THE INFLUENCE OF THE WEAR PATH ON THE WEAR RATES IN TOTAL KNEE REPLACEMENT

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ABSTRACT

Total knee replacements (TKR) are increasingly being implanted into younger and more active patients. This may lead to an increase in long-term failure as a result of wear. This study used a combination of explicit finite element modelling and experimental data to assess the shape of the wear path of the PFC Sigma total knee replacement under three kinematic loading conditions and to relate the effect of this on polyethylene wear.

INTRODUCTION

An estimated 30000 total knee joint replacements are implanted each year in the UK, and the numbers are steadily increasing. The number of knee replacements implanted into younger, more active patients is also rising and this is leading to a need for implants to last longer. Long-term failures (5 years or more) may be due to wear of the polyethylene tibial component and this is considered to be a limiting factor in the longevity of total knee joint replacement. Not only could the implant wear out, but the generation of third body debris may cause an adverse tissue reaction [1, 2].

Fisher and Dowson [3] state that the wear volume is proportional to the load and the sliding distance from simple wear theory. However, it was also found that the type of motion has a marked effect on the wear rate. The aim of this study was to use explicit finite element modelling to determine the shape of the wear path of selected points on the surface of the polyethylene tibial component and to relate this to polyethylene wear.

METHOD

Displacement-controlled knee replacement data was taken from laboratory simulations using the method described by Barnett *et al.* [4]. There were four input parameters: flexion-extension angle, axial force, anterior-posterior (A/P) displacement and internal-external (I/E) rotation. This data was then applied to a finite element (FE) model of the PFC Sigma total knee replacement (TKR) (DePuy). Three models were run using high, low or intermediate kinematics. For each model, the flexion extension and the axial force were the same. Different A/P displacements and I/E rotations were applied to give a high or low kinematic model. High kinematics were defined as A/P displacement of 0–10mm and I/E rotation of $\pm$ 5 degrees, whilst low kinematics were defined as A/P displacement of 0-5 mm and I/E rotation of $\pm$ 2.5 degrees. The intermediate model was defined by high rotation with low A/P displacement. The input parameters for A/P displacement and I/E rotation are shown in figure 1.

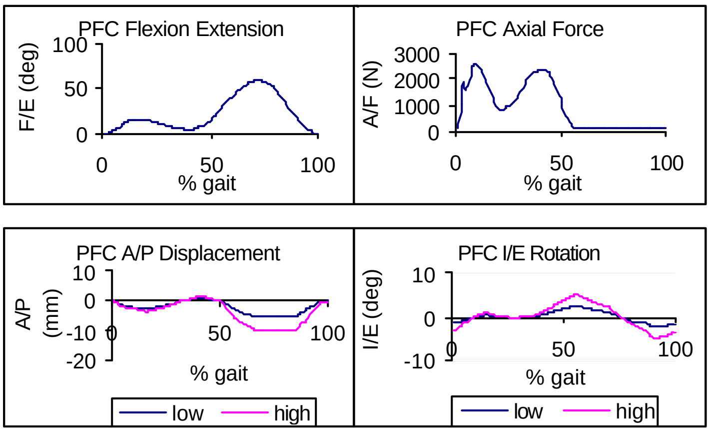

Figure 1. Flexion extension, axial force, A/P displacement and I/E rotation input parameters

In the finite element model, the A/P displacement and the I/E rotation angle were applied to the centre of the rigid (lower) surface of the polyethylene component. In order to drive the femoral component, the flexion-extension angle and the axial force were applied to the centre of gravity of the femoral component.

The three models were run using the FE software PAM-CRASH-SAFE and the outputs (A/P, medial-lateral M/L and inferior-superior displacement) were recorded. Wear path generation was achieved by manually selecting nodes from the contacting surface of the polyethylene from both the medial and lateral sides. Each of the nodes selected was in contact with the femoral component at some point during the stance phase of gait (0 - 60%). Figure 2 shows the position of these nodes.

