Kinematics of the Knee after Posterolateral Corner Reconstruction - An In Vitro Robotic Investigation

Peter S. Vezeridis, M.D., M.M.S., Ali Hosseini, Ph.D., Frank W. Gwathmey, Jr., M.D., Kwan K. Park, Xudong Liu, Guoan Li, Ph.D., Thomas J. Gill, M.D..
Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA.

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Introduction: The posterolateral corner (PLC) of the knee is a region with complex anatomy that has been poorly understood until recently. PLC injuries may result in posterolateral rotatory instability of the knee [1, 2]. Untreated PLC injuries increase forces applied to the ACL and PCL and therefore may lead to failure of concurrent ACL and PCL reconstructions [3, 4]. Recently there has been a trend amongst surgeons to use reconstruction techniques that attempt to more closely reestablish the PLC anatomy. The modified Larson technique is a fibular-based reconstruction that consists of passing a tendon allograft through an anteroposterior drill hole in the fibular head and securing both ends of the allograft in a lateral femoral drill hole [5, 6]. A more complex reconstruction technique that involves the use of two separate grafts with origins from both the tibia and fibula has been developed [7]. The purpose of the present study was to analyze the biomechanical integrity of these two PLC reconstruction techniques using a sophisticated robotic biomechanical testing system that enables analysis of joint kinematics under simulated physiological loads and simulated muscle loads. We tested the hypothesis that a fibular-based docking technique and a more complex tibial-fibular-based technique for PLC reconstruction would restore normal knee joint kinematics under simulated loads.

Methods: Eight fresh frozen cadaveric human knee specimens were tested (4 left, 4 right; 50 to 70 years old). The biomechanical robotic testing method has been validated in our laboratory and is able to learn the complex motion of the knee specimen in response to external loads [8]. Each specimen was installed on the robot, and a passive flexion path was determined from full extension to maximal flexion of the knee. The specimen was then subjected to external tibial torque (5 N·m) and varus loading torque (5 N·m), and kinematics of each specimen were measured at 30°, 60°, and 90° of flexion. Following testing of the intact specimen, the posterolateral corner was sectioned, and biomechanical testing of the specimen was performed using the same protocol. Next, PLC reconstruction was performed using a fibular-based docking PLC reconstruction technique (Fig. 1a), and the specimen was tested again. Finally, tibial-fibular-based PLC reconstruction was performed (Fig. 1b), and the kinematic response was determined using the robot. At each flexion angle, knee rotations in response to the applied loads were compared between the PLC-intact knee, the PLC-deficient knee, and the PLC-reconstructed knee. Statistical analyses utilized repeated-measures analysis of variance (ANOVA) and Student-Newman-Keuls test. Statistical significance was set as p < 0.05.

Results: Under application of external tibial torque, ER increased from 19.9° in the intact state to 30.0° in the PLC deficient state at 30° of knee flexion (Fig. 2). The fibular-based reconstruction decreased ER to 18.7°, while the tibial-fibular-based reconstruction reduced it further to 14.9°. At 60° of flexion, ER was 19.8° in the intact state and increased to 29.3° with PLC deficiency. ER decreased to 22.4° after fibular-based reconstruction and further decreased to 15.7° after tibial-fibular-based reconstruction. At 90° of flexion, ER increased from 19.7° in the intact state to 26.3° with PLC deficiency. The fibular-based reconstruction decreased ER to 23.5°, while the tibial-fibular-based reconstruction reduced ER to 15.4°. Under application of a varus load, varus rotation increased from 0.44° in the intact knee to 4.95° with PLC deficiency at 30° of knee flexion (Fig. 3). Fibular-based reconstruction decreased varus rotation to 0.38°, and tibial-fibular-based reconstruction decreased rotation to 1.56°. At 60° of flexion, varus rotation increased from 2.46° in the intact state to 6.07° in the PLC deficient state and subsequently decreased to 1.82° after fibular-based reconstruction and to 1.64° following tibial-fibular-based reconstruction. Finally, at 90° of knee flexion, varus rotation was 3.15° in the intact knee, 3.53° in the PLC deficient knee, 2.70° following fibular-based reconstruction, and 1.83° following tibial-fibular-based reconstruction.

Discussion: There was a significant increase in ER from the intact to the PLC deficient state at all angles of knee flexion under application of external tibial torque. Both PLC reconstruction techniques reduced the increased tibial ER of the PLC deficient knee at 30° and 60° of knee flexion. At 60° of flexion, the tibial-fibular-based reconstruction decreased ER to a statistically significant degree compared to the intact specimen and to the fibular-based PLC reconstruction, thereby over-constraining ER. At 90° of knee flexion, the tibial-fibular-based reconstruction reduced the increased ER to a statistically significant level while the fibular-based reconstruction did not. When varus loading was applied, there was a significant increase in varus rotation from the intact knee to the PLC deficient state and a significant decrease following both reconstructions at 30° and 60° of knee flexion. At 90° of knee flexion, there was no statistically significant difference between the four groups.

These results partially support our hypothesis that both techniques restore normal knee joint kinematics under simulated
muscle loads. The fibular-based technique restored ER and varus rotation at 30° and 60° of flexion. The tibial-fibular-based technique restored ER at 30° and 90° of flexion, over-constrained ER at 60° of knee flexion, and restored varus rotation at 30° and 60° of flexion. Both techniques are efficient in restoration of knee joint rotation. Future study should investigate the kinematic responses of patients after PLC reconstruction.

Significance: A fibular-based docking technique and a tibial-fibular-based technique for PLC reconstruction may be considered for surgical treatment of high-grade PLC injuries. Future studies must compare long-term outcomes for patients treated with each reconstruction technique.

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Figure 1. External rotation under application of external tibial torque (5 Nm) in three different knee flexion angles. Error bars represent standard deviation. Statistically significant difference denoted by *.

Figure 3. Varus rotation under application of varus load (5 Nm) in three different knee flexion angles. Error bars represent standard deviation. Statistically significant difference denoted by *.

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