Retaining the Posterior Cruciate Ligament increases Femoral Rollback in Medial Congruent Total Knee Arthroplasty: A Computational Study

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INTRODUCTION: Medial congruent (MC) polyethylene designs in total knee arthroplasty (TKA) are intended to enhance anterior-posterior (AP) stability and reproduce the "medial pivot" behavior of the native knee joint [1]. The design allows retention or resection of the posterior cruciate ligament (PCL); however, the impact of the PCL on femoral rollback in this more congruent medial articulation is not well understood. Therefore, significant clinical controversy exists regarding whether the PCL needs to be retained in MC-TKA [2]. Moreover, PCL insertion anatomy exhibits heterogeneity among knees [3]. Unfortunately, the relationship between the level of bone resection in MC-TKA, PCL insertion anatomy, and femoral rollback is also unclear. Therefore, we addressed two research questions *in silico*: (1) How does simulated PCL resection affect rollback of the medial and lateral femoral condyles from 0° to 90° of knee flexion? (2) Is PCL anatomy, specifically the femoral insertion of the PCL with respect to the bone resection sites, related to the amount of femoral rollback in flexion? We hypothesized, first, that retaining the PCL will increase the posterior translation of the medial and lateral femoral condyles in flexion, and, second, that the smaller the distance of the femoral insertion of the PCL is to the plane of the distal bone resection the greater is the femoral rollback.

METHODS: Computational models derived from 10 independent cadaveric left lower limbs including the entire femur and tibia (five males, five females; mean age: 63.7±10.5 years) were virtually implanted with an MC tibial insert and cruciate retaining femoral component (Persona, Zimmer-Biomet, Warsaw, IN). The computational model used a multibody dynamics framework, which includes a rigid body articular contact formulation and tension-only nonlinear elements representing the PCL, collaterals, and capsular ligaments (Fig. 1a) [3]. Specifically, the PCL was composed of the posteromedial bundle (PMB) with 4 elements (1-4) and the anterolateral bundle (ALB) with 3 elements (5-7) (Fig. 1b). A previously published optimization algorithm was used to define ligament slack lengths while population mean structural properties were selected from the literature [4]. A geometric ratio (*DPRatio*) for each PCL fiber was defined as the ratio of the perpendicular distances from the femoral insertion of each PCL fiber to the femoral distal cut and to the femoral posterior cut (Fig.1 c and d). The knee was flexed from 0 to 90° under 500 N of compression simulating a clinical exam of passive flexion with the PCL-retained and resected. Femoral rollback was defined as the AP translation of the tibiofemoral contact points on the tibial insert from 0° to 90° of flexion. For our first research question, a nonparametric signed-rank test was performed to compare femoral rollback between the PCL-retained and -resected conditions (α=0.05). For the second research question, linear regression was performed to identify correlations between the femoral rollback and the *DPRatio* of each PCL fiber. All regression coefficients (β) and their corresponding p-values ($\alpha = 0.05$) were reported as were the coefficients of determination (R^2).

RESULTS: Regarding question one, with the PCL retained, the medial femoral condyle translated posteriorly 2.3 [2.0 2.8] mm more than with the PCL resected (p=0.002) (Fig. 2); this difference was 3.4 [3.1 4.0] mm for the lateral compartment (p=0.0009). Concerning question two, posterior translation of the medial and lateral condyles was greater in subjects with a smaller *DPratio* for the fibers comprising the ALB, which corresponded to fibers 5 through 7 in our PCL model. (Fig. 3). Fiber 6 had the greatest regression coefficient medially (β=23.5 mm, $p = 0.001$) and fiber 7 laterally (β=17.7 mm, $p = 0.002$).

DISCUSSION: Retaining the PCL in medial congruent TKA increased femoral rollback in passive flexion on both the medial and lateral compartments, which supports our first hypothesis. Our findings suggest that retaining the PCL aids in femoral rollback even with the more congruent medial compartment in MC-TKA. Interestingly, we found that femoral rollback was heterogeneous among the ten knee models. However, femoral rollback was correlated with the location of the femoral insertion of the AL fibers of the PCL but not for the PM fibers. Specifically, the knee models with AL fibers closer to the distal femoral cut than the posterior femoral cut (i.e., a smaller *DPRatio*) showed more femoral rollback. This finding suggests that *DPratio* of the PCL fibers could help estimate the amount of femoral rollback, preoperatively. For example, additional distal bone resection (assuming a fixed posterior cut) yields a smaller *DPratio* and thus greater femoral rollback. Therefore, assessing the distance between the femoral insertion of the more vertically oriented AL fibers of the PCL and the distal and posterior bony cuts could help surgeons more predictably target a desired level of femoral rollback.

SIGNIFICANCE/CLINICAL RELEVANCE: The PCL acts to increase femoral rollback in MC-TKA. Considering patient-specific insertion anatomy of the PCL can help surgeons strategize targeted bony resections in MC-TKA to achieve a desired level of femoral rollback.

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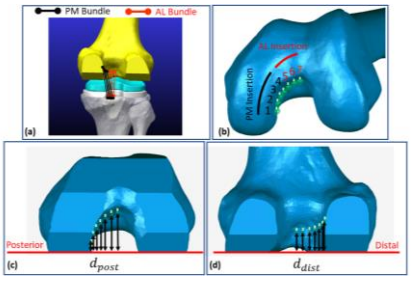

Figure 1: Description of the PCL fibers in the computational model (a) and the femoral insertion of the PCL fibers (b). Illustration of the distance of the femoral insertion of the PCL fibers from the posterior (c) and distal (b) bony resection planes.

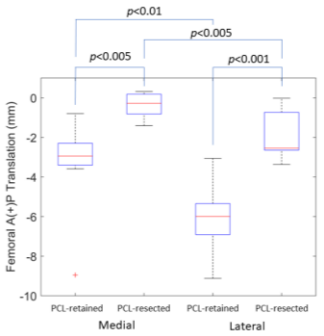

Figure 2: Box plots of AP translation of the medial and lateral compartments with the PCL-retained and PCL-resected. More femoral rollback corresponds to a more negative number.

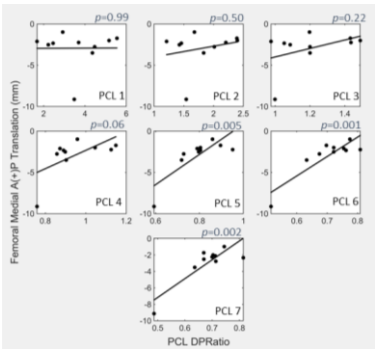

Figure 3: Linear regressions relating femoral rollback of the medial condyle with the *DPRatio* for each fiber of the PCL (PCL-1 to PCL-7).