

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

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INTRODUCTION: While cobalt-chrome (CoCr) alloy currently is the default material for femoral total knee arthroplasty (TKA) components, polyetheretherketone (PEEK-OPTIMATM) 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 femur and implant.

Previous finite element (FE) studies typically focused on parametric variations in a single 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 femoral micromotions? 2) Are femoral micromotions sensitive to patient characteristics (gender, age and BMI)?

METHODS: A CT database was created including 35 patients (70 femora) with known information on gender, age, weight and height. The CT data was used to create FE models of femoral TKA reconstructions, in which the femoral component was assigned with the material properties of either PEEK (3.7 GPa) or CoCr (210 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 phase. Implant-specific tibiofemoral and patellofemoral contact forces and centers of pressure of gait and squat activities 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 for (numerical) settling of the implant. 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 multivariate linear regression analysis was used to determine significant factors affecting implant-bone interface micromotions.

RESULTS SECTION: The largest resulting micromotions were located at the anterior flange of both PEEK and CoCr models and additionally on the lateral distal side of the PEEK models (Figure 1). The PEEK models generated larger peak micromotions than the CoCr models (63 vs. 48 μ m on average). Micromotions of both the PEEK and CoCr femoral models significantly increased with BMI (Figure 2). Neither gender nor age of the patients had a significant effect on the micromotions of the PEEK and CoCr models.

DISCUSSION: The results of this FE study indicate that the peak femoral micromotions were larger for PEEK implants compared to CoCr implants. However, in the larger part of the femoral component micromotions were below the threshold for bone ingrowth (40 μ m) [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 femoral 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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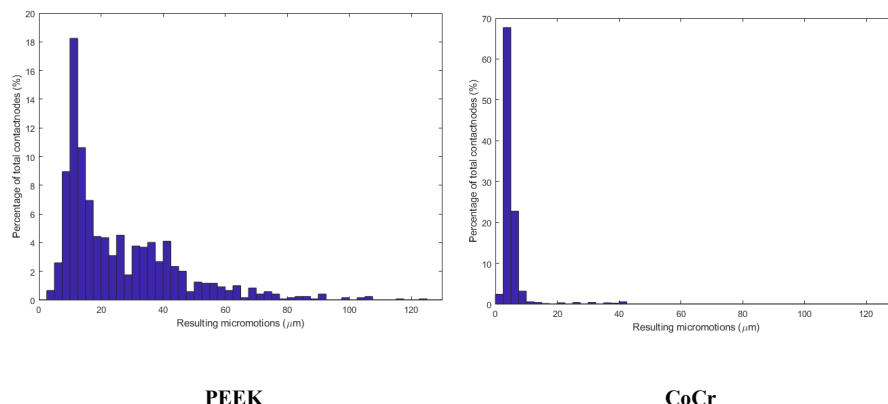


Figure 1. Resulting micromotion distribution (μ m) at right femoral component interface after 4th squat cycle.

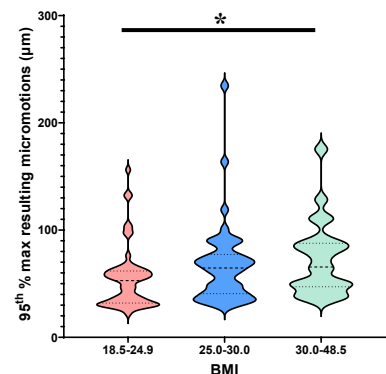


Figure 2. Violin plots of all PEEK models per BMI classification.