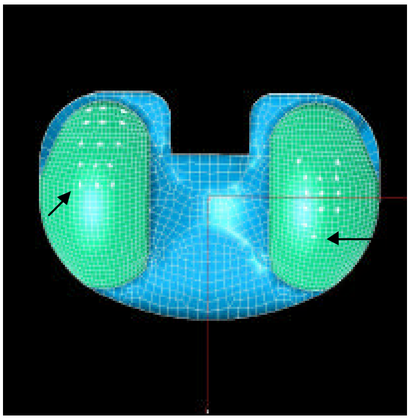

Figure 2 Nodes selected from the polyethylene tibial tray – left hand side is medial, right hand side is lateral. Nodes indicated with an arrow have their wear paths included in the results section.

RESULTS AND DISCUSSION

The mean wear rate with 95 % confidence limits for the PFC Sigma TKR when subjected to high, intermediate and low kinematics in the knee simulator were 22.75 ± 5.95, 9.85 ± 3.7 and 5.2 ± 3.77 mm^3 per million cycles, respectively.

To compare the relative wear paths of the three models, only the A/P and M/L displacement were plotted because the inferior-superior displacement simply followed the shape of the femoral component. Figures 3 and 4 show an example of the wear paths for the first 60% of the gait cycle for a medial and lateral node respectively.

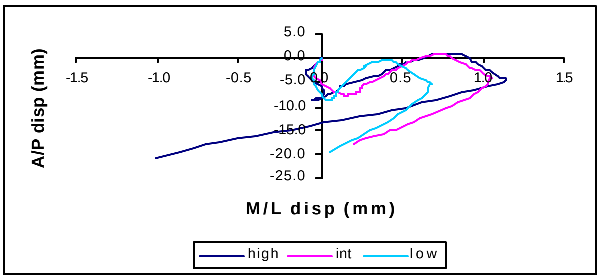

Figure 3. Representative wear paths for a medial node

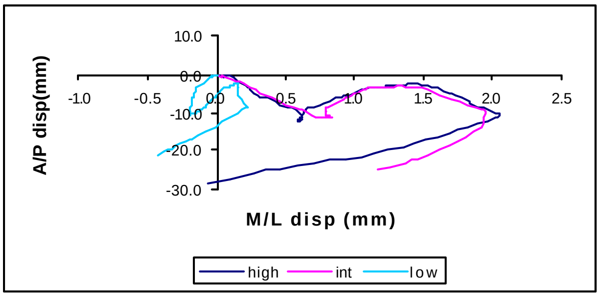

Figure 4. Representative wear path for a lateral node

It can be clearly seen from the above figures that all three models exhibit a looped wear path. As expected, the high kinematics model demonstrated the wear path with the greatest M/L displacement and the low kinematics model displayed the least M/L displacement on both the medial and lateral sides. The medial wear paths show little difference between models in the A/P direction. The high and intermediate kinematics models show similar A/P displacement on the lateral side but the low kinematics models has less A/P displacement.

The looped wear path is significant because the loop will introduce shear stresses, increasing the rate of wear. Wear theory states that wear volume is proportional to contact pressure and sliding distance [5]. A looped wear path will give a greater sliding distance than a linear path and thus increase the volume of wear exhibited per cycle. Increased M/L translation results in greater cross shear transverse to the principal direction of motion, which is parallel to the anterior-posterior motion in TKR. This accelerates wear in polyethylene due to strain hardening in the principal direction of motion and strain softening in the M/L direction.

CONCLUSION

This study has shown that the wear path for the PFC Sigma total knee replacement is looped, which will lead to increased wear due to greater cross shear on the articulating surface of the bearing. The finite element study has shown that the wear path is directly related to the wear rate that was found experimentally. The size of the loop is dependent on the input kinematics applied to the finite element model and this influences the rate of polymer wear.

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