

The Role of the Oblique Popliteal Ligament and Other Structures in Preventing Knee Hyperextension

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Background: Ligament restraints to terminal knee extension are poorly understood.

Hypotheses: (1) As with other motions of the knee, genu recurvatum is limited primarily by a named, identifiable structure. (2) As the largest static structure of the posterior knee, the oblique popliteal ligament is uniquely suited to act as a checkrein to knee hyperextension.

Study Design: Descriptive laboratory study.

Methods: Twenty fresh-frozen human knees were divided into 3 groups for a ligament sectioning study. Extension moments of 14 and 27 N·m were applied before and after sectioning of each ligament, and motion changes were recorded. In group 1, the oblique popliteal ligament was sectioned first, followed by the fabellofibular ligament, ligament of Wrisberg, anterior cruciate ligament, posterolateral structures, and posterior cruciate ligament. In group 2, the order was altered to section the anterior cruciate ligament first; no other changes were made. Similarly, the cutting order for group 3 was altered to section the posterior cruciate ligament first. The sagittal tibial slope of each specimen was documented off a lateral radiograph.

Results: The greatest increase in knee hyperextension was observed after sectioning the oblique popliteal ligament. This was independent of cutting order, consistent across groups, and statistically significant. In all groups, the increase in knee hyperextension after sectioning the oblique popliteal ligament approached or exceeded the increases seen after sectioning the anterior and posterior cruciate ligaments combined. Overall, less knee hyperextension was seen in knees with increased posterior tibial slope.

Conclusion: The oblique popliteal ligament was found to be the primary ligamentous restraint to knee hyperextension.

Clinical Relevance: Further studies are needed to determine if surgical repair or reconstruction of the oblique popliteal ligament can restore normal motion limits in patients with symptomatic genu recurvatum. Patients with decreased posterior tibial slope would have increased recurvatum with posterior structure injury, which increases the likelihood of increased symptoms in this population.

Keywords: genu recurvatum; oblique popliteal ligament; posterior tibial slope

In our tertiary referral sports medicine practice, we have seen a subset of patients with symptomatic posttraumatic genu recurvatum. These patients complain of knee hyperextension with normal gait or when stepping into holes or when ambulating on uneven terrain. Symptomatic, non-osseous genu recurvatum as a source of posttraumatic

functional morbidity is poorly understood. The nature of the anatomical injury has not been identified, and this lack of anatomical understanding has made therapeutic intervention problematic. Clinically, it has been noted that patients with pain and functional genu recurvatum had damage to posterior knee structures in the absence of other sources of ligamentous injury.²⁹

While a primary stabilizer against knee hyperextension has not been identified, previous authors have hypothesized such a role for many structures of the knee. These structures include the cruciate ligaments,^{27,30} the bony anatomy of the distal femoral condyles,⁷ the collateral ligaments,^{14,22,30} the posterior capsule,^{7,19,30} the fabellofibular ligament,³² the medial and lateral menisci,¹⁶ and the oblique popliteal ligament.⁴ To our knowledge, no author to date has performed the biomechanical studies necessary to test these hypotheses.

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Previous investigators have analyzed the posterior knee with forced hyperextension to assess which structures fail.¹ The posterior capsular structures failed first, followed by the posterolateral structures, and then the posterior cruciate ligament. Only one biomechanical sectioning study has been performed on posterior knee structures.²⁰ Interpretation of this study's data is problematic, however, as multiple structures in the posterior knee were sectioned simultaneously. Significantly, hyperextension was not tested, nor was the oblique popliteal ligament specifically mentioned by name.

Our purpose was to analyze the static restraint to terminal extension using the sequential sectioning technique on the major structures of the posterior knee, posterolateral knee, and the cruciate ligaments. Our hypothesis was that the oblique popliteal ligament, the largest structure of the posterior knee and one which crosses the posterior joint line, would have a significant role in preventing knee hyperextension.

