Biomechanical evaluation of two reconstruction techniques for posterolateral instability of the knee


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We evaluated two reconstruction techniques for a simulated posterolateral corner injury on ten pairs of cadaver knees. Specimens were mounted at 30° and 90° of knee flexion to record external rotation and varus movement. Instability was created by transversely sectioning the lateral collateral ligament at its midpoint and the popliteus tendon was released at the lateral femoral condyle. The left knee was randomly assigned for reconstruction using either a combined or fibula-based treatment with the right knee receiving the other. After sectioning, laxity increased in all the specimens. Each technique restored external rotatory and varus stability at both flexion angles to levels similar to the intact condition. For the fibula-based reconstruction method, varus laxity at 30° of knee flexion did not differ from the intact state, but was significantly less than after the combined method.

Both the fibula-based and combined posterolateral reconstruction techniques are equally effective in restoring stability following the simulated injury.

Injury to the posterolateral corner of the knee can lead to severe disability and is being increasingly diagnosed as our understanding of this injury increases. Unrecognised and untreated posterolateral instability is thought to be a contributing factor in the failure of cruciate ligament reconstruction.

Patients with posterolateral instability have increased external rotation and varus laxity of the tibia with respect to the femur. This combination leads to posterior subluxation of the lateral tibial plateau with external rotation. The best approach to treating this instability and thereby reducing morbidity continues to evolve. While numerous surgical strategies to address posterolateral instability exist, the current trend is towards anatomical reconstruction.

We evaluated laxities following two distinctly different procedures used to reconstruct a simulated severe posterolateral corner knee injury. We compared a combined tibia and fibula-based with a fibula-based procedure. Our hypothesis was that both procedures would reduce external rotation and varus laxity and that there would be no procedure-based difference in laxities.

Materials and Methods

Specimens
Ten pairs of fresh cadaver knees, eight women, two men; who died between 53 and 92 years of age were obtained from the State Anatomy Board. The specimens, each transected 20 cm above and below the knee, were wrapped in saline-soaked towels, double-bagged, and frozen at -20°C. Each specimen was thawed overnight at room temperature prior to testing. None had obvious pathological ligament laxity or restriction of movement. Each was free of underlying arthritis based on Faxitron x-ray (Faxitron, Lincolnshire, Illinois). The left and right specimens of each pair were randomly assigned on the day of testing to one of the two reconstruction groups.

The femur and tibia were potted in polyvinylchloride cylinders using an epoxy resin (Bondo, Mar-Hyde Corp., Atlanta, Georgia) and held with smooth Kirschner (K)-wires to prevent slippage and to align the longitudinal axis of the bone with the potting fixtures ensuring proper alignment within the testing frame. Once potted, the specimen was mounted on to a custom frame taking care to avoid anteroposterior loading of the joint. This procedure is similar to that presented by Scopp et al.

The specimens were then secured by means of set screws. Indelible ink marks on the polyvinylchloride pipe verified realignment when the potted knees were replaced in the frame for subsequent tests. The experimental frame incorporated two transducers to record internal/external rotation and varus/valgus movement. Reference transducer readings were
recorded for the intact knee at 30° and 90° of flexion to be consistent with clinical assessment. We used a predetermined test sequence, either an internal/external or varus/valgus torsional load of 5 Nm was applied at a rate of 5 Nm/sec to each knee at 30° and 90° of flexion via a pulley system attached to the actuator of a materials testing machine (Instron, Canton, Massachusetts). A table of the various permutations was followed to minimise potential order effects. Data for torsional load, varus/valgus, and internal/external rotation were recorded at 500 Hz. This loading rate was within the ranges previously reported.12,13

