The role of the popliteofibular ligament and the tendon of popliteus in providing stability in the human knee

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Techniques for the selective cutting of ligaments in cadaver knees defined the static contributions of the posterolateral structures to external rotation, varus rotation and posterior tibial translation from $0^\circ$ to $120^\circ$ of flexion under defined loading conditions.

Sectioning of the popliteofibular ligament (PFL) (group 1) produced no significant changes in the limits of the knee movement studied. Sectioning of the PFL and the popliteus tendon (femoral attachment, group 2) produced an increase of only $5^\circ$ to $6^\circ$ in external rotation from flexion of $30^\circ$ to $120^\circ$ ($p < 0.001$). Even when other ligaments were sectioned first (group 3), the maximum effect of the PFL was negligible.

Our findings show that the popliteus muscle-tendon-ligament complex, lateral collateral ligament, and posterolateral capsular structures function as a unit. No individual structure alone is the primary restraint for the movements studied. Operative reconstruction should address all of the posterolateral structures, since restoration of only a portion may result in residual instability.

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During arthroscopic reconstruction of the anterior (ACL) or posterior (PCL) cruciate ligament, an associated injury to the posterolateral ligamentous structures may require operative reconstruction. Failure to recognise associated insufficiency of these structures may lead to abnormal loads on the ACL or PCL graft and its subsequent failure. The complexity of the treatment of posterolateral injuries and the associated injury to other ligamentous structures has been emphasised. However, clinical reports on the surgical reconstruction of the posterolateral ligamentous structures involve a variety of operative procedures with variable rates of success and differences in opinion as to which procedures should be used and what anatomical structures should be reconstructed. In this study, we have used a previously described method for selective cutting of ligaments. In 12 cadaver knees to define the role of the popliteofibular ligament (PFL) alone, in combination with the popliteus tendon, and in knees with other associated ligaments sectioned. We considered that the PFL provided a functional attachment of the popliteus tendon to the fibula, but that removal of the fibular attachment alone would have little effect on the limits of movement as long as the femoral and tibial attachments of the popliteus muscle remained intact. Our hypothesis questioned the published results of other studies which have reported a primary role of the PFL in resisting posterior subluxation of the lateral tibial plateau, possibly related to the order of sectioning of the knee ligaments in cadaver studies, and thus representing an artifact based on the experimental design.

The anatomy of the posterolateral structures is complicated and includes the static contribution of a number of ligamentous structures which resist external tibial rotation, lateral joint opening, posterior translation, and hyperextension of the knee. These include the lateral collateral ligament (LCL), the popliteus muscle-tendon-ligament unit (PMTL), the fabellofibular ligament, and the arcuate ligament and posterolateral capsule. The PMTL includes: 1) the muscular tibial origin; 2) the fibular origin (popliteofibular ligament (PFL)); 3) merging of both of these components to a tendon inserting on the lateral femoral condyle adjacent to the articular cartilage; 4) inferior and superior popliteomeniscal fascicles which form the popliteal hiatus; and 5) soft-tissue attachments to the lateral meniscus and posterior tibia. The dynamic stabilising function of
the popliteus muscle is to act as an internal rotator of the knee.7,29,30 Sudasna and Harnisriwattanagir1 reported that the popliteal tendon and the PFL were the most important structures for preventing external tibial rotation, although no specific biomechanical data were collected. Other authors have stressed the importance of the fibular origin of the popliteal tendon to the stability of the posterolateral knee because of its consistent presence and large size.9,11,21,27,31,32 Maynard et al22 reported the mean length of the PFL to be 47 mm and the mean cross-sectional area 6.9 mm². The mean maximal force to failure was about 425 N (204 to 778) compared with 750 N (317 to 1203) for the LCL.

The results of biomechanical studies on the stabilising role of the PFL and the other posterolateral structures have resulted in disagreements and a lack of consensus among authors.13,20,23,33 Shahane et al32 sectioned the popliteus muscle and the PFL and reported increases in external tibial rotation of 3˚ and 9˚ at 60˚ and 90˚ of knee flexion, respectively. They concluded that the PMTL was a primary restraint to external tibial rotation and that the LCL was a secondary restraint. However, they did not carry out studies in which the LCL was cut first to determine if increases in external tibial rotation occurred before sectioning of the PMTL unit. In knees in which the LCL was divided, reconstruction of the PFL alone did not restore stability. Veltri et al13,33 found that cutting of the PFL after sectioning of the LCL with the popliteus tendon intact, produced only small additional increases in external tibial rotation (0.9˚ to 1.9˚). When the PFL was divided last, after sectioning of the LCL and the tibial attachment of the popliteus tendon, increases in external rotation occurred (7.0˚ to 10.0˚). Grood et al20 reported that increases in external tibial rotation in cutting studies on selective ligaments were highly dependent on the order of sectioning. The last remaining component of the posterolateral structures sectioned (LCL, popliteus muscle tendon, PFL, or posterolateral capsule) provided for the largest increase in external tibial rotation since the other static contributions had been removed. All of the posterolateral structures functioned as a unit and only small increases in external rotation or varus rotation limits occurred when one or two of the structures were sectioned with the remaining components intact.

