Introduction: Scratching of articulating surfaces in total joint arthroplasty is an important cause of accelerated wear [1-3] due to the presence of "pile-up" (raised edges) along the sides of a scratch [4-5]. Ceramic materials such as magnesia-stabilized zirconia (Mg-PSZ) offer much higher scratch resistance than metals such as CoCr alloy [6], but even ceramics can be scratched *in vivo* [7], while scratches in CoCr tend to be polished out by normal articulation [1,8]. The purpose of this study was to determine the increase in XLPE wear due to damaged Mg-PSZ heads in a hip wear simulator. We hypothesized that a raised edge on a damaged ceramic head would not get worn down over time. In addition, we expected damaged Mg-PSZ heads to cause more liner wear than undamaged ceramic heads, comparable to undamaged CoCr heads.

Materials and Methods: Six 28 mm diameter Mg-PSZ (ASTM F2393) femoral heads were used in this study. The heads were commercial samples (Signal Medical Corp.) with no surface anomalies except the phrase "DO NOT IMPLANT" laser etched in a circle at an angle of 30º from the pole. Baseline roughness (average roughness, Sa) of the pole region of each femoral head and the height of the raised edge caused by the laser etching was measured by optical profilometry at 10X magnification (Fogale ZoomSurf 3D; Figure 1). Nine UHMWPE acetabular cups (six test specimens and three soak controls) were machined from GUR 1050 bar stock that had been cross-linked to 10 Mrad and re-melted. The cups 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 [9] at 1.2 Hz with peak loads of 2.4 kN. A solution of 25% bovine serum with 20 mM EDTA and 0.3% sodium azide was used as a lubricant, and a peristaltic pump dripped distilled water into each station to replace evaporated water during the tests. Each test began after 500,000 cycles, XLPE wear was measured gravimetrically and corrected to the soak controls. Damaged Mg-PSZ wear data were compared to previous wear data from undamaged CoCr and Mg-PSZ femoral heads [8], which were generated using the same hip wear simulator and test conditions (and used acetabular liners from the same lot), with p < 0.05 for significance.

Results: Pre-test roughness measurements revealed the specimen had a "baseline" roughness of Sa = 12.7 nm, which increased to over 1 µm in laser-etched areas. Each laser-etched line was about 250 µm wide × 4 µm deep, with a raised edge about 1 µm tall along each side (Figure 1). During the wear tests, all liners initially gained weight relative to their soak controls, and test liners became qualitatively scratched compared to soak controls (Figure 2). The steady-state wear rate for liners bearing against Mg-PSZ and damaged Mg-PSZ was similar (p = 0.09), while a 2nd-order polynomial best described the wear of liners bearing against undamaged CoCr heads (Figure 3). At 8M cycles, liners bearing against undamaged Mg-PSZ head exhibited no net wear, while liners bearing against damaged Mg-PSZ heads exhibited 71% less wear than liners bearing against undamaged CoCr heads (p = 0.04). Small scratches in the damaged heads were observed, but the raised edge did not appear to wear or break down after 8M cycles, and the "baseline" roughness of the damaged Mg-PSZ heads did not significantly increase (p > 0.72).

Discussion: This study found that an artificially damaged Mg-PSZ ceramic femoral head causes significantly higher XLPE wear than that of an undamaged ceramic head, but wears at a lower rate compared to undamaged CoCr alloy femoral heads. Unlike CoCr alloy bearing surfaces [1,8], the raised edge on the damaged ceramic heads was not gradually polished smooth during the test, but accelerated wear was not observed through 8M cycles. In pin-on-disc tests, 1 µm of pile-up along a scratched stainless steel pin was found to increase the wear rate of non-cross-linked UHMWPE by a factor of 70 after the equivalent of 10 years of wear [5], while hip wear simulator studies found severely roughened CoCr heads to increase wear by an order of magnitude against liners cross-linked to 5 Mrad [10]. While ceramic femoral heads are less likely to be damaged in vivo than metal heads, they should be noted in cases where a fractured alumina component is revised [11-13] or when multiple closed reductions have been performed following recurrent dislocation, leading to metal transfer on ceramic heads [14].

In summary, Mg-PSZ ceramic femoral heads damaged to create a 1 µm tall raised edge led to lower XLPE wear compared with undamaged CoCr alloy femoral heads. Unlike CoCr femoral heads, the use of damaged ceramic heads did not lead to accelerated XLPE liner wear through 8M cycles, even though the raised edge was not polished away.

