal bearing couple is significantly increased by the introduction of impingement in the gait cycle on the hip simulator. The increased wear is due to the neck-rim impingement but also due to increased wear at the balls surface, possibly due to microseparation phenomena. This simulator study shows the importance of implant designs and surgical techniques which avoid impingement.

REFERENCES