How Much CoCr is Lost During Wear After TKA? An Analysis of Scratched CoCr Femoral Components

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**INTRODUCTION**

- Elevated Co and Cr levels have been reported in patients with metal-on-polyethylene THA and TKA.
- Adverse reaction to metal debris is a potential complication of metal-on-metal THA and hip resurfacing.
- Some increase in metal ions may result from tribocorrosion at modular interfaces.
- Even when bearing against UHMWPE, CoCr alloy is still subject to adhesive and third-body wear.
- Articular surface of cast CoCr components is prone to abrasive wear due to the excavation of hard carbides during normal wear.
- Lose hard carbides become third body wear particles and cause scratches.
- Purpose: estimate the mass lost via abrasive wear from CoCr femoral components used in a knee wear simulator.

**MATERIALS AND METHODS**

- Six cast CoCr (ASTM F75) femoral components were tested in a knee wear simulator bearing against conventional UHMWPE, with high kinematics/high load input waveforms.
- The simulator was paused after 100, 1100, and 101,100 total cycles to scan scratches on the femoral components via optical profilometry (ZoomSurf 3D) at 10x and 32x magnification.
- Femoral components were fixtured at angles of 0, 8, 15, 30, and 45 degrees of flexion, allowing scratches to be scanned along their entire length.
- Measurements of scratch depth and cross-sectional area were taken at multiple points along scratches; curvature of the femoral component was ignored because the radius of the femoral component was much greater than the scratch depth.
- The total volume (in μm$^3$) was multiplied by the density of cast CoCr alloy (8.3 g/cm$^3$) to quantify the amount of material lost due to abrasive wear.

**RESULTS**

- Typical scratches in CoCr femoral components were aligned with the A-P direction (Figure 1).
- Quantity of scratches and volume of material lost increased at each interval of testing.
- Scratches vary vastly in depth and cross-sectional area.
- Most scratches were observed at the surfaces that experienced the highest load during articulation.

**DISCUSSION**

- First attempt to quantify amount of metal lost from CoCr femoral component in a knee wear simulator, with more than 8,000 scratch measurements thus far.
- The amount of material lost is at least an order of magnitude lower than the volumetric steady-state wear rates reported in metal-on-metal hip wear simulator studies, but femoral oral components bear against UHMWPE and would be expected to yield less CoCr wear.
- Two clinical studies have reported increased serum levels of Co and Cr ions after TKA.
- Limitation: this study only quantifies mass lost from abrasive wear, not adhesive wear.

**CONCLUSIONS**

- Mass loss in a metal-on-UHMWPE knee femoral component is at least 10x less than that observed on a metal-on-metal hip tests.
- The most abrasion is observed near the apex of each condyle.
- After 100,000 cycles, the wear rate has not yet reached steady-state; thus, it is too early to determine a trend in mass loss.
- Future work will include extending the test to 500,000 and then 1,000,000 wear cycles to further evaluate abrasive wear during normal use.

**Figure 1. Image of a typical scratch on a CoCr Component taken on an optical profilometer**

**Figure 2. Column graph illustrating the mean mass lost (in ng) for each stage**
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**Introduction:** Adverse reaction to metal debris, a term that includes ALVAL, metallosis, and pseudotumor [1] is a potential complication of metal-on-metal THA and hip resurfacing. However, elevated Co and Cr levels have been reported in patients with metal-on-polyethylene THA [2] and TKA [3-7]. Some of the increase in metal ions may result from tribocorrosion at modular interfaces [8], but even when bearing against UHMWPE, CoCr alloy is still subject to adhesive and third-body wear [9]. The articular surface of cast CoCr components is especially prone to abrasive wear due to the excava\(\text{tion of hard carbides during normal wear, which become third body particles and cause scratches [9]. The purpose of this study was to estimate the amount of mass lost via abrasive wear (scratches), from CoCr femoral components used in a knee wear simulator.}\