Simulation of posterolateral laxity
An 8 cm curvilinear incision was extended proximally from Gerdy’s tubercle to expose the posterolateral structures. The iliotibial band was split along its axis to the level of the lateral femoral condyle and the interval between the band and the underlying lateral capsule was exposed. The lateral head of gastrocnemius was carefully separated from the posterolateral capsule. A posterolateral injury was simulated by transversely sectioning the capsule from the lateral border of the patellar tendon to the midline posteriorly, superior to the lateral meniscus. With transection of the capsule, the lateral collateral ligament (LCL) was sectioned transversely approximately at the midpoint. The popliteus tendon was released from its attachment at the lateral femoral condyle effectively releasing both the popliteofibular and popliteus-tibial components of the popliteus complex. The posterior cruciate ligament (PCL) was not sectioned. This produced a ‘worse-case’ scenario which is more severe than the partial injury commonly seen in the outpatient clinic.

The potted knee specimens were re-fitted to the material testing machine. The fit was verified and then tested as described for the intact specimens. The two senior authors (WGC, CTM) performed all the procedures.

Reconstruction techniques
Combined tibial- and fibula-based reconstruction. The combined reconstruction used a split Achilles allograft to create both a tibia-based and fibula-based graft construct (Fig. 1).

After exposure of the posterolateral corner, the fascia over the proximal medial insertion of the tibialis anterior, just below Gerdy’s tubercle (the site of insertion of the iliotibial band), was incised and the underlying muscle was elevated over the proximal tibia. A K-wire was placed just below the tubercle and drilled posteriorly, exiting about 2.0 cm below the joint line just medial to the fibular head at the midportion of the posterolateral corner of the tibia. A transverse tibial tunnel was created using an 8 mm cannulated reamer over the K-wire.

The insertion of the popliteal tendon was identified. A K-wire was placed into the lateral femoral condyle at the level of the most anterior aspect of the insertion of the popliteal tendon by drilling in a medial and proximal direction, avoiding the intercondylar notch. A 10 mm cannulated reamer was then used to drill the femoral tunnel to a depth of 20 mm.

A tendo Achillis allograft was split in half. A 20 mm × 10 mm bone plug was created from the bony end of the graft. The attached tendon strip was sutured to create a tube of 8 mm in diameter. A No. 5 Ethibond (Johnson and Johnson, New Brunswick, New Jersey) suture was woven through the lead tendon end for passage of the graft. The bone plug was pressed into the femoral tunnel with the cancellous bone facing away from the articular surface and secured with a metallic interference screw (7 mm × 20 mm) (Arthrex, Naples, Florida). The graft was passed medial to the sectioned lateral collateral ligament into the posterior entrance of the tibial tunnel. Using a graft-passer and the lead suture, the graft was passed posterior to anterior through the tibial tunnel. With the tibia in maximal internal rotation and the knee flexed at 30°, the graft was fixed to the anterior aspect of the tibia with two staples in a belt-buckle fashion. Then, a K-wire was drilled from anterior-to-posterior through the base of the fibular head and a transverse fibular tunnel was created with a 7 mm cannulated reamer placed over the K-wire. The femoral insertion of the lateral collateral ligament was identified proximal and posterior to the insertion of the popliteus tendon on the lateral femoral condyle. A guide wire was drilled into the lateral femoral condyle and a 20 mm deep femoral tunnel was created using a 10 mm cannulated reamer. A 20 mm × 10 mm bone plug was fashioned from the remaining half of the tendo Achillis attachment and the tendon was sutured to create a tube to fit within the 7 mm
fibular tunnel using a No. 5 Ethibond suture woven through the lead tendon to assist in passage of the graft. A 7 mm × 20 mm metallic interference screw secured the bone block that was pressed into the femoral tunnel. A tendon passer was used to pass the graft deep to the iliotibial band (but superficial to the tibial-based graft) and through the fibular tunnel in a posterior-to-anterior direction. The lead tendon edge was then passed proximally, crossing over the femoral bone block. With the knee at 30° of flexion and a valgus force, the graft was fixed to the femur with the double staple technique. The two arms of the fibular-based graft were then sutured to each other with a No. 2 absorbable suture. Closure was performed in layers with a No. 1 absorbable suture and then a No. 2 nylon suture in a continuous fashion to the skin.