**Figure 1.** Surface plot (500 µm × 250 µm) and profile from optical profilometry scan of laser-etched "scratch" in a ceramic femoral head.

**Figure 2.** Typical XLPE liners: A. Soak control with machining marks; B. Liner after 8M cycles against a damaged Mg-PSZ femoral head.

**Figure 3.** Plot of XLPE liner wear (mg) as a function of the number of wear cycles. Through 8M cycles, both damaged and undamaged Mg-PSZ heads exhibited linear wear rates, while the undamaged CoCr regression curve was best described with a 2nd-order polynomial.

**References:**
INTRODUCTION

- Scratching of articular surfaces in total joint arthroplasty is an important cause of accelerated wear due to the presence of raised edges along the sides of a scratch
- Purpose: to determine the increase in cross-linked polyethylene (XLPE) wear due to damaged magnesia-stabilized zirconia (Mg-PSZ) heads in a hip wear simulator

MATERIALS AND METHODS

- Six 28 mm diameter Mg-PSZ (ASTM F2393) commercial sample femoral heads, with the phrase “DO NOT IMPLANT” laser etched in a circle at the pole, were used
- Baseline roughness (average roughness, Sa) of the pole region of each femoral head and the height of the raised edge caused by the laser etching was measured by optical profilometry at 10× magnification
- Nine UHMWPE acetabular cups (six test specimens and three soak controls) were machined from GUR 1050 bar stock that had been cross-linked to 10 Mrad and re-melted, and pre-soaked until weight gain ceased
- Specimens were tested in a hip wear simulator using a Paul profilometry at 10× magnification
- Specimens were tested in a hip wear simulator using a Paul
- After each stage of 500,000 cycles, XLPE wear was measured gravimetrically and corrected to the soak controls, and pre-soaked until weight gain ceased
- Damaged Mg-PSZ wear data compared to previous wear data from undamaged CoCr and Mg-PSZ femoral heads, with p < 0.05 for significance

RESULTS

- Damaged Mg-PSZ heads cause more liner wear than undamaged ceramic heads, comparable to undamaged CoCr alloy femoral heads
- Undamaged CoCr alloy heads led to an accelerated rate of wear at 8M cycles, possibly due to XLPE degradation (lipid absorption), an increasingly loose fit from normal wear, and/or degradation/corrosion of the CoCr surface
- While ceramic femoral heads are less likely to be damaged in vivo, care should be taken when a fractured alumina component is revised or after recurrent dislocation

DISCUSSION

- This study found that an artificially damaged Mg-PSZ ceramic femoral head causes significantly higher XLPE wear than an undamaged ceramic head, but wears at a lower rate compared with undamaged CoCr heads
- Damaged Mg-PSZ heads produced more wear than undamaged heads but had similar steady-state wear rates, with no signs of accelerated wear

CONCLUSIONS

- Undamaged CoCr alloy heads led to an accelerated rate of wear at 8M cycles, possibly due to XLPE degradation (lipid absorption), an increasingly loose fit from normal wear, and/or degradation/corrosion of the CoCr surface
- While ceramic femoral heads are less likely to be damaged in vivo, care should be taken when a fractured alumina component is revised or after recurrent dislocation

- Mg-PSZ ceramic femoral heads damaged to create a 1 μm tall raised edge led to lower XLPE wear compared with undamaged CoCr alloy femoral heads

- Unlike CoCr femoral heads, damaged ceramic heads did not lead to accelerated wear after 8M cycles, even though the raised edge was not polished away

Figure 1. Surface plot (500 μm × 250 μm) and profile from an optical profilometry scan of laser-etched “scratch” in a ceramic femoral head. Magnification: 10x

Figure 2. Photographs of typical XLPE liner surfaces: A. Soak control with machining marks. Liners after 8M cycles of wear against B. CoCr alloy, C. Mg-PSZ, and D. damaged Mg-PSZ heads. Magnification: 300x

Figure 3. Contrast map of a laser etching in a Mg-PSZ specimen at A. 3M and B. 8M cycles. Magnification: 300x

Figure 4. Plot of XLPE liner wear as a function of the number of wear cycles for CoCr, Mg-PSZ, and damaged Mg-PSZ heads, each with its best fit regression line.

Table 1. A. Wear data; B. Curve fitting parameters

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