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Anatomic, Arthroscopically Assisted, Mini-Open Fibular Collateral Ligament Reconstruction

An In Vitro Biomechanical Study

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Background: The fibular collateral ligament (FCL) is the primary restraint to varus rotation of the knee joint. Arthroscopic techniques are widely used and minimally invasive, but anatomic arthroscopic reconstruction of an isolated FCL injury has not been reported.

Hypothesis: Anatomic reconstruction of an isolated FCL injury can be performed arthroscopically and will restore the knee to near-normal stability.

Study Design: Controlled laboratory study.

Methods: A total of 12 nonpaired, fresh-frozen cadaveric knees were biomechanically subjected to a 10-N·m varus moment and 5-N·m external and internal rotation torques at 0°, 15°, 30°, 60°, 90°, and 120° of knee flexion, respectively (0° only for varus loading). Testing was performed with an intact and sectioned FCL and also after an anatomic reconstruction of the FCL by arthroscopic technique. Kinematics of each knee under various loading conditions was determined with a robotic universal force/moment sensor testing system.

Results: After sectioning, significant increases were found in varus rotation at 0°, 15°, 30°, 60°, 90°, and 120° of knee flexion; in external rotation at 15°, 30°, and 60° of knee flexion; and in internal rotation at 30°, 60°, and 90° of knee flexion. After reconstruction, full recovery of knee stability was observed in varus rotation at 0°, 15°, 30°, and 60°; in external rotation at 0°, 15°, 30°, 60°, 90°, and 120°; and in internal rotation at 0°, 15°, 30°, 60°, 90°, and 120°. When the sectioned and intact FCL knee conditions were compared, significant increases of 3.4° at 90° of flexion and 3.4° at 120° of flexion were found ($P < .001$, both conditions); when the reconstructed and sectioned FCL knee conditions were compared, significant decreases of 1.7° at 90° of flexion and 1.7° at 120° of knee flexion were found ($P = .033$ and .043, respectively).

Conclusion: An anatomic reconstruction of the FCL can be performed by an arthroscopically assisted mini-open technique with an isolated FCL injury, and near-normal stability of the knee can be restored.

Clinical Relevance: Anatomic reconstruction of the FCL by an arthroscopically assisted mini-open technique is a viable, less invasive option to treat nonrepairable isolated FCL injury.

Keywords: fibular collateral ligament; anatomic reconstruction; arthroscopic technique; biomechanics

The fibular collateral ligament (FCL) is the primary restraint to varus rotation of the knee joint,[2,7,8] and as long as the FCL remains intact, varus rotation is not increased with sectioning of other posterolateral structures or cruciate ligaments.[8] The FCL also plays important roles in stabilizing both external rotation and internal rotation about the knee.[2] Isolated injury to the FCL can cause gross lateral instability, insufficiency of the anterior cruciate ligament, muscle weakness, and posttraumatic osteoarthritis of the injured knee.[10] Moreover, it has been demonstrated that varus instability secondary to FCL injury can significantly increase the force on both anterior and posterior cruciate ligament reconstruction grafts in multiple-ligament injuries of the knee joint.[12,13] Therefore, proper treatment of FCL injuries is vital in addressing these pathologic abnormalities.

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A number of surgical techniques for FCL treatment have been described in the literature, such as direct repair,[1] advancement of the femoral attachment,[18] augmentation with a strip or whole segment of biceps femoris tendon,[24] and reconstruction at nonanatomic attachment sites.[4,15] To achieve better biomechanical and clinical results, an anatomic FCL reconstruction technique has been proposed,[2,14] and current opinion is that the FCL should be reconstructed at anatomic sites. Anatomic reconstruction of the FCL with a traditional open technique has achieved good results.[2,14] However, a long incision running across the knee joint, fascial incisions, and iliotibial band splitting are unavoidable, and a relatively long period of rehabilitation might be needed. Additionally, arthroscopic surgery is needed during the traditional open FCL reconstruction to treat injuries of the cruciate ligaments and the menisci. Arthroscopic techniques are widely used and minimally invasive, and previous studies reported that an arthroscopic technique could be used in extra-articular operations with good results.[5,20,21] Motivated by these reports, we developed an anatomic, arthroscopically assisted, mini-open FCL reconstruction technique to minimize the damage associated with FCL reconstruction and to improve outcomes. With this technique, intra-articular injuries, such as injuries of cruciate ligaments and menisci, could be treated simultaneously.

To our knowledge, this is the first time that the FCL has been reconstructed with this minimally invasive technique. Our hypothesis was that an anatomic, arthroscopically assisted, mini-open reconstruction of an isolated FCL injury by use of semitendinosus autograft would restore the injured knee to near-normal stability.

MATERIALS AND METHODS

Twelve fresh-frozen human cadaveric knees (mean age ± standard deviation, 43 ± 15.1 years; range, 21-60 years) were used in the study. Specimens were stored at −20° until 24 hours before testing and then were thawed at room temperature.[27] Physical examination and arthroscopic exploration were done to ensure that the range of motion was normal and to verify that there was no ligament injury or arthritis. The femur and tibia were cut approximately 20 cm from the joint line. The fibula was fixed in its anatomic position by inserting a cortical bone screw (3 mm in diameter) transversely through the fibula and the tibia. All soft tissues more than 10 cm from the joint line were removed to expose the bones. During the experiment, specimens were kept moist with 0.9% saline. The femur and tibia ends were secured in custom-made aluminum clamps using a heavy-duty epoxy resin.

