The Influence of Edge Loading on the Wear of Fourth Generation Ceramic-on-Ceramic Bearing in Total Hip Replacements

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INTRODUCTION
Ceramic-on-ceramic (CoC) bearings in total hip replacements (THR) have become of great interest due to the substantial improvements in the manufacturing techniques and material properties [1]. They have substantially lower wear rates than metal or ceramic on polyethylene bearings [2] and wear particles were found to be less biologically active than particles produced by other types of bearings [3]. Clinical studies on CoC bearings couples have shown a stripe-like wear scar on the femoral head with a corresponding wear area on the acetabular cup [4]. Clinically, stripe wear has been associated with edge loading and steep inclination angle of the acetabular cup [5].

The aim of this study was to assess the wear of fourth generation alumina matrix composite bearing couples under steep cup inclination angles and microseparation (edge loading) conditions and compare their performance to earlier generation CoC bearing couples.

MATERIALS AND METHODS
The six-station Leeds Mark II Physiological Anatomical Hip Joint Simulator was used in this study. The fourth generation alumina matrix composite (AMC, BIOLOX® delta, CeramTec AG, Germany) with a bearing size of 28mm was investigated. Three liners were mounted to provide a clinical angle of 55°, and the remaining three liners were mounted to provide a clinical angle of 65°.

The test ran for a total of 5 million cycles. The first two million cycles were under standard gait conditions; flexion/extension of -15°/+30°, internal/external rotation of ±10° and a twin peak Paul load with a maximum load of 3kN and swing phase load of 0.3kN. Microseparation was introduced to the gait cycles for the subsequent three million cycles as described by Nevelos et al. [4]. Microseparation was achieved by applying a lateral movement to the cup (0.4-0.5mm) using a spring load resulting in head-rim contact at heel strike. The displacement occurred during swing phase when the load was minimal (dropped from 0.3kN to approximately 0.05kN).

The lubricant used was 25% new born calf serum. The wear volume was ascertained through gravimetric analysis using a Mettler AT201 balance (Leicester, UK), which was undertaken every million cycles. Wear stripe analysis was undertaken at every measurement point after the introduction of the microseparation condition using a contacting profilometer (Form Talysurf, Taylor Hobson, UK). Three traces were taken across the wear scar 5mm apart and the average penetration depth was determined. Statistical analysis was performed using One Way ANOVA (significance taken at p<0.05) and the 95% confidence limits were calculated.

RESULTS
Increasing the cup inclination angle from 55° to 65° had no influence on the wear rate of BIOLOX® delta CoC bearing couples under standard or microseparation conditions. The mean wear rate after two million cycles under standard gait conditions was 0.05mm/million cycles for both cup inclination angles (Figure 1). The introduction of microseparation to the gait cycle increased the wear rate of BIOLOX® delta bearing couples to 0.13mm/million cycles for cup inclination angle of 55° and to 0.11mm/million cycles for cup inclination angle of 65° (Figure 1). The wear rate of BIOLOX® delta was significantly lower (p<0.005) than that previously reported for BIOLOX® forte (1.84mm/million cycles [6]) under the same microseparation conditions (Figure 1).

A stripe-like wear area was formed on the femoral head with a corresponding wear area on the cup when microseparation was introduced to the gait cycle (Figure 2), which increased the surface roughness (Ra) from approximately 5nm to between 20 and 24nm. The mean maximum penetration depth of the wear scar was 7.8μm for the 55° cup inclination angle and 7.3μm for the 65° cup inclination angle with no significant difference (p>0.6) between the two groups.

DISCUSSION
Cup inclination angle did not influence the wear rate of BIOLOX® delta bearing couples in this study which was consistent with the results obtained for the BIOLOX® forte bearing couples in previous studies [7]. When the microseparation condition was introduced to the gait cycle, the wear rate of BIOLOX® delta bearing couples increased by approximately 2.5 fold whereas that of BIOLOX® forte increased by approximately 30 fold [6]. The wear rate of BIOLOX® delta was approximately 15 times lower than that of BIOLOX® forte under microseparation conditions.

CONCLUSION
In conclusion, microseparation (head offset deficiency) increased the wear rate of ceramic-on-ceramic bearing couples however, increasing the cup inclination angle did not increase the wear rate in this study. Finally, the fourth generation alumina matrix composite (BIOLOX® delta) has shown higher resistance to wear under severe hip simulator conditions compared to the earlier third generation HIPed alumina ceramics (BIOLOX® forte).

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REFERENCES