MATERIALS AND METHODS

Approval for the study was obtained through the Institutional Review Board at the University of Minnesota. Five pilot knees were first tested to establish the study design and determine the cutting order of the posterior knee structures and cruciate ligaments. The experiment detailed here was subsequently performed on an additional 20 paired fresh-frozen knees. Clinically significant hyperextension was estimated using published hyperextension values for anterior cruciate ligament impingement within the intercondylar notch of $6.3^\circ \pm 3.8^\circ$.⁹ An a priori power analysis was then performed to determine sample size using StatMate Software (GraphPad Software Inc, San Diego, California). With an expected standard deviation of 1° and setting the significance level (α) at .05, the minimum group size was determined to be 5 knees to detect a 2.5° change.

Preparation, dissection, and sectioning were performed using a standardized protocol. The posterior knee was exposed to the superficial crural fascial layer with all individual posterior knee structures left intact (Figure 1). The neurovascular bundle was removed to improve visualization. Each knee was mounted into the testing apparatus via an intramedullary femoral rod secured into place with polymethylmethacrylate (Figure 2). A second intramedullary rod was cemented into the tibia for application of a static weight and manipulation of the joint during hyperextension and rotation experiments. The Polhemus FASTRAK electromagnetic 3-D tracking system (Polhemus Inc, Colchester, Vermont) was used to monitor the movement of the femur and tibia. Angles measured within the coordinate systems were calculated by the software that runs the Polhemus FASTRAK device. The accuracy of alternating current electromagnetic tracking devices has previously been reported to be within 0.25° and 0.1 mm.¹⁷ Coordinate systems were developed for both the femur and tibia using digitized bony landmarks within the

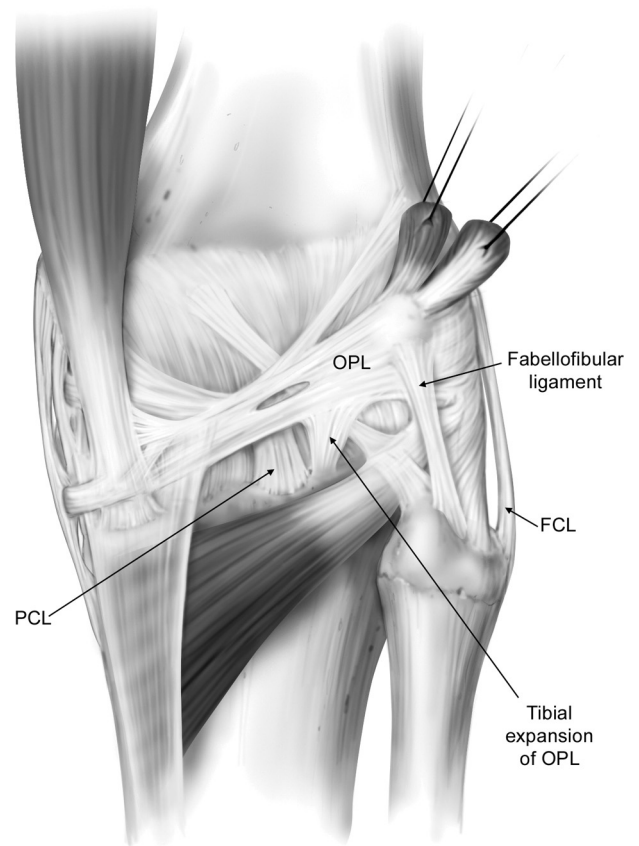


Figure 1. The posterior aspect of the human right knee. OPL, oblique popliteal ligament; FCL, fibular collateral ligament; PCL, posterior cruciate ligament. Modified and reprinted with permission from *The Journal of Bone and Joint Surgery*.

electromagnetic field. The center of rotation of each knee was defined to be the epicondylar axis. The y-axis for the femur was defined as a line through the center of the proximal femoral shaft, measured 18 cm proximal to the joint line, and the centroid of a line connecting the medial and lateral femoral epicondyles. The x-axis was then defined as a line perpendicular to the longitudinal axis. The z-axis was defined as perpendicular to the x-axis with its origin at the centroid of the line between the epicondyles. The coordinate system of the tibia was established in a similar manner using the femoral epicondyles to calculate the tibia's longitudinal axis. The origin of the tibial coordinate system was then defined as the centroid of a line connecting the medial and lateral aspects of the posterior cruciate ligament facet on the tibia. This allowed measurement of tibial translation with respect to the femur.