Our aim was to change the order of ligament sectioning, focusing on the PFL, to determine if the results would support our hypothesis that the PFL functions in a more minor role and instead forms one of a group of posterolateral structures in providing stability of the knee.

**Materials and Methods**

**Experimental design.** The limits of tibiofemoral movement were measured in unembalmed cadaver knees using a technique previously described.34,35 The tests were first performed in the intact knee, then repeated after selected ligaments and capsular structures had been cut. The limits of movement were measured from 0˚ to 120˚ of knee flexion for three joint-loading conditions, namely, a posterior force of 100 N, varus moment of 10 Nm and an external moment of 5 Nm.

After measuring movements in the intact knee, the tests were repeated after selective divisions as detailed in Table I. In group 1, the PFL was sectioned before cutting the popliteus tendon and the opposite cutting sequence was performed in group 2. We realised that cutting the popliteus tendon at the femoral attachment would also remove the function of the PFL. In order to determine the stabilising function of the posterolateral structures in a PCL-deficient knee, the PCL was sectioned first in group 3. The technique of sectioning involved cutting the PCL, including the meniscofemoral ligaments, from its femoral insertion, the LCL at the joint line, the posterolateral capsule, including the arcuate ligament and fabellofibular or short lateral ligaments, at

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*POP, popliteus tendon, femoral attachment; CAP, posterolateral capsule including arcuate and fabellofibular ligaments

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*Fig. 1* Diagram showing the experimental rig. The knee was tested with the tibia vertical and upside down so that its weight produced a small compressive force at the joint. The proximal femoral shaft was attached by a femoral grip to a platform which was supported by a bearing located near the centre of rotation of the knee. Flexion and extension were achieved by rotation of the femoral platform while the tibia remained vertical. External rotation and varus moments were applied to a threaded rod which was fixed within the medullary canal of the tibia. Posterior forces were applied just distal to the joint line.

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**Table I.** The ligament cutting sequences

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the joint line, the PFL at its fibular origin, and the popliteus tendon at its femoral insertion.

Preparation of specimens. There were six male and six female specimens with a mean age at the time of death of 66 ± 9 years (54 to 90). We excluded specimens if there was evidence of extensive osteoarthritic changes, previous knee surgery, or tibiofemoral deformities. All the limbs were stored at -30˚C until the night before testing, when they were allowed to thaw overnight at room temperature. Soft tissues were removed from the proximal two-thirds of the femur to allow gripping of the bone. The distal one-half of the tibia and fibula was amputated and a 0.5 inch threaded steel rod was cemented into the intramedullary canal of the tibia. This was used to attach a torque ring for application of rotational moments. Surgical exposures to the posterolateral structures and PCL were made before mounting the specimen. All surgical exposures were closed in a routine fashion before each testing sequence to prevent any contribution of open incisions to movement of the knee.

Apparatus. The proximal one-third of the femur was clamped to a testing platform which has been previously described. This had been modified to allow for testing with the limb inverted which eliminated distraction forces at the knee because of the weight of the tibia (Fig. 1). The knee was flexed and extended by rotating the femoral platform.

Measurements. Three-dimensional movements of the knee were measured using a six-degrees-of-freedom instrumented spatial linkage (ISL) with an accuracy of 0.5˚ and 0.5 mm. The ISL was connected to mounting blocks which were rigidly attached to the medial aspect of the distal femur and proximal tibia with unthreaded steel pins. Data were collected using a microcomputer at a rate of 25 Hz over a period of 10 s as the knee was placed through a range of movement from 0˚ to 120˚ of flexion. The testing sequence was performed twice and the results averaged.

At the conclusion of testing, all soft tissues were removed from the tibia and femur and the ISL was used to measure the co-ordinates of selected anatomical landmarks which were required to determine the axes of flexion and tibial rotation by calculations previously described. Movements of the joint were described between anatomically-based co-ordinate systems. A point midway between the spines of the intercondylar eminence was selected as the tibial origin.

