Reduced Wear Using Magnesia-Stabilized Zirconia Femoral Components after 9M Cycles in a Knee Simulator

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Introduction
Magnesia stabilized zirconia (Mg-PSZ, ASTM F2393) has long been used as a bearing surface in the hip [1,2], but ceramic materials have rarely been used in TKA. Mg-PSZ has been shown to exhibit superior wear characteristics compared to those made of CoCr alloy, and would also be suitable for patients with metal sensitivity [4]. The purpose of this study was to compare the wear performance of Mg-PSZ and CoCr femoral components bearing against conventional UHMWPE. We hypothesized that the use of ceramic femoral components would result in lower wear.

Materials and Methods
Stock CoCr (ASTM F75) and custom Mg-PSZ femoral components, and tibial inserts made of non-cross-linked UHMWPE (GUR 1020; Symmetric Total Knee, Signal Medical Corp.), were donated for testing in a knee wear simulator (AMTI). The articular surface of the tibial inserts was stock, while the backside of the inserts was modified with a dovetail allowing them to be locked for testing but easily removed to measure gravimetric wear. All components were sterilized by EtO gas.

One side of the simulator (three wear and two load/soak stations) tested Mg-PSZ femoral components, while the other side used CoCr femoral components. Optical profilometry was used to measure the roughness and polarity of the femoral components [2,5]. Wear tests were performed at a frequency of 1 Hz (ISO 14243-3). A solution of 25% bovine serum with 20 mM EDTA and 0.3% NaCl was used as a lubricant. The test was paused periodically to measure gravimetric wear of the dovetailed inserts, corrected by the fluid absorption of the load/soaks stations, up to a total of 9M wear cycles.

Results
Pre-test roughness measurements revealed that the CoCr and Mg-PSZ femoral components to have similar average (Sa), RMS (Sq), and peak (Sp) roughness values, but different valley roughness (Sv) and completely opposite polarities (Ssk and surface polarity ratio; Table 1). The topography of CoCr components was characterized by positive features (mainly carbides) while that of Mg-PSZ was characterized by negative features.

In wear tests, the tibial inserts initially gained mass due to protein adsorption, which appeared to plateau after 1.5M cycles. Thereafter, the liners steadily lost mass (Figure 1). After 9M cycles, inserts bearing against CoCr femoral components had lost an average of 4.1g, while those bearing against Mg-PSZ femoral components had lost an average of 0.8g. Plotting the wear data (Figure 1), the steady-state wear rate for inserts bearing against CoCr femoral components was significantly higher (p < 0.0005) than that of the inserts bearing against Mg-PSZ, by a factor of 3.8. After 9M cycles, the topography of CoCr femoral components was characterized by deep scratches, with non-trivial amounts of metal lost, while the topography of Mg-PSZ femoral components did not change (Figure 2).

Discussion
Although the basic roughness parameters of the CoCr and Mg-PSZ ceramic femoral components were similar, their surfaces were markedly different. Positive features such as raised edges lead to a positive surface polarity, and have been reported to adversely affect wear rates in the lab [6,7]. In contrast, the surface polarity of the Mg-PSZ femoral components was strongly negative, which would tend to entrap lubricant for better wear characteristics [8]. After 9M wear cycles of a simulator test, the use of Mg-PSZ femoral components resulted in a significant decrease in the wear rate of conventional UHMWPE compared to CoCr femoral components. Previous studies featuring all-ceramic femoral components have reported mixed results. Knee simulator studies comparing Y-TZP and CoCr femoral components bearing against cross-linked UHMWPE reported less wear using Y-TZP femoral components [9,10]. Other simulator studies using non-crosslinked inserts likewise revealed inserts bearing against Y-TZP or alumina femoral components had lower wear compared to those bearing against CoCr femoral components [11].

However, clinical studies revealed no clear advantage in using alumina instead of CoCr femoral components [11,12]. While the clinical benefits of using Mg-PSZ as a bearing surface in TKA remain to be seen, the loss of metal from scratches in CoCr femoral components may lead to a clinically significant reaction.

Significance
This abstract describes the first knee wear simulator test using Mg-PSZ femoral components, which may result in less UHMWPE wear compared to CoCr femoral components and thus would be more suitable for younger/more active patients. The use of Mg-PSZ femoral components may also be useful for patients with metal sensitivity.

Table 1. Pre-test roughness and surface polarity measurements from CoCr and Mg-PSZ femoral components (8 scans each, n = 3 per group), compared by a t-test.

