

Abrasive Wear Comparison of CoCr Femurs to TiN-Coated Femurs

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Introduction: It is well known that surface roughness of femoral components can influence polyethylene wear rate in total knee replacements (1).

Traditional cobalt chromium femoral components, which have demonstrated strong clinical survivorship, have been compared to alternative materials (i.e., oxidized zirconium) that have demonstrated less surface roughness via surface profilometry and therefore less wear debris (2; 3; 4). Alternative coating on bearing surfaces, such as titanium nitride (TiN), has been introduced to reduce exposure to common metal sensitizers (5). As such, in this knee simulator study we sought to evaluate the effect of third-body wear debris on the surface roughness of a TiN-coated femoral component.

Methods: Three Titanium Nitride (TiN) coated Ti-6Al-4V substrate femoral components were utilized for this study. All femoral components were size 1 and articulated on a corresponding size 1, 9mm thick highly crosslinked UHMWPE tibial insert seated in a size 1 titanium baseplate. All femoral components and baseplates previously underwent 5.0 mc of clean wear testing prior to this study. All components were cleaned prior to test setup and White Light Interferometry (WLI) was obtained on all femoral components to obtain the surface roughness prior to testing. Surface roughness data was reported as the arithmetic mean height of the surface (Sa). In order to provide a more detailed qualitative assessment of the TiN coating, Scanning Electron Microscopy (SEM) was conducted as well prior to testing. A six-station knee joint simulator was utilized and all components tested in accordance with ISO 14243-3 (6). The femur was cemented with bone cement to the flexion arm fixture which provided flexion as well as anterior-posterior (AP) translation of the femur with respect to the tibia. The tibial insert was placed in the tibial baseplate which was cemented into the tibial specimen chamber and centered under the femoral component. The axial load and internal-external (IE) rotation were provided through the tibial specimen chamber via an axial/torsional actuator. To induce clinically relevant third-body abrasion, one 500µm TiN-coated Ti-6Al-4V substrate particle was embedded in the center of the articulating region on each condyle of the polyethylene inserts.

Following particle embedding, the tibial specimen chambers were filled with Alpha Calf Fraction serum (Hyclone Labs, Logan, UT) diluted to 50% using DI water to obtain a physiologically relevant protein level (20 g/L) and combined with Gentamicin (5mL/L) and Amphotericin (10 mL/L) to retard serum decomposition (7). Testing was conducted for 3.0 million cycles (mc) with the test stopping every 0.5 mc to hand clean and inspect the inserts, as well as obtain WLI data on the femoral components. During inspection, if the TiN-coated particle was deemed dislodged, a new particle was embedded. At the completion of testing, all femoral components were visually inspected for signs of wear. Additionally, WLI and SEM data was obtained for comparison to the 0mc time point. The average and standard deviation for the WLI data was determined. In addition, the SEM data was qualitatively assessed in accordance with ASTM C1624-22 (8). The surface roughness data from the TiN-coated femurs in this study was compared with CoCr surface values found in the literature (4; 1; 9). A one-sample T-test was used to determine whether the mean surface roughness for the TiN-coated femurs in this study was significantly different than the mean surface roughness reported for CoCr in the literature.

Results: Light scratches were observed for all femoral components and can be seen in Figure 1. The TiN-coated femurs showed no signs of cracking, delamination, gross spallation, or substrate exposure as supported by the SEM data. As expected, the surface roughness of the TiN-coated Ti-6Al-4V substrate femoral components increased throughout the course of third-body testing due to the introduction of light scratches to the coating (Figure 1). That said, the average Sa for the TiN-coated femoral components after 3.0 mc of third-body testing (Figure 2) was lower than roughness values observed on retrieved CoCr femurs in literature (Figure 2). Heyse et. al observed a mean Sa of 210 nm on ten conventional CoCr components with varying durations of implantation (4). Muratoglu et. al reported a similar range on five retrieved femoral components and Levesque et. al reported a 200 nm mean Ra for ten cemented CoCr femurs and 500 nm for ten uncemented CoCr femurs (1; 9). A one-sample T-test confirmed that the average surface roughness reported for CoCr femurs (264 nm) was significantly different than the average surface roughness for the TiN femurs in this study (85 nm) with a p value of 0.001.

Discussion: The results of this knee simulator study demonstrated only light scratching of the TiN femoral components with the introduction of third-body wear debris as measured by both WLI and SEM and no catastrophic wear of the TiN coating or polyethylene insert was noted. Furthermore, the amount of scratching observed as measured by the change in surface roughness was less in the TiN-coated femoral components compared to CoCr femoral components in previous studies (4; 1; 9).

Significance: Scratch resistance with a TiN-coated femoral component was statistically superior to traditional CoCr femoral components documented in literature. Implants with TiN coating may offer surgeons an alternative option for patients with common metal sensitivity concerns (5), without increasing the potential for polyethylene wear.



Figure 1: Representative image of scratches on a TiN-coated Ti-6AL-4V substrate femoral. Arrows indicate the direction and location of the scratches.

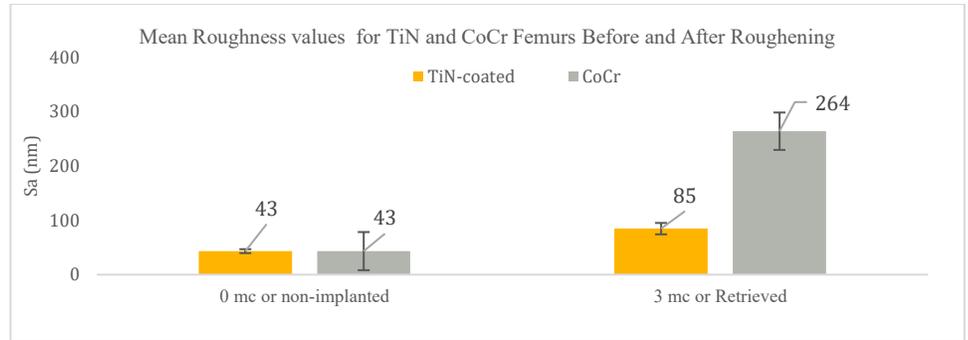


Figure 2: Surface roughness (S_a) of TiN-coated Ti-6Al-4V substrate femurs before and after 3.0 mc of third-body testing compared with averaged values for nonimplanted and retrieved CoCr femurs found in the literature (4; 1; 9). The TiN-coated femurs underwent 5.0 mc of clean wear testing prior to the 3.0 mc of 3rd body testing and were tested against new inserts.

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