The popliteofibular ligament
AN ANATOMICAL STUDY OF THE POSTEROLATERAL CORNER OF THE KNEE
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We designed an experimental study to prove the existence of the popliteofibular ligament (PFL) and to define its role in providing static stability of the knee. We also examined the contribution of the lateral collateral ligament (LCL).

We found this ligament to be present in all eight human cadaver knees examined. These specimens were mounted on a specially designed rig and subjected to posterior, varus and external rotational forces. We used the technique of selective sectioning of ligaments and measured the displacement with a constant force applied, before and after its division. We recorded the displacement in primary posterior translation, coupled external rotation, primary varus angulation and primary external rotation. Statistical analysis using the standard error of the mean by plotting 95% confidence intervals, was used to evaluate the results.

The PFL had a significant role in preventing excessive posterior translation and varus angulation, and in restricting excessive primary and coupled external rotation. Isolated section of the belly of popliteus did not cause significant posterolateral instability of the knee. The LCL was also seen to act as a primary restraint against varus angulation and secondary restraint against external rotation and posterior displacement. Our findings showed that in knees with isolated disruption of the PFL stability was restored when it was reconstructed. However in knees in which the LCL was also disrupted, isolated reconstruction of the PFL did not restore stability.

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The anatomy of the posterolateral corner of the knee is complex and poorly understood. The presence of the fibular attachment of the popliteus was mentioned by Higgins as early as 1894 and later by Taylor and Bonney, but it was then largely ignored until 1950 when Last emphasised its existence and called it the “short external lateral ligament” of the knee. Despite this, it was not mentioned in standard anatomy texts at that time.

This error of omission did not remain unchallenged for long and there have since been many references to the popliteofibular ligament (PFL) as a distinct clinical entity. Baker, Norwood and Hughston described an injury to both the posterior cruciate ligament (PCL) and the posterolateral complex, emphasising the importance of repairing both of them and noting that considerable disability persisted if either was left untreated. The PFL was not described. Hughston and Jacobson were the first to publish the long-term results of surgical treatment for chronic posterolateral instability of the knee, describing the problems which may otherwise develop in the medial compartment. They stated that reconstruction of the anterior cruciate ligament (ACL) was doomed to failure if an associated posterolateral instability was missed or left untreated. This fact was highlighted much later by Wroble et al who described the role of lateral extra-articular restraints in an ACL-deficient knee. Gollehon, Torzilli and Warren used the technique of selective section to demonstrate the contribution of each structure to the posterolateral stability at various angles of flexion, but they failed to specify the exact role of the PFL.

It has now been recognised that failure of reconstructions of the cruciate ligament may be due to associated damage to the posterolateral corner. Stäubli and Birrer were the first to acknowledge the presence and importance of this structure. Veltri et al stated that the PFL was an integral part of the posterolateral complex (PLC) and mentioned its static role in stability. The same authors later defined the PFL as an independent entity attributing various functions to it, and Maynard et al described it as a key element in posterolateral stability.

Our aim was to demonstrate the presence of the PFL in the human knee and to define its role together with that of the lateral collateral ligament (LCL) in maintaining posterolateral stability.
Materials and Methods

Eight knees were obtained at postmortem from six men and two women. Their mean age was 63 years (56 to 77). The cause of death was neoplasia in three, myocardial infarction in three and a cerebrovascular accident in two.

The specimens were removed with at least 13 cm of bone on each side of the joint line. They were preserved at -68°C until 24 hours before the tests. They were then allowed to thaw in a refrigerator at +4°C.

The femur, tibia and the fibula were denuded of all extraneous muscle and soft tissue. The entire quadriceps mechanism was removed with the patella, the hamstrings, the gastrocnemius, the muscles on the medial side of the knee and the neurovascular structures at the back of the joint. These provide dynamic stability to the knee and their removal would not have affected the results. The collateral ligaments, menisci, cruciate ligament and the PLC were preserved.

The attachment of the popliteus muscle to the posterolateral aspect of the tibia was dissected out and its tendinous insertion was traced to the lateral femoral condyle. The PFL was clearly identified in all eight specimens (Fig. 1). The popliteomeniscal fibres of the lateral meniscus were also identified. The LCL was dissected and its integrity confirmed in all of the specimens (Fig. 1). The fibres of the arcuate ligament were also identified and removed. They were clearly distinguished from those of the PFL by their different orientation.

