Wear and Deformation of Metal-on-Polyethylene Hip Replacements under Variations in Surgical Positioning

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Introduction

Preclinical testing methods are being developed to test hip joint replacements under a wide range of conditions [1,2]. Variations in component positioning can lead to dynamic separation resulting in edge loading conditions of hip joint implants [3]. For hard-on-soft bearings, edge loading may lead to abnormal wear scars, damage and cracking at the rim of the acetabular cup [4].

Aim

The aim of this study was to determine the effect of rotational and translational positioning of the cup on the magnitude of dynamic separation, wear rates and deformation of metal-on-polyethylene bearings.

Materials and Equipment

Fourteen 36mm diameter metal-on-ultra-high molecular weight polyethylene (UHMWPE Marathon™, DePuy Synthes Joint Reconstruction, Leeds, UK) hip replacements were tested on a ProSim electromechanical hip joint simulator (EM13, Simulation Solutions, Stockport, UK).

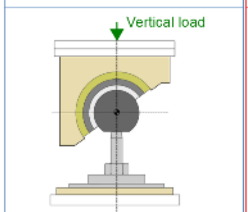
Methods

EM13 hip joint simulator test conditions

Axial load	3000N twin peak load with 300N swing phase load for standard concentric conditions, 70N swing phase load for edge loading conditions
Flexion/extension	+25°/-18°
Internal/external	+2°/-10°
Adduction/abduction	+7°/-4°
Translational positioning	4mm translational mismatch
Lubrication	25% new-born calf serum
Test duration	2 million cycles (for each test)

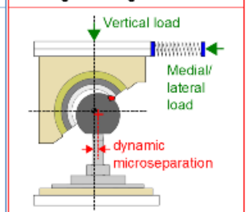
Note: Axial load and angular displacement inputs from ISO 14242 [5].

Standard concentric conditions



Test samples: cup inclination angles 45° (n=3) 65° (n=3)

Edge loading conditions

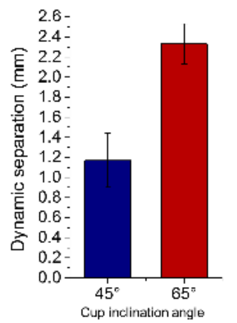


Test samples: cup inclination angles 45° (n=3) 65° (n=3)

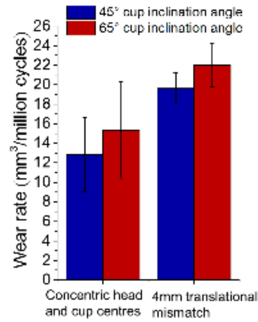
Load only samples: cup inclination angles 65° (n=2)

- The dynamic separation between the head and cup was measured using a position sensor.
- Gravimetric and geometric analysis was carried out at one and two million cycles using a coordinate measurement machine and microbalance.
- Statistical analysis: One-way ANOVA with post-hoc Tukey tests and independent samples t-tests, significance taken at $p \leq 0.05$.

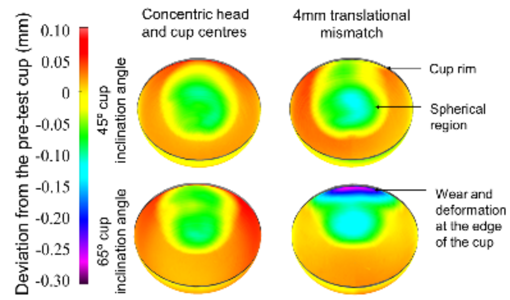
Results



Mean dynamic separation under 4mm translational mismatch (±95% confidence limits).



Mean wear rates per million cycles of polyethylene (±95% confidence limits).



Maximum penetration depth of load only sample was 0.03mm.

Wear and deformation of polyethylene liners at two million cycles. Negative values indicate penetration on the cup.

Discussion

- Increasing the inclination angle from 45° to 65° did not result in a significant increase in the wear rate of polyethylene under standard concentric conditions ($p>0.19$).
- Edge loading conditions due to translational mismatch resulted in a significant increase in wear of the polyethylene liner compared to the wear under standard concentric conditions ($p<0.01$).
- For 4mm translational mismatch input, the magnitude of dynamic separation at a 65° cup inclination angle was greater than 2mm, and was significantly larger than that under the 45° cup inclination angle condition ($p<0.01$).
- Although the wear rate of the polyethylene liners was similar at cup inclination angles of 45° to 65° for a translational mismatch of 4mm, the level of deformation at the rim increased significantly ($p=0.01$).
- Larger magnitude of creep and plastic deformation at the rim of the cup with a 65° inclination angle and translational mismatch of the centres leading to edge loading may influence fatigue life and lead to fracture at the rim [6].

Significance

Minimising the occurrence and severity of edge loading and reducing the magnitude of dynamic separation in vivo may reduce the failure rates of polyethylene. Surgical positioning is an important factor to consider for the long term clinical success of hip joint implants.

References

[1] Fisher. J., Semin Arthroplasty, 2012. [2] Jennings, L.M., Orthop Trauma, 2012. [3] J. Fisher, J Bone Joint Surg Br, vol. 93-B, 2011. [4] S. Tower et al., J Bone Joint Surg Am, vol.89, 2007. [5] ISO14242-1:2014 [6] X. Hua et al., J Biomech, vol. 47, 2014.

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