Ten knees were tested with the oblique popliteal ligament sectioned first (hereafter referred to as group 1). This directly tested our hypothesis. In group 1 (10 knees),

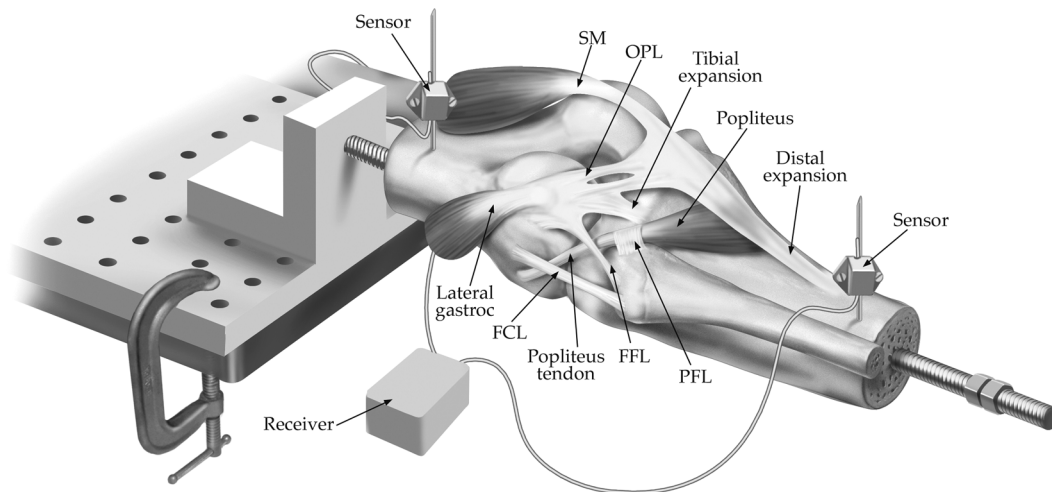


Figure 2. The testing apparatus. SM, semimembranosus; OPL, oblique popliteal ligament; FCL, fibular collateral ligament; FFL, fabellofibular ligament; PFL, popliteofibular ligament. Posterior aspect of the left knee.

the cutting order was as follows: (1) oblique popliteal ligament; (2) fabellofibular ligament; (3) ligament of Wrisberg; (4) anterior cruciate ligament; (5) popliteus tendon, popliteofibular ligament, and fibular collateral ligament together as the posterolateral corner³¹; and (6) posterior cruciate ligament. The individual anatomical structures were then sectioned under direct visualization; the anterior and posterior cruciate ligaments were sectioned through a mini-open medial parapatellar incision. Posttesting dissections were performed to confirm that all ligaments had been sectioned completely.

Two additional experimental groups, groups 2 and 3 (5 knees each), were also established with the objective of more directly testing whether the cruciate ligaments had a primary role in resisting knee hyperextension. The cutting orders for groups 2 and 3 were identical to that of group 1 except for a single change; in group 2, the anterior cruciate ligament was sectioned first, and in group 3, the posterior cruciate ligament was sectioned first.

Hyperextension experiments were performed by applying moments of 14 and 27 N·m to the tibia using loads of 44 and 88 N applied 30.5 cm distal to the joint line. Values were based upon published values of peak hyperextension torques recorded in patients with and without knee hyperextension during gait, suggesting these groups see between 0.13 ± 0.06 N·m/kgm and 0.27 ± 0.18 N·m/kgm, respectively.¹¹ Measurements of the load applied via a load cell (Interface, Scottsdale, Arizona) during evaluation of genu recurvatum to measure heel height difference clinically in 2 patients (24 N·m) were found to be comparable with our applied hyperextension moments. Statistical analysis of hyperextension experiments was performed using GraphPad InStat Version 5.01 (GraphPad, San Diego, California) and included mean and standard deviation, correlation coefficients, and 1-way analysis of variance with posttest Bonferroni multiple comparisons.

Tibial slope was measured on digitized lateral radiographs using a published protocol.⁵ Angles were measured

3 times using Photoshop CS3 Extended (Adobe Systems, Mountain View, California) and recorded. The a priori assumption for analysis of tibial slope data was that there would be a negative correlation between the final hyperextension observed and the specimen's tibial slope as measured on a lateral radiograph. We based this assumption on literature suggesting that a proximal tibial osteotomy to increase a knee's tibial slope can reduce knee hyperextension.^{2,3,18,29} Correlation analysis of the tibial slope data was performed using GraphPad Prism Version 5.01 to calculate the Pearson correlation coefficient and a 2-tailed *P* value.

