INTRODUCTION
The American Society of Testing Materials (ASTM) provides a standard mechanical testing protocol of total knee implants to determine constraint criteria. Posterior-stabilized (PS) implants are constrained in the anterior-posterior (AP) direction by a cam and post mechanism and rotationally by curved bearing surfaces.

Computational prediction of constraint within total knee implants has two potential advantages over standard bench-top testing. First, inherent experimental inaccuracies and variation in testing devices between facilities may invalidate implant comparisons. Second, a computational model that accurately predicts constraint could be used as a design tool before resources are spent in prototyping and physical testing of implants. Similar computational approaches have been used to predict wear and constraint within knee implants in a mechanical tester (1,2). The purpose of this study was to develop a computer model that could predict the constraint demonstrated by a PS knee implant in a mechanical knee tester undergoing standard ASTM protocol (3).

METHODS
A Duracon PS knee implant (Stryker Orthopedics) was mechanically tested for AP and rotational constraint at 0°, 30°, 60°, 90°, and 120° flexion in an MTS 858 Bionix Test Frame. For the AP trials the tibial insert was cycled at a frequency of 0.125 Hz from neutral position to peak posterior/anterior displacement and the required force to produce this motion was collected. For the rotational trials, the tibial insert was locked in place and the femoral component was rotated at the same frequency through ±20° internal/external rotation. Similarly, the required torque to produce this motion was collected. In all trials the femoral component was free to move in varus/valgus and to translate vertically.

The experimental setup was modeled as 7 segments, two of which were the femoral and tibial implants. Segmental masses, geometry, damping and compliance parameters were measured and prescribed within the model. Manufacturer supplied CAD files defined the implant surfaces, and joint contact was implemented using a rigid body spring model (4). Polynomial and Fourier fitted curves were used to model the compressive load that varied from 0 – 300N throughout the trials. Prescribed motion for each simulation matched the corresponding experimental trial.

Equations of motion were formulated and integrated forward in time via the SIMM/Dynamic Pipeline (Musculographics, Inc.) and SD/FAST (Parametric Tech Corp.) software packages. Custom MATLAB (Mathworks Inc.) software was used to compute root mean square (RMS)
differences between model and experimental forces and torques.

RESULTS AND DISCUSSION

Computer model constraint forces and torques for both AP and rotational simulations, respectively, compared favorably to experimental outputs (Figure 1). The curves had qualitatively similar shapes, but since contact friction was not included the computer model forces and torques were slightly less than the experimental values. The RMS differences between model and experimental averaged 31.8 N for AP tests and 1080.3 N·mm for rotational tests.

![Figure 1](image1.png)

**Figure 1.** Rotational constraint comparison for a given flexion angle. Qualitatively the curves matched well for all flexion angles.

The purpose of the ASTM standard is to build a database of constraint criteria for the unbiased comparison of total knee implants (3). Such a database could serve as a clinical tool in the selection of implants for specific patients based upon constraint criteria. However, inherent inaccuracies and artifacts present in bench-top experiments could bias this database. In the present setup, there was found to be fixture compliance within the vertical testing arm. Computer simulations of AP constraint trials without this measured fixture compliance resulted in significantly larger forces when the cam contacted the posterior aspect of the post (Figure 2A). Similarly all simulations were sensitive to the initial starting or “neutral” point (Figure 2B). Computer models such as this are promising as a means for meaningfully comparing constraint differences between implants because they are free from experimental artifacts.

![Figure 2](image2.png)

**Figure 2.** Sensitivity to AP fixture compliance (A) and to starting “neutral” position (B) on model constraint force during an AP simulation.

REFERENCES


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