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Title: Comparison of two surgical techniques for reconstructing posterolateral corner of the knee: a cadaveric study evaluated by navigation system

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ABSTRACT

Purpose: This study aimed to evaluate the immediate effect on knee kinematics by two different techniques of posterolateral corner (PLC) reconstruction.

Methods: Five intact formalin preserved cadaveric knees were used in this study. Navigation system was employed to measure knee kinematics (posterior translation, varus angulation and external rotation) after applying constant force and torque to the tibia. Four different conditions of the knee including intact knee, PLC sectioned knee and PLC reconstructed knees by the double-femoral-tunnel technique and single-femoral-tunnel technique were evaluated during the biomechanical test.

Results: Sectioning the PLC structures resulted in significant increase in external rotation at 30 degrees of flexion from 11.2 (2.6) degrees to 24.6 (6.2) degrees, posterior translation at 30 degrees of flexion from 3.4 (1.5) mm to 7.4 (3.8) mm, varus angulation at 0 degree of flexion from 2.3 (2.1) degrees to 7.9 (5.1) degrees. Both reconstruction techniques significantly restored the varus stability. The external rotation and posterior translation at 30 degrees of flexion after reconstruction with double-femoral-tunnel technique were 10.2 (1.3) degrees and 3.4 (2.7) degrees respectively, which were significantly better than that of single-femoral-tunnel technique.

Conclusion: Both techniques of reconstruction showed improved stability compared with PLC sectioned knees. Double-femoral-tunnel technique in PLC reconstruction showed a better rotational stability and resistance to posterior translation without comprising the varus stability than single-femoral-tunnel technique.

Clinical Relevance: PLC reconstruction by a double-femoral-tunnel technique would achieve a better rotational control and resistance to posterior translation.

Key Words: Kinematics, PLC reconstruction, method

INTRODUCTION

The posterolateral instability was reported to be a significant disabling condition[1, 2]. Failure to recognize the posterolateral (PLC) injury would lead to failure in reconstructing anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL)[3-7]. The understanding of anatomy and biomechanics of PLC was improved in the past two decades, but the best technique to reconstruct PLC was not well established[3, 5, 8-10].

The anatomy of the PLC is complex and it is composed of both static and dynamic stabilizers. Previous studies[4, 7, 11-15] reported that there were three primary stabilizers of PLC including the lateral collateral ligament (LCL), popliteus muscle tendon unit and popliteao-fibular ligament (PFL), which served as the primary restrainers of tibial external rotation maximally at 30 degrees of flexion. The LCL was suggested to act as a primary restraint to varus angulation, whereas the PFL and the popliteus as a secondary stablizers to varus angulation.

Larson and coworkers[16] described a technique of reconstruction in 1996 that involved the utilization of a free semitendinosis graft as a figure of eight through a transfibular tunnel and the fixation at an isometric point of LCL and PFL by screw and washer in the lateral femoral condyle. In the past decades, various modifications of reconstruction technique and development on anatomical reconstruction of PLC were reported[8, 17-19]. Kumar and coworkers[17] described a technique in 1999 by drilling a tunnels in the fibular head and the lateral femoral epicondyle. The PLC structure was reconstructed by using autogenous tendon graft passing through the tunnels and secured with an interference screw in the lateral epicondyle tunnel. However, residual laxity was reported after PLC reconstruction with this technique[8]. It was suggested that the single isometric femoral tunnel did not address the different insertion sites of popliteus tendon and LCL. In 2005, Arciero[8] suggested another technique that aimed to provide a more anatomical reconstruction of the PLC by recreating the insertion sites of the LCL and the popliteus on the femur using a dual femoral sockets technique.

The purpose of this study was to compare the immediate effect of double-femoral-tunnel technique and single-femoral-tunnel technique for PLC reconstruction on knee kinematics, using an isolated cadaveric injury model. It was hypothesized that the knee kinematics was better restored by double-femoral-tunnel technique.

