Simulator Kinematic Inputs and Experimental Setup Influence the Wear of Knee Replacements

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Introduction: Experimental and computational wear simulation is used pre-clinically to determine the wear performance of total knee replacements (TKR). However, there can be a wide variation in simulation kinematic inputs and experimental setup testing parameters between different test centres. In experimental wear simulation a substantial body of work has been reported using the approach that has set the centre of rotation of femoral components on their distal radius and drives the anterior-posterior (AP) motion in order to facilitate femoral rollback [1]. The aim of this study was to investigate the influence of kinematic inputs (the amplitude and polarity of anterior-posterior displacement, femoral roll back versus anterior shift) and femoral setup (the position of the centre of rotation) on wear.

Methods: In the experimental simulation, six Sigma CR fixed bearing TKRs (DePuy Synthes, Leeds, UK) with curved moderately cross-linked polyethylene inserts (XLK) were tested in a Prosim knee simulator (Simulation Solutions Ltd, Stockport, UK) for three million cycles under each test condition, lubricated with 25% bovine serum, and wear was determined gravimetrically.

The femoral bearing was set up with the centre of rotation on either the distal radius [1], or according to the ISO specification 14243-3 [2]. Standard Leeds kinematic input conditions [1] were used for the TKR’s set up on the distal radius, with a maximum anterior-posterior displacement of either 10mm (high) or 5mm (intermediate), with a polarity (anterior shift of tibia relative to femur) that produced femoral rollback. For the ISO set up, the direction of the anterior-posterior displacement was reversed with anterior translation of the femoral component, preventing femoral roll back and keeping the contact in the centre of the tibial insert.

Statistical analysis was performed using one way ANOVA (significance at p<0.05) and 95% confidence limits were calculated.

The computational wear model was based on the contact area and an independent experimentally determined non-dimensional wear coefficient, previously validated against experimental data [3]. The computational wear model was used to predict wear under the same test conditions as the experimental simulation, but was further used to decouple the influence of the kinematic inputs and experimental femoral set up.

Results: The mean wear rates with 95% confidence limits from the experimental simulation are shown in Figure 1. The ISO set up with anterior translation of the femoral component, produced a significantly lower wearing configuration with a wear rate of 3.1 mm³/million cycles (MC) for Sigma CR XLK, compared to the historical Leeds set up on the distal radius and an AP motion polarity producing
rollback with a wear rate of 6.7 mm$^3$/MC ($p<0.01$). In the Leeds set up with AP motion polarity producing roll back, a reduction in the magnitude of the AP motion significantly reduced wear to 2.6 mm$^3$/MC ($p<0.01$).

The computational predictions showed good agreement with the experimental results, as shown in Figure 1. Further, the computational model showed that under the condition of distal centre of rotation and reversed intermediate AP motion, the wear rate was lower than that of the same (distal) centre of rotation with standard Leeds intermediate polarity. It was not possible to run either the experimental or computational simulation under any other combination of conditions due to the femoral component rolling off the tibial insert.

**Discussion:** The polarity and amplitude of AP motion had most effect on wear, for both set ups, with an anterior tibial shift with flexion producing femoral roll back and generating the highest level of wear. This posterior shift of the contact area generated increased cross shear and wear of the polyethylene, which was confirmed in the computational model. The current ISO set up with reversed AP polarity and anterior femoral shift on AP motion, which has been introduced to keep the contact in the centre of the tibia and prevent femoral roll back, produced a lower cross shear, lower wearing simulation, which will not replicate the range of kinematic conditions and wear rates found clinically.

**Significance:** These experimental and computational studies have shown that the most important factor influencing the wear of TKRs was the position of the relative contact point at the femoral component and tibial insert interface.