RESULTS

The average age of the specimens was 57.2 years (range, 22-76). None of the knees had any evidence of previous injury or arthritis. All structures were present in the 20 specimens examined.

Increases in Knee Hyperextension

The effect of sectioning the oblique popliteal ligament was similar in each study group and was similar to the 2.5° change in hyperextension used for the study's power analysis. In group 1, in which the oblique popliteal ligament was sectioned first, the oblique popliteal ligament had the largest contribution to the ultimate amount of hyperextension seen, resulting in 37% of the total increase in recurvatum seen at experiment's end (2.15° of 5.89° total). This was a significant difference when compared with all structures when tested with a 14-N·m extension moment (Figure 3). When tested with a 27-N·m extension moment, this difference was significant when compared with the fabellofibular ligament, ligament of Wrisberg, anterior cruciate ligament, posterolateral corner structures, and posterior cruciate ligament.

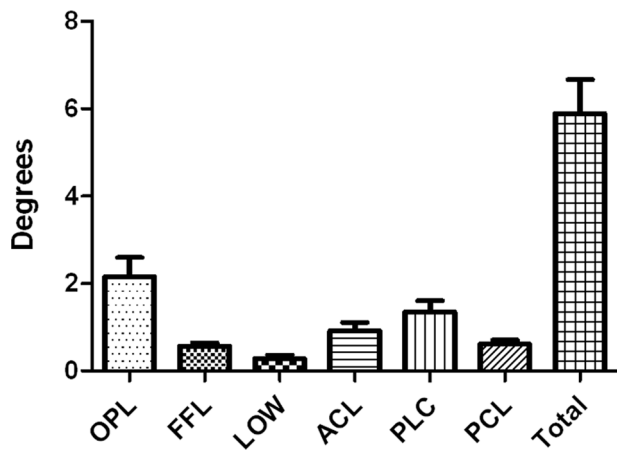


Figure 3. Change in loaded hyperextension compared with intact knee with standard error of the mean. The oblique popliteal ligament (OPL) was sectioned first in participants in Group 1. FFL, fabellofibular ligament; LOW, ligament of Wrisberg; ACL, anterior cruciate ligament; PLC, posterolateral corner; PCL, posterior cruciate ligament.

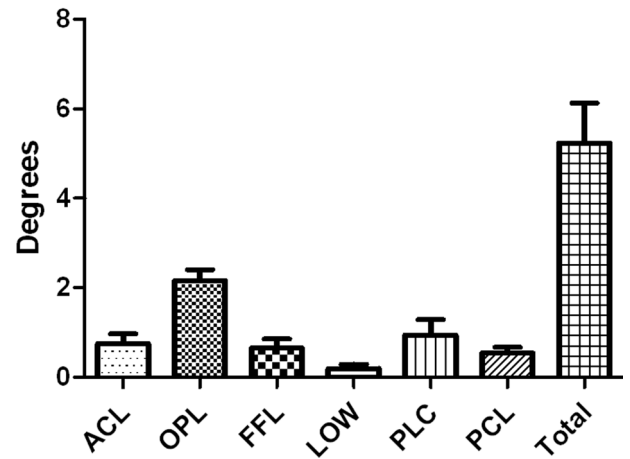


Figure 4. Change in loaded hyperextension compared with intact knee with standard error of the mean. The anterior cruciate ligament was sectioned first (ACL) in participants in group 2. OPL, oblique popliteal ligament; FFL, fabellofibular ligament; LOW, ligament of Wrisberg; PLC, posterolateral corner; PCL, posterior cruciate ligament.

In group 2, in which the anterior cruciate ligament was sectioned first, the oblique popliteal ligament had the largest contribution to the ultimate hyperextension seen, resulting in 41% of the total increase in hyperextension (2.15° of 5.24° total). This was a significant difference when compared with all other structures when tested with a 14-N·m extension moment (Figure 4). When tested with a 27-N·m extension moment, this difference was significant when compared with the fabellofibular ligament, ligament of Wrisberg, anterior cruciate ligament, posterolateral corner structures, and posterior cruciate ligament.