METHOD

Specimen Preparation: Ten intact human cadaveric formalin preserved knees were used in this study. The specimens were checked by inspection, palpation and physical examination including Lachman test and varus/valgus stress test to detect any obvious bony deformity, previous fracture and ligamentous laxity. Four knees were used for the development of research protocol. One cadaveric knee was found to have severe degeneration after dissection that was not suitable for the study. Five cadaveric knees were finally employed in the experimental test.

For all cadaveric specimens, the femur was sawed at 15cm above the joint line and the ankle was disarticulated, keeping the distal tibio-fibular joint intact. The skin and muscle 10cm above and below the joint line were removed, keeping the interosseous membrane intact. The soft tissue was carefully dissected by a single surgeon while keeping the following structures intact: medial collateral ligament, posteromedial complex, ACL, PCL, popliteus muscle tendon unit, LCL, PFL and menisci. Apart from the above structures, all other soft tissues were removed including the capsule, patellar tendon, iliotibial band, biceps tendon and hamstring tendons. The above procedures aimed to minimize the effects of the muscle tone, restrain caused by capsule so that the two reconstruction techniques were compared in a well controlled condition.

The dissected knees were put on a custom made testing apparatus in which the distal femur was rigidly held and it allowed a free moving of tibia and fibula for conducting biomechanical test. A custom-made 8mm diameter intrameduallary nail with an adapter over the distal end was inserted from distal tibia to shaft of tibia. Two 4.5mm shanz screws were inserted to the tibia through two locking holes of the intramedually nail for anchoring the trackers of the navigation system (Figure 1). A torque sensor (FUTEK, USA) with accuracy less than 0.02Nm was attached to the distal end of intrameduallary nail for application of external rotation torque during the test. Another two parallel 4.5mm shanz screws were inserted over distal shaft of femur for anchoring the trackers of the navigation system.

Testing protocol: Intra-operative navigation system (BrainLab, Germany) was employed for measuring the testing parameters. The BrainLab ACL reconstruction system version 2.0 was used to measure the degrees of external rotation and posterior translation while the BrainLab Total Knee Replacement System version 2.1 was used to measure the varus angulation. For the biomechanical test, constant force and torque were firstly applied to the tibia of the intact knee. It included anterior and posterior pulling forces of 133N[20] for measuring anterior-posterior laxity at 30/90 degrees of flexion; rotational torques of 5Nm[20] for measuring internal/external rotational laxity and varus/valgus laxity at 30/90 and 0/30 degrees of flexion respectively. The degree of flexion and extension was guided by the navigation system.

The popliteus, PFL and the LCL structures of the knee was then sectioned through its mid substance. Same testing procedures were repeated to document the laxity of the sectioned knee. Two different techniques of PLC reconstruction were performed. In both techniques, a formalin fixed tibialis anterior tendon allograft was harvested from the same leg and both ends of the tendon were whipstitched by ethibon 5 suture for 1.5cm. The details of both reconstruction techniques were described in the following paragraphs. The same testing procedures were employed after each reconstruction.

Surgical technique: Technique A (Figure 2) - This technique aimed to reconstruct the LCL and PFL in a more anatomical way by creating two femoral tunnels according to the footprint of the LCL and the popliteus tendon as decribed by Arciero[8]. A 2.4mm guide pin was inserted at the anterior and inferior to the fibula insertion of the LCL. It then posteromedially exited to the posterior aspect of the fibula head at level of the proximal tibio-fibular joint. A 7mm diameter transfibular tunnel was created by the cannulated reamer. A 2.4mm guide pin was inserted to the centre of the footprint of LCL over the lateral epicondyle of femur towards the medial cortex. A 7mm femur tunnel was created by cannulated reamer for the reconstruction of the LCL. The popliteofibular tunnel was created after establishing the tunnel for the LCL by inserting a 2.4mm guide pin to the centre of the footprint of the popliteus tendon. A 7mm popliteofibular tunnel was created by the cannulated reamer. The tendon graft was passed through the transfibular tunnel. The posterior limb was passed along the posterior aspect of the proximal tibio-fibular joint, through the popliteus hiatus and then through the poplitealfibula tunnel towards the medial cortex. The anterior limb was passed over the posterior limb, then through the LCL tunnel towards the medial cortex. The graft was tensioned at 30 degrees of flexion, internal rotation and slight valgus. It was then fixed by sutures tied around a post created by a 4.5mm cortical screw with washer.