The specimen was then mounted in a robotic universal force/moment sensor (UFS) testing system. The femoral side was rigidly fixed to the base, and the tibia was fixed to the sensor of the robot (Figure 1). The robotic UFS testing system was developed by a biomechanical laboratory to study the biomechanics of knee joint, similar to equipment previously reported.[17,28] The robot (KR 150-2, KUKA Robots, Augsburg, Germany) allows movement of the knee at 6 degrees of freedom (DOF). The position and orientation repeatability of the robotic manipulator are 0.15 mm and 0.2°, respectively. The UFS (model Delta SI-660-60, ATI Inc, Apex, North Carolina) can measure 3 forces and 3 moments in a Cartesian coordinate system, and the resolution is 0.25 N for forces and less than 0.075 N·m for moments.

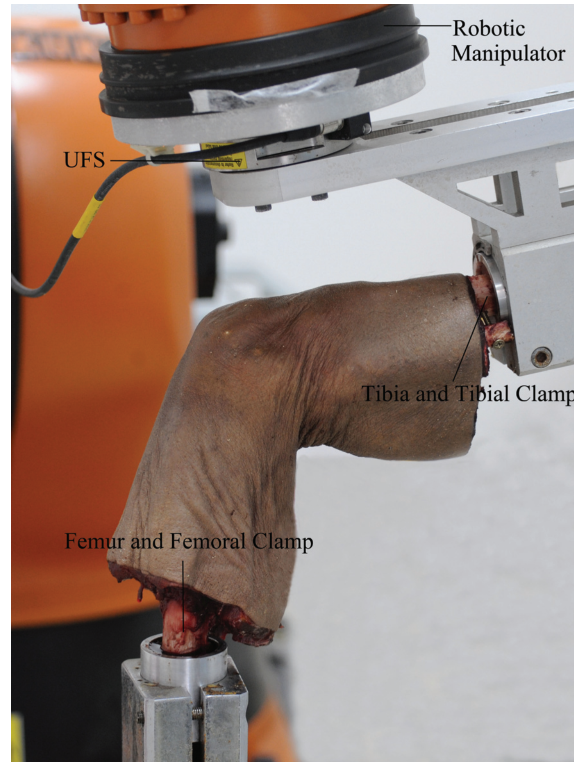

Figure 1. Human cadaver knee model tested with robotic universal force/moment sensor (UFS) testing system.

The robotic UFS testing system was used to determine a passive flexion path of the intact knee from 0° to 120° in 1° increments of flexion. At each incremental flexion angle of the knee, the forces and moments that were generated by the specimen in the remaining 5 DOF were minimized by an iterative algorithm of the robot control software. The position that satisfied the minimum force and moment at each incremental flexion angle was determined.[17,28] This passive flexion path was repeated 5 times before the kinematics under the external loads at each knee condition was determined.[6] The positions at 0°, 15°, 30°, 60°, 90°, and 120° of flexion were used as the starting positions for applying external tibial loads throughout the test.

After determination of the passive flexion path, the following external loading conditions were applied to the tibia at each starting position: (1) 10-N·m varus torque at 0°, 15°, 30°, 60°, 90°, and 120° of flexion; (2) 5-N·m external tibial torque at 15°, 30°, 60°, 90°, and 120° of flexion; and (3) 5-N·m internal tibial torque at 15°, 30°, 60°, 90°, and 120° of knee flexion.[2] Five DOF kinematic responses of the intact knee under various loads were recorded.

The head of the fibula was palpated to identify the location of fibular attachment of the FCL. Then a longitudinal incision about 2 cm long was made in the anterolateral aspect of the fibular head, the skin and subcutaneous tissues were dissected, and the anterior arm of the long head of the biceps femoris was exposed. The anterior arm was incised in line with its fibers, with an incision about 1.5 cm long and 1 cm proximal to the lateral aspect of the fibular head, which opened the FCL-biceps femoris bursa. The attachment site of the FCL on the lateral aspect of the fibular head was identified through this bursa. Then, the distal FCL was cut but the surrounding tissue was kept intact, which minimized changes in knee behavior attributable to surrounding structure damage. The incision was repaired in layers by sutures. After sectioning of the FCL, kinematics of the FCL-deficient knee was determined under the same external loading conditions that were used to test the FCL-intact knee.

