Development of a Deep Knee Bend Knee Simulator
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Introduction: Most knee simulators are designed for wear testing of total knee replacements (TKR). Few are designed to test a cadaver knee with dynamic activation of the muscles and even fewer, if any, include the capability for a deep knee bend motion. With the use of TKRs in patients requiring greater ranges of motion, these implants require in vitro testing that includes comparable motions and loadings. The purpose of this study was to develop and validate a muscle activated knee testing simulator that would allow deep knee bend motion of intact cadaver knees.

Materials and Methods: The design requirements include quadriceps and hamstrings force activation, tibial torsional loading, knee abduction/adduction, and knee flexion/extension as might be seen during a deep knee bend motion. A five actuator servohydraulic system was developed based upon an existing MTS loading frame (fig 1). Each channel can be controlled under either displacement or load control. Adjustable guides and pulleys redirect the force from the actuators to the clamps attached to the quadriceps and hamstrings. Hamstrings loading is divided as follows: 50% to the biceps femoris, 25% to the gracilis and 25% to the semitendinosus. Tibial rotation or torques are applied via a torsional actuator mounted beneath the tibia. A medial/lateral slider located at the simulated ankle causes knee ab/adduction. A 6 degree of freedom load cell mounted above the ankle provides feedback for tibial torque and knee ab/adduction forces. The MTS 18 inch vertical actuator permits a shallow knee bend cycle from 20 to 110 degrees of flexion or a deep knee bend motion of 72 to 150 degrees of flexion. For both motions, data from Nagura et al[1] was used to compute quadriceps and hamstrings forces. Tibial rotation was controlled to have 0 tibial torque, and ab/adduction was controlled to have either a fixed position or with a zero ab/adduction force. Five fresh frozen cadaver knees were tested using a deep knee bend motion and 3 were tested with a shallow knee motion. Tests were repeated in each knee with increasing loads until 100% of the desired load was reached.

Results: Although the simulator could achieve 150 degrees of knee flexion and this was also achieved in 2 knees (figure 2), some knees could not reach 150 degrees manually. In fact in one knee, just as the knee started to extend in the simulator from 150 degrees, the femoral condyles fractured due to it being flexed beyond its passive flexion limit and the high quadriceps force. As a result, quadriceps forces were limited to 2000 N (figure 3) and motion to each knee’s passive limit. Good tracking between the desired and actual forces was achieved (figure 4). The average absolute error was 4.2 N for the quadriceps force, 3.5 N for the hamstrings force and 0.15 N-m for the tibial torque.

Discussion: A muscle activated knee simulator that permits testing of cadaver knees with a deep knee bend motion was successfully developed. Physiological loads and motions of up to 150 degrees can be achieved. Some knees however, may have anatomical limitations which restrict flexion to less than 150 degrees of motion.


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