Technique B (Figure 3) - This was the modified Larson technique[16] described by Kumar[17], which involved the use of single femoral tunnel for the fixation of both anterior and posterior limb of the graft. The transfibular tunnel created in technique A was reused. The femoral tunnel over the femoral insertion of the LCL created in technique A was used, with the tunnel enlarged to 9mm diameter. Graft was passed through the transfibular tunnel, both anterior and posterior limb were passed through the femoral tunnel with the whipping suture. The graft was tensioned at a position of 30 degrees of flexion, internal rotation and slight valgus. The grafts were fixed by sutures tied around a post created by a 4.5mm cortical screw.

Statistical Analysis: One-way multivariate analysis of variance (MANOVA) with repeated measures was emplyed to examine the difference in all dependent variables. One-way analysis of variance (ANOVA) with repeated measures was employed on each parameter to examine any significant differences between all testing conditions, which included intact knee, sectioned knee and reconstructed knees. Least Square Difference (LSD) post-hoc pairwise comparisons was used between the different conditions. All statistical tests were calculated by statistical analysis software (SPSS version 16.0, USA). The level of significance was set at p=0.05. Results were presented as mean (SD).

RESULTS

MANOVA showed that knee kinematics was significantly affected by the four different conditions of the knee ($P<0.05$). ANOVA also showed that all dependent variables except posterior translation at 90 degrees of flexion was significantly affected by the four conditions of the knee ($P<0.05$). The results of the post-hoc pairwise comparsions in different conditions of posterior translation, external rotation and varus angulation were summarized in table 1.

Posterior Translation (Figure 4): After sectioning the structures of the PLC, there was a significant increase in posterior translation at 30 degrees of flexion from 3.4 (1.5) mm to 7.4 (3.8) mm after application of posterior pulling force. After reconstruction of the PLC by technique A, there was an improvement at 30 degrees of flexion to 3.4 (2.7) mm, which showed a significance difference compared to the sectioned knee ($p<0.05$). There was no significant difference compared to the intact knee ($p>0.05$). Reconstruction of PLC by technique B decreased posterior translation from 7.4 (3.8) mm to 5.0 (2.3) mm compared to sectioned knee, which was not significant ($p>0.05$). Moreover, reconstruction by technique B showed inferior result in resisting posterior translation when compared with technique A ($p<0.05$).

External rotation (Figure 5): The external rotation of the intact knee was 11.2 (2.6) degrees and 15.0 (5.3) degrees at 30 and 90 degrees of flexion respectively. There was significant increase in external rotation after sectioning the PLC structures, which measured as 24.6 (6.2) degrees at 30 degrees of flexion ($p<0.05$) and 26.6 (7.3) degrees at 90 degrees of flexion ($p<0.05$). Both techniques of PLC reconstruction improved the rotational laxity when compared to the sectioned knee ($p<0.05$). Reconstruction by technique A improved the external rotation at 30 degrees of flexion from 24.6 (6.2) degrees to 10.2 (1.3) degrees, which was comparable to the intact knee ($p>0.05$). The reconstruction with technique A showed a better result than that of technique B, which measured as 14.4 (1.5) degrees ($p<0.05$). There was no significant difference in external rotation at 90 degrees of flexion between technique A and technique B ($p>0.05$).