In group 3, in which the posterior cruciate ligament was sectioned first, the oblique popliteal ligament again demonstrated the largest contribution to the ultimate hyperextension seen when compared with all other structures tested, resulting in 36% of recurvatum seen at experiment's end (1.17° of 4.69° total). When tested with a 14-N·m extension moment, this difference was significant when compared with the posterior cruciate ligament, the fabellofibular ligament, and the ligament of Wrisberg (Figure 5). Findings were identical when tested for a 27-N·m extension moment.

One-way analysis of variance was performed to investigate the influence of cutting order. Increases in hyperextension produced by sectioning a ligament were found to be independent of the structure cutting order. This was true across all specimens ($P > .05$; range, .37-.74). When all specimens were analyzed independent of cutting order, sectioning of the oblique popliteal ligament resulted in the largest increase in hyperextension of all structures for a 27-N·m applied extension moment (Figure 6).

Across the 3 experimental groups, and under the 2 experimental conditions (14 and 27 N·m), the oblique popliteal ligament showed a significantly larger increase

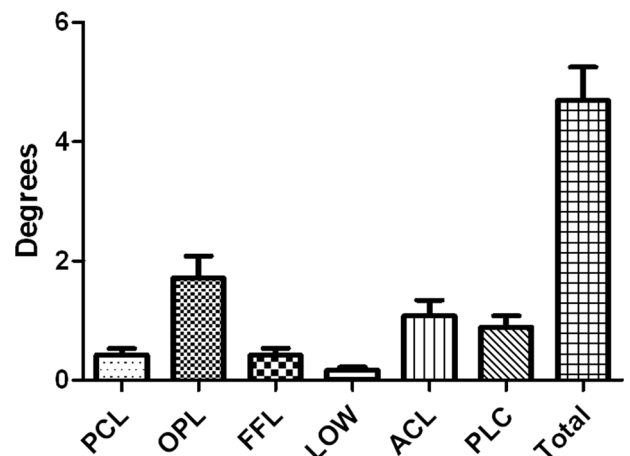


Figure 5. Change in loaded hyperextension compared with intact knee with standard error of the mean. The posterior cruciate ligament (PCL) was sectioned first in participants in group 3. OPL, oblique popliteal ligament; FFL, fabellofibular ligament; LOW, ligament of Wrisberg; ACL, anterior cruciate ligament; PLC, posterolateral corner.

($P < .05$) in all but 5 of 30 circumstances. These 5 cases were observed when the oblique popliteal ligament was compared with the posterolateral corner with 27 N·m of force in group 1 and when the oblique popliteal ligament was compared with the anterior cruciate ligament and posterolateral corner with 14 and 27 N·m of force in group 2. When all knees were combined, this remained consistent with only the oblique popliteal ligament compared with the posterolateral corner at 27 N·m not meeting criteria for statistical significance.

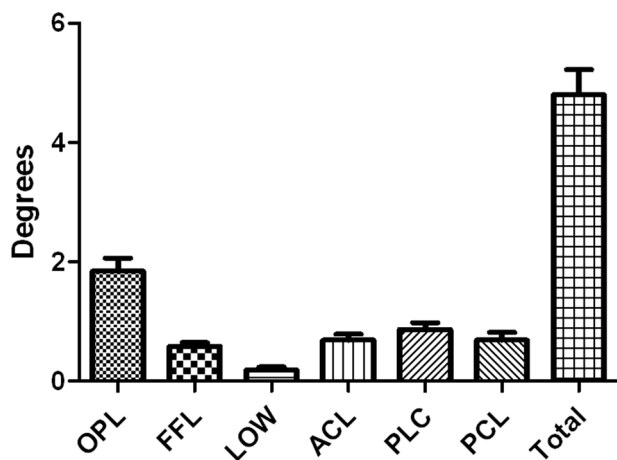


Figure 6. Change in loaded hyperextension compared with intact knee. Groups 1, 2, and 3 combined. The oblique popliteal (OPL) ligament contributed the largest increase when compared to all other structures ($P < .001$). FFL, fabellofibular ligament; LOW, ligament of Wrisberg; ACL, anterior cruciate ligament; PLC, posterolateral corner; PCL, posterior cruciate ligament.