Surgical Technique

After testing of the FCL-deficient knee, arthroscopic anatomic FCL reconstruction was performed with a semitendinosus tendon autograft as follows. The surgeon began by harvesting the semitendinosus tendon that was used as the graft material for FCL reconstruction. Then the arthroscope was introduced through the anterolateral portal, and the attachment of the popliteus tendon was seen. The shaver was introduced through an accessory portal about 3 cm proximal to the anterolateral portal, and the synovium and capsule behind the attachment of the popliteus tendon were debrided. The proximal FCL was then identified with partial removal of the aponeurosis of the long head of the biceps femoris muscle (Figures 2 and 3A). The femoral attachment of the FCL was removed, leaving a visible footprint. In cases where the remnant of the FCL is not visible, intraoperative radiographic methods reported previously for femoral tunnel placement would be used.[9,19]

Under direct vision with the arthroscope, a spinal needle was inserted through the skin with its tip just in the center of the footprint of the femoral attachment of FCL. The needle was pulled out and a 1-cm incision was made; then the incision was extended through the subcutaneous tissue down to the footprint of femoral attachment of FCL. An extra portal just lateral to the femoral attachment of the FCL was prepared. An eyelet pin was introduced through this portal and was drilled proximally and medially across the distal femur through the center of the femoral attachment of the FCL. A 7-mm reamer was then drilled to a depth of 35 mm over the eyelet pin (Figure 3B).

The distal incision was reopened to expose the distal attachment of the FCL; extension of the incision may be needed in some patients. The stump was debrided, and the footprint of the fibular attachment of the FCL was identified. A guide pin was drilled distally along the axis of the fibular head through the center of the FCL fibular attachment. A 7-mm reamer was then drilled to a depth of 3 cm over the guide pin. A horizontal tunnel placed 4.5 mm anterolateral to posteromedial was created in the anterolateral aspect of fibula, beginning 3 cm distal to the center of the FCL fibular attachment site; only the anterolateral unilateral cortex was drilled through. The 2

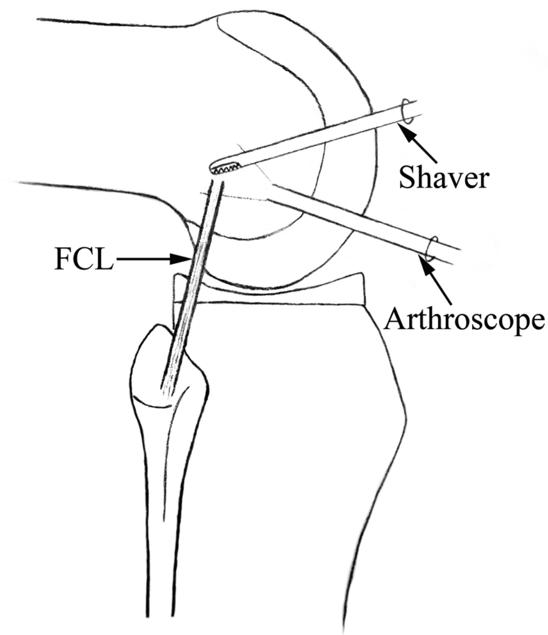

Figure 2. Partial removal of the aponeurosis of the long head of the biceps femoris muscle to show the proximal fibular collateral ligament (FCL). The shaver was introduced through an accessory portal about 3 cm proximal to the anterolateral portal.

tunnels were joined together into 1 tunnel with a curved curette, and a guide suture was passed through it (Figure 4). Care was taken to avoid injury to the peroneal nerve because it wraps around the fibular neck in this area. Injury to the peroneal nerve is one of the risks of this technique that may outweigh the potential benefits. A previous study defined a "safe" area in the anterolateral aspect of the proximal fibula that can be used during a biopsy of the proximal fibula (Figure 5).[22] This safe area was applied to our study to avoid injury to the peroneal nerve when the distal horizontal tunnel was created in the anterolateral aspect of the proximal fibula. The semitendinosus autograft was then passed from proximal to distal through the fibular tunnel by guide suture, and its length was adjusted to ensure that about 3 cm of graft remained in the femoral tunnel for later fixation. The graft was fixed in the fibular head tunnel with a 7×23-mm bioabsorbable screw (Depuy Mitek, Neuchatel, Switzerland) (Figure 4). The distal free end of the graft was then routed proximally and sutured to itself with No. 2 nonabsorbable sutures (Ethicon, Somerville, New Jersey) to serve as supplemental fixation (Figure 6). A blunt trocar was passed along the normal course of the FCL from distal to proximal under the lateral aponeurosis of the long head of the biceps femoris and the superficial layer of the iliotibial band to make a soft tissue tunnel. Then, an eyelet pin with a guide suture passed through this tunnel, and the guide suture was pulled out from an extra portal just lateral to the femoral attachment of the FCL by a probe (Figure 3, C and D). The FCL graft was passed proximally along the same

