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Development of a Muscle Actuator System

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ABSTRACT

Pre-clinical testing methods of total knee replacement (TKR) implants use different simulator platforms for characterizing the anticipated biomechanics of a reconstructed joint. Each system manipulates the joint using a different type of control. Muscle-controlled simulators apply forces to the quadriceps to generate motion, whereas force- and displacement-controlled simulators directly manipulate bone. Simulator costs limit testing to a single platform at a time. Limitations of each system prevents a full understanding of factors contributing to joint instability after TKR surgery. The aim of this study is to develop a joint motion simulator capable of muscle, force, and displacement-controlled loading.

In this work, a crouching rig is being developed and mounted on a VIVO joint motion simulator. A pneumatic actuator system simulates quadriceps muscle forces to extend a mechanical phantom knee. It includes pneumatic cylinders that apply tension forces through low-friction cabling to simulate the quadriceps. Muscle-controlled knee flexion is generated with an imported motion waveform. The system can be controlled to vary the control signal update frequency and period allotted for one waveform cycle. Torques applied by the VIVO generate flexion moments. These are counteracted by the crouching rig's simulated quadriceps extension which controls the knee through the prescribed motion. The combined effects of update frequency (5 levels), cycle period (3 levels) and reaction torque (3 levels) were examined. Desired and measured joint flexion angle was recorded for each test. The root-mean-square error (RMSE) is reduced with increasing cycle periods but increased with higher reaction torques. Further testing is needed to assess the effects of modifying the update frequency. The highest and lowest average RMSE for joint flexion angle are 13.6 ± 0.4° and 3.4 ± 0.1°, respectively.

Forces were measured before and after the low-friction cabling to measure friction losses. These were shown to increase with higher reaction torques and decrease with longer cycle periods. Losses remained relatively consistent across update frequencies. The highest and lowest average losses due to friction are 15.7 ± 0.7N and 4.8 ± 0.1N. Simulated quadriceps forces were observed to behave similarly to friction losses. The highest and lowest average quadriceps forces are 156.7 ± 2.7N and 45.1 ± 1.7N.

The comparative assessment between the tested parameters demonstrates that the crouching-rig being developed has potential to become a valid means of performing muscle-based motion on a force-displacement simulator. Once complete, the system will be validated against results measured using a standard Oxford rig in literature.

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