Analysis of experiments designed to test the cruciate ligaments' role in resisting hyperextension was also performed. For a 14-N·m extension moment, sectioning of the anterior cruciate ligament in group 1 resulted in 16% of increased recurvatum seen with a mean and standard deviation of $0.9^\circ \pm 0.64^\circ$. Sectioning of the anterior cruciate ligament in group 2, in which it was the first structure sectioned, resulted in 14% of the increased knee hyperextension with a mean and standard deviation of $0.76^\circ \pm 0.49^\circ$. Sectioning of the anterior cruciate ligament in group 3 resulted in 23% of the increased knee hyperextension seen with a mean and standard deviation of $1.06^\circ \pm 0.59^\circ$. Observations made after sectioning of the posterior cruciate ligament for a 14-N·m extension moment were similar. Sectioning of the posterior cruciate ligament in group 1 resulted in 10% of increased recurvatum seen with a mean and standard deviation of $0.63^\circ \pm 0.29^\circ$. Sectioning of the posterior cruciate ligament in group 2 also resulted in 10% of the increase in recurvatum seen with a mean and standard deviation of $0.52^\circ \pm 0.33^\circ$. Sectioning of the posterior cruciate ligament in group 3, in which it was the first structure sectioned, resulted in 9% of the increase in recurvatum seen with a mean and standard deviation of $0.42^\circ \pm 0.22^\circ$.

The increase in knee hyperextension seen with sectioning of the fabellofibular ligament, ligament of Wrisberg, and the posterolateral corner structures was consistent across groups and less than that seen with sectioning the oblique popliteal ligament. This was statistically significant across all groups and independent of the amount of force applied. Sectioning of the fabellofibular ligament in group 1 resulted in 10% of the increased knee hyperextension seen in that group with a mean and standard deviation of $0.79^\circ \pm 0.71^\circ$. Sectioning of the fabellofibular

ligament in group 2 resulted in 13% of the increase in recurvatum seen in group 2 with a mean and standard deviation of $0.84^\circ \pm 0.25^\circ$. Sectioning of the fabellofibular ligament in group 3 resulted in 9% of increased recurvatum seen in group 3 with a mean and standard deviation of $0.40^\circ \pm 0.23^\circ$.

Sectioning of the ligament of Wrisberg in group 1 resulted in 5% of the increase in recurvatum seen in that group with a mean and standard deviation of $0.34^\circ \pm 0.32^\circ$. Sectioning of the ligament of Wrisberg in group 2 resulted in 4% of increased recurvatum seen in group 2 with a mean and standard deviation of $0.20^\circ \pm 0.20^\circ$. Sectioning of the ligament of Wrisberg in group 3 also resulted in 4% of the increase in recurvatum seen in that group and with a mean and standard deviation of $0.16^\circ \pm 0.11^\circ$.

Sectioning of the posterolateral corner structures in group 1 resulted in 23% of increased recurvatum seen in that group with a mean and standard deviation of $1.2^\circ \pm 0.88^\circ$. Sectioning of the posterolateral corner in group 2 resulted in 18% of increased recurvatum seen in group 2 with a mean and standard deviation of $0.94^\circ \pm 0.77^\circ$. Sectioning of the posterolateral corner in group 3 resulted in 19% of increased recurvatum seen in group 3 with a mean and standard deviation of $0.90^\circ \pm 0.41^\circ$.

Influence of Posterior Tibial Slope on Knee Hyperextension

The average posterior sagittal slope of the tibia as measured on lateral radiographs was 6.6° (range, 1.1° - 12.5°). There was a significant correlation found between the final hyperextension observed at the end of each experiment and the radiographic posterior tibial slope (Figure 7). A lower amount of hyperextension was found to correlate with a higher degree of posterior tibial slope ($P < .02$; $R^2 = .35$; 95% confidence interval, -0.85 to 0.11).