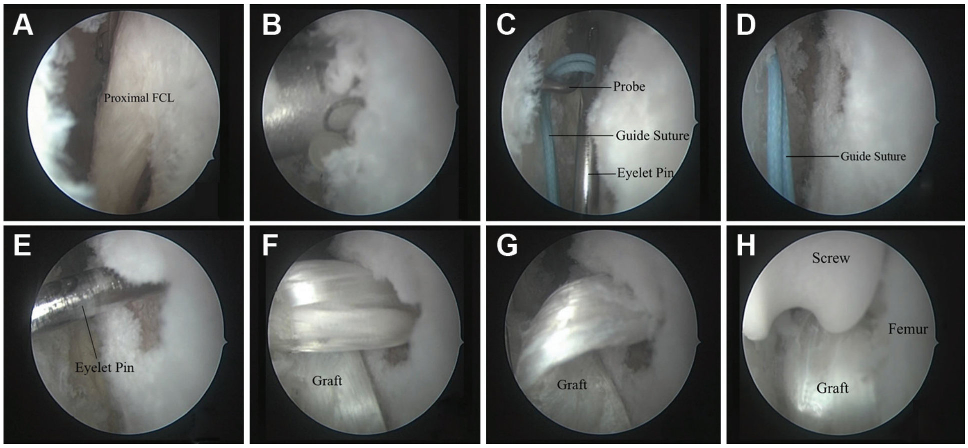

Figure 3. Fibular collateral ligament (FCL) reconstruction under direct vision with the arthroscope. (A) The proximal FCL was identified arthroscopically. (B) A 7-mm reamer was placed over the eyelet pin that was drilled through the center of the femoral attachment of the FCL. (C) An eyelet pin with a guide suture was passed through the soft tissue tunnel, and the suture was pulled out from an extra portal just lateral to the femoral attachment of FCL (lateral portal) by a probe. (D) A guide suture was left in the soft tissue tunnel. (E) An eyelet pin was introduced through the lateral portal and passed through the femoral tunnel. (F and G) The proximal free end of FCL graft was pulled into the lateral portal and passed through femoral tunnel by the guide suture. (H) The screw was placed at the superior aperture of the reconstruction tunnel (above the graft).

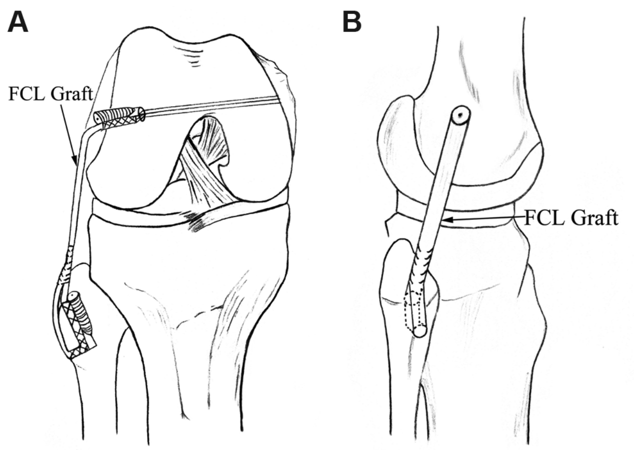

Figure 4. An isolated fibular collateral ligament (FCL) reconstruction procedure with a semitendinosus autograft. (A) Anteroposterior view, right knee; the longitudinal tunnel and horizontal tunnel in the fibular head were joined together into 1 tunnel through which the graft was passed. (B) Lateral view (except for the screw in fibular tunnel), right knee.

course, and the proximal free end was pulled out from the portal. An eyelet pin with a guide suture was introduced through the same portal and passed through the femoral tunnel (Figure 3E). Then, the proximal free end of the FCL graft was pulled into the portal and was placed into the femoral tunnel by the guide suture (Figure 3, F and G). Medial traction forces of 88 N were applied to tension the graft while it was secured in the femoral tunnel by a 7 $\times$ 30-mm bioabsorbable screw (Depuy Mitek) with the knee at 0° flexion and in neutral rotation (Figure 4). The screw was placed at the superior aperture of the reconstruction tunnel (Figure 3H). The incisions were then repaired by sutures anatomically, and the FCL reconstruction was finished (Figure 4). Kinematics of the FCL-reconstructed knee was determined by use of the same protocol as described above. All the reconstruction procedures were performed by a single surgeon.

Statistical Analysis

Statistical data analysis of each of the 3 motions was performed with repeated-measures analysis of variance. We compared the intact, sectioned, and reconstructed states of the knees at each flexion angle using the general linear model multivariate analysis with Bonferroni multiple comparisons. Statistical analysis was performed with SPSS 18.0 (SPSS Inc, Chicago, Illinois). The significance level was set at $P < .05$.

RESULTS

No graft fixation problems or evidence of graft slippage was found in any of the specimens.

Varus Data

After sectioning of the FCL, varus rotations significantly increased at all selected flexion angles compared with those of the FCL-intact knee (P = .001 at 0°; P = .003 at 15°; P = .001 at 30°; P = .01 at 60°; P < .001 at 90°; P < .001 at 120°). The FCL reconstruction significantly reduced the varus rotations of the FCL-deficient knee at all selected flexion angles (P = .001 at 0°; P = .003 at 15°; P = .001 at 30°; P = .013 at 60°; P = .033 at 90°; P = .043