**Fibula-based reconstruction.** The fibula-based construct used a semitendinosus autograft to create a ‘figure-of-eight’ graft from the lateral condyle of the femur to the proximal fibula, reconstructing the LCL and popliteofibular ligament8 (Fig. 2). The posterolateral corner was exposed as described and then the pes anserinus through a straight 4 cm incision. The semitendinosus tendon was harvested with a commercial tendon stripper (Linvatec, Largo, Florida). The 26 cm graft was cleaned of soft tissue and a No. 5 Ethibond suture was woven through both ends using a baseball-stitch to pass and tension the graft. The anterior and posterior margins of the fibular head were exposed by careful reflection of the overlying soft tissues. A 7 mm anterior-to-posterior fibular tunnel was created using a cannulated reamer maintaining a complete corticocancellous bone-bridge around the margins of the tunnel. We identified a point approximately halfway between the insertion of the lateral collateral ligament and the popliteus tendon on the lateral femoral condyle and used a 2.5 mm drill to create a hole to a depth of approximately 30 mm, aiming slightly proximally to avoid the intercondylar notch. A self-tapping, low-profile cancellous screw (6.5 mm × 30 mm) with a spiked 18 mm soft-tissue washer was inserted into the predrilled track. The doubled semitendinosus graft was passed through the fibular tunnel where the anterior and posterior arms were brought proximal (deep to biceps femoris and the iliotibial band) using a blunt Kelly clamp. The posterior arm of the graft was passed over the anterior aspect of the screw and the anterior arm of the graft was passed over the posterior aspect of the screw. Thus, a figure-of-eight construct was created with both suture ends anterior for subsequent tensioning. The knee was placed at 30° of flexion, and the tibia was held in internal rotation. Applying a valgus moment to the tibia reduced the lateral tibiofemoral compartment. Tension was placed on the graft by pulling the suture tails to remove any laxity in the arms of the figure-of-eight construct. The tendon grafts were secured when the screw and washer were advanced flush to the lateral femur. The suture tails were tied together for supplementary fixation. Closure was performed in layers with No. 1 Vicryl and the skin was closed with a continuous No. 2 nylon suture.

**Statistical analysis.** External rotation and varus were analysed using a mixed design repeated measures of analysis of variance (ANOVA) with one between subjects factor (reconstruction method, combined vs fibular-based) and two within subjects factors (status, intact, sectioned, reconstructed; flexion angle at 30° and 90°). Significant F ratios were followed up using Tukey’s procedure. A p-value of ≤ 0.05 was considered statistically significant.

**Results**

We found no significant differences between the reconstruction groups for pre-injury external rotation (Table I) or varus (Table II) at 30° or 90° of flexion. After sectioning, the knees displayed significant increases in laxity, except for external rotation at 90° of flexion, compared with the intact state. Each method restored external rotation and varus to levels consistent with, or slightly less than the intact condition.

Both techniques significantly reduced external rotation relative to their respective sectioned values at 30° and 90° of flexion (Table I). There were no significant differences in external rotation between the two reconstruction techniques at 30° and 90°. Both techniques restored varus stability at 30° and 90° of flexion (Table II). The varus from the fibula-based technique was significantly less than that of the combined technique at 30° of flexion (p < 0.05).
However, at 90° of flexion there were no differences between the two techniques.

Discussion

The posterolateral corner of the knee has been referred to as the ‘dark side of the knee’. Anatomical studies have tried to define the corner’s anatomy, structural variability, and inconsistent nomenclature. Numerous techniques have been attempted to correct postero- lateral instability but no consensus has emerged as to the best procedure. The low prevalence of posterolateral corner injury, differences in surgical outcome, severity and chronicity of the injury, and post-operative rehabilitation make comparisons between techniques difficult.