Statistical analysis. These data were divided into three experiments which corresponded to the three loading conditions investigated (posterior forces, varus moments and external rotation moments). The experimental treatment factors were the anatomical structure(s) which had been cut and the angle of flexion of the knee. The response measures investigated were posterior tibial translation, varus rotation and external rotation. The experiments were modelled as described below, the data were fitted to the model, and the residual tested to determine if they were normal and homoscedastic. Examination of the residuals showed no serious violation of homoscedasticity. Departures from normality were noted to be largely due to a high degree of kurtosis, i.e. thick-tailed distributions. To correct for this, a rank transformation was applied to the data since this approach reduces the effect of outliers. Analysis of variance on the original data and on the transformed data showed the same pattern of significance. Consequently, we decided to present the statistical results performed on the original, non-transformed, data.

Analysis of variance was performed using a split-split plot model. The whole plot was the cutting sequence (POP, PFL, etc) and the second split plot factor was the flexion angle (12 levels from -5˚ to 120˚). Specimens were modelled as a random factor and interactions with other factors were included in the model. All other factors were modelled as fixed factors. Type-I error was controlled by using alpha.
Table II. Maximum increases in knee movement (degrees) due to cutting of the PFL. Data shown are the mean ± SEM at the flexion angle where maximum increase occurred. None of these increases was statistically significant.

<table>
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<th>Varus rotation</th>
<th>Posterior translation</th>
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<td>1st CUT (PCL+CAP+LCL)</td>
<td>0.8 ± 0.6 at 75°</td>
<td>0.4 ± 0.1 at 0°</td>
<td>0.5 ± 0.6 mm at 0°</td>
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Results

**Popliteofibular ligament.** Cutting the PFL in the intact knee (group 1) produced no statistically significant changes in external rotation, varus rotation, or posterior translation (Table II). Sectioning of the PFL after previous sectioning of the PCL, the posterolateral capsule (CAP), and the LCL (group 2) produced a small increase in external rotation ranging from 3° to 5°, with the popliteus tendon still intact, but not in varus rotation or posterior translation.

**Popliteus tendon and popliteofibular ligament.** Sectioning of the popliteus tendon (POP) and the PFL in the intact knee (groups 1 and 2 combined) produced small but statistically significant increases in external rotation (Fig. 2, p ≤ 0.001). A statistically significant change was found in varus rotation only at 120°, and no statistically significant change was found in posterior translation.

Sectioning of the POP and PFL in knees with the PCL, LCL, and posterolateral structures removed (group 3) caused significant increases in all three movement limits (Fig. 3). These increases, as a result of cutting the POP and PFL and excluding the change which occurred when the PCL, LCL and posterolateral structures were removed, were as follows. External rotation increased by a maximum of 23° (p < 0.001) at 45° of flexion and was accompanied by a coupled posterior translation of 14.6 mm (Fig. 3C). By contrast, external rotation increased by only 4.6° at 45° of flexion when the PFL was sectioned and the POP left intact (Fig. 3B). Varus rotation increased by a maximum of 9.6° (p < 0.001) at 75° of flexion (Fig 3B) when the POP and PFL were cut and this was accompanied by a coupled external rotation of 9.9° (Fig. 3A) and a coupled posterior translation of 7.3 mm (Fig. 3C). By contrast, varus rotation increased by only 3° at 60° of flexion when the PFL was sectioned and the POP left intact (Fig. 3B). Posterior translation increased by a maximum of 14.4 mm (p < 0.005) at 60° of flexion (Fig. 3C) and was accompanied by a coupled external rotation of 13.5° (Fig. 3A). By contrast, posterior translation increased by only 2.4 mm at 60° of flexion when the PFL was sectioned and the POP left intact (Fig. 3C).
Discussion

Our aim was to determine if the PFL has a unique role as a primary restraint in limiting external rotation, varus rotation and posterior translation of the knee and in acting as a ligament structure alone or in combination with the entire PMTL. The results in all 12 specimens were consistent throughout the three separate cutting routines, indicating no effect of the PFL alone as a primary restraint for external tibial rotation, varus rotation, or posterior translation. In the first series, sectioning of the PFL produced no discernible change in external tibial rotation. In the second series sectioning of the PFL and popliteus tendon produced an increase of only 5° to 6° in external rotation (p < 0.001). In the six cadaver specimens (group 3) in which only the PFL and PMTL remained (PCL, LCL, posterolateral capsule sectioned), sectioning the PFL produced only small changes in external tibial rotation. Thus, in all 12 specimens in which the PFL had been sectioned, we consistently found minimal or no discernible effects.

