INTRODUCTION:
High-flexion total knee replacements have been developed to accommodate a large range of motion (ROM > 120°) after total knee arthroplasty (TKA). In a recent clinical study, Han et al. [1] reported a disturbingly high incidence of aseptic femoral loosening for high-flexion TKA. They observed that the femoral component loosened particularly at the implant-cement interface beneath the anterior flange. Highly flexed knee replacements may be more sensitive to femoral loosening [2] as the knee load is relatively high during deep knee flexion [3], which may result in increased tensile and/or shear stresses at the femoral implant fixation site.

The objective of the current study was to analyze the load-transfer mechanism at the femoral implant-cement interface during deep knee flexion (ROM ≥ 155°). For this purpose, a three-dimensional finite element (FE) knee model was developed including high-flexion TKA components. Zero-thickness cohesive elements were used to model the femoral implant-cement interface. The research questions addressed in this study were whether high-flexion leads to an increased tensile and/or shear stress at the femoral implant-cement interface and whether this would lead to an increased risk of femoral loosening.

METHODS:
The FE knee model utilized in this study has been described previously [3] and consisted of a proximal tibia and fibula, TKA components, a quadriceps and patella tendon and a non-resurfaced patella (Figure 1a). For use in this study, the distal femur was integrated in the FE model including cohesive interface elements and a 1 mm bone cement layer (Figure 1b). High-flexion TKA components of the posterior-stabilized PFC Sigma RP-F (DePuy, J&J, USA) were included in the FE knee model consistent with the surgical procedure. One full weight-bearing squatting cycle was simulated in this study (ROM = 50°-155°).

The femoral implant-cement interface stresses computed with the FE knee model were decomposed into tensile, compressive and shear components. Experimental strength data of the implant-cement interface were used to define an interface failure index (FI). Based on the local normal and shear stresses the failure index described the severity of failure at the femoral implant-cement interface. Instant interface debonding was assumed for FI ≥ 1.

RESULTS:
During deep knee flexion, tensile stress concentrations were found at the femoral implant-cement interface particularly beneath the anterior flange (Figure 2a-c). Shear stress concentrations were observed at the interface beneath the anterior flange and the posterior femoral condyles (Figure 2d-f). The peak tensile interface stress increased from 1.6 MPa at 90° of flexion to 4.8 MPa at 155° of flexion at the interface beneath the anterior flange. The peak shear stress was even higher at this interface location and increased from 4.1 MPa at 90° of flexion to 10.4 MPa at maximal flexion (155°). Based on interface strength experiments, 1.3% of the integration points at the implant-cement interface beneath the anterior flange were marked as failed (FI ≥ 1) at 90° of flexion, whereas this number increased to 10.8% during deep knee flexion (see anterior data points, Figure 3).

DISCUSSION:
Obviously, the FE knee model utilized in this study contains limitations which may have affected the interface stresses and the amount of interface failure predicted by the model. However, the results presented here clearly demonstrate increasing tensile and shear stresses in substantial parts of the femoral implant-cement interface during deep knee flexion. Based on experimental interface strength data, the anterior interface stresses calculated by the FE knee model lead to local interface debonding during deep knee flexion, which increases the risk of femoral loosening. Proper anterior fixation of the femoral component is essential to reduce the risk of femoral loosening for high-flexion TKA.

REFERENCES:

ACKNOWLEDGEMENT: DePuy International Ltd., Leeds, UK.