Introduction: Catastrophic wear as a result of delamination of the polyethylene component can result in the premature failure of total knee joint replacements. There are a number of factors that may contribute to delamination of polyethylene, with excessive stresses being a major factor. Excessive stresses can be generated within the polyethylene as a result of poor implant kinematics which, in turn, can result from poor positioning of the components relative to the bone and relative to each other; inadequate balance of the soft-tissues and poor design of the implant. Retrieval studies have shown that delamination often occurs on the most medial or lateral aspect of the polyethylene insert, suggesting that edge loading is occurring. Using fluoroscopic kinematic analysis, Stiehl et al. (1999) have demonstrated that in up to 90% of patients lift-off of one condyle may occur. They have shown that lift-off may occur in either the medial or lateral compartment and is as likely to occur during the weight bearing phase of gait and the non-weight bearing phase. Lift off of up to 2mm has been measured during the weight bearing phase of gait.

The aim of this study is to compare the polyethylene stresses which are generated during normal gait and when lift-off occurs using finite element analysis.

Methods: A three dimensional finite element model of a Freeman-Samuelson total knee joint replacement (Sulzer Orthopaedics, Switzerland) was generated. Due to symmetry only half of the implant was generated. The femoral component was modeled as a rigid surface (Fig.1).

The polyethylene component was modelled as a continuum, with elastic plastic material behaviour (initial yield stress = 10 MPa). It was assumed that the distal surface of the polyethylene component was rigidly fixed and the appropriate constraints were applied to the symmetry plane. Unlike similar finite element analyses, the model was force driven, allowing the polyethylene component to move freely with respect to the femoral component. The vertical and anterior-posterior loads during the gait cycle were applied to according to Walker et al. (2000) and results obtained at every 2% of the gait cycle. The peak vertical force was 2433 N and the peak posterior force was 265 N. In order to simplify the analysis, the effects of torsional loads have been ignored. Two analyses were performed. The first assumed bi-condylar loading (50% per condyle) for a well orientated knee. In the second analysis, the femoral component was rotated in the frontal plane by 0.25 degree to simulate lift-off. This corresponds to 0.25mm of lift-off of the other condyle.

Results: A comparison of the typical stress distribution patterns for the two load cases are shown in figure 2. Lift-off results in significantly higher polyethylene stresses which occur on the edge of the polyethylene insert. As can be seen from figure 3, lift-off results in stresses 4 - 6 MPa higher than those found in the normally loaded knee.

Discussion and Conclusions: The prosthesis examined is a high conformity design which under normal loading conditions produces polyethylene stresses well below the yield stress of the material. However, lift-off, during any phase of the gait cycle, results in a significant increase in the polyethylene stresses. If lift occurs during the periods of peak axial load (10-20% and 30-60% of the gait cycle) then the stresses are sufficient to cause significant plastic deformation of the polyethylene. If the knee were subjected to repeated load cycles of this nature, this would be likely to result in delamination of the polyethylene in this region.

For the purpose of this study the femoral component has modelled as lifting off through out the gait cycle. In reality, lift-off is likely to occur during discrete periods of the gait cycle. However, the net result would be the same with a significant increase in the polyethylene stresses. This study has also only examined a single lift-off distance, of 0.25mm. Stiehl et al. (1999) reported that lift-off can be as large as 2mm during the stance phase of gait. Increasing the lift-off distance may result in higher polyethylene stresses, as the contact area will decrease and therefore the presented results may be considered to be a conservative estimate.

The region of the plastic deformation correlates well with areas of delamination observed in retrieved polyethylene inserts.

References