

What Insights Can Computational Analysis Provide on Hinged TKR Wear?

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INTRODUCTION: Knee wear testing is an industry standard and required by many regulatory bodies when developing total knee replacement (TKR) products. Although wear tests are common, they are also costly and time consuming to perform. Computational wear models have successfully been developed to reduce the burden of performing physical tests for primary TKR (1). To the knowledge of the authors, no computational wear models for hinged TKR have been published to date. Compared to primary TKR, hinged TKR adds a level of complexity as the implant must replace the functions of the ACL, PCL, MCL, and LCL, while also maintaining acceptable patella kinematics and internal/external rotation between the tibial and femoral implants. The objective of this work was two-fold: first, to develop a computational model to assess hinge TKR wear, and second, to compare the wear behavior of a novel Hinge to two commercially available, contemporary hinged knee replacements.

METHODS: A computational wear analysis was performed to evaluate the wear performance of a novel Hinge, the Attune Revision Hinge knee implant, relative to two comparator systems: posterior axle single radius hinge knee System and the Zimmer NexGen Rotating Hinge Knee (RHK). All constructs were modeled using finite element analysis (FEA) in Abaqus v2019, leveraging a previously validated 6-DOF knee simulator framework (Fitzpatrick et al., 2016) and a wear algorithm developed at the University of Leeds (Abdel et al., 2011). The Attune Revision Hinge construct included a femoral component, bushing, pin, shroud, post, insert, and tibial tray. Similar features were included in the comparator constructs (Fig. 1). Mid-size configurations were selected for each construct's simulation. Polyethylene components (insert, bushing, shroud) were modeled using antioxidant polyethylene. Plastic deformation was captured using a multilinear isotropic hardening model. Metallic components were treated as rigid due to their significantly higher stiffness. Simulations replicated ISO 14243-1 force-controlled wear conditions during level gait, with internal-external rotation applied using displacement profiles from ISO 14243-3. Flexion-extension was defined along the central pin axis of each hinge construct. Varus-valgus torque was applied to achieve 60% medial loading, while the medial-lateral axis remained unconstrained throughout the cycle. Penalty-based contact definitions were used with a friction coefficient of 0.04, consistent with prior studies (Fitzpatrick et al., 2016). All contact interfaces were modeled to capture realistic sliding and pressure distributions. All components were meshed using 3D tetrahedral elements (C3D4). Polyethylene parts were meshed with a maximum edge length of 0.75 mm. The Abaqus v2019 explicit solver was employed with standard convergence criteria. Contact mechanics outputs — sliding distance (SD), contact pressure (CP), contact area (CA), and cross shear (CS)—were post-processed using the Abdel et al wear algorithm. Calculated wear metrics included average CS, average volumetric wear, total CA, CP*CA, and SD*CA. Identical analyses were repeated for the other two Hinge designs and wear metrics were compared. Wear metrics were normalized to the posterior axle single radius hinge to facilitate comparative analysis across constructs.

RESULTS: Wear metrics were normalized to the contemporary hinge design, a posterior axle single radius, to facilitate comparative analysis (Fig 2). The Attune Revision Hinge demonstrated equal or superior wear performance across all assessed metrics.

Combined Wear Metrics (Insert + Bushing + Shroud):

- Attune: Lower in 4 of 5 metrics compared to the contemporary posterior axle single radius hinge knee; all 5 metrics lower than RHK.

Component-Level Wear:

- **Bushing:** Attune showed significantly lower wear than RHK (volumetric wear: 0.397 vs. 0.796, respectively).
- **Insert:** Attune and RHK had similar wear profiles, with Attune trending lower in CP*CA and SD*CA.
- **Shroud:** Attune outperformed RHK across all metrics.

DISCUSSION: This study evaluated the wear behavior of Attune Revision Hinge compared to two commercially available, contemporary hinged knee replacements, while also proving the capabilities of predictive wear computational modeling. The model showed Attune Revision Hinge outperformed the posterior axle single radius hinge knee System in four of the five metrics and RHK in all five metrics. It shall be noted, due to the unknown material properties of the two commercially available knees, all three hinge constructs were modeled with the same antioxidant polyethylene. This assumption could have predicted better wear results for the posterior axle single radius hinge knee System and RHK. These findings suggest that the Attune Revision Hinge construct offers wear performance that is at least equivalent to, and in most cases superior to, the comparator systems. Furthermore, these results demonstrate the ability to predictively model wear for hinged TKR.

SIGNIFICANCE/CLINICAL RELEVANCE: The results demonstrate the ability to model wear as a predictive tool for hinged TKR, which could be beneficial during the product development phase of an implant design project.

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IMAGES AND TABLES:

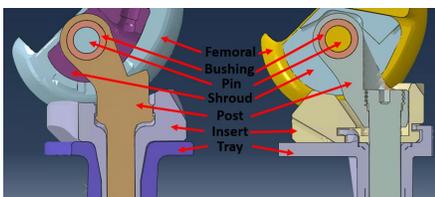


Figure 1: Cross-sectional view of Attune Revision Hinge (left) and RHK (right).

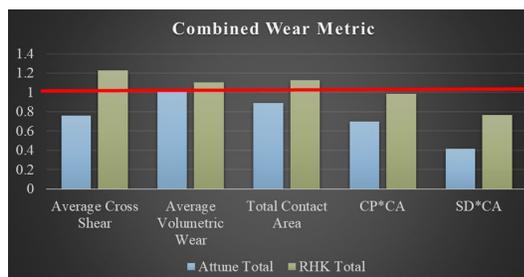


Figure 2: Combined normalized wear metrics of Attune Hinge and RHK, normalized to the Posterior axle hinge knee.