**Materials and Methods:** Six cast CoCr (ASTM F75) femoral components were tested in a knee wear simulator bearing against conventional UHMWPE, with high kinematics/high load input waveforms [10,11]. The test was paused after 100, 1100, and 101,100 total cycles so that scratches on the femoral components could be scanned at 10x and 32x magnification under an optical profilometer (ZoomSurf 3D). Femoral components were fixtures at angles of 0, 8, 15, 30, and 45 degrees of flexion, allowing scratches to be tracked along their entire length, with multiple measurements of scratch depth and cross-sectional area per scratch. As the radii of curvature of the femoral component bearing surfaces were much larger than the depth of the scratches, the amount of material removed from each scratch due to abrasive wear was estimated by modeling them as "straight" instead of curved. Thus, the volume of material removed from each scratch was calculated by multiplying the cross sectional area of each scratch times the length of the section of the scratch in the field of view. The total volume (in \(\mu\)m\(^3\)) was multiplied by the density of cast CoCr alloy (8.3 g/cm\(^3\)) to quantify the amount of material lost due to abrasive wear.

**Results:** Typical scratches in CoCr femoral components were aligned with the A-P direction (Figure 1). At the three intervals tested (100, 1000, and 10k cycles), the mean mass of material lost from the lateral and medial condyles was 137, 552, and 5375 ng, respectively (Figure 2), based on an average of 155, 595, and 594 scratch measurements per component, respectively. After 101,100 wear cycles, the amount of material lost from the lateral condyle was greater than that of the medial condyle, which has shed 20,026 ng from the medial and 2690 ng from the lateral condyle.

**Discussion:** This study attempted to estimate the amount of metal lost from CoCr femoral components due to abrasive wear during normal use in vivo, by examining the scratches observed on femoral components that had been used in a knee wear simulator. Similar scratches have been observed in retrieved long-term femoral components, and the presence of these scratches begs the question of how much mass was lost, and how quickly it was lost.

To the best of the authors’ knowledge, this is the first attempt to estimate the amount of metal lost from CoCr femoral components in a knee wear simulator. The amount of material lost in the current study is at least an order of magnitude lower than the volumetric steady-state wear rates reported in hip wear simulator studies (Table 1) [12-14]. The femoral components are larger (two condyles, each with a 51.7mm effective diameter) but bear against UHMWPE, thus, the lower CoCr wear rate is not surprising.

Two clinical studies reported increasing serum ion levels in well-functioning TKA with time in vivo, which concur with the results of this study. Luetzner et al. reported greater serum levels of Cr and Co in a TKA group compared to a control group [3]. A study by Friesenbichler et al. also found increasing serum metal ion levels following rotating-hinge TKA [6].

This study has several limitations. First, the wear rate in the current test may not yet be at steady state. Thus, this test will be extended but paused after 500,000 and 1,000,000 total wear cycles for additional measurements. In addition, this study only estimated CoCr mass lost from scratches (due to abrasive wear from third body carbides, not from the surface (adhesive wear) [9]. If enough measurements are taken to produce a true pixel cloud, CMM scans of the articulating surfaces before and after wear tests may offer the best estimate of surface wear. Finally, the knee simulator is limited to n = 6 femoral components, but the data thus far is based on 8,061 scratch measurements.

**Significance:** This study is the first to demonstrate a rapid increase in CoCr material lost from abrasive wear in TKA. While these are early data, adverse reaction to metal debris is an increasing concern to orthopedic surgeons, and our work may have profound implications in the chronically painful knee.


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**Table 1.** Summary of steady-state wear rates from metal-on-metal hip simulator studies compared with the total wear rate of the current study.

<table>
<thead>
<tr>
<th>Metal-on-metal studies, diameter [ref.]</th>
<th>Steady-state volumetric wear rate mm/10^6 cycles</th>
<th>Crabrous wear rate g/10^6 cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>28mm, F75 [12]</td>
<td>0.063</td>
<td>6.3 x 10^{-3}</td>
</tr>
<tr>
<td>30mm, F1537 [13]</td>
<td>0.07</td>
<td>7.0 x 10^{-3}</td>
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<td>36mm, F1537 [13]</td>
<td>0.65</td>
<td>6.5 x 10^{-2}</td>
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<td>28mm, F1537 [13]</td>
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<td>4.5 x 10^{-2}</td>
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<tr>
<td>40mm, 35° cup [14]</td>
<td>0.24</td>
<td>2.4 x 10^{-2}</td>
</tr>
<tr>
<td>Current study: TKA vs. UHMWPE</td>
<td>6.41 x 10^{-2}</td>
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**Figure 1.** Photo of typical scratches on a CoCr femoral component.

**Figure 2.** Column graph illustrating the mean mass lost (in ng) for each stage.

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