Impact of Selective PCL Fiber Release on Femoral Rollback in Cruciate-Retaining Total Knee Arthroplasty: A Computational Study

Reza Pourmodheji[1], Cynthia A. Kahlenberg[2], Eytan M. Debbi[2], Brian P. Chalmers[2], William J. Long[2], Timothy M. Wright[1], Geoffrey H. Westrich[2], David J. Mayman[2], Peter K. Sculco[2], Carl W. Imhauser[1]
[1]Department of Biomechanics, [2]Adult Reconstruction and Joint Replacement, Hospital for Special Surgery, New York, NY
Email of Presenting Author: pourmodhejir@hss.edu

Disclosures: Reza Pourmodheji (N), Cynthia A. Kahlenberg (N), Eytan M. Debbi (N), Brian P. Chalmers (N), William J. Long (Depuy/J&J, TJO, Orthodevelopment, Globus, Microport), Timothy M. Wright (Exactech, Lima, Mathys, Orthobond, Stryker), Geoffrey H. Westrich (Exactech, Stryker), David, J. Mayman (Stryker, OrthAlign, Smith and Nephew), Peter K. Sculco (Depuy/J&J, EOS, Intellijoint, Lima), Carl W. Imhauser (Corin)

INTRODUCTION: Among all the primary total knee arthroplasty (TKA) cases in the United States, cruciate-retaining (CR) designs have the highest utilization with 49.7% of all cases in 2021 [1]. In CR-TKA, femoral rollback is achieved by preserving the posterior cruciate ligament (PCL), to enable knee flexion [2]. However, partial or total release of the PCL is often performed intraoperatively in knees with excessively tight flexion gaps or with larger than desired femoral rollback [3]. Despite this common operative practice, the effect of serial release of selected PCL fibers on femoral rollback in CR-TKA is not well understood. This knowledge gap leaves surgeons with limited rationale for what portion and how much of the PCL to release. Therefore, we addressed the following research question *in silico*: 1) How does serially releasing the PCL fibers affect posterior translation of the medial and lateral femoral condyles through a range of knee flexion from 0 to 90°?

METHODS: Computational models derived from nine independent cadaveric left knees (four male, five female; age: 60.9±13.6 years) were virtually implanted with CR femoral components and standard CR tibial inserts (Persona, Zimmer-Biomet, Warsaw, IN) following the manufacturer's protocols including 7° of posterior tibial slope. The computational modeling pipeline utilized a multibody dynamics framework including a rigid body contact formulation to describe the articular interactions. The ligaments were described with 27 nonlinear spring elements representing the PCL, collaterals, and capsular ligaments The PCL was composed of seven elements, identified by a numbering convention based on the femoral insertion anatomy where the most posterior and medial femoral was fiber one and the most anterior and lateral fiber was fiber seven (Fig. 1). A previously published optimization algorithm was used to define ligament slack length while population mean stiffnesses were selected from the literature [4]. The knee was flexed from 0 to 90° under 500 N of compression representing a clinical test of passive flexion. The knee was flexed with all PCL fibers intact (PCL retained) and after serially deactivating each fiber to simulate their release starting with fiber seven and finishing with fiber one. Fibers were serially sectioned in this order because the most anterolateral fibers (fibers 5-7) are more anisometric and, therefore, could provide the greatest contribution to femoral rollback. Rollback of both the medial and lateral femoral condyles was quantified as the anterior-posterior (AP) distance between the contact points on each tibial compartment at 0° and 90° of flexion with anterior translation designated as positive. A Kolmogorov-Smirnov test ($p<0.05$) revealed that our data were not normally distributed; therefore, we reported medians and quartiles. To compare femoral rollback between each successive release of a PCL fiber, we used a nonparametric Kruskal-Wallis test with Least Significant Difference (LSD) post-hoc correction for multiple comparisons ($\alpha=0.05$).

