WEAR AND FRICTION CHARACTERISTICS OF THE TRI-POLAR ALL CERAMIC HIP PROSTHESIS

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### Introduction
There is increasing interest in the use of ceramic on ceramic bearings for hip replacement worldwide, due to recognition of their extremely low wear and biocompatibility of the wear debris [1]. Recent developments in ceramic matrix composites and the introduction of Biolox Delta with improved fracture toughness, further reduces the risk of fracture and also extends the design flexibility of the material. A stripe wear morphology has been frequently observed on the femoral head of ceramic-on-ceramic hip prostheses, which is believed to be due to micro-separation of the components and contact of the head on the rim of the cup [2]. The double-mobility polyethylene hip prosthesis has been extensively used in France, this prosthesis provides improved function and stability. However there remain concerns about polyethylene wear and osteolysis. A novel tri-polar all ceramic hip prosthesis, 3™ (CeramConcept L.L.C., USA) has been designed and developed, which combines the functional advantages of the double-mobility hip with the tribological advantages of ceramic bearings [3].

The aim of this study was to evaluate the wear and friction characteristics of this novel tri-polar all ceramic artificial hip joint.

### Materials and Methods
The tri-polar hip prosthesis (CeramConcept L.L.C., USA) comprised a 22 mm ceramic head, a 22/32 mm mobile ceramic head, a 32 mm internal diameter ceramic acetabular insert, and a polyethylene retaining ring. All ceramic components were manufactured from Biolox Delta ceramic matrix composite (CeramTec AG, Germany).

The wear of the tri-polar bearing was compared to a 28 mm ceramic on ceramic (Biolox Delta) bearing couple in the Leeds II Physiological Anatomical hip joint simulator over 5 million cycles, using 25% bovine serum as a lubricant. The test conditions comprised of physiological twin peak time dependent loading with an elliptical wear path. Simulator studies were carried out under these standard ISO conditions, but also under novel micro-separation conditions which replicate head/cup rim contact at heel strike and simulate stripe wear on a conventional femoral head as found on conventional ceramic on ceramic retrievals [2]. Two or three specimens were studied for each case. Wear was determined gravimetrically.

Friction testing was performed using a pendulum friction simulator (Simulation Solutions, UK). Flexion/extension motion of ±25° was applied to the head and a dynamic loading profile with a 3 kN peak load was used. Three tri-polar bearings were tested. Similar to the wear study, 25% bovine serum was used as the lubricant and the results were compared to a 28 mm Biolox Delta ceramic on ceramic bearing.

### Results
The wear rates for the tri-polar and conventional Biolox Delta hip bearings are detailed in Table 1. Under standard conditions the wear of the tri-polar and conventional ceramic on ceramic bearing were very low. The wear of the tri-polar all ceramic hip was less than 0.01 mm³/million cycles, the detection limit for wear measurement, while the conventional ceramic on ceramic bearing produced a wear rate of 0.07 mm³/million cycles. The difference between these very small wear rates is not clinically significant. Under micro-separation conditions there was a significant difference in the wear performance. For the conventional Biolox Delta ceramic on ceramic bearing, stripe wear was found on the head with a bedding in wear of 0.32 mm³/million cycles and a steady state wear of 0.12 mm³/million cycles, resulting in an overall wear rate of 0.16 mm³/million cycles. The all ceramic tri-polar bearing did not reveal stripe wear on either articulating component and the overall wear could not be detected, being less than 0.01 mm³/million cycles. Wear of the polyethylene ring could also not be detected gravimetrically.

The frictional torque of the tri-polar bearing was lower at 0.7 Nm, compared to 1.8 Nm for the conventional Biolox Delta ceramic on ceramic bearing. This resulted in a 50% reduction in friction coefficient for the tri-polar bearing, as detailed in Table 2.

### Discussion
Low wear rates of under 1 mm³/million cycles for Biolox Delta ceramic on ceramic hip prostheses under both standard conditions and micro-separation has been previously reported [4]. Under standard conditions even lower wear was observed for the tri-polar bearing due to the small head diameter. The majority of the sliding distance in the tri-polar hip occurred at the 22 mm diameter ball head, and since wear is proportional to the sliding distance this resulted in lower wear than a conventional 28 mm ceramic hip.

Under micro-separation conditions the wear of the tri-polar bearing was low due to the absence of edge loading and hence absence of stripe wear. The design of the tri-polar bearing with the mobile ceramic head prevented edge loading of the head on the edge of the cup, so significantly reducing wear under these severe, but clinically relevant micro-separation conditions.

The tri-polar hip also showed improved frictional characteristics with a reduced frictional torque due to articulation at the smaller diameter 22 mm inner femoral head.

Previous studies have shown increased stability and range of motion with the tri-polar hip prosthesis design [3, 5, 6].

### Table 1 Wear Rates (mm³/million cycles) ± Standard Error for Tri-polar and Conventional Biolox Delta Ceramic on Ceramic Bearings

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<th>Standard ISO</th>
<th>Micro-Separation</th>
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<tr>
<td>3™ Tri-polar</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Conventional</td>
<td>0.07 ± 0.03</td>
<td>0.16 ± 0.05</td>
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### Table 2 Coefficient of Friction for Tri-polar and Conventional Biolox Delta Ceramic on Ceramic Bearings

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<tbody>
<tr>
<td>3™ Tri-polar</td>
<td>0.02</td>
</tr>
<tr>
<td>Conventional</td>
<td>0.04</td>
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### Conclusion
The tri-polar all ceramic hip prosthesis examined in this study showed improved wear and friction characteristics in comparison with a conventional Biolox Delta ceramic on ceramic bearing. Most importantly wear could not be detected under micro-separation conditions, and stripe wear was not observed.

### Acknowledgements
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### References

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Abrasive wear can be defined as removal of any part of material due to friction by hard particles and protuberances [8]. Depending on the hardness values of the rubbing surfaces two types of abrasive wear are defined: two and three body abrasive wear. The first type is characterized by the fact that asperities of the harder surface will plough through the softer surface. Properties (wear rate decreases with increasing hardness) and lubricant characteristics. Figure 2.10 Surface topographies of the tested samples, reproduced from [25]

Figure 2.10 shows the evolution of the surface topography from two different friction tests, conducted on a ball-on-disc tester [25] using different types of lubricants (SAE 40 and N16). The frictional force in stable period is of the same order as Saikko (2009) and can be obviously distinguished between the two tested samples. The frictional force of the x-linked UHMWPE acetabular cup is nearly 10% lower than the UHMWPE’s, which shows that the trend is in accordance with the volumetric wear, making the new friction measurement module valid for the biotribological investigation of hip prostheses. Correspondingly, friction of the implant product proves to be a key factor affecting the wear performance in joint articulation. Wear comparison between a dual mobility total hip prosthesis and a typical modular design using a hip joint simulator. Wear 268, 617–621. doi: 10.1016/j.wear.2009.10.011. CrossRef Full Text | Google Scholar. Friction-induced moments and subsequent cup loosening can be the reason for total hip joint replacement failure. The aim of this study was to measure the in vivo contact forces and friction moments during walking. Instrumented hip implants with Al2O3 ceramic head and an XPE inlay were used. In vivo measurements were taken 3 months post-operatively in 8 subjects. However, contact forces and friction moments varied greatly between individuals. The friction moment increased during the extension phase of the joint. The average coefficient of friction also increased during this period, from 0.04 (0.03 to 0.06) at contralateral toe off to 0.06 (0.04 to 0.08) at contralateral heel strike. During the flexion phase, the coefficient of friction increased further to 0.14 (0.09 to 0.23) at toe off.