# Developing Loading Conditions for Experimental and Computational Knee Simulators

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**Statement of Purpose:** Experimental knee simulators are valuable tools in testing new materials and geometries for total knee replacement (TKR). In order to offset the extensive time and cost associated with performing long running, million-cycle iterations, computational simulators have been developed as complementary tools to the experiments (Figure 1). These models facilitate efficient design-phase iteration of implants which fit within the timeframe associated with product development (Knight LA. J Biomech. 2007;40:1550-1558). The International Standards Organization (ISO) prescribe loading conditions for a single representative gait cycle when evaluating wear in TKR implants. However, the variation in joint loads that are experienced by TKR patients in vivo is expansive. Joint loads are a function of implant design, surgical technique and patient-specific factors such as weight, limb alignment, and muscle forces. A single gait cycle cannot adequately evaluate the wear of a component on a population-basis. The purpose of the current study was to develop physiological loading conditions based on measured in vivo tibiofemoral (TF) joint load and kinematic data. These loads may be applied to both experimental and computational wear simulators to create comprehensive test-beds for wear evaluation in prospective TKR designs.

**Methods:** Published data from telemetric TKR patients has reported measured six-degree-of-freedom (6-DOF) in vivo TF joint loads during dynamic activities (Kutzner I. J Biomech. 2010;43:315-326). Video fluoroscopy has been used to measure TF joint kinematics for numerous patients and implant designs (Dennis DA. Clin Orthop Relat Res. 2003;416:37-57). A computational model of the lower limb was developed which derived the external loading conditions required to match either in vivo joint loading or kinematic data. CAD geometry of the implant used in in vivo data collection, was virtually implanted in the computational model. A proportional-integral-derivative (PID) control system was integrated with the finite element (FE) environment so that external loads applied through actuators in the model were updated to reproduce either telemetric joint loads, or fluoroscopically measured joint kinematics. The accuracy of the model in matching the in vivo motions or in vivo loads were assessed for three fluoroscopy patients during a squat and three telemetric patients during chair rise, step down, and squat, respectively.

**Results:** When reproducing fluoroscopy data, in vivo anterior-posterior (A-P), internal-external (I-E) motions and TF flexion was achieved through the control system with a root-mean-square (RMS) accuracy of less than 1mm, 0.1° and 1.4°, respectively, for the lower limb model (Figure 2). When reproducing telemetric data, in vivo compressive joint load, medial-lateral load split and I-E torque were achieved with an accuracy of 80 N, 2% and 0.3 Nm, respectively (Figure 3). There was substantial range in external loading profiles and resulting TF joint loads between patients.

**Conclusions:** The PID-controlled model described in this study was able to reproduce both in vivo joint loads and kinematics with a high degree of accuracy. This model can be used to derive loading conditions for experimental and computational wear simulators that better represent physiological loading conditions than wear standards. With a larger sample of in vivo data, the range of external loads in the patient population can be derived. Loading profiles for wear simulators can be developed which explore the range of physiological loads, as well as the 'mean' profile.

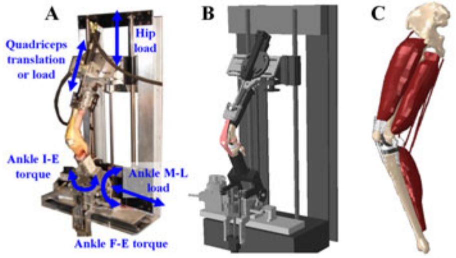

Figure 1: Experimental and computational versions of knee simulator (A&B), lower limb model (C).

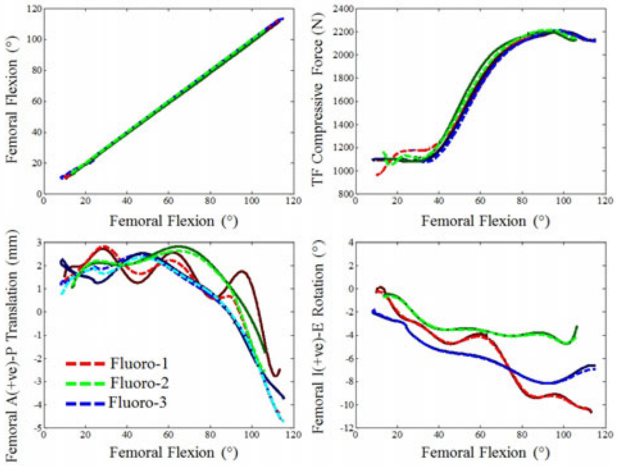

Figure 2: Comparison between experimental (solid line) and FE model predicted (dashed line) TF kinematics and compressive load for three fluoroscopy patients

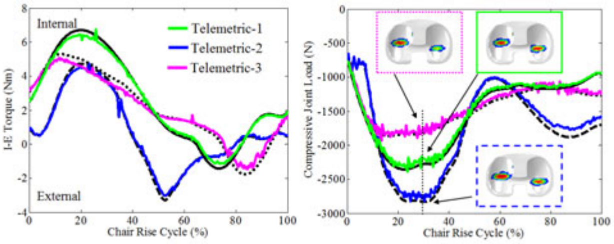

Figure 3: Comparison between experimental (black lines) and FE model predicted (colored lines) TF joint loads for three telemetric patients

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