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Computational Corroboration of a Force-driven Knee Simulation Platform

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Force-driven (FD) simulation offers potential advantages for knee-implant testing; kinematics can adapt to implant geometry [1]. To be effective FD testing must produce well-defined, repeatable conditions – this requires a robust control scheme, leading to greater overall system complexity. It is important to understand the 'holistic' operation of the test system (mechanics and control), in order to correctly interpret results; for example, whether specific test outcomes are an artefact of implant design, input waveforms, controller operation, or rig mechanical dynamics. Therefore when using a commercial platform, there is considerable benefit in using computational modelling to augment the testing process, providing additional visualisation capabilities to gain insights into the test. This requires an *in-silico* model encompassing the full system (controller and mechanical rig) and capturing all aspects of the test dynamics.

Computational models of the AMTI 6-station knee wear simulator have been reported previously[2, 3]. The study by Lanovaz et al is noteworthy in that it identified unintentional system dynamics (flexion arm pliancy). However these models were displacement-driven. We have previously reported a similar displacement-driven model of the simulator, using rigid-body dynamics software[4]. Here, we describe the augmentation of this mechanical model with FD control-system simulation, and subsequent corroboration to validate this model.

The controller was developed in MATLAB/Simulink, using closed-loop PID control coupled with post-hoc dynamically iterating adaptive algorithms and progressive ramping on the different input channels (as with the *in-vitro* controller). Simulation times were found to increase, and because of the post-hoc nature of the control scheme, multiple trials were required per analysis. We circumvented this increase in computational overhead by initially using high-speed 'surrogate' models based on Hertzian contact, and subsequently switching to more detailed 'discretised' contact representation only once the tracking error was within a specified tolerance. This provides dynamically-adjustable control over the "performance-accuracy trade-off" through the simulation process.

The *in-silico* model was verified using bespoke experimental data for several simplified test-cases, and then for full FD ISO-specified gait[5]. Further mechanical pliancy was identified *in-vitro* (on the tibial side) which needed to be included to reproduce *in-vitro* results. Tracking was found to be greatly improved through the use of the adaptive controller.

This work paves the way for a better understanding of historical FD test data on this platform, better characterises the mechanics of the *in-vitro* rig, and provides additional visualisation capability, to analyse contact area, pressures, low-point and contact point motion, and cross-shear *in-silico*. Ultimately, it is hoped that this more holistic analysis approach can help to answer important questions on the best use of FD simulation in knee implant wear assessment.

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