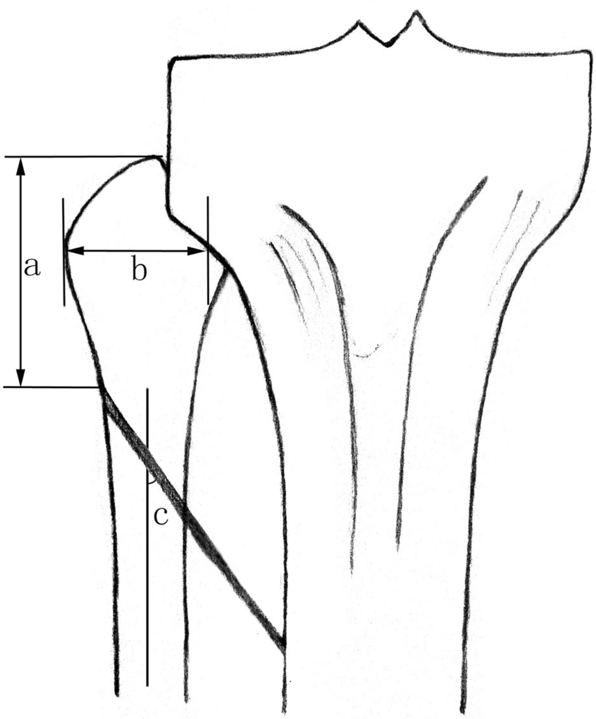

Figure 5. Three parameters to clearly establish the boundaries of the ''safe'' area (anteroposterior view of the right knee): a, distance between the apex of the fibular head and the point of origin of the deep peroneal nerve (mean ± standard deviation [SD], 26 ± 0.32 mm); b, distance between the most lateral prominence of the fibular head and the anterior intermuscular septum (mean ± SD, 15 ± 0.19 mm); c, angle between the deep peroneal nerve and the fibular axis (mean ± SD, 23.5° ± 3.5°).[22]

at 120°). When comparing the reconstructed to intact knee conditions, we found small but significant increases of 1.7° at 90° of knee flexion (P = .033) and 1.7° at 120° of knee flexion (P = .043). No significant differences were found between these 2 conditions at 0°, 15°, 30°, or 60° of knee flexion (Figure 7).

External Rotation Data

After sectioning of the FCL, external rotations significantly increased at 3 selected flexion angles compared with those of the FCL-intact knee (P = .008 at 15°; P = .005 at 30°; P = .023 at 60°). There were no significant differences in the intact versus sectioned states at 90° and 120° of knee flexion. The FCL reconstruction significantly reduced the increased external rotations of the FCL-deficient knee at 3 flexion angles (P = .041 at 15°; P = .04 at 30°; P = .049 at 60°). No significant differences were observed at 90° and 120° of knee flexion. When the reconstructed FCL and the intact conditions were compared, there were no significant differences in any of the flexion angles measured (Figure 8).

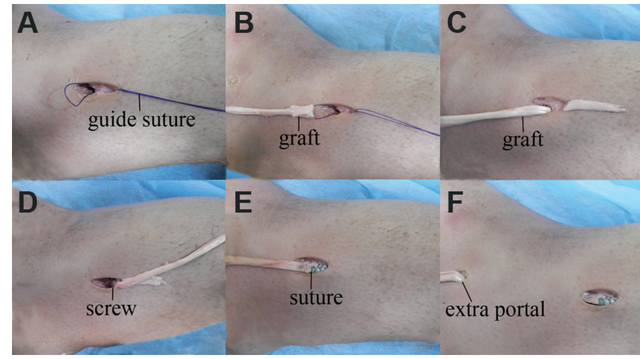

Figure 6. (A) A guide suture passed through the fibular tunnel. (B and C) The distal free end of the fibular collateral ligament (FCL) graft was pulled into the fibular tunnel by a guide suture. (D) The graft was fixed in the fibular head tunnel with a 7 × 23-mm bioabsorbable screw. (E) The distal free end of the graft was then routed proximally and sutured to itself with No. 2 nonabsorbable sutures to serve as a supplemental fixation. (F) The graft was pulled out from an extra portal just lateral to the femoral attachment of the FCL by a guide suture.

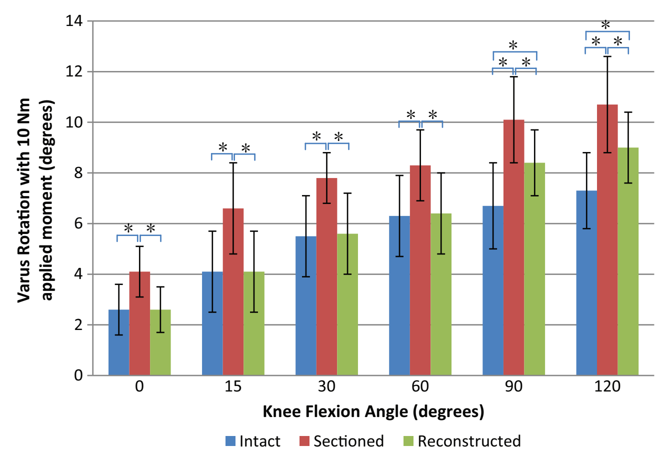

Figure 7. Angulation change in varus rotation with an applied moment of 10 N·m for intact, sectioned, and reconstructed fibular collateral ligament knee conditions at each flexion angle. *Significant difference.