RESULTS: Serially releasing PCL fibers seven through five had minimal effect on rollback of both the medial and lateral femoral condyles. Subsequently, serial release of fiber four in combination with fibers five through seven reduced the femoral rollback compared to the PCL-retained condition by a median of 1.4 [0.8 2.1] mm ($p=0.01$) and 1.3 [1.2 2.5] mm ($p=0.04$) medially and laterally, respectively. Subsequent serial release of the remaining PCL fibers also did not further impact femoral rollback.

DISCUSSION: Our most important finding was that simulated serial release of the PCL fibers in our computational model reduced femoral rollback in a nonlinear manner. The largest reduction in femoral rollback occurred after releasing PCL fiber four after releasing fibers seven through five. PCL fiber four was located at the middle of the femoral insertion site of the PCL (Fig. 1). This fiber was the most anterior fiber of the posteromedial bundle of the PCL on the femur. Although we utilized a simplified 7-fiber representation of the PCL, the fibers spanned the insertion areas of the PCL and reflected the orientation of the PCL (Fig. 1). Our results suggest that a targeted or partial release of PCL in CR-TKA to achieve a desired femoral rollback should be performed with a focus on the fibers in the central aspect of the PCL, given the high dependency of femoral rollback on these fibers.

SIGNIFICANCE/CLINICAL RELEVANCE: Our study provides biomechanical rationale for what portion and how much of the PCL to section to achieve more targeted femoral rollback in CR-TKA.

REFERENCES: [1] AJRR 2022 Annual Report. [2] Williams 1996 CORR. [3] Scott 2008 J. Arthroplasty. [4] Kia 2016 J. Biomech. [5] Cousin 2021 Orthop. Traumatol-Surg.
ACKNOWLEDGEMENTS: The Clark and Kirby Foundations. Implants donated by Zimmer Biomet, Inc.

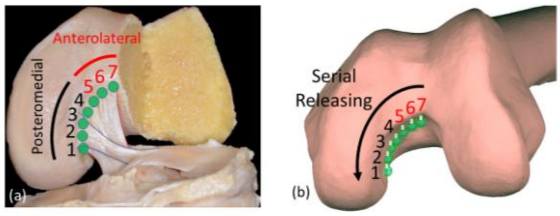

Figure 1: Femoral insertion of the PCL fibers numbered from 1 to 7 where fibers 1 to 4 represent the posteromedial bundle and fibers 5 to 7 represent the anterolateral bundle (a). Serial release of the PCL fibers began with fiber 7 and ended with fiber 1 (b). Cadaver image adapted from Cousin et al [5].

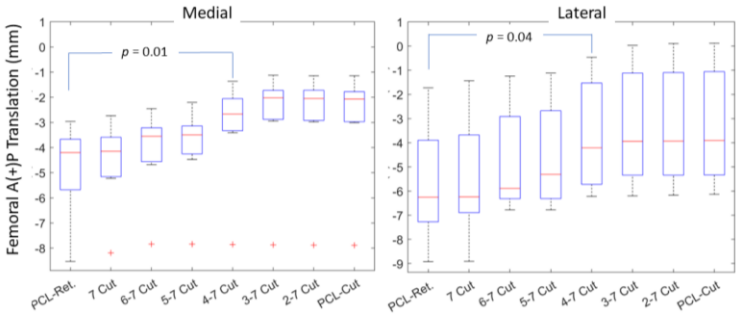

Figure 2: Box plots of femoral anterior-posterior translation of the medial (left) and lateral (right) condyles as a function of serial release of the PCL fibers. Red lines and boxes represent medians and quartiles, respectively. The whiskers extend to the most extreme data points not considered outliers. An outlier (red cross) is a value that is more than 1.5 interquartile range (IQR) away from the top or bottom edge of the box. The anterior translation of the femur is positive. PCL-Ret = PCL-retained, 7-Cut indicates that only PCL fiber 7 was deactivated. 6-7 Cut indicates that PCL fibers 6 and 7 are deactivated and so on. PCL-Cut indicates that all PCL fibers were deactivated.