Varus angulation: At 0 degree of flexion, varus angulation significantly increased from 2.3 (2.1) degrees to 7.9 (5.1) degrees after sectioning the structures of PLC ($p<0.05$). Both reconstruction techniques restored the varus laxity to 2.0 (1.5) degrees in technique A and 1.0 (0.5) degrees in technique B, which showed no significant difference between the reconstructed knees and the intact knee ($p>0.05$). However, there was no significant difference between the two reconstruction techniques ($p>0.05$). At 30 degrees of flexion, the varus angulation significantly increased from 4.0 (3.5) degrees to 12.8 (5.5) degrees ($p<0.01$). After reconstruction by technique A, the varus laxity significantly decreased from 12.8 (5.5) degrees to 4.9 (2.9) degrees ($p<0.05$). There was no significant difference between the sectioned knee and the reconstructed knee with technique B; and between the reconstructed knees with both techniques.

DISCUSSION

There were numerous surgical techniques proposed for restroing the posterolateral instability in the literature, which included acute repair, augmentation by the surrounding structures and reconstruction by using allograft or autograft. In the 1980s, Hughston and Jacobsen[21] used a lateral gastrocnemius, capsular, LCL and popliteus advancement procedure that relied on the integrity of posterolateral structures. However, the result was not satisfactory. Clancy and coworkers[1] diverted the biceps tendon and fixed it to the lateral femoral condyle by a screw and washer that aimed to reduce the external rotation of the knee, but the PLC function could not be completely restored. Muller[22] employed a strip of the ilotibial band along the line of the popliteus tendon as a popliteal bypass procedure. The clinical outcomes and the degrees of residual laxity of this technique was not clearly reported.

In 1990s, Larson and coworkers[16] advocated a technique utilizing a free semitendinosis graft as a figure of eight through a fibula tunnel and around a screw and washer in the lateral femoral condyle to reconstruct the LCL and the PFL. The tunnel technique was similar to the one proposed by Kumar and coworkers[17] but it was simplified that the semitendinosis loop formed a triangle and was secured in the lateral epicondyle by using an interference screw. In 2004, the two-tailed technique was described by La Prade and coworkers[23] that offered a more anatomical reconstruction by adding a tibial tunnel to reconstruct the popliteus, which stressed the reconstruction of the three primary stabilizers (Popliteus, PFL and LCL). Nau and coworkers[24] in 2005, compared the two-graft technique and a two-tunnel technique that only stressed the reconstruction of static stabilizing structures of the PLC in a cadaveric study. It was reported that both techniques restored the external rotation laxity at 30 and 90 degrees of flexion, varus laxity in 0 and 30 degrees of flexion. The two-tunnel technique was similar to the technique A in the current study, which supported the previous result.

The anatomy over the lateral side of the knee was firstly described[7] in 1982 that it was divided into three layers from superficial to deep. The biomechanics of PLC was then studied by sequential sectioning of the various structures in cadaver[4, 7, 11-15]. From these studies, the LCL was found to be the primary restraint to varus movement. The PFL and popliteus tendon were reported for resisting the external rotation of the knee.

Both ACL and PCL served as the secondary restraint to the varus angulation and external rotation. Moreover, the structures of PLC were secondary restraints to posterior translation, which the current result showed an increased posterior translation after sectioning the PLC structures.

Brinkman and coworkers[25] quantitatively documented the insertion geometry of the LCL and popliteus tendon and found that the popliteus tendon inserted around 11mm distally and 0.84mm either anterior or posterior to the LCL. Therefore, it was concluded that single-femoral-tunnel technique could not restore the normal anatomy. The current study showed that single-femoral–tunnel technique did not completely restore the rotational laxity in the sectioned knee and it was inferior to the double-femoral-tunnels technique as well. There was no significance difference in external rotation and varus angulation between the intact knee and the reconstructed knee with double-femoral-tunnel technique. The reconstruction with double-femoral-tunnel technique included two femoral tunnels with two separate limbs of soft tissue graft to simulate the function of the LCL and PFL, which explained the experimental results of better rotational control. Apart from using the tendon graft of tibialis anterior for the reconstruction, literature suggested using Achilles tendon allograft[9], split Achilles tendon allograft[26] for reconstructing PLC with double-femoral-tunnel technique.