The results of this study are in agreement with our previous studies.20,25,34 In 1981, we presented the concept of primary and secondary ligament restraints and measured the six-degrees-of-freedom movement limits and tibiofemoral positions in cadaver knees under specified loading conditions before and after sectioning of the posterolateral structures (LCL, PMTL, posterolateral capsule) and the PCL.34 We noted that as the individual posterolateral structures were sectioned, only small increases in external tibial rotation occurred. For example, sectioning of any two of the three posterolateral structures (LCL, popliteus tendon, posterolateral capsule) produced a mean increase of only 6° of external rotation at 30° of knee flexion. We concluded that all three of the structures comprising the posterolateral complex provided a restraint to external tibial rotation. The position of knee flexion for rotation testing to determine the competency of the posterolateral structures was recommended to be at 30° of knee flexion instead of the traditional position of 90°. Additionally, the PCL was reported to be an important restraint to external tibial rotation at greater angles of knee flexion, since increases in external rotation at 90° of knee flexion required sectioning of the PCL and all of the posterolateral structures.

Noyes et al25 described the increase in millimetres of posterior subluxation of the lateral tibial plateau which occurred due to combined rotational-translational coupling after sectioning of the posterolateral structures alone and in combination with the PCL. A mean increase of posterior translation of the lateral tibial plateau of 8 mm (5.7 to 10.6) occurred at 30° of flexion after sectioning of the posterolateral structures; no significant increase occurred at 90° of knee flexion (mean 2.7 mm). After sectioning the PCL and the posterolateral structures, the increase in posterior translation of the lateral tibial plateau over the intact state was 17.8 mm and 23.5 mm at 30° and 90°, respectively. The tibiofemoral rotation test (dial test) was devised to be performed in the supine position at 30° and 90° of knee flexion, with palpation of the medial and lateral tibiofemoral subluxations with internal and external tibial rotation. In addition, the medial shift in the axis of tibial rotation was described in injuries to the posterolateral ligament. The posterior subluxation of the lateral tibial plateau after sectioning of the posterolateral ligament was dependent on the physiological laxity of the PCL in the intact state. For the purposes of discussion, the results of our study are compared for each ligament or tendon structure sectioned with those previously reported in other experimental studies.

Popliteofibular ligament (PFL). The results of our study differ from others which have emphasised the role of the PFL in providing posterolateral stability of the knee.22,23,32 Maynard et al22 concluded that the PFL may be the “missing link” to posterolateral stability based on varus stress-to-failure studies on the PFL, POP and LCL. The cutting order used by these authors was LCL, PFL, and POP muscle belly. They showed that it was only after cutting the LCL that the PFL appeared to resist varus stress. We found that sectioning of the PFL produced no significant changes in varus rotation or any other movement as long as the LCL was intact. This suggests that the LCL is a primary restraint while the PFL is a secondary restraint along with other structures20,25 to resisting varus loads.

Veltri et al33 performed selective ligament sectioning of the PFL and posterolateral structures. They found only small increases in external rotation, varus rotation, and posterior translation after division of the PFL (LCL sectioned, popliteus tendon intact). We found that both the fibular attachment (PFL) and femoral attachment of the popliteus had to be removed in order to show an overall effect of the PMTL. It thus appears from our observations, and a critical review of published findings, that the PFL should not be regarded as a primary stabilising structure in resisting posterolateral tibial subluxations. The PFL serves as a secondary restraint in providing a fibular origin to the PMTL. In acute injuries of the posterolateral ligament, we believe that this fibular attachment should be repaired along with the other ligament structures which comprise the posterolateral complex.3,4,25,37

Popliteus tendon (POP). Our study and previous observations agree that the PMTL contributes an important role along with other posterolateral structures in limiting external rotation, varus rotation and posterior translation.13,14,20,24,25,33 When the popliteus was the first or second structure sectioned, it served mainly to limit external rotation (2° to 5° increase) with the maximal effect seen at 90° to 120° of flexion. There was no significant change in varus rotation or posterior translation.

Lateral collateral ligament (LCL). The LCL has long been recognised as the primary restraint to a varus loading. Previous studies have shown that the increases in the limits of varus movement after cutting the LCL are small (2° to 5°),20,22,24,30,33 and yet are consistently the largest increases in varus limits seen when any single structure is cut in the
intact knee. Isolated injuries to the LCL do occur rarely and may be difficult to detect on physical examination unless there is a combined injury to other posterolateral structures.

