An Experimentally Validated Computational Model of a Six Axis Artificial Patella Femoral Joint Simulator during the Gait Cycle

[1]Maiti, R; [1]Fisher, J; [1]Jin, Z; +[1]Jennings, L M
+[1]Institute of Medical & Biological Engineering, School of Mechanical Engineering University of Leeds, UK
L.M.Jennings@leeds.ac.uk

Introduction

Patella femoral contact mechanics plays an important role in the success of total knee joint replacements. Computational modelling is an efficient way to analyse the biomechanics of patella femoral joint. The aim of this study was to develop computational models for the kinematics of a 6-axis patella femoral joint simulator and validate it against experimental simulation.

Materials and Methods

A PFC sigma® femoral component and round dome patella were considered for this study and supplied by DePuy International (Leeds, UK). An experimental simulation was carried out using the Leeds ProSim six station patella femoral joint simulator [1] for a total duration of 12 million cycles (MC). Kinematic measurements were taken at two time points, unworn (t=0) and worn (t=12 MC), to validate the multi-body dynamics model. The kinematic driven control strategies used for the study were flexion extension (FE) -12.5^{o} to +12.5^{o}, superior inferior (SI) displacement -5mm to 17mm, medial lateral (ML) rotation 0.2^{o} to -0.8^{o} and anterior posterior (AP) load 1300N to 400N [2]. The ML tilt and ML displacements were unconstrained. A moment representing the lateral ligament was applied to the patella to resist patella slip [3]. The change in shape of the patella in terms of maximum penetration depth was measured using a Form Talysurf stylus profilometer (Rank-Taylor Hobson, Leicester, UK).

Computationally, the articulation was modelled in multi-body dynamics at the two discrete time points. The patella (unworn and worn) geometry was obtained by scanning in Microtomography (MicroCT) and the femoral CAD geometry was supplied by the manufacturer. The MicroCT scans were reconstructed in ScanIP (Simpleware software, UK) and exported to MSC Adams/VIEW R3 (MSC.Software Corporation, CA) for rigid body analyses. The contact algorithm was Hertz penalty-based contact. The control strategy in the computational model was the same as used experimentally. The femoral component was constrained in the transverse plane and loaded by a force in the vertical direction. The patella was constrained in vertical direction but free to move in the transverse plane. A calibration of the model was performed so that the kinematics were linked with the ML displacements from the experimental results. The computational model predicted the ML displacement, ML tilt and AP displacement. Mean difference and concordant correlation coefficients were employed for validating the computational predictions against experimental results.

Results

The ML and AP displacements for unworn and worn patella specimens followed the same waveform shape as the FE rotation and SI displacement. The ML and AP displacement decreased for the worn specimen as compared to unworn at highest flexion (Figure 1 and Figure 2). The tilt for the unworn patella specimen fluctuated from lateral tilt at 4^{o} at the beginning of the cycle to 2^{o} medial tilt at 40% of the gait cycle before returning to lateral tilt at the end of the cycle. However, a constant lateral tilt of -1.5^{o} was obtained for the worn patella specimen throughout the gait cycle (Figure 3). The maximum penetration depth or deformation of the patella was 1.2 mm. The mean difference and concordant correlation coefficient for the computational prediction and experimental validation was 0.28mm (ML and AP displacements) and 0.95 respectively.

Discussion

The ML displacement observed was due to the inclination of the PFC sigma femoral groove from the axis of the femoral condyles towards the medial direction. An increase in ML and AP displacement was observed with increasing FE rotation and SI displacement. The difference in the ML and AP curve for worn specimen as compared to the unworn specimen was likely due to the change in shape caused during the wear test.

The geometry of the patella femoral groove at the beginning of the gait cycle and the lower conformity of the articulating surface led to a higher change in tilt from lateral to medial in the unworn patella specimen. The lateral tilt was due to the ligament load at the beginning of the gait cycle. The presence of deformation and subsequent higher conformity in the worn patella specimen led to low or constant lateral tilt for both experimental and computational simulations.

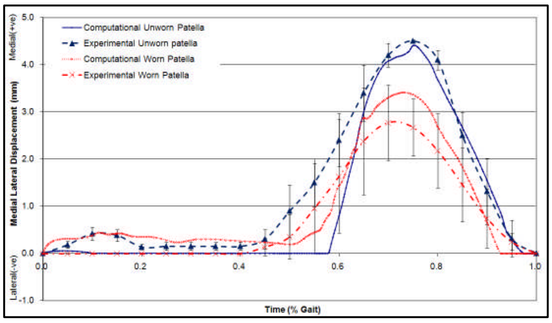

Figure 1: Variation of ML displacements for worn and unworn patella specimen during the gait cycle.

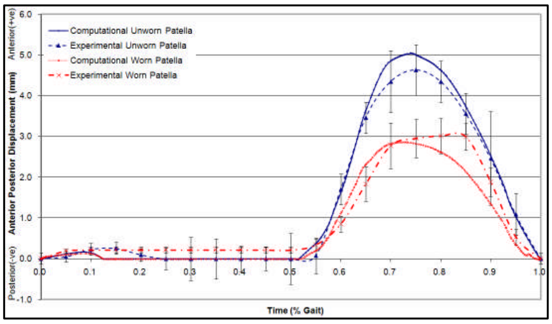

Figure 2: Variation of AP displacements for worn and unworn patella specimen during the gait cycle.

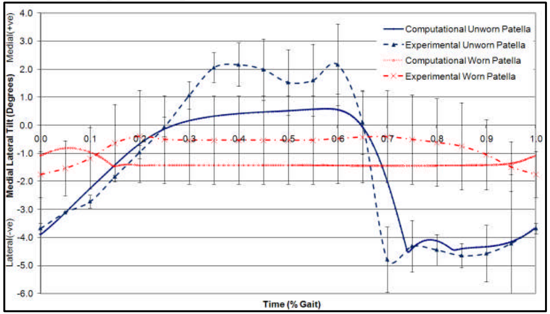

Figure 3: Variation of ML patellar tilt for worn and unworn specimen during the gait cycle.

Conclusion

Good overall agreement between the computational prediction and experimental validation was obtained. The unworn patella specimen had higher values of patellar tilt, ML and AP displacements as compared to worn specimen due to the change in shape caused in the specimen during the wear test.

References

1. Maiti, R., et al., ASME SBC conference 2011
2. Ellison, P., et al., J. of Biom, 2008(**41**): p 1407-1416
3. Singerman, R., et al., J. of Arthro, 1999(**14**): p 603-609

Acknowledgement

This research was supported by the EPSRC, NIHR, and LMBRU and DePuy, a Johnson & Johnson Company.