In the literatures, most of the studies employed interference screws as a method of fixation for the soft tissue graft in the femoral tunnels. During the development of the research protocol, interference screw was firstly used for fixation and it was found that the graft loosened during biomechanical test especially after the rotational torque applied. One of the possible reasons was that the formalin fixed specimen affected the bone quality, graft quality and the subsequent fixation. Therefore, the graft was fixed by the tie-on post technique in the current study. In clinical practice, it was suggested that the graft should be adequately protected postoperatively or double fixation method should be employed.

The navigation system developed for ACL reconstruction would assist surgeon to evaluate the anteroposterior translation and rotation displacement at 30 and 90 degrees of flexion. Due to the accurate measurement provided by the system, it was employed in the current study to measure knee kinematics. Another software in the navigation system (BrainLab Total Knee Replacement System version 2.1) was used to evaluate the treatments effect on varus angulation. The real time changes in knee kinematics presented by the system provided valuable information for surgeon to examine the intact, sectioned and reconstructed knees under anaesthesia. During operation in human, it involved passing the graft through various soft tissue plane and bone tunnels, it might be possible of trapping soft tissue within these tunnels and might result in insufficient graft tensioning. Utilization of navigation system to verify knee kinematics before and after reconstruction greatly avoided the problem of insufficient tensioning.

The cadaveric knees in this study were fixed by formalin, which caused a limitation in the range of motion and the degree of ligament laxity. This negative effect was avoided by using each specimen to serve as its control. The measurements were conducted in the same knee for four conditions including intact knee, sectioned knee and reconstructed knee with both techniques. There was another limitation in this study that the biomechanical test was not able to fully simulate the in-vivo conditions. Moreover, the function of dynamic stabilizers was not addressed in this study. During the PLC reconstruction in human, the anterior limb of the graft was tunneled deep to the biceps femoris tendon insertion and adjacent to the native LCL, but these procedures could not be repeated in the current study as the muscle tone of biceps was absent. Lastly, the graft healing and maturation, which are the most important clinical issues, were not investigated. In this study, the real physiological condition could not be simulated but the tested conditions could be isolated clearly, Therefore, the results were reproducible, which facilitated the experiemnt to determine the differences between the two reconstruction techniques.

CONCLUSION

Both techniques of PLC reconstruction in the current study showed improved stability compared with PLC-sectioned knee. The PLC reconstruction with double-femoral-tunnel technique showed a better rotational stability and resistance to posterior translation without comprising the varus stability than the single-femoral-tunnel technique.

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Figure 1. A line diagram showing how the intrameduallary nail was fixed inside the distal tibia by two shanz screws connected with navigation trackers. The distal end of the intrameduallary nail was connected to the torque sensor for application of the controlled torque.

Figure 2. PLC reconstruction by technique A. Two femoral tunnels measured 7mm diameter were created according to the footprint of LCL and Popliteus tendon. The tendon graft was passed through the 7mm transfibular tunnel, the posterior limb was passed to the popltealfibula tunnel and the anterior limb was passed over the posterior limb, then through the LCL tunnel towards the medial cortex. It was then fixed by sutures tied around a post created by a 4.5mm cortical screw with washer.

Figure 3. PLC reconstruction by technique B. A single femoral tunnel measured 9mm in diameter was created over the lateral epicondyle for the passage of both anterior and posterior limbs of the graft. The graft was fixed by sutures tie around a post.

Figure 4. The posterior translation (mm) for each tested knee state (intact, sectioned, technique A, technique B) at 30 degree of flexion. Technique A, double-femoral-tunnel technique; Technique B, single-femoral-tunnel technique. Asterisks (*) indicate a significant difference ($p<0.05$).

Figure 5. The external rotation (deg) for each tested knee state (intact, sectioned, technique A, technique B) at 30 degrees of flexion. Technique A, double-femoral-tunnel technique; Technique B: single-femoral-tunnel technique. Asterisks (*) indicate a significant difference ($p<0.05$).

Table 1. Statistical results of different parameters camparing the four testing conditions (intact, sectioned, technique A and technique B)