Internal Rotation Data

After sectioning of the FCL, internal rotations significantly increased at 3 flexion angles compared with those of the FCL-intact knee (P = .03 at 30°; P = .018 at 60°; P = .016 at 90°). There were no significant differences in the intact versus sectioned states at 15° and 120° of knee flexion. The FCL reconstruction significantly reduced the increased internal rotations of the FCL-deficient knee at 3 flexion angles (P = .039 at 30°; P = .042 at 60°; P = .04 at 90°). No significant differences were observed at 15° and 120° of knee flexion. When the reconstructed FCL and the intact conditions were compared, there were no significant differences in any of the flexion angles measured (Figure 9).

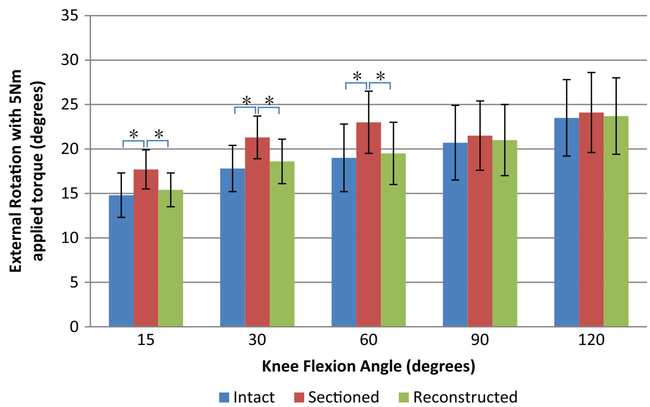

Figure 8. Angulation change in external rotation with an applied torque of 5 N·m for intact, sectioned, and reconstructed fibular collateral ligament knee conditions at each flexion angle. *Significant difference.

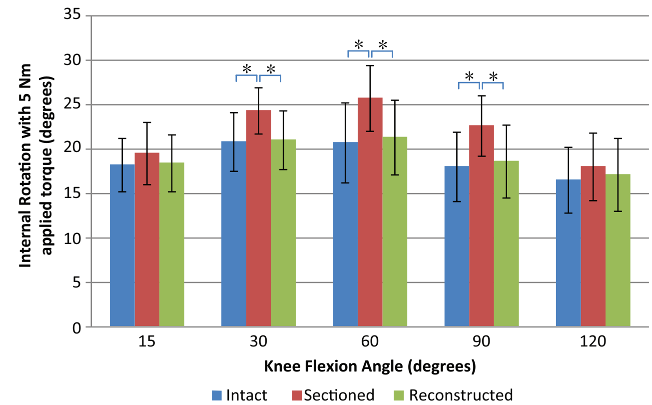

Figure 9. Angulation change in internal rotation with an applied torque of 5 N·m for intact, sectioned, and reconstructed fibular collateral ligament knee conditions at each flexion angle. *Significant difference.

DISCUSSION

For varus rotation, we found significant increases in instability after FCL sectioning at all flexion angles studied. Similar results were observed in other studies.[2,7,8] These findings further demonstrate that the FCL is an important restraint to varus rotation. The FCL reconstruction significantly decreased this instability at all knee flexion angles and additionally restored the varus rotation to the level of the FCL-intact knee at 0°, 15°, 30°, and 60°. However, at 90° and 120° of knee flexion, small increases of 1.7° and 1.7°, respectively, were seen between the reconstructed and intact states. Considering the large amount of varus instability that was recovered at these 2 flexion angles, we believe that the near-normal varus rotation stability of the knee joint can be efficiently restored by arthroscopic FCL reconstruction, and we don't believe that these small differences would be important clinically. Currently, the cause of failure to fully restore varus stability at 90° and 120° of knee flexion is unknown, and further research is needed to improve varus stability at terminal flexion. Furthermore, isolated FCL sectioning created significant amounts of increased external rotation at 15°, 30°, and 60° of knee flexion. Significant increases in internal rotation at 30°, 60°, and 90° of knee flexion were also observed after FCL sectioning. Our data demonstrated that the FCL was both an important external rotation stabilizer and an important internal rotation stabilizer of the knee. These findings were consistent with the observations of a previous study.[2] Our results showed that both external rotation instabilities and internal rotation instabilities were fully recovered after the FCL reconstruction. Therefore, these data supported our hypothesis that an anatomic, arthroscopically assisted, mini-open reconstruction of an isolated FCL injury by use of semitendinosus autograft could restore the injured knee to near-normal stability level biomechanically.

Anatomic FCL reconstruction with traditional open technique to treat isolated FCL injuries was reported previously; in that report, full recovery of varus instability at 0°, 60°, and 90° was found, and small increases of 0.8° and 0.7° were observed at 15° and 30°, respectively, between the reconstructed and intact states.[2] Our technique provided full recovery of varus instability at 0°, 15°, 30°, and 60°; small increases of 1.7° and 1.7°, respectively, were observed at 90° and 120° between the reconstructed and intact states. Considering the large amount of varus instability that was recovered in both the previous study and our study, we believe that after FCL sectioning both techniques can restore near-normal varus stability biomechanically. For external rotation instability created by the FCL sectioning, full recoveries were found at all knee flexion angles in both the previous study[2] and the current study. As to internal rotation instability after FCL sectioning, the previous study[2] reported full recovery of stability at 0° and 30° of knee flexion but did not report recovery at 60° and 90° of knee flexion; full recovery was found at all knee flexion angles in our research. This suggests that our less invasive FCL reconstruction technique may better restore internal rotation instability after FCL sectioning compared with the traditional open technique. Because of the differences in test methods between the 2 studies, further research is needed.