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Roughness Parameters (nm)</th>
<th>Surface Polarity</th>
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<tbody>
<tr>
<td></td>
<td>Sa</td>
<td>Sq</td>
</tr>
<tr>
<td>CoCr</td>
<td>22.8</td>
<td>30.7</td>
</tr>
<tr>
<td>Mg-PSZ</td>
<td>17.7</td>
<td>26.9</td>
</tr>
<tr>
<td>p-value</td>
<td>0.13</td>
<td>0.45</td>
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Figure 1. Gravimetric wear (corrected to load/soaks) of tibial inserts bearing against CoCr (○) and Mg-PSZ (×) femoral components. Steady state wear rates are indicated by linear regression.

Figure 2. Typical surface topography of A. CoCr and B. Mg-PSZ femoral components after 9M cycles. Each image is about 398 μm x 346 μm. Magnification = 10x.

References
2. Sebastian et al., Trans ORS 1288; 2011.
3. Roy et al., CORR 469:2337; 2011.
5. Roy et al., Trans Soc Biomater 698; 2009.
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INTRODUCTION

• Magnesia stabilized zirconia (Mg-PSZ, ASTM F2393) has long been used as a bearing surface in the hip, with lower UHMWPE wear compared to CoCr alloy in hip simulator tests, but all-ceramic materials have rarely been used in TKA.
• Purpose: to compare the wear performance of Mg-PSZ and CoCr femoral components bearing against conventional UHMWPE.

Table 1. Pre-test roughness and surface polarity measurements from CoCr and Mg-PSZ femoral components (8 scans each, n = 3 per group), compared by a t-test.

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• Pre-test roughness measurements revealed the CoCr and Mg-PSZ femoral components to have similar average (Sa), RMS (Sq), and peak (Sp) roughness values, but different valley roughness (Sv) and opposite polarities (Ssk and surface polarity ratio).

RESULTS

Figure 1. Typical surface topography of A. CoCr and B. Mg-PSZ femoral components. Each image is about 427µm x 320µm. Magnification = 10x.

• The topography of CoCr components was characterized by positive features (mainly carbides) while that of Mg-PSZ was characterized by negative features.

Figure 2. Gravimetric wear (corrected to load/soaks) of tibial inserts bearing against CoCr (o) and Mg-PSZ (x) femoral components. Steady state wear rates are indicated by linear regression.

• Tibial inserts initially gained mass due to protein adsorption, then steadily lost mass.
• After 9M wear cycles:
  - Inserts bearing against CoCr femoral components had lost an average of 4.1g.
  - Inserts bearing against Mg-PSZ femoral components had lost an average of 0.8g.
• The steady-state wear rate for inserts bearing against CoCr femoral components (0.60 mg/Mc) was significantly higher (p < 0.0005) than that of the inserts bearing against Mg-PSZ (0.16 mg/Mc), by a factor of 3.8.

Figure 3. Contrast maps showing surface topography of A. CoCr and B. Mg-PSZ femoral components. Each image is about 398 µm x 298 µm. Magnification = 10x.

• After 9M cycles, the topography of CoCr femoral components was characterized by deep scratches, with non-trivial amounts of metal lost.
• The topography of Mg-PSZ components did not change.

Figure 4. Typical CoCr scratch dimensions illustrated as surface plots (633 µm x 475 µm, vertical axis amplified 10%) and as profiles perpendicular to the scratch direction (with the same vertical scale). Magnification = 10x.

DISCUSSION

• Despite similar roughness values, CoCr and Mg-PSZ femoral components had markedly different surfaces.
  - Positive features such as raised edges lead to a positive surface polarity, and have been reported to adversely affect wear rates in the lab.
  - In contrast, the surface polarity of the Mg-PSZ femoral components was strongly negative, which would tend to entrap lubricant for better wear characteristics.
  - Mg-PSZ also has been shown to be hydrophilic compared to wrought CoCr.

• In this first knee wear simulator test using Mg-PSZ femoral components, we found a significant decrease in the wear rate of conventional UHMWPE compared to CoCr femoral components.
  - Previous knee simulator studies also reported less wear using all-ceramic components instead of CoCr.
  - Clinical studies revealed no clear advantage in using alumina instead of CoCr femoral components.
• The loss of metal from scratches in CoCr femoral components may lead to a clinically significant reaction.

CONCLUSIONS

• The clinical use of Mg-PSZ femoral components may result in less UHMWPE wear compared to CoCr femoral components, and thus would be more suitable for younger/more active patients.
• The use of Mg-PSZ femoral components also may be indicated for patients with metal sensitivity.
• Future work will continue this test by using the same components under high kinematics/high load conditions, up to 15M total cycles.