Population-based FE study on the primary fixation of a cementless PEEK tibial component

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INTRODUCTION: While titanium alloy currently is the default material for tibial total knee arthroplasty (TKA) components, polyetheretherketone (PEEK-OPTIMA™) is of interest as alternative implant material in patients with metal hypersensitivity. As an additional benefit, PEEK has a stiffness that is similar to the stiffness of human bone, which may contribute to reducing peri-prosthetic stress-shielding. However, this difference in stiffness may also influence the primary fixation. In cementless fixation, adequate primary fixation is required to ensure for the long-term fixation through bone ingrowth. Primary fixation can be evaluated by studying micromotions between the tibia and tibial tray.
Previous finite element (FE) studies typically focused on parametric variations in a single tibial model, while the outcome may depend on patient factors such as age, gender and BMI, which requires a population-based approach. The research question of this study is twofold: 1) What is the effect of implant material on tibial micromotions? 2) Are tibial micromotions sensitive to patient characteristics (gender, age and BMI)?

METHODS: A CT database consisting of 74 healthy knees including the patient information on gender, age and BMI was created. An automated workflow was used to build FE models of tibial reconstructions, including a tibial tray and a polyethylene insert. The tibial tray was assigned with a Young's modulus of either PEEK (3.7 GPa) or titanium (109 GPa). Bone was assigned with elastic-plastic material properties to account for bone deformations that exceeded the yield limit during implant insertion or during the loading cycles. The implant-specific tibiofemoral contact forces and centers of pressure of a gait and squat movement were derived from a musculoskeletal model. The contact forces were scaled based on the patient's bodyweight and applied during four loading cycles to allow the implant to (numerically) settle. As an outcome measure, the resulting micromotions were analyzed visually via the distributions at the interface of the femoral component and quantitatively using violin plots depicting the 95th percentile of the maximum micromotions for all models. The 95th percentile was taken to exclude the nodes with potential (numerical) outliers. A multiple regression analysis was used to determine significant factors affecting implant-bone interface micromotions.

RESULTS SECTION: The largest resulting micromotions were typically located at the anterior and posterior lateral regions of the tibial tray, with similar distributions for the PEEK and titanium tibial trays (Figure 1). The PEEK models generated larger peak resulting micromotions than the titanium models (68 vs. 39 µm on average). BMI significantly influenced micromotions for both the PEEK and titanium models, with higher micromotions with increasing BMI (Figure 2). Gender and age did not have a statistically significant effect on the micromotions.

DISCUSSION: The results of this FE study indicate that the peak tibial micromotions were larger for PEEK implants compared to titanium trays. However, in the larger part of the tray micromotions were below the threshold for bone ingrowth (40 µm) [1] for both implant materials. Further research is required to further elucidate the relation between implant stiffness and primary fixation, and whether there is an optimal stiffness that provides a good balance between primary fixation and long term effects such as stress shielding. This study furthermore demonstrated that the micromotions increased with BMI. Future work will focus on a more in-depth multivariate analysis to investigate underlying mechanisms and interactions. Moreover, an outlier analysis will be performed to investigate the potential high-risk factors of patients.

SIGNIFICANCE/CLINICAL RELEVANCE: The current study gives preliminary insights into the safety of using a more flexible cementless tibial knee implant in a cohort of computational models with varying patient characteristics.

REFERENCES: [1] Engh, et al. Quantification of implant micromotion, strain shielding, and bone resorption with porous-coated anatomic medullary locking femoral prostheses. Clin. Orthop. Relat. Res., 285, 13 – 29 (1992).

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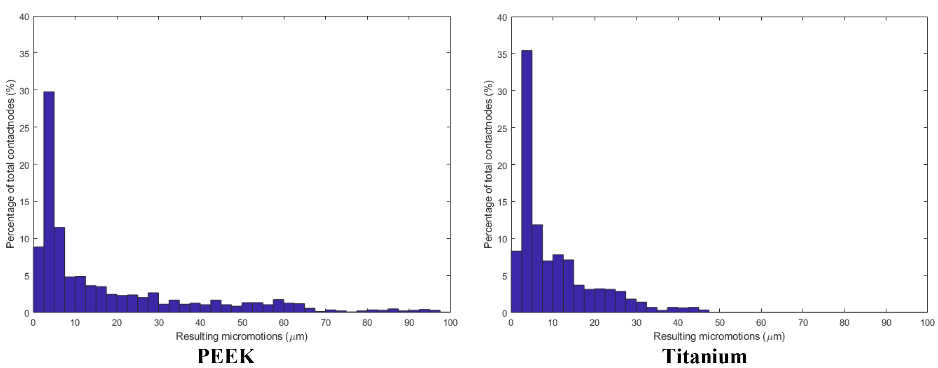

Figure 1. Resulting micromotion distribution (µm) at tibial tray interface after 4th squat cycle.

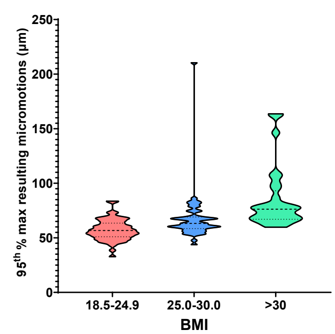

Figure 2. Violin plots of all PEEK models per BMI classification.