An autogenous semitendinosus graft was used in previous studies of FCL reconstruction.[2,14] There are several advantages in using this graft to reconstruct the FCL, and good results were achieved.[2,14] Therefore, semitendinosus tendon autograft was also used in the current study. Meister et al[16] showed that the attachment sites of FCLs were maximally separated in full extension and then progressively approximated as the knee was flexed, so that by 130° of flexion, the separation of the femoral and fibular attachment points decreased to a mean of 88% of the length measured in extension, and the rate of approximation was somewhat greater for the first 30° of flexion. Then, if an FCL graft centered over the femoral and tibial footprint of the FCL was tensioned and fixed with the knee

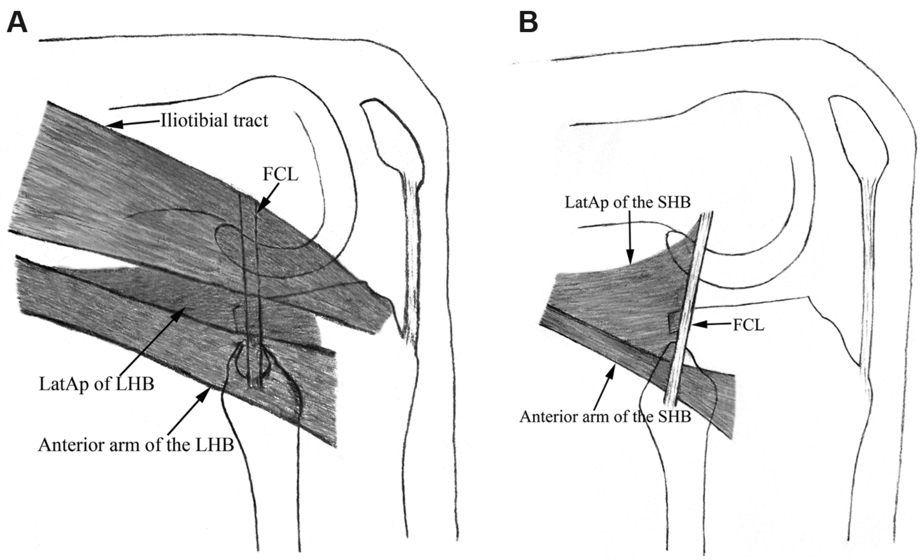

Figure 10. (A) The superficial layer of the iliotibial tract surrounds the lateral aspect of the knee, below the iliotibial tract, the fibular collateral ligament (FCL) is covered laterally by the lateral aponeurosis (LatAp) of the long head of the biceps femoris (LHB); and the distal fourth of the FCL is covered laterally by the anterior arm of the LHB. (B) Deep to the iliotibial tract, the posterior aspect of the FCL is directly connected to the lateral LatAp of the short head of the biceps femoris (SHB), and the anterior arm of the SHB passes medial to the distal FCL.

in 30° of flexion, it would lengthen when the knee was extended to 0°, and the resulting increase in FCL graft loading might cause the graft to permanently stretch or even fail during the healing period. Given the normal kinematics of the FCL, we prefer that the FCL graft be tensioned and fixed with the knee in full extension.

There are some important structures around the FCL, especially on its lateral aspect. A previous study reported that the superficial layer of the iliotibial tract surrounded the lateral aspect of the knee (Figure 10).[23] Below the iliotibial tract, the posterior aspect of the FCL was directly connected to the lateral aponeurosis of the short head of the biceps femoris and was covered laterally by the lateral aponeurosis of the long head of the biceps femoris (Figure 10).[23] The distal fourth of the FCL was covered laterally by the anterior arm of the long head of the biceps femoris, and the anterior arm of the short head of the biceps femoris passed medial to the distal FCL (Figure 10).[23] A published study also reported that the FCL shortened significantly and became slack as the knee flexed and that the FCL appears to be dynamically controlled by the actions of the short and long heads of the biceps femoris and their attachments to the FCL.[3] This can be demonstrated in vivo by applying a muscle stimulator to the muscle fibers of the short head of the biceps femoris and observing its bowstring effects on the FCL during its contraction.[3] Although the clinical relevance of dynamic stability to the success of FCL reconstruction is unclear and further research is needed, the FCL and structures around it appear to form an anatomic and functional complex, and minimizing the damage to these structures during FCL reconstruction should play an important role in restoring function of the FCL.

The FCL is an extra-articular structure located inside the knee joint; visualizing the FCL arthroscopically is the first step during arthroscopic FCL reconstruction, and exposing the proximal FCL with an arthroscopic technique is difficult. LaPrade et al[11] located the popliteus insertion site 18.5 mm distal and anterior to the femoral attachment of the FCL. Because the popliteus tendon insertion lies inside the knee joint, the anatomic location of the femoral attachment of the FCL can be identified by the location of the popliteus insertion. Through anatomic research, in the current study we found that there were only a few soft tissues between the popliteus insertion and the femoral attachment of the FCL. With this arthroscopic technique, the synovium and capsule proximal and posterior to the popliteus femoral insertion were removed; then the arthroscope could be introduced into the space between the iliotibial band and the femoral attachment of the FCL. There was only a thin aponeurosis overlying the femoral attachment of the FCL, and the attachment could be seen clearly under arthroscopic examination with partial removal of the aponeurosis. The femoral tunnel preparation, graft passage, and fixation were all performed arthroscopically with an extra portal just lateral to the femoral attachment of FCL.

