**In-vitro wear simulation of different materials for total hip replacement under stop-dwell-start (SDS) conditions**


**Introduction**
Total hip arthroplasty (THA), is a widely used solution to help restore hip function following arthritic disease. In vitro wear simulation is an important aspect of the development of joint replacements to better understand devices and more accurately predict performance in vivo.

**Hip wear simulation: the status quo**
- Kinematics and loads characteristic of normal walking applied to the joint for up to 10 million cycles (mc)
- Components are periodically examined to evaluate the degree of wear and change in geometry
- Highly accurate method for comparing different types of implants and predicting their performance once in a patient
- Does not account for the varying walking patterns of patients throughout a typical day

**The hip patient**
- An average THA patient typically walks in bursts of around 10 steps before pausing or changing to another activity such as stair climbing or sitting
- When pausing during walking, the most frequent duration of a pause was shown to be 2.5s

**New wear simulation techniques: Stop-dwell-start**
- Introduction of a periodic pause during walking simulation
- Shown to cause significant increases in MOM (metal-on-metal) wear when a high dwell walking ratio was employed

**Hypothesis**
- Ceramic-on-ceramic (COC), metal-on-polyethylene (MOP) and ceramic on polyethylene (COP) THA bearing materials will exhibit similar characteristics to MOM: an increase in wear under the demanding stop-dwell-start (SDS) conditions

**Methods**

**Test Specimens** 36mm diameter femoral heads and inserts used with Pinnacle® acetabular shells (DePuy Synthes, Leeds, UK)
- MOM (n=10) (wrought CoCrMo/ wrought CoCrMo (ASTM F1537))
- COC (n=5) (Ceramax™ Biolox® Delta / Ceramax™ Biolox® Delta)
- MOP (n=5) (wrought CoCrMo (ASTM F1537) / Marathon™ Cross-Linked Polyethylene)
- COP (n=5) (Ceramax™ Biolox® Delta / Marathon™ Cross-Linked Polyethylene)

**Simulator** 10 station ProSim Deep Flexion Hip Wear Simulator (Simulation Solutions, UK) (Fig. 1,2)

**Lubricant** Newborn bovine serum 25% (v/v) (SeraLabs, UK), equivalent to a minimum of 17g/L of protein. Serum was changed every 0.5 million cycles (mc) throughout the test. Sodium azide (0.1% w/v) and EDTA (0.02% w/v) were added to the serum.

**Kinematics** Based on ISO 14242
- Flexion / extension +30° / -15°
- Internal / external rotation ±10°

**Loading** Twin peak ‘Paul’ type waveform
- Peak load 3KN
- Swing phase load 300N
- Dwell phase load 1250N

**Walking Simulation** The kinematic and load inputs were applied continuously at a frequency of 1Hz. Samples were gravimetrically analysed every 0.5 million cycles (mc) and the tests were run for a total of 2mc (Fig. 3)

**Stop-dwell-start (SDS) simulation**
- The load and motion cycle described above was applied once followed by a ten second dwell period This was repeated continuously for a total of 0.5mc, with gravimetric analysis every 50,000 cycles (Fig. 3)

**Results & Discussion**

**Volumetric wear rates calculated over 2mc for the samples in the walking test, and over 0.5mc for the samples in the SDS tests**
- Significant increases in absolute mean wear rate were observed for all material types under SDS conditions when compared with the continuous walking condition (Table 1, Fig. 4,5)
- Relative increase in wear rate from walking to SDS simulation significantly higher for MOM and COC bearings than for MOP and COP (Table 1, Fig. 5)

**Effect of SDS wear simulation**
- Results support the hypothesis: MOP, COP and COC bearings demonstrate a significant increase in wear rate under in vitro SDS simulation compared with normal walking, as demonstrated previously on MOM devices
- Lubrication film deteriorates during dwell; two to three cycles of walking are needed to restore lubrication after the dwell
- If a repeated single step occurs, the lubricant film is never fully restored to a continuous walking condition, therefore overall wear increases

**Effect of material type**
- Greater absolute wear observed on hard-on-hard (MOP & COP) bearings
- Greater relative increase in wear from walking to SDS simulation observed on hard-on-hard (MOM & COC) bearings
- Different lubrication regimes exist in the different materials: MOM operates in the mixed regime, COC in the fluid end of mixed lubrication and MOP and COP in the mixed / boundary regime.
- As Lambda ratio (λ) increases, and lubrication tends from a boundary, through mixed to a fluid film regime:
  - Wear reduces, BUT
  - Susceptibility to SDS increases (Fig. 6)

**Clinical significance**
Hip wear simulation is a proven technique for the pre-clinical evaluation of devices, however existing standards for testing only simulate continuous walking and do not account for the varying activities of typical patients.

The simulator inputs used in this SDS study, where the ‘patient’ takes a single step before pausing, are a worst case scenario for this type of wear simulation, however this could be representative of an elderly or very infirm patient, or one in the early stages of recovery.

**References**

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