# Increasing the Posterior Tibial Slope Lengthens the Collateral ligaments without Altering the Cruciate Ligaments Under Two Sets of Combined loads

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**Introduction:** Anterior-closing or anterior-opening wedge high tibial osteotomies (HTO) are orthopaedic procedures that alter the proximal tibial geometry to modify the posterior tibial slope (PTS), affecting the native ligament tension [1]. Increasing the PTS has been shown to increase medial compartment loading [2] and anteriorly shift the pressure on the medial tibiofemoral cartilage [3]. Understanding how increased PTS alters ligament length is crucial, as ligament length changes affect stability and proprioception [4]. The objective of this study was to quantify the effect of increasing the PTS on the length of the collateral and cruciate ligaments in response to external loadings. Based on previously published studies [5, 6], an increased PTS was hypothesized to increase the length of the collateral and anterior cruciate ligaments and decrease the length of the posterior cruciate ligament.

**Methods:** A six degree of freedom robotic testing system (MJT Model FRS2010) was used to apply external loads to seven fresh-frozen cadaveric knees (mean age: 50.1 ± 13.1 years, 30% female). Inclusion criteria for the specimens included ligamentous stability at manual examination and intact menisci, cruciate, and collateral ligaments confirmed via diagnostic arthroscopy. The following loads were continuously applied from full extension to 90° of flexion: 1) 200 N axial compression + 134 N anterior tibial load, and 2) 5 Nm internal tibial + 10 Nm valgus torque. Ligament lengths were measured for two PTS states: 1) Native PTS and 2) Increased PTS. Anterior opening wedge HTO was performed to increase the slope by 10 degrees [4]. A spanning external fixator and wedge were used to stabilize the osteotomy and allow for accurate slope adjustment. The medial (MCL) and lateral collateral (LCL) ligaments were assessed as three separate bundles: anterior, intermediate, and posterior [8]. The length of the MCL bundles was measured using two segments: femoral insertion to inflection point and inflection point to tibial insertion. The inflection point, defined as the most prominent edge of the tibial plateau, was approximately 65 mm from the MCL tibial insertion [8, 9]. The anterior (ACL) and posterior (PCL) cruciate ligaments were defined as one bundle, spanning between the centroid of their femoral and tibial footprints. The length of the ligaments was determined by the 3D distance between their femoral and tibial insertions using a registration block technique [10]. A three-way repeated-measures ANOVA analyzed length changes in each collateral ligament bundle (anterior, intermediate, posterior) at full extension, 30°, 60°, and 90° of flexion in both PTS states and loading conditions. A two-way repeated measures ANOVA was used to analyse length changes in each cruciate ligament at full extension, 30°, 60° and 90° of flexion in both PTS and under both loading conditions. Significance was set at $p < 0.05$.

**Results:** Anterior opening wedge HTO significantly increased the PTS from 10.0 ± 3.4° to 16.6 ± 3.3° ($p < 0.05$). Under 200N axial compression + 134N anterior tibial load, the length of the anterior bundle of the LCL showed the greatest changes at full extension (+2.0 mm, 3.6%, $p < 0.05$) while the posterior bundle showed its largest change at 60° of knee flexion (+3.3 mm, 5.6%, $p < 0.05$). Both bundles were significantly longer at each knee flexion angle in the increased PTS state. For the MCL, the anterior and intermediate bundles were both significantly longer at full extension, 30° (intermediate only) 60°, and 90° of knee flexion and showed their largest changes at knee full extension with +4.4 (+4.9%) and +4.1 (4.4%) mm, respectively. Under 5Nm internal tibial torque + 10Nm valgus torque, the anterior and posterior bundles of the LCL showed their largest changes in length at full extension (+2.2 mm, 4.0%, $p < 0.05$) and 90° (+3.3, 6.1%, $p < 0.05$) of knee flexion, respectively. No significant changes were observed in individual MCL bundles. The ACL showed its largest changes at 60° of knee flexion under 200N axial compression + 134N anterior tibial load (+1.0 mm, 0.5%, $p > 0.05$) and PCL showed its largest change at 90° of knee flexion under 5Nm internal tibial torque + 10Nm valgus torque (-1.7 mm, -5.2%, $p > 0.05$). No other significant changes were observed for the ACL and PCL.

**Discussion:** The increased PTS lengthened the LCL and MCL under both loading conditions. The anterior bundle of the LCL likely experiences greater tension at full extension due to the anterior displacement of the lateral femoral condyle [11], while the posterior bundle is more affected at higher flexion angles due to increased posterior displacement of the lateral femoral condyle [12]. The anterior and intermediate bundles of the MCL lengthened significantly at most knee flexion angles under 200N axial compression + 134N anterior tibial load, likely due to the HTO shifting their tibial insertions further from their femoral insertions. The proximity between the posterior bundle of the MCL and the hinge point of the HTO explains the non-significant changes. The absence of significant changes of length of the MCL bundles under 5Nm internal tibial torque + 10Nm valgus torque is attributed to the posterior displacement of the tibial insertions during tibial internal rotation which likely limits the effect of the increased PTS on the anterior and intermediate bundles. Although increased PTS induces an anterior tibial displacement [13], the ACL showed no significant difference under either loading conditions, possibly due to three-dimensional change in the position of its tibial insertion site, which causes the tibial and femoral ACL insertion sites to converge [6]

**Clinical relevance:** Increased PTS significantly elongates the collateral ligaments at various knee flexion angles under external loading conditions. Longer ligaments experience larger loads, which may affect knee range of motion, potentially causing overstretching, stiffness and knee pain [4] and making it essential to assess ligament length after the PTS adjustments to limit iatrogenic tension.

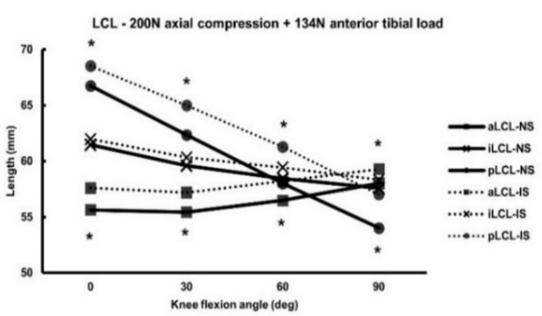


**Figure 1.** Lateral collateral ligament bundles length after increasing the posterior tibial slope under 200 N axial compression + 134 N anterior tibial load. *aLCL: anterior, iLCL: intermediate, pLCL: posterior bundles.* Full lines = native PTS, dotted lines = increased PTS. (*) = Statistical difference between native and increased PTS (p<0.05).

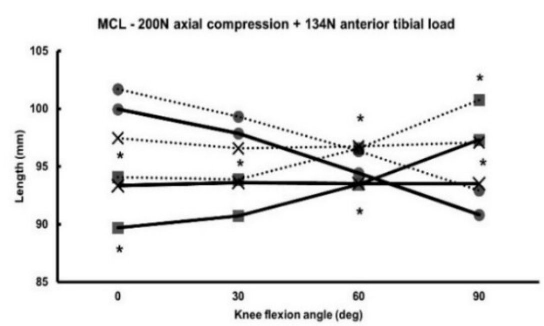


**Figure 2.** Medial collateral ligament bundles length after increasing the PTS under 200 N axial compression + 134 N anterior tibial load. aMCL*: anterior, iMCL: intermediate, pMCL: posterior bundles.* Full lines = native PTS, dotted lines = increased PTS. (*) = Statistical difference between native and increased PTS (p<0.05).

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