The specimens were then firmly secured within metal cylinders using bone cement and screws to create a mounted assembly accurately aligned with the axes of the long bones. This was then mounted on a specially designed knee-testing apparatus.

The following forces were applied to the knees at 0°, 30°, 60° and 90° of flexion:
1) A posterior displacement force of 125 N while monitoring the primary posterior translation and the coupled external rotation of the tibia (Fig. 2).
2) A varus force of 5 Nm while monitoring the primary varus angulation of the knee (Fig. 3).
3) An external torque of 5 Nm while monitoring the primary external rotation of the tibia (Fig. 4).

We measured primary posterior translation and varus angulation using a ruler calibrated to an accuracy of 0.5 mm. An electronic transducer system was used to measure primary and coupled external rotation. The application of load was in the form of dead weights imposing a constant strain throughout the experiment.
Primary movements were defined as the resultant translation or rotation along an axis coincident with the axis of the applied force and coupled movements as resultant translations or rotations along an axis differing from that of the applied force. During the application of the primary posterior translation force, the tibial fixation was seen to have an adequate degree of rotational freedom to measure coupled external rotation simultaneously.

The forces were applied initially to an intact knee and then repeated in sequence after the following procedures: 1) sectioning of the belly of the muscle of popliteus; 2) sectioning of the PFL; 3) reconstruction of the PFL after sectioning; 4) section of the LCL after the PFL reconstruction had been removed; and 5) reconstruction of the PFL after division of the PFL and LCL.

At each step, the forces were applied at 0°, 30°, 60° and 90° of flexion and observations made. Each single observation for a given step at a given angle was performed five times (called the replicates) and the final reading was calculated as the mean of these five.

The PFL was reconstructed using a Leeds-Keio ligament orientated appropriately and fixed to the femur at the lateral epicondyle using a staple and washer. A drill hole was then made in the head of the fibula in a posteroanterior direction; the ligament was threaded through it and fixed to the lateral surface of the upper tibia using the same technique. During the fourth step in dividing the LCL, care was taken to remove the PFL reconstruction in order to simulate total posterolateral instability.

**Statistical analysis.** We calculated the standard deviation and the standard error of the mean. Values were plotted on graphs and the 95% confidence intervals calculated. It is inferred that intervals without overlap indicate ‘significantly different’ displacements.

**Results**

We assumed that the division of the ligaments at any stage would not cause any significant difference in anterior translation, valgus angulation or primary internal rotation.

**Primary posterior translation with a posterior force.** Figure 5 shows primary posterior translation at the principal positions of flexion, for each of the stages of sectioning as listed in order. Division of the PFL produced the most increase in translation especially at 30° flexion. Reconstruction of the PFL, while the LCL remained divided, did much, but not all, to restore stability.

**Coupled external rotation with a posterior force.** Figure 6 shows the effect of serial sectioning on external rotation with a posterior force. Again, division of the PFL gave the greatest increase in angulation, most pronounced at 30°, and reconstruction of the PFL restored stability. The worst situation was shown with the PFL and LCL divided, and it was not completely restored by reconstruction of the PFL alone.
Primary varus angulation with a varus force. Figure 7 shows the same series of sections, under varus strain. The contribution of the PFL is clear and its reconstruction restored most of the instability even with the LCL divided.

Primary external rotation with an external torque. Figure 8 shows the rotational instability under external torque. The contribution of the PFL is shown and confirmed by reconstruction; it was most important in external rotation at 60° and 90°. This was more marked with the LCL divided.

Discussion

We have demonstrated the presence of the PFL as a stout ligamentous structure descending from the musculotendinous junction of the popliteus to the posterosuperior prominence of the fibular head, just adjacent to the insertion of the LCL, in all specimens. Half of this ligament was partially covered by the origin of the LCL and meticulous dissection was needed to separate them. The arcuate ligament was seen to hide the PFL and blend with it but was differentiated from it by the different orientation of its fibres. In its distal two-thirds the orientation of the fibres of the PFL is nearly vertical and similar to that of the LCL. In its proximal one-third it was seen to fuse with the popliteal tendon and was orientated more obliquely.

