

Scratch Resistance of Alternative Femoral Components: Oxidized Zr vs. Ion Beam Deposited TiN

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INTRODUCTION: Total knee replacement (TKR) femoral components manufactured from alternative materials are available for use in patients who may be sensitive to Cobalt, Chrome or Nickel ions. These implants may be utilized in the case of a potential metal sensitivity, reported as high as 20% in patients with well-functioning total joint replacements [1], or in order to avoid the use of CoCr entirely. Patients with well-functioning CoCr TKR have been observed to have elevated levels of CoCr ions in serum and urine [2-3]. Alternative femurs utilize surface treatments to reduce ion leaching from CoCr substrates and/or to harden non-CoCr substrates to improve wear performance of these softer materials. Zirconium alloy femurs with a 5 μm oxidized zirconia surface layer (OxZr - OXINIUM, Smith & Nephew, Memphis TN) have a successful clinical history [4]. Another alternative TKR femoral component is manufactured from Ti6Al4V alloy with a 5 μm Titanium Nitride (TiN) layer created by an Ion Beam Enhanced Deposition (IBED) process (IBED TiN - AURUM, Total Joint Orthopedics, Salt Lake City UT). The latter components have shown comparable wear to CoCr under adverse 3rd body conditions [5]. In the current study our aim was to compare the scratch resistance and scratch adhesion of surface hardened zirconium and titanium metals, the former with a zirconia surface layer and the latter with an IBED TiN surface layer.

METHODS: Two separate femoral components were tested: one OxZr and one IBED TiN. The OxZr component was explanted due to infection after 6.5 years of in vivo service; samples for testing were cut from an anterior section of the component where very little wear damage was observed. Similar samples were cut from the new IBED TiN component for testing. The scratch adhesion and scratch hardness of each material was tested using macroscratch testing according to ASTM C1624 [6] and ASTM G171 [7] using a Revetest Scratch system (Anton Paar, Ashland VA). Samples were scratched with a 200 μm spherical diamond tipped stylus. For scratch adhesion, the stylus was drawn across the surface of the test material under a normal force which increased from 0.5N to 125N (Fig 1), and three critical loads were measured: L_{C1} , defined as the onset of coating crack, L_{C2} , defined as the onset of local spallation, and L_{C3} , defined as the onset of gross spallation (Fig 2). Scratch hardness was measured as the stylus was drawn across the surface of the test material under a constant load – both 10N and 80N were run. A Student's t-test was used to determine statistical significance between the results from the two materials tested.

RESULTS SECTION: The onset of coating crack (L_{C1}) happened under 8.2 ± 0.7 N for IBED TiN and 8.0 ± 1.4 N for OxZr ($p=0.76$). The onset of local spallation (L_{C2}) happened under 38.3 ± 1.3 N for IBED TiN and 26.8 ± 2.4 N for OxZr ($p=1.5 \times 10^{-8}$), while the onset of gross spallation (L_{C3}) happened under 75.3 ± 3.5 N for IBED TiN and 58.0 ± 4.3 N for OxZr ($p=8.9 \times 10^{-8}$). Under 10N of constant load – a load above L_{C1} but below L_{C2} for both materials – the scratch width was 71.4 ± 0.8 μm on IBED TiN and 86.6 ± 0.9 μm on OxZr ($p=2.2 \times 10^{-50}$), giving a scratch hardness of 5.0 ± 0.1 GPa for IBED TiN and 3.4 ± 0.1 GPa for OxZr ($p=2.8 \times 10^{-37}$). Under 80N of constant load – a load above L_{C3} for both materials – the scratch width was 204.8 ± 3.7 μm on IBED TiN and 252.7 ± 5.2 μm on OxZr ($p=1.2 \times 10^{-45}$), giving a scratch hardness of 4.9 ± 0.2 GPa for IBED TiN and 3.2 ± 0.1 GPa for OxZr ($p=6.5 \times 10^{-39}$).

DISCUSSION: OxZr implants have been utilized in clinical practice since the 1980s, demonstrating favorable clinical outcomes. On the other hand, IBED TiN implants have only recently been introduced for clinical use, resulting in limited clinical exposure. Our objective was to analyze and compare the surface properties of these two materials in a laboratory setting to project their potential in vivo performance. The preclinical findings presented herein indicate that there is no significant disparity in the initiation of coating cracks between IBED TiN and OxZr. When subjected to load, local spallation occurred at a 30% lower threshold on OxZr in comparison to IBED TiN. Oxinium exhibited gross spallation at a 23% lower load compared to IBED TiN. As a result, it can be inferred that surface hardness traits of IBED TiN are anticipated to be on par with those of OxZr, implying comparable in vivo performance.

SIGNIFICANCE/CLINICAL RELEVANCE: There is a pressing requirement for metallic implants that mitigate the release of potentially detrimental ions such as Co and Cr. Applying a durable surface coating onto softer metals such as zirconium and titanium emerges as a highly promising option for substituting CoCr alloy implants.

REFERENCES: [1] Hallab NJ, et al. J Orthop Res 2005. [2] Leutzner J, et al. Clin Orthop Relat Res 2007. [3] Tower SS, et al. JAMA Netw Open 2021. [4] Vertullo CJ, et al. J Bone Joint Surg Am 2017. [5] Muratoglu OK, et al. ISTA Meeting 2022. [6] ASTM Standard C1624, 2022, "Standard Test Method for Adhesion Strength and Mechanical Failure Modes of Ceramic Coatings by Quantitative Single Point Scratch Testing," ASTM International, West Conshohocken, PA, 2022. [7] ASTM Standard G171, 2017, "Standard Test Method for Scratch Hardness of Materials Using a Diamond Stylus," ASTM International, West Conshohocken, PA, 2003.

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IMAGES AND TABLES:

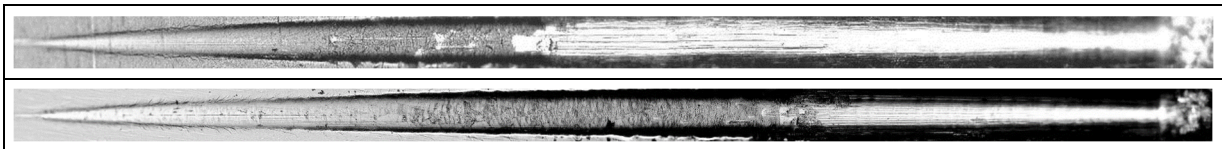


Fig 1. Representative scratch adhesion test track of OxZr (top) and IBED TiN (bottom). The stylus was dragged across the surface from left to right, while the load was increased linearly from 0.5N to 125N.

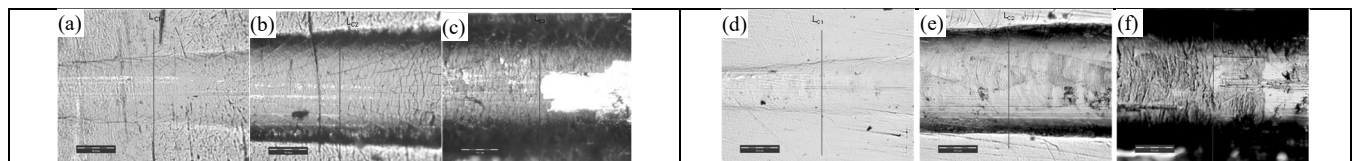


Fig 2. Magnified section of the representative scratch adhesion test track on OxZr (a-c) and IBED TiN (d-f) showing L_{C1} (a,d), L_{C2} (b,e), and L_{C3} (c,f).