Cadaver studies have improved our understanding of the structure of the posterolateral corner, biomechanics, rotary stability, and changes in primary and coupled motions after injury. For example, studies show that the LCL is dominant in resisting varus forces and the posterolateral capsule resists external rotational forces. Combined sectioning of the LCL and the posterolateral capsule results in greater varus and external rotation instability than isolated division of either structure. Gollehon et al demonstrated that between 0° and 90° of movement, the LCL and deep popliteus-arcuate ligament complex prevented varus and external rotation of the tibia whereas the PCL prevents posterior translation. The application of an external rotation torque by Csintalan et al produced a predictable injury to the LCL, anterior cruciate ligament (ACL), and the posterolateral corner in all of their six cadavers. Other biomechanical studies using selective sectioning techniques on cadavers reported similar findings.

Various reconstruction techniques have been described on a limited number of patients and these have led to moderate clinical success. An earlier technique used an anterior and proximal advancement of the LCL and popliteus tendon away from their normal insertion sites which could alter the mechanics of the normal knee. Another operation for treating the chronic injury was biceps femoris tenodesis to the lateral femoral condyle. Combining the tenodesis procedure with an arthroscopically assisted PCL reconstruction, has also been described. However, while the tenodesis was effective in eliminating abnormal external and varus movement, stability was obtained at the expense of overconstraining the knee. This technique did not address the key posterolateral stabilisers of the tibia, the popliteus tendon and the popliteofibular ligament.

Wiley et al induced a severe posterolateral corner injury by dividing the PCL, LCL, popliteus tendon, posterolateral capsule and arcuate complex, to compare the kinematics of single- versus double-bundle PCL reconstructions. The double-bundle procedure restored posterior laxity closer to that of an intact knee at all angles tested, similar to other reports. They had concerns about overconstraint with the double-bundle technique and neither procedure was as successful as the anatomical reconstruction demonstrated that popliteus or popliteofibular reconstructions were effective in controlling varus and external rotational instability. In addition, the reconstructions overconstrained varus rotation when compared with an intact LCL, raising...
questions about graft tension and flexion angle. A recent comparison of open versus arthroscopic inlay to reconstruct the PCL and posterolateral corner reported that the technically challenging arthroscopic procedure was as effective at restoring stability to the posterolateral corner deficient knee as the open inlay procedure. 28

Overconstraint is not an unusual finding. Reconstruction leads to limited external rotation, 21 but overconstraint can lead to subluxation. 22 Although, single-bundle grafts are known to stretch following surgery, 23 there is no evidence that this might reduce overconstraint and thereby lead to subluxation. 24, 29

However, our study has inherent limitations as do other cadaver studies. The age of the donors was older than the typical patient with a posterolateral corner injury. Noted cadaver studies. The age of the donors was older than the variation in cadaver specimens 30 may suggest anatomical issues with instrumentation for measurement and methodology for an anatomical reconstruction using common grafts, preparation of the laboratory and clinical evaluation of a patient. As a result, the clinical observation that a PLC reconstruction may not achieve the same degree of constraint as described here may be a result of the limitations with the cadaver model. While, cadaver studies cannot be compared directly with the clinical situation, laboratory studies improve our understanding of the biomechanics of joint injury and reconstructive techniques.

In conclusion, advances in treating posterolateral instability continue to improve our understanding of this complex area of the knee. The current trend for posterolateral corner stabilisation has shifted towards an anatomical reconstruction using common grafts, preparation, and fixation techniques to restore normal stability and mechanics. Both of our procedures were equally effective at restoring external rotation and varus stability to a knee after sectioning the posterolateral capsule, LCL, and the popliteus tendon. The similar biomechanical performance and ease of the fibula-based technique coupled with preservation of the remaining tissue provide advantages that may tip the balance in favour of this approach.

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References