Many authors have attributed dynamic and even static properties to the popliteus tendon. Our initial hypothesis was that it exerts its influence at the posterolateral corner of the knee by virtue of its dynamic properties but that static stability is provided by the PFL. The popliteus is actively responsible for the ‘screw home motion’. Veltri et al. performed selective sectioning on two groups of knees.
and described the individual importance of the tibial and the fibular attachments of the popliteus in stability of the knee, particularly in preventing posterior translation and varus and external rotation. The LCL was divided first in both these groups and the instability produced was increased by division of the popliteus. Isolated instability resulting from sectioning of the PFL could not be shown.

We have modified their experiment to see if reconstruction of the PFL could restore normal posterolateral stability. We began by testing an intact knee. The popliteus tendon was then sectioned proximal to the attachment of the PFL to the fibula and the steps described above repeated. Cutting the tendon of popliteus proximal to the attachment of the PFL was likely to cause slackness in this ligament, but its overall integrity was maintained by the remaining intact tendon of the popliteus. We were unaware of any other way by which we could test the static contribution of the popliteus muscle belly and the PFL individually because one attachment of the PFL is to the popliteus tendon itself. The third step was to divide the PFL and perform the same tests. Maynard et al.\(^{15}\) found that an average of 400 N of force was required to cause failure of the PFL.

Sectioning of the arcuate ligament was not included as a separate step because an earlier study carried out by Gollon et al.\(^{11}\) had confirmed that tibial translation did increase after division of the popliteus tendon and that no additional increase was seen after sectioning the arcuate ligament.

Numerous techniques have been described for reconstructing the posterolateral complex, many by restoring the function of popliteus. We reconstructed the PFL using the Leeds-Keio ligament orientated in the line of the fibres. This principle of femoral to fibular reconstruction has been described by using the tendon of biceps femoris. However, this simulates the LCL because the attachment of the biceps tendon is anterior to the PFL and does not reproduce the latter ligament exactly. Sidles et al.\(^{20}\) used the tendon of semitendinosus as a graft for reconstruction. If the LCL was intact, but the posterolateral complex was disrupted in isolation, they rerouted the semitendinosus tendon from the femoral epicondyle to the posterior aspect of the fibula through a drill hole to its anterior aspect and then fixed it to the tibia. This is similar to our technique. If, on the other hand, the LCL was also damaged, they swung this same graft from the anterior aspect of the fibula to the femoral epicondyle in a figure-of-eight fashion to reconstruct the LCL. They also believed that the entire fibular head is isometric to the lateral femoral epicondyle throughout the range of knee movement but that there is slightly more isometry from the posterior aspect of the fibula to the anterior aspect of the epicondyle and from the anterior aspect of the fibula to the posterior aspect of the epicondyle, hence the figure-of-eight loop.

Our next step was to section the LCL after removing the PFL reconstruction and repeating the same tests. In the final stage, we reconstructed the PFL and repeated the steps. In this situation, the anatomical PFL and LCL had both been divided. The PFL and the LCL are both located in the posterolateral corner of the knee and both provide static stability to this area. This part of the experiment was carried out to confirm their individual importance and to investigate whether, when both the PFL and LCL were torn, reconstructing the PFL alone would restore stability.

Biomechanical studies of knee ligaments can be carried out by various methods. We maintained a constant force measuring the displacement before and after sectioning the ligament. The displacement or increased laxity which follows sectioning of ligaments depends on the order in which they are cut and so precise function of a single ligament is difficult to define. We have attempted to overcome this by repairing the PFL in a tested fashion.

We believe that dynamic stability to the posterolateral corner of the knee is provided by the iliotibial band, the
lateral head of the gastrocnemius, biceps femoris and popliteus. Static stability is provided by the PFL, LCL, patellofibrular ligament and the arcuate ligament as described accurately by De Lee et al.\textsuperscript{16}

**Posterior translation.** In an intact knee the maximum posterior translation was exhibited at 30° of flexion. After dividing the popliteus there was an insignificant increase at all angles of flexion but sectioning of the PFL increased translation at all angles, maximally at 30° at which the PCL is least effective. However, at 90° the PCL prevents any increase in posterior translation even in the absence of the posterolateral structures.\textsuperscript{11,17}

When the PFL was reconstructed, the primary posterior translation reverted to normal at all angles except at 90° of flexion. With posterolateral damage primary stability is experienced at almost full extension and early flexion when the knee tends to buckle posteriorly and into varus. We therefore reconstructed the PFL with the knee in extension, allowing some slackness at 90°.

