Institute of Medical & Biological Engineering

Variations in Component Positioning Leading to Dynamic Separation and Edge Loading Influences the Deformation and Wear of Metal-on-Polyethylene Hip Replacement Bearings

UNIVERSITY OF LEEDS

Murat Ali, Mazen Al-Hajjar, Louise M. Jennings, John Fisher
Institute of Medical and Biological Engineering, School of Mechanical Engineering, University of Leeds, UK
+Contact email: m.al-hajjar@leeds.ac.uk

Introduction

There are many factors that can affect the wear and deformation of polyethylene in the hip prosthesis. Edge loading and contact may occur due to a translational mismatch between the head and cup bearing centres and/or steep cup inclination angles [1, 2] (Fig. 1). This may lead to an increase in deformation, damage, cracking and wear, at the rim of the cup [3].

Rotational surgical position | Translational surgical position

Figure 1. Variations in component positioning.

Aim

The aim of this study was to assess the occurrence and severity of edge loading of metal-on-polyethylene bearings, then to assess the wear and deformation of polyethylene at different medial-lateral translational and rotational positions.

Materials and Equipment

Metal-on-moderately crosslinked polyethylene (UHMWPE, Marathon™, DePuy Synthes Joint Reconstruction, Leeds, UK) hip replacements were set up on the ProSim electromechanical hip joint simulator (Fig. 2, EM13, Simulation Solutions, Stockport, UK).

Figure 2. ProSim EM13.

Methods

- Biomechanical tests (stage one) were carried out at 45° and 65° cup inclination angles with 1, 2, 3 and 4 (mm) medial-lateral translational mismatch between the centres of the head and cup (n=3 under each condition, Fig. 3).
- For the wear study (stage two), different conditions were considered, conditions with 0, 2 and 4 (mm) translational mismatch for three million cycles for cups inclined at 45° (n = 6) and 65° (n = 6).
- For all tests, a gait cycle consisting of a twin peak input load of 3 kN and swing phase load of 70 N was applied along with three axes of rotation conditions.
- Gravimetric analysis was carried out at one, two, three and five million cycle intervals using a microbalance (Mettler Toledo XP205, Greifensee, Switzerland). Statistical analysis was carried out using ANOVA and post-hoc tests with significance levels taken at $p < 0.05$.

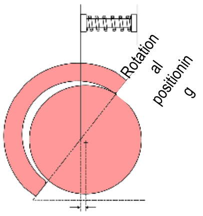


Figure 3. Rotational and translational positioning of the cup.

Results

- The largest level of dynamic separation occurred at 4 mm mismatch & 65° cup inclination angles ($p < 0.01$, Fig. 4).
- The wear rate increased as the level of translational mismatch increased. There was no significant difference in the wear rates for the same level of translational mismatch at 45° and 65° cup inclination angles (p=0.14, Fig. 5).
- The maximum mean penetration depth at the edge of the cup at 2mm translational mismatch was 0.03 ± 0.01 mm at 45° and 0.22 ± 0.02 mm at 65° cup inclination angles ($p < 0.01$). At 4 mm translational mismatch the maximum mean penetration depth at the edge of the cup was 0.10 ± 0.05 mm at 45° and 0.28 ± 0.04 mm at 65° cup inclination angles ($p < 0.01$, Fig. 6).

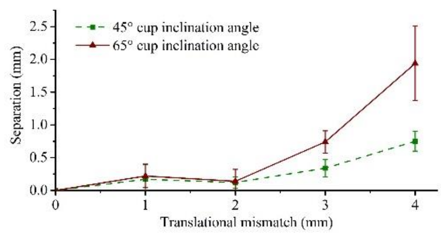


Figure 4. Dynamic medial-lateral separation (mean ± 95% confidence limits) of metal-on-polyethylene bearings at different levels of translational mismatch at 45° (n=3) and 65° (n=3) cup inclination angles.

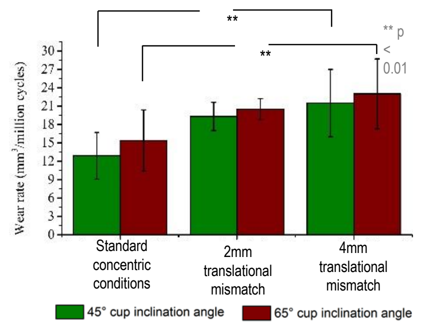
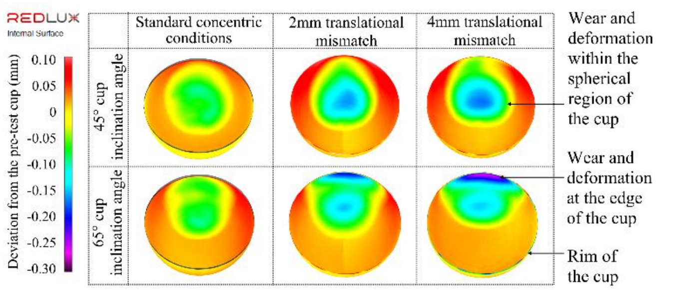


Figure 5. Wear of polyethylene (mean ± 95% confidence limits) for concentric, 2 mm and 4 mm translational mismatch at 45° (n=6) and 65° (n=6) cup inclination angles.

Figure 6. Combined wear and deformation of polyethylene liners at 45° and 65° cup inclination angles with 0, 2mm and 4mm translational mismatch conditions at three million cycles of testing. Negatives values indicate penetration on the cup.



Discussion

A two stage method was used to firstly assess the effects of component positioning on the occurrence of edge loading, then to determine the wear and deformation of polyethylene liners.

- 4mm translational mismatch between the head and the cup resulted in approximately twofold increase in wear at highest inclination angle.
- 4mm translational mismatch between the head and the cup resulted in substantial deformation of the cup rim for both inclination angles, with three fold more deformation with 65° compared to 45° cup inclination angles.

Significance

Rotational and translational positioning of the acetabular cup are important factors in the long term clinical success of hip joint implants. Good component positioning which will reduce the magnitude of dynamic separation and reduce the occurrence and severity of edge loading in vivo may reduce the potential for deformation, fatigue damage and failure of polyethylene.

References
[1]Fisher, JBJS, 2011. [2] Hua et al., J. Biomechanics, vol. 47, pp. 3303-3309, 2014. [3] S. S. Tower et al., J Bone Joint Surg Am, vol.89, 2007.

Acknowledgements
This study was funded by Innovation and Knowledge Centre in Medical Technologies which is funded by the EPSRC, TSB and BBSRC. It was partially funded through WELMEC, a Centre of Excellence in Medical Engineering funded by the Wellcome Trust and EPSRC, under grant number WT 088908/Z/09/Z. The simulator was manufactured by Simulation Solutions.

Financial Disclosure
J. Fisher is an NIHR Senior Investigator and his research is supported through the NIHR Leeds Musculoskeletal Biomedical Research Unit. DePuy Synthes, a Johnson & Johnson company, supplied the components. John Fisher is a paid consultant to DePuy Synthes.