Reduction in wear using magnesia-stabilized zirconia femoral heads in a hip simulator

Introduction: Recent clinical series reported no reduction in acetabular liner wear using metastable yttria-stabilized zirconia (Y-TZP) femoral heads instead of cobalt-chromium alloy (CoCr) heads [1-5]. The purpose of this study was to compare the wear performance of CoCr and magnesia-stabilized zirconia (Mg-PSZ) femoral heads, a more stable form of zirconia [6,7], and to evaluate whether a hard diamond-like carbon (DLC) coating reduced wear compared to Mg-PSZ.

Materials and Methods: Eight 28 mm diameter femoral heads were used in this study: two wrought CoCr alloy (ASTM F799, F1537), three Mg-PSZ (ASTM F2393), and three Mg-PSZ heads with a proprietary DLC coating (an amorphous hydroxynitrogenated coating with 20-30% sp3 bonding, according to the coating vendor). The DLC coating was about 3 µm thick [8] with a nanohardness of 23 GPa [9]. Mg-PSZ and DLC-Mg-PSZ heads exhibited comparable roughness with hydrophilic surfaces (and a small but significant reduction in contact angle after DLC coating), while CoCr heads had a significantly rougher and more hydrophobic surface that was dominated by carbide inclusions [10]. Eleven UHMWPE acetabular liners (eight test specimens and three soak controls) were machined from GUR 1050 bar stock that had been cross-linked to 100 kGy and re-melted. The liners were pre-soaked at room temperature until weight gain ceased. Specimens were tested in a MATCO hip wear simulator, an inverted design, using a Paul curve [11] at 1.2 Hz with peak loads of 2.3-2.4 kN (up to 3M cycles) and 2.4-2.5 kN thereafter (up to 11M cycles). A solution of 25% bovine serum with 20 mM EDTA and 0.3% NaN3 was used as a lubricant, and a peristaltic pump dripped distilled water into each station to replace evaporated water during the tests. After each stage of 375,000 cycles (up to 3M) and 500,000 cycles thereafter, XLPE wear was measured gravimetrically and corrected to the soak controls. Regression curves were calculated from the wear data and compared with p < 0.05 for significance.

Results: During the wear tests, all liners initially gained weight relative to the soak controls, possibly due to protein adsorption. Liners bearing against CoCr heads began to lose weight after 1.125M cycles, while liners interacting with Mg-PSZ and DLC-Mg-PSZ heads began to lose weight after 3.5M cycles but overall exhibited a net mass gain up to 8.5M cycles (Figure 1). After 1.1M total wear cycles, the original machining marks were completely obliterated (Figure 2). Regression analyses revealed that a second-order polynomial provided the best overall fit (p < 0.0001) for liners bearing against CoCr heads, while linear regression was better for the Mg-PSZ and DLC-MG-PSZ data (p < 0.0001; Figure 1, Table 1A). Comparing data from the last 2M cycles only (Table 1B) revealed CoCr femoral heads to induce a steady-state wear rate seven times higher than Mg-PSZ femoral heads (p = 0.0161), while DLC-coated Mg-PSZ femoral heads exhibited a higher wear rate compared to uncoated Mg-PSZ (p = 0.0647, power = 0.75).

Discussion: The current study found a significant reduction in wear using Mg-PSZ rather than CoCr femoral heads. Unlike Y-TZP, Mg-PSZ femoral heads have been previously shown to be stable in vivo, maintaining their low surface roughness [6,7]. The lower surface roughness and greater hydrophilicity of Mg-PSZ [10] likely enhanced lubrication and reduced wear relative to liners bearing against CoCr femoral heads, which exhibited consistent XLPE mass loss similar to previously reported hip simulator data up to 5M cycles [12]. The rapid increase in wear of the XLPE liners bearing against CoCr after about 8M cycles may be due to increased macroscopic roughness of the head, such as a raised edge that was gradually worn down with subsequent wear [13-15]. A similar increase in wear was not observed for Mg-PSZ or DLC-Mg-PSZ femoral heads.