When the LCL was sectioned and the PFL reconstruction removed, the posterior translation increased at all angles with a peak at 30°. After reconstruction of the PFL but not the LCL the primary posterior translation was less but still remained significant at 30°, 60° and 90°.

**Coupled external rotation.** In an intact knee, the coupled external rotation increased progressively from 0° to 90°. When the popliteus was divided, there was a significant increase in coupled external rotation at 30°. Division of the belly of popliteus may cause some slackening of the PFL and thus compromise some of the static stability offered by it. Although the substance of the PFL was intact, this factor may have contributed to the increase in primary and coupled external rotation at certain angles. Although statistically significant, when an overview of the remaining displacements was taken into consideration, these increases were only slight. On sectioning of the PFL, there was a significant increase in coupled external rotation at 30°, 60° and 90°, maximal at 30° at which point posterior translation was also maximal. At complete extension there was no significant increase in coupled external rotation in an intact knee, in a popliteus-sectioned knee or in a PFL-sectioned knee since the secondary restraints (LCL and PCL) were intact.

In PFL-reconstructed knees after only the PFL had been divided, the coupled external rotation reverted to normal at all angles of flexion. On sectioning of the LCL (PFL reconstruction removed), the coupled external rotation increased at all angles with a peak at 30°. The importance of the LCL as a secondary restraint in preventing this movement is thus confirmed. After reconstruction of the PFL (PFL and LCL divided), the coupled external rotation was reduced, but still remained significant at 30° and 60°.

**Varus angulation.** In an intact knee the primary varus angulation progressively increased from zero to 90°. After division of the popliteus, the increase in primary varus angulation was not significant at any angle. On sectioning the PFL, the varus angulation increased from zero to 90° but became significant only at 60° and 90°. The intact LCL being a primary restraint to varus angulation probably prevented a significant increase at zero and 30°.

In PFL-reconstructed knees when only this ligament had been divided, the primary varus angulation reverted to normal at all angles. After sectioning of the LCL with the PFL reconstruction removed, varus angulation increased at all angles very significantly indicating its importance as a primary restraint. On reconstruction of the PFL with the PFL and LCL divided, the varus angulation remained high at 60° and 90°. Restoration of stability at zero and 30° may be accounted for by the fact that the reconstruction was carried out with the knee in full extension.

**External rotation.** In the intact knee, the primary external rotation was maximal at 90° with a slight decrease at 60°. With popliteus divided, there was a significant increase at 60° and 90°. The reasoning for this is the same as that mentioned earlier for the increase seen in coupled external rotation after this sectioning. On sectioning the PFL, the primary external rotation increased significantly at all angles with a peak at 90°. Although the LCL was intact, it is not seen as a primary restraint to external rotation and so the sectioning of the PFL increased the primary external rotation at all angles.

In knees in which only the PFL had been divided and then reconstructed, the primary external rotation decreased significantly at zero and 30° but still remained significant at 60° and 90°, probably because the reconstruction was done with the knee fully extended. On sectioning of the LCL after removal of the PFL reconstruction, primary external rotation increased at all angles, with a peak at 90°. After reconstruction of the PFL after division of the PFL and LCL, primary external rotation remained significant at 30°, 60° and 90°. We were not able to complete the experiment by reconstructing the LCL\textsuperscript{20} to see if adequate stability was then restored since our knees were too damaged by then. Our experimental knees had taken so much abuse by the time this stage was reached that they were deemed in no fit condition for further tests. The experiment was stopped at that stage.

**Conclusions**

1. The PFL is an integral structure in the posterolateral corner of the knee.
2. The popliteus muscle has static and dynamic functions. The latter is attributable to the muscle belly originating from the posterolateral corner of the tibia. The static function is served by the popliteofibular ligament.
3. The PFL plays an important part in stabilising the posterolateral corner of the knee by preventing posterior translation, varus angulation and coupled and primary external rotation.
4. The LCL also prevents posterior translation, coupled external rotation and primary external rotation by acting as
a secondary restraint. It prevents excessive varus angulation probably by acting as a primary restraint.

5) In posterolateral disruption in which the LCL is intact, reconstruction of the PFL restores posterolateral stability of the knee.

6) In knees with posterolateral disruption including disruption of the LCL, reconstruction of the PFL alone is not adequate; independent reconstruction of both the PFL and LCL is required.

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