Introduction: The stress distribution within the polyethylene component of a TKR is ultimately dependent on the kinematics of the replaced knee. In turn, the kinematics are dependent on the design of the implant, the relative alignment of the components and tensions of the surrounding soft tissues. Clinical fluoroscopy studies have shown that unicondylar loading occurs in up to 90% of replaced knees [1]. However, the impact on the polyethylene stresses is unknown. The aim of this study was to examine the influence of unicondylar loading during a gait cycle on the predicted kinematics and stresses generated by a commercially available TKR.

Methods: A three-dimensional explicit finite element model of a PFC Sigma TKR (DePuy International, Leeds, UK) has been developed. The femoral component was modelled as rigid body using four noded shell elements and the polyethylene insert was modelled using eight noded hexahedral elements. The polyethylene was modelled as an elastic-plastic material with an initial yield stress of 15 MPa. A coefficient of friction of 0.04 was assumed to act at the contact interface. The boundary conditions applied to the model were defined according to the experimental protocol used in the Stanmore TKR (DePuy International, Leeds, UK) has been developed. The femoral internal-external torque, anterior-posterior force and flexion-extension angle aimed at reproducing the mechanical environment existing in the Stanmore the contact interface. The boundary conditions applied to the model were defined according to the experimental protocol used in the Stanmore knee simulator [2]. The boundary condition time histories for the axial force, internal-external torque, anterior-posterior force and flexion-extension angle were defined according to the experimental protocol used in the Stanmore knee simulator. The springs which represent the soft-tissue structures of the knee in the wear simulator were modelled using spring elements with a translational stiffness of 10.4 N/mm and a rotational stiffness of 0.3 Nm°. The finite element simulations were performed over 1 Hz, simulating a walking pace of one step per second.

The affects of eccentric loading were simulated by displacing the point of application of the axial load medially, along the flexion-extension axis. Five load cases were simulated; 0mm offset replicating a bi-condylar load case (50:50 loading to the medial and lateral compartments) and 5, 10, 15 and 20 mm offsets. The 20mm offset places the load over the centre of the medial condyle and will be referred to as the uni-condylar load case. The predicted anterior-posterior translations and the internal-external rotations of the prosthetic components have been compared for the different load cases. The variation of the predicted contact pressure distributions, the peak von Mises stresses and permanent strain with time have also have also been reported. All analyses were performed using PamCrash (ESI, Paris, France).

Results: Increasing the medial offset of the vertical force, by up to 15mm, produced a marginal increase in the peak posterior displacement of the tibial component, increasing from approx. 4 mm to 5.2 mm at 38% of the gait cycle. Increasing the medial offset to 20 mm produced a significant increase in the posterior displacement, increasing to approx. 9mm (Figure 1). Increasing the medial offset by up to 15mm only had a marginal effect on the I-E rotations. The peak internal rotation, which occurred at 58% of the gait cycle, increased from 4.9 degrees to 7.3 degrees. Increasing the offset 20mm, produced a significant increase in the peak internal rotation, to approx. 20 degrees and this occurred earlier at 45% of the gait cycle (Figure 1). The peak von Mises stresses appear to be more sensitive to small changes in the medial offset of the axial force. The peak von Mises stresses, which tend to occur in the medial condyle, increased by approximately 3MPa, from approx 10-15 MPa, through out the stance phase of gait when the vertical load was offset by 10mm. An offset of 20mm further increased the peak von Mises stresses by up to 3MPa. Although this seems only a small increase in the stresses, due to the elastic-plastic material model, this means the generation of significant amounts of plastic strain. The residual plastic strain also causes the peak von Mises stresses to remain at approx. 10MPa during the swing phase of gait, as compared to 5-6 MPa for the 0 and 10 mm offset models. At no point in any analysis was contact lost between the femoral component and the polyethylene liner in the lateral compartment.

Discussion and conclusions: Explicit finite element analysis has for the first time enabled us to simulate the abnormal kinematics caused by unicondylar loading and the associated changes in the polyethylene stresses. For the particular design examined, uneven bicondylar loading had a minor affect on the kinematics but did increases the polyethylene stresses. Unicondylar loading significantly affected both the kinematics and the polyethylene stresses and produced areas of high plastic deformations in similar regions as delamination is observed in retrieval studies. It is interesting to note that at no point in any of the analyses did the lateral condyle lose contact, thus true “lift-off” never occurred. However, the significant internal rotation caused the femoral component to ride up the anterior flange of the polyethylene insert. This motion could be perceived as “lift-off” if the relative motion is measured with respect to the tibial base plate rather than the polyethylene insert.

References: