A Biomechanical Analysis of a PEEK-Optima® Femoral Component on Implant Fixation, Construct Integrity and Bone Remodeling Opportunities in Total Knee Arthroplasty

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Introduction: Current clinical practice in total knee arthroplasty (TKA) is largely based on metal on polyethylene bearing couples. A potential adverse effect of the stiff metal femoral component is stress shielding, leading to loss of bone stock, periprosthetic bone fractures and eventually aseptic loosening of the component. The use of a polymer femoral component may address these problems. In theory a softer implant has great potential. Bone-like material properties could allow for a more natural stress throughout the femoral bone. However, when expecting higher stresses from the femoral component towards the femur, concerns arise on the structural integrity of the construct. This may present itself by increased stress levels in the femoral component or the bone cement. Furthermore, it may have consequences for the fixation of the femoral component because of the expected potential to introduce local stress peaks on the interface.

The objective of this study was to analyze the effects of using a polyether-etherketone (PEEK-Optima®) femoral component on the stresses in the implant, at the cement and implant-cement interfaces, and the stress levels in the underlying femur. We analyzed the stress distribution occurring during normal gait, and compared this to results obtained with a standard CoCr component.

Methods: A Finite Element (FE) model was created, consisting of a femoral component cemented onto a femur, and a polyethylene tibial component. A standard loading regime was applied mimicking an adapted gait cycle, according to ISO14243-1. The implant-cement interface was modelled as a zero-thickness layer connecting the implant to the cement layer. Femoral flexion/extension was prescribed for the femur in a displacement controlled manner, while the joint loads were applied to pivoting nodes attached to the tibial construct, consistent with the ISO standard. Implant material properties were provided by the manufacturer. Implant-cement interface properties were adopted from a previous study on CoCr interface debonding[1]. The femoral bone was defined as a homogeneous isotropic material (E=3GPa). Implant fixation was assessed by the Hoffman failure index (FI), based on the combination of tensile, compressive and shear stresses at the implant-cement interface. An FI≥1 implies acute implant loosening. FI=0.5 indicates the limit for long-term loosening. On construct integrity the Von Mises stresses were assessed in the femoral component and bone cement. Stresses were normalized to yield stress.

Results: The highest stresses in the construct were found during the heel strike phase of the walking cycle. Surprisingly, at this stage interface FI for the PEEK-Optima® implant peaked at 0.32, while this maximum for CoCr was 0.44. Another interesting difference was found in the location of stresses along the interface surface. Figure 1C shows that the highest stresses were found near the chamfers of the posterior condyles for PEEK-Optima®, which is the location where tibiofemoral contact occurred. The highest interface stress concentrations for the CoCr implant were found at the proximal aspect of the anterior and posterior flanges, consistent with literature[1]. For PEEK-Optima®, CoCr and bone cement these were 90MPa, 600MPa and 70MPa, respectively. In both implant cases cement Von Mises stress did not exceed 12 percent of yield (Figure 1B). Similarly, both femoral components performed equally, with PEEK-Optima® reaching 20 percent en CoCr reaching 17 percent of yield (Figure 1A). A glance at bone preservation in the periprosthetic region was provided by the strain energy density (SED) in the bone. The highest SED was found in the ‘PEEK’-femur, at 0.0125 Nm/mm3. For CoCr this was 0.00623 Nm/mm3. Total (integrated over the volume) SED was 102 and 65 Nm for PEEK-Optima® and CoCr, respectively (Figure 1D).

Discussion: In contrast to our initial assumption, the current results show that the implant-cement interface stresses with a PEEK-Optima® component were lower and more functionally located than with a CoCr component. However, the significance of this difference is yet unknown, as additional data on the strength of the implant-cement interface strength of PEEK-Optima® components is needed for the prediction of implant loosening. The difference between the implants on construct integrity is negligible. The stresses in both the femoral component and the bone cement are well within the range of safe usage as the maximum in either part reached but 20 percent of failure stress. The hypothesis that a softer implant material would result in less periprosthetic bone resorption seems to be corroborated by the findings on strain energy density. However, the current femoral material model does not allow spatial differences in stiffness, which is required for more reliable bone remodelling simulations.

We furthermore intend to expand the current simulations with more demanding tasks, such as stair climbing and rising from a
chair, as such high flexion tasks may be more detrimental to the implant-cement interface. The current study only focuses on biomechanical aspects of implant material substitution. Wear and friction were not assessed. In conclusion, this study warrants further investigation of the use of PEEK-Optima® as a substitute for CoCr in femoral TKA components.

**Significance:**

**Acknowledgments:**


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