INTRODUCTION:
The anterior cruciate ligament (ACL) maintains not only the anteroposterior stability of the knee, but also the rotational stability together with the medial and lateral structures. While the ability of ACL reconstructions to restore normal anterior stability has been well documented, restoring the rotational kinematics remains a challenge. It has been demonstrated that increased external tibial rotation directly correlates with changes in peak contact pressures of the patellofemoral joint. Few biomechanical studies have quantitatively investigated the joint rotation after ACL reconstruction in response to physiological loads.

The purpose of this study was to measure the kinematics of the ACL intact, deficient, and reconstructed knees under various applied loads. In particular, we sought to determine whether ACL reconstruction could restore not only anterior stability but also knee joint rotation under simulated muscle loads.

METHODS:
Eight fresh-frozen human cadaver knee specimens (age 52-78) were tested using a six degrees-of-freedom robotic joint testing system. The knee kinematics were measured at 0°, 15°, 30°, 60°, and 90° of flexion in response to the applied loads. An anterior tibial load of 130 N was applied to the knee joint first to simulate examinations (such as Lachman and anterior drawer tests) used clinically to evaluate ACL injury and reconstruction. Next, two different muscle loading conditions were applied to the knee: (1) an isolated quadriceps force of 400 N; (2) and a combined quadriceps and hamstrings load (400 N and 200 N, respectively).

After the intact knee kinematics were measured, the ACL was resected to simulate an “ACL deficient” knee, without removing the knee from the robotic testing system. The kinematics of the ACL-deficient knee were measured using the same protocol as described above for the intact knee. Then, ACL reconstruction was performed with two-incision technique using a bone-patella tendon-bone (BPTB) graft. The knee was then tested using the same protocol as described above and the resulting knee joint kinematics were measured again. This procedure allowed for the direct comparison of intact, ACL deficient and ACL reconstructed states of the same knee.

A repeated-measures analysis of variance and Student-Newman-Keuls test were used to analyze the effect of ACL deficiency and reconstruction on joint kinematics under applied loads. The significance level was set at P< 0.05.

RESULTS:
Kinematics Under the Anterior Load
Under the anterior load, the tibia of the ACL-intact, -deficient knee, and -reconstructed knee translated 9.5 ± 3.1 mm, 19.7 ± 2.6 mm, and 11.4 ± 3.4 mm anteriorly, respectively, at 30° of flexion. The anterior tibial translation of the deficient knee was significantly greater than the intact knee at all flexion angles (P < 0.05). Reconstruction of the ACL significantly reduced anterior tibial translation at all flexion angles compared to the deficient knee (P < 0.05). No statistically significant differences in translation were detected between the intact and ACL reconstructed knees.

The tibia of the ACL-intact, -deficient, and -reconstructed knee rotated 8.9 ± 4.4°, 9.3 ± 4.4°, and 6.8 ± 4.7° internally, respectively, at 30° of flexion (Fig. 1B). At low flexion angles, internal tibial rotation of the reconstructed knee was significantly reduced compared to the intact and the deficient knees (P < 0.05).

Kinematics Under the Combined Quadriceps and Hamstring Load
Under the quadriceps load, the tibia of the ACL-intact, -deficient knee, and -reconstructed knee translated 5.8 ± 3.0 mm, 10.1 ± 3.3 mm and 5.7 ± 1.8 mm anteriorly, respectively, at 30° of flexion (Fig. 1A). The anterior tibial translation of the deficient knee was significantly greater than the intact knee at low flexion angles (0-30°) (P < 0.05). Reconstruction of the ACL significantly reduced anterior tibial translation at all flexion angles compared to the deficient knee (P < 0.05). No statistically significant differences in translation were detected between the ACL intact and reconstructed knees.

The tibia of the ACL-intact, -deficient and -reconstructed knee translated 5.8 ± 3.0 mm, 10.1 ± 3.3 mm and 5.7 ± 1.8 mm anteriorly, respectively, at 30° of flexion (Fig. 1A). The anterior tibial translation of the deficient knee was significantly greater than the intact knee at low flexion angles (0-30°) (P < 0.05). Reconstruction of the ACL significantly reduced anterior tibial translation at all flexion angles compared to the deficient knee (P < 0.05). No statistically significant differences in translation were detected between the intact and ACL reconstructed knees.

DISCUSSION:
In our study, ACL reconstruction resulted in a clinically satisfactory level of anterior tibial translation under anterior load. At 30° of flexion, the mean difference in tibial translation between the intact and reconstructed knees under anterior load was 1.93 mm. The data also demonstrated that tibial rotation in reconstructed knees was significantly different from that of either ACL-deficient or intact knees at low flexion angles under muscle loads. These data show that reconstruction decreased internal tibial rotation and over-constrained the knee under muscle loads. Decreased internal rotation in the ACL reconstructed knees may increase the patellofemoral joint pressures and therefore may predispose it to degenerative changes.

The reason for the altered knee rotation may be that the reconstruction of the ACL does not reestablish the anatomy of the ACL. Further research is necessary to develop an anatomic ACL reconstruction that can reproduce normal knee kinematics.

REFERENCES:
†Department of Orthopedic Surgery, Mokdong Hospital, Ewha University, Seoul, Korea.
‡Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA.