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Bills, Paul J., Racasan, Radu, Hart, A.J., Skinner, J., Jiang, Xiang and Blunt, Liam

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Using metrology to bridge the gap in understanding between engineering and biological failure: the case of metal-on-metal hip replacements.

P Bills¹, R Racasan¹, A Hart², J Skinner³, X. Jiang¹, L Blunt¹
¹EPSRC Centre for Innovative Manufacturing in Advanced Metrology, University of Huddersfield, UK; ²London Implant Retrieval Centre, Institute of Orthopaedics and Musculoskeletal Science, University College London, UK; ³Royal National Orthopaedic Hospital, Breastley Hill, Stanmore, UK.

Background

- Worldwide interest in failure of Metal-on-Metal (MoM) hips.
- >150,000 large diameter MoM hips implanted in UK.
- Failure rate of 29% reported in some Large Head MoM at 6 years [1].
- Three designs of MoM hips have been removed from the market in past 4 years
- NJR data suggests 43% of hip failures are unexplained
- Edge loaded cups have greater linear wear rate than non-edge loaded
- Disparity between wear of LHMoM & observed blood ion levels could be due to taper wear/corrosion

Measurement Requirements

- Wear analysis is vital tool in understanding failure mechanisms
- Full material loss determination at both the bearing and taper interface.
- Typical linear wear rates for explanted hips are:
  - Cup: 0 – 180 μm/year
  - Head: 0 – 750 μm/year
- Accuracy required ~ 1 μm.

- Volumetric accuracy not quoted or incorrectly determined.
- Determination of volumetric and linear wear based without a priori knowledge of unworn geometry key factor in accuracy of measurement method and is stable only if done post process.
- Small wear volumes and linear wear depths mean that measurement uncertainty must be understood and controlled.

\[ U = k \times \sqrt{(u_{\text{ab}}^2 + u_{\text{bc}}^2 + u_{\text{cc}}^2)} + |b| + |c| \]  

[2]

Equipment setup:
- Zeiss PRISMO CMM with an MPE = 1.9μm + L/300
- Stylist: 2mm ruby ball
- Measurement speed: 3mm/s

Strategy:
- The bearing surface is digitised using 400 polar scan lines. Angular spacing between traces is 0.9° with linear point pitch of 0.1mm
- Total number of data points per scan is 150,000-300,000.

Data analysis:
- Iterative intelligent least squares fitting is employed to determine the unworn geometry, linear wear, volumetric wear and material loss distribution.

Wear measurement results

- Over 100 retrieved component pairs were analyzed
  - Mean material loss at the bearing surface (pair): 21.2mm³ (0.6 – 30.9 mm³)
  - Edge wear found in majority of cups.
  - Mean material loss at the taper interface (head taper): 2.4mm³ (0.1 – 25.2 mm³)
  - Area of highest wear observed at distal end of taper.

Case study

- Revised at 56 months due to severe tissue reaction
  - All trochanteric muscle destroyed
  - Relatively low wear rate of bearing surface and low taper wear
  - Suggests patient susceptibility to CoCr

Conclusions

- Interactive user selection of the unworn surface is critical in minimizing analysis uncertainty in bearing analysis.
- Roundness machine ideal for taper measurement due to high resolution and low observed wear volumes.
- Maximum linear taper wear at distal end consistent with taper size mismatch.
- Female head taper surface exhibits imprint of the male taper surface.
- What is a clinically relevant level of wear? – Observations suggest any level of wear could trigger failure.

References


http://www.hud.ac.uk/cimam/
paul.bills@hud.ac.uk