INTRODUCTION:
There is currently a great deal of interest in the wear of metal-on-metal bearings and potential concerns about elevated metal ion levels \textit{in vivo}. Generally, wear of metal-on-metal hip prostheses has been shown to be low in laboratory simulator studies [1]. Slightly higher and more variable wear rates have been found clinically [2]. In metal-on-metal bearings, start-dwell-start motion testing in a hip simulator has been shown to increase the wear rate by a small amount [3].

Following hip replacement surgery the tension of soft tissues and the laxity of the joint may vary. Variations in surgical approach, technique and fixation method may influence the level of force applied across the prosthesis during gait. It is hypothesized that increased joint tensioning may increase loading of hip replacements during the swing phase; leading to elevated wear and friction due to depleted fluid film lubrication. This study aimed to assess the effect of swing phase load on the friction, lubrication and wear of metal-on-metal hip replacements.

MATERIALS AND METHODS: Cobalt chrome 28mm metal-on-metal hip replacements (which are in clinical use; Ultima, DePuy International) were tested in a physiological hip simulator (Prosim, UK). Components were tested in the anatomic position with the insert inclined 55 degrees to the vertical loading axis. The simulator applied two independently controlled motions; flexion-extension and internal-external rotation, which resulted in open elliptical wear paths. A Paul-type twin peak loading curve was applied, which was modified to provide different swing phase load conditions; (1) ISO swing phase load (280N, as per Standard ISO 14242-1) and (2) low swing phase load (<100N). Tests were carried out in 25% (v/v) new born bovine serum, with wear measurements completed gravimetrically every million cycles up to five million cycles. Friction testing was conducted using a pendulum friction simulator (Prosim, UK). Components were mounted in an inverted position and flexion-extension of 525 degrees applied to the head. Tests were carried out with a peak load of 2kN and swing phase loads of 100N and 280N.

Theoretical lubrication modeling was carried out using elasto-hydrodynamic lubrication theory. All the governing equations were solved numerically for the lubricant film thickness between the articulating surfaces under the transient dynamic conditions with different swing phase loads specified [4].

RESULTS:
The volumetric wear rates for the different swing phase conditions are shown in Table 1.

Table 1: Volumetric wear rates of metal-on-metal hip replacements under different swing phase loads.

<table>
<thead>
<tr>
<th>Swing phase load</th>
<th>Wear rates mm/million cycles (mean ± 95% CL)</th>
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<tbody>
<tr>
<td>Bedding-in</td>
<td>0.131±0.08</td>
</tr>
<tr>
<td>Steady-state</td>
<td>0.05±0.04</td>
</tr>
<tr>
<td>Overall</td>
<td>0.06±0.039</td>
</tr>
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Overall mean wear rate was 10-times greater in total hip replacements tested with an ISO swing phase load in comparison to prostheses tested with low swing phase loads. The coefficients of friction of the metal bearings were 0.129 and 0.173 respectively for the low and ISO swing phase conditions.

Theoretical lubrication modeling demonstrated a decrease in the predicted lubricant film thickness when the swing phase load was increased, particularly during the stance phase as shown in Figure 1.

DISCUSSION:
Little attention to date has been paid to the importance of swing phase load on the wear rate of hip replacements in simulator testing. In metal-on-metal hip simulator testing has demonstrated a 10-fold increase in wear, when the swing phase load was increased from 100N to 280N. Coefficients of friction measured were higher in testing with increased swing phase loads. It was hypothesized that increased wear and friction in testing with elevated swing phase loads could be attributed to the depletion of fluid film lubrication. Theoretical lubrication modeling supported this hypothesis and demonstrated a reduced fluid film thickness with increased swing phase loads. These results are consistent with the findings under start-dwell-start motion [5], which showed depletion of fluid-film lubrication leading to accelerated wear rates. Elevated wear of metal-on-metal bearings has also been observed in testing with simulated jogging cycles [5] (increased speed and peak load); such conditions would also diminish fluid film lubrication.

The results demonstrate that the performance of metal-on-metal total hip replacements is highly dependent on swing phase load conditions. A previous study [6] has demonstrated that wear of metal-on-metal bearings is increased further (1.58mm\(^2\) per million cycles mean overall wear) by joint laxity (microseparation of components during the swing phase). It is postulated that fixation method and surgical technique can effect the swing phase load. This study has demonstrated that over-tensioning of the tissues may also accelerate wear. These observations may explain some of the variations found in clinical wear rates.

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