Passing the graft along its native course without exposure of the FCL body, which is challenging, is crucial in minimizing damage to the surrounding structures of the FCL. In the current study, a soft tissue passage along the native course of the FCL was created by blunt trocar from distal to proximal with the guidance of the FCL remnant. Given the connection between the FCL and the structures around it, the remaining FCL tissue was left in situ to minimize damage to the surrounding structures of the

FCL. If the remnant of the FCL was obscured or obliterated, the anterior arm of the short head of the biceps femoris could be used as an anatomic reference because it was the only structure passed medial to the distal FCL and could be identified during the fibular tunnel preparation. When the blunt trocar passed the anterior arm of the short head of the biceps femoris, there was only synovium and capsule medial to it; thus, the blunt trocar can be observed arthroscopically, and the remaining proximal passage can be created arthroscopically.

The distal FCL is covered laterally only by the anterior arm of the long head of the biceps femoris; thus, the lateral aspect of the distal FCL can be exposed with mini-open surgery during FCL reconstruction. In this study, a l.5-cm-long incision in line with the fibers of the anterior arm of the long head of the biceps femoris was made and the distal FCL was clearly exposed; the incision may need to be longer in some patients. We believe that a l.5-cm-long incision that is in line with the fibers of the anterior arm of the long head of biceps femoris causes only minor injury. Therefore, we managed to reconstruct the FCL arthroscopically (except for the fibular tunnel), and damage to the structures surrounding the FCL was avoided as much as possible. Of course, these FCL reconstructions were performed in normal cadaveric knees, and it might be more difficult in knees with prior FCL injury and considerable scarring.

In our study, the anatomic femoral attachment site of the FCL was clearly identified arthroscopically, and the femoral tunnel was located accurately in the center of the footprint of the femoral attachment of the FCL. However, the lateral epicondyle, the important anatomic reference, was obscure arthroscopically. The femoral attachment (or footprint) of the FCL was the anatomic reference and was necessary in our reconstruction procedure. Previous open surgery studies have reported that in cases of posterolateral knee injuries, it could be difficult to locate the femoral attachment of the FCL during intraoperative procedures, especially in cases involving chronic injuries of the posterolateral knee, where tissue retraction and scarring can further obscure the locations of these structures and their attachments.[19] Additionally, normal landmarks may be obscured or obliterated in revision posterolateral knee surgeries given the presence of previous reconstruction tunnels or hardware.[19] To solve this problem, intraoperative fluoroscopic techniques to identify the attachment site of the FCL have been developed, and these techniques have proven to be useful tools for tunnel placement during FCL reconstruction.[9,19] In view of the above-mentioned facts, we thought that the tunnel location during arthroscopic FCL reconstruction would be problematic in such cases, which involve both chronic injuries and revision posterolateral knee surgeries. Therefore, the intraoperative radiographic method for femoral tunnel placement would be useful in cases in which the femoral attachment or footprint of the FCL couldn't be identified clearly. In this research, the fibular attachment of the FCL was exposed through the mini-open approach, and the fibular tunnel was located accurately in the center of the footprint of the fibular attachment of the FCL. Considering the differences between a cadaveric test and clinical operations, especially for revision surgeries and multiligamentous knee injuries, the intraoperative radiographic method for fibular tunnel placement might be helpful in some cases.

In the current research, the FCL graft was passed along its native course with both femoral and fibular tunnels positioned at the anatomic attachment sites of the FCL, and only a little damage was inflicted on the surrounding structures of the FCL. Therefore, our technique achieved anatomic reconstruction of the FCL and minimized the damages associated with FCL reconstruction.

There are several limitations of the current study that need to be addressed. A semitendinosus autograft was used in this study; the elastic modulus of tendon is substantially greater than that of ligament,[26] and the discrepancy in structural stiffness between the tendinous graft and the FCL may result in an "overconstraining" effect,[25] although no such effect was found in our study. This research was performed in vitro, which differs significantly from the in vivo condition. This study didn't recapitulate the dynamic stability provided by the muscles around the knee. In addition, it was a time zero test, and tissue healing may have altered the loading of the graft. Twelve specimens were used in this study, which may have affected the statistical analysis, and although statistical differences were found in some data, the testing of additional specimens may have resulted in statistical differences in other data.

In conclusion, the current study has shown that an anatomic reconstruction of the FCL can be performed by arthroscopically assisted, mini-open technique with an isolated FCL injury, and near-normal stability to the knee can be restored. This new technique hasn't been used in our institute clinically, and prospective studies to evaluate outcomes in patients with an anatomic isolated FCL reconstruction using arthroscopically assisted mini-open technique are recommended.

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