The LCL plays an important role in limiting external rotation, particularly at low angles of flexion. Our study shows the POP to be important in limiting external rotation at higher flexion angles (Fig. 3). The functional restoration of the LCL is an important part of the surgical treatment of posterolateral ligamentous injuries. In the absence of restoration of function to the LCL, the PMTL would lose the load-sharing function of the LCL and act alone under potentially deleterious high loads as a primary restraint to movements of varus and external tibial rotation.

Sugita and Amis measured the orientation and length of the LCL and PFL in ten cadaver knees and noted that the LCL slackened with knee flexion and achieved a vertical position at 70˚ of knee flexion thereby decreasing the ability of the LCL to resist external tibial rotation or posterior tibial translation at neutral tibial rotation. By comparison, the PFL maintained a less vertical orientation, increasing its ability to resist external tibial rotation and posterior tibial translation. These authors stressed the importance of surgical reconstruction of the PFL when disrupted with less emphasis on the LCL as a restraint to external tibial rotation. We believe that a limitation of this study was that the measurements of the orientations of the site of attachment of the LCL and PFL were made only at neutral tibial rotation and not at the limits of external tibial rotation which acts to bring the LCL into a position as a functional restraint to external tibial rotation.

Clinical application of study results. Our results are pertinent to the surgical procedures which are recommended to restore function in the treatment of acute and chronic injuries to the posterolateral ligamentous structures. They further demonstrate that the PMTL complex, LCL, and posterolateral capsular structures function as a unit in load-sharing to resist external tibial rotation and varus rotation. No individual structure alone, including the PMTL or PFL ligament, is the primary restraint for the movements studied. Because of the orientation of the structure of each ligament with progressive knee flexion, the LCL initially provides a higher contribution to resisting varus rotation and the PMTL a higher contribution to resisting external tibial rotation and posterior tibial translation. The posterolateral capsule slackens with knee flexion, providing less of a contribution to resisting external tibial rotation, varus rotation, and posterior tibial translation.

The surgical treatment of injury to the posterolateral ligamentous structures involves repair or reconstruction of all of these functional soft-tissue components. Restoration of only one or two structures may result in residual instability of the knee and unacceptably high loads in the absence of load-sharing between all components. We have previously published the indications for the three types of surgical reconstructive procedure, advancement, augmentation or anatomical replacement, which involve restoration of all three components of the posterolateral complex. We have encountered knees previously operated on for posterolateral ligamentous injury in which a revision of the posterolateral reconstruction was required because, at the first operation, only the PMTL was restored leaving a partially insufficient LCL. The abnormal increased opening in the lateral joint places high forces on the PMTL which has to resist varus moments in the absence of a functional LCL. We recommend performing the ‘gap test’ during arthroscopy to measure accurately the millimetres of lateral opening under a varus load at 30˚ of knee flexion. An increase in lateral opening indicates decreased function of the LCL in resisting varus loading and a consequent decrease in resisting external tibial rotation. Performing only reconstruction of the LCL in knees with ruptures of posterolateral ligamentous structures is ill-advised and we believe that it is necessary also to restore the PMTL and capsular structures. For restoration of the static portion of the PMTL, a semitendinosus double-strand autograft or allograft of tendo Achillis should be placed at the femoral anatomical attachment with the graft exiting at the most lateral tibial attachment distal to the joint line. This provides restoration of only the static femorotibial portion of the popliteus muscle-tendon and creates a new ligament restraint to external tibial rotation. We recommend that the LCL be replaced with a bone-patellar-tendon-bone allograft or autograft. Sutures are placed in the lateral portion of the static popliteus graft adjacent to the LCL graft for additional attachment to the fibula. Some operative procedures involve repair or replacement of the PFL without an additional graft reconstruction of the popliteus static arm to the posterolateral tibia. We believe this to be a less satisfactory reconstruction and recommend repair of both the tibial and fibular static components of the PMTL. Alternatively, we have described a posterolateral reconstruction using a circular graft to augment the LCL and posterolateral structures, but this is a less precise anatomical reconstruction of the individual components comprising the posterolateral structures.

The load-sharing relationship between the posterolateral structures and both the PCL and ACL deserves special emphasis. Intact posterolateral structures which resist abnormal external tibial rotation and posterior subluxation of the lateral tibial plateau decrease excessive loading of a reconstruction of the PCL. Equally, intact posterolateral structures which resist varus moments and abnormal lateral joint opening avoid potentially deleterious forces in the ACL graft after reconstruction. Unrecognised injury to posterolateral ligamentous structures has been reported to be one of the more common causes for failure of the graft in both ACL and PCL reconstructions and the need for a subsequent revision operation.

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No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.
References