No reduction of wear was achieved by DLC-coating Mg-PSZ femoral heads despite a modest but significant increase in wettability from the DLC coating [10]. Given the excellent abrasive wear resistance of DLC-coated Mg-PSZ [8] and the difficulty in removing 100% of all debris after alumina component fracture [16], the use of DLC-Mg-PSZ may be indicated at revision of such cases. However, the added cost of DLC coating is not justified by its wear performance.

In summary, the steady-state wear rate of cross-linked UHMWPE liners articulating against Mg-PSZ heads was significantly lower than that of CoCr heads, probably due to the lower roughness and greater wettability of Mg-PSZ. The use of Mg-PSZ femoral heads should lead to reduced wear in vivo compared to CoCr heads, but the clinical benefit of DLC-coated Mg-PSZ heads is unclear.

**Reduced Wear Using Magnesia-Stabilized Zirconia Femoral Heads in a Hip Simulator**

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**INTRODUCTION**

- Recent clinical series reported no reduction in acetabular liner wear using metastable yttria-stabilized zirconia (Y-TZP) femoral heads instead of cobalt chromium alloy (CoCr) heads
- Purpose:
  - to compare the wear performance of CoCr and magnesia-stabilized zirconia (Mg-PSZ) femoral heads, a more stable form of zirconia
  - to evaluate whether a hard diamond-like carbon (DLC) coating reduced wear compared to Mg-PSZ

**MATERIALS AND METHODS**

- Eight 28 mm diameter femoral heads were used:
  - two wrought CoCr alloy (ASTM F799, F1537)
  - three Mg-PSZ (ASTM F2393)
  - three Mg-PSZ heads with an amorphous hydrogenated DLC coating about 3 µm thick

**Materials and Methods**

- A. CoCr alloy:
  - Roughness Sa = 24.8 ± 5.2 nm
  - Contact angle = 93.0° ± 1.0°

- B. Mg-PSZ:
  - Roughness Sa = 8.49 ± 0.95 nm
  - Contact angle = 78.6° ± 3.2°

- C. DLC-coated Mg-PSZ:
  - Roughness Sa = 8.20 ± 0.39 nm
  - Contact angle = 70.5° ± 1.4°

**Results**

- During the wear tests, all liners initially gained weight relative to the soak controls, possibly due to protein adsorption
- Liners bearing against CoCr heads began to lose weight after 1.125M cycles, whereas liners interacting with Mg-PSZ and DLC-Mg-PSZ heads began to lose weight after 3.5M cycles but overall exhibited a net mass gain up to 8.5M cycles
- Regression analyses revealed that a second-order polynomial provided the best overall fit (p < 0.0001) for liners bearing against CoCr heads, while linear regression was better for the Mg-PSZ and DLC-Mg-PSZ data (p < 0.0001; Figure 2, Table 1A)
- Comparing data from the last 2M cycles only (Table 1B), CoCr femoral heads induced a steady-state wear rate seven times higher than Mg-PSZ femoral heads (p = 0.0161), while DLC-coated Mg-PSZ femoral heads exhibited a higher wear rate compared with uncoated Mg-PSZ

**Discussion**

- The current study found a significant reduction in wear using Mg-PSZ rather than CoCr femoral heads.
- Unlike Y-TZP, Mg-PSZ femoral heads have been previously shown to be stable in vivo, maintaining their low surface roughness
- The lower surface roughness and greater hydrophilicity of Mg-PSZ likely enhanced lubrication and reduced wear relative to liners bearing against CoCr femoral heads
- The rapid increase in wear of the XLPE liners bearing against CoCr after about 8M cycles may be due to increased macroscopic roughness of the head

**Conclusions**

- The steady-state wear rate of cross-linked UHMWPE liners articulating against Mg-PSZ heads was significantly lower than that of CoCr heads, probably due to the lower roughness and greater wettability of Mg-PSZ
- A similar increase in wear was not observed for Mg-PSZ or DLC-Mg-PSZ femoral heads
- No reduction of wear was achieved by DLC-coating Mg-PSZ femoral heads
- Given the excellent abrasive wear resistance of DLC-coated Mg-PSZ, its use may be indicated at revision after alumina component fracture
- However, the added cost of DLC coating is not justified by its wear performance in the current study