DISCUSSION

We found that the oblique popliteal ligament was a primary restraint to genu recurvatum of the knee. Information in the English literature concerning symptomatic genu recurvatum, including its incidence, diagnosis, morbidity, and treatment, is limited.¹⁸ To our knowledge, there has been no previous quantitative work published studying the ligamentous restraints to knee hyperextension or a study addressing the biomechanical role of the oblique popliteal ligament or other structures in resisting knee hyperextension. Brantigan, in a descriptive study using fresh cadaveric specimens, reported that the oblique popliteal ligament became "tense" in hyperextension and postulated that it, along with other structures, resisted hyperextension.⁴ Similarly, Watanabe et al³² published their observation that the fabellofibular ligament became tense as the knee came into extension and relaxed with flexion of the knee. No objective data, however, were forthcoming from any of these studies. The effect of sectioning the oblique popliteal ligament in our study was similar in each study group and was similar to the 2.5°

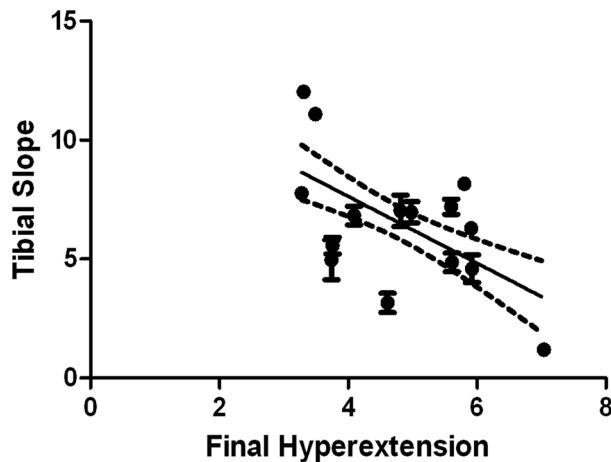


Figure 7. Change in loaded hyperextension compared with tibial slope shown with 95% confidence intervals.

change in hyperextension used for the study's power analysis. Our study, which identifies the oblique popliteal ligament as a primary ligamentous restraint to knee hyperextension, is the first to offer objective analysis of the static restraints to one of the primary degrees of freedom of the human knee.

Currently, the clinical incidence of symptomatic genu recurvatum is unknown, and information on it as a clinical entity is limited to publications describing osteotomies that increase posterior tibial slope for its correction.^{2,3,15,18,29} It has been postulated that the incidence of symptomatic genu recurvatum is underestimated.¹³ This may be partly due to current documentation practices. For example, the International Knee Documentation Committee (IKDC) 2000 is one of the most widely used knee documentation and objective scoring instruments, and it includes a clinical grading system for range of motion.⁸ Normal range of motion in the IKDC 2000 is defined as the condition of lacking a significant motion deficit (<3° decrease in extension and from 0°-5° decrease in flexion), but it does not provide a means to score for increases in knee hyperextension compared with the contralateral normal knee. By using a scoring system without an option to grade excessive knee hyperextension, clinicians reporting their objective results via the IKDC are all but required to underreport, or ignore, genu recurvatum either as a preoperative diagnosis or as a postoperative result. We question whether this may be especially relevant when reviewing studies that address multiple-ligament knee injuries.

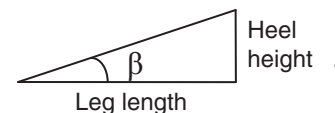
Routine documentation of knee hyperextension by the orthopaedic community is the only means by which patients with symptomatic genu recurvatum will be identified and is a prerequisite to increasing our knowledge of this condition. While the presence of recurvatum after multiple-ligament knee injuries is clinically recognized in the literature, such findings are not routinely reported by investigators.^{6,21,24}

We suggest that examination for and documentation of genu recurvatum be considered a standard part of a routine knee examination. Differences in genu recurvatum may be

measured in 1 of 2 ways. The first method is that with the patient in the supine position, the examiner stabilizes the distal femur above the epicondyles while the other hand applies an anteriorly elevating force to the leg by lifting up the great toe. This maneuver is performed on both the symptomatic and asymptomatic limbs, and any asymmetry is measured. An average individual with a foreleg (calf and foot/ankle) of roughly 5 kg will experience a force of approximately 50 N using this clinical maneuver.²³ This force, in a clinical examination setting, is likely to be similar to the 44-N force used in our study. Using the average knee height measured in the Framingham Offspring Study (54.2 ± 2.8 cm for adult males)²⁵ as an estimation of the distal moment arm of a functionally hyperextensible knee, we calculated that a clinician lifting the heel 1 cm from the examination table (or observing a centimeter of increased hyperextension in the free, prone lower leg) would produce a 1.06° increase in knee extension ($\sin A = \text{heel height divided by length of the foreleg when } A \text{ is the increase in hyperextension measured in degrees}$):

