Virtual Reconstruction of the Posterior Cruciate Ligament for Mechanical Testing of the Knee
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INTRODUCTION
In order to replicate clinically relevant kinematics when testing cruciate-retaining total knee replacements (TKR) under force control, it is essential to simulate the restraint obtained from the soft tissues of the knee. To accomplish this, the AMTI VIVO (AMTI, Waterford, MA) six-axis hydraulic testing machine allows for the creation of virtual ligaments. Therefore, our objective was to determine if virtually reconstructing the PCL in a six-axis hydraulic testing machine could substitute in the absence of the physical ligament.

MATERIALS AND METHODS
- Three cadaveric knees dissected, such that all soft tissue removed with the exception of the cruciate and collateral ligaments, and mounted in the AMTI VIVO six-axis hydraulic testing machine.
- PCL attachment points on femur and tibia digitized using Microscribe (RevWare, Raleigh, NC).
- PCL properties determined through testing of intact knee and after cut PCL:
  - Characterization testing:
    - Anteroposterior (AP) drawer (+/- 50N) at 0°, 45°, and 90° flexion.
  - Kinematic Assessment:
    - Stair-Climbing [1]
    - Deep Knee Bend [2]
- Virtual PCL constructed of three virtual ligament fibers (Figure 1).
- Testing repeated and PCL parameters optimized until AP displacement of the PCL-deficient knee with the virtual PCL was within 10% root mean square error (RMSE) of the intact knee.

RESULTS
Figure 1. The PCL was simulated with 3 virtual ligament fibers. One fiber represented the PM bundle (blue) with two fibers representing the AL bundles (pink and yellow).

Figure 2. The virtual PCL was able to replicate kinematics within the goal of 10% RMS for all three specimens. One cycle of stair climb for specimen 2 is shown. RMS error this specimen was 6%.

The same trend in kinematics was seen for all 3 specimens, with notable additional posterior translation occurring following transection of the PCL (Figure 2). Furthermore, the RMSE of the difference in kinematics between the virtually reconstructed knee and the intact knee was found to be within 6-8% for all tests.

DISCUSSION
In this study, we demonstrated the ability to restore native kinematics, within a goal of 10% RMSE, through the use of a virtual PCL with the AMTI VIVO six-axis hydraulic testing machine. The results of this work suggest that such a three-fiber virtual ligament model, although much simpler than the native anatomy, may sufficiently replicate the kinematics of the knee. The goal of this study was not to replicate a precise and anatomically detailed model of the ligament, but to construct a model which generates a physiologically relevant simulation of the biomechanical properties of the ligament. While this study focused on the PCL, a similar approach may be used to virtually reconstruct the collateral ligaments.

REFERENCES