$$\tan^{-1} \frac{\text{Heel height}}{\text{Leg length}} = \beta = \text{degrees of recurvatum,}$$

where the foreleg and examination table form the hypotenuse and base, respectively, of a right triangle



The increase in recurvatum seen in our cadaveric specimens after sectioning of the oblique popliteal ligament would therefore clinically result in a several centimeter increase in heel height, a height consistent with patients with a diagnosis of symptomatic genu recurvatum and one that the examiner should be easily able to detect.

Alternatively, this test may be performed with the patient prone and positioned so that the knee and leg of both limbs extend freely from the table, with genu recurvatum defined in this method as the heel height difference between the affected and unaffected knee. Heel height measurement is performed with the patient in the prone position and has been described.²⁶ In the average adult, it has been reported that a 1° increase in hyperextension would equal approximately 1 cm of change in heel height.²⁶ Thus, when performed on the average patient, either of these maneuvers should elicit 1° of hyperextension for every centimeter of heel height difference.

Radiographically, measurement of the posterior tibial slope may provide insight in treating patients with symptomatic genu recurvatum due to injury. In our study, we found a significant inverse correlation between the posterior tibial slope and cumulative postsectioning increases in hyperextension; knees with decreased posterior tibial slopes exhibited more genu recurvatum. This finding is consistent with the current reported operative treatment for patients with symptomatic genu recurvatum, which is an osteotomy to increase the posterior sagittal slope of the tibial

plateau.^{2,3,15,18,29} We postulate that patients with a lower than average posterior tibial slope may be less able to tolerate injury to the knee's static extension restraints. This may, in part, explain the variable symptoms we have clinically observed in patients who have sustained a knee hyperextension injury. We theorize that patients with an increased posterior tibial slope may be anatomically predisposed to better compensate for this injury.

We recognize that our study has some limitations. First, this study does not address the role of the medial structures of the knee¹² in the restraint of terminal extension. Although sectioning the medial and posteromedial structures did not result in an increase in terminal extension in our pilot study, we recognize the limitations of such an approach. We believe, however, that our pilot data were a reasonable methodological basis for study design when the literature provided little information on the question under investigation. Furthermore, we believe that this initial pilot data were indeed indicative of the true biomechanics of the knee; those structures not included in the final study design are likely poor candidates to act as static restraints to hyperextension. For example, the posterior oblique ligament attaches on the lateral aspect of the proximal tibia posterior to the center of rotation of the knee. While it may therefore theoretically play a role in restraining extension, a recent report of 92 posterior oblique ligament injuries did not report an occurrence of genu recurvatum.²⁸ Similarly, injuries to the superficial and deep medial collateral ligaments are commonly seen clinical entities. No clinical evidence, however, exists suggesting this injury results in increased hyperextension of the knee.

We recommend that magnetic resonance imaging scans should be examined for injury to the oblique popliteal ligament and that consideration should be given to the role of the oblique popliteal ligament in normal knee biomechanics when planning surgical intervention for patients with symptomatic (nonosseous) genu recurvatum. In addition, evaluation of the posterior tibial slope should be performed in patients with chronic injuries where an increase in the posterior tibial slope should be considered.

In conclusion, we found that the oblique popliteal ligament is a primary restraint to genu recurvatum. While cadaveric studies do not reproduce the active forces that stabilize the knee during gait, the consistency of the results across sectioning groups seen in this study suggests that the role of the oblique popliteal ligament is pivotal in the static stabilization of the knee at the extreme of extension. This was found to be particularly important in knees with decreased posterior tibial slopes where the amount of recurvatum was noted to be increased. Reconstruction and biomechanical testing in a cadaveric model may provide insight into the utility of reconstructing this structure in patients with symptomatic posttraumatic genu recurvatum.

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