Biomechanical Comparison Between the Rectangular-Tunnel and the Round-Tunnel Anterior Cruciate Ligament Reconstruction Procedures With a Bone—Patellar Tendon—Bone Graft

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Purpose: The purpose of this study was to evaluate the effectiveness of 2 anterior cruciate ligament (ACL) reconstruction techniques using a bone—patellar tendon—bone (BPTB) graft with femoral tunnel, either a rectangular tunnel (RET) or a round tunnel (ROT). **Methods:** For experiment 1, nine fresh-frozen human cadaveric knees were tested with a robotic/universal force-moment sensor system to determine the initial optimal tension: the amount of graft tension at 15° of flexion most closely resembling the anterior laxity of a normal knee. The value was estimated by repeatedly measuring anterior laxity when 100 N of anteroposterior drawer load was applied to the knees at 30° of flexion after RET ACL or ROT ACL reconstruction. For experiment 2, six fresh-frozen human cadaveric knees were selected. On the basis of the initial tension determined in experiment 1, RET ACL reconstruction was conducted with the graft tensioned to 10 N, followed by ROT ACL reconstruction on the same knee at 40 N of initial tension, and the biomechanical efficacy of the 2 methods was compared. **Results:** For experiment 1, the mean laxity match tension at 15° of flexion was 8.6 ± 4.8 N and 34.8 ± 9.2 N for RET- and ROT-reconstructed knees, respectively. For experiment 2, both RET and ROT ACL reconstructions were successful in controlling anterior tibial translation under anterior tibial loads, with the graft initially tensioned to 10 N in the former and to 40 N in the latter. However, the greater tensioning in ROT reconstruction led to proximal, posterior, and lateral displacement of the tibia along with its external and valgus rotation. **Conclusions:** The RET ACL—reconstructed knee more closely resembled the normal knee in biomechanical behavior. Although ROT reconstruction successfully controlled anterior translation with greater initial tensioning to the graft, the normal positional relation between the tibia and femur was impaired. **Clinical Relevance:** Rectangular femoral ACL fixation constructs and grafts may prove more efficacious at restoring in vivo ACL kinematics than round femoral tunnels.

In anterior cruciate ligament (ACL) reconstruction surgery, there is still a controversy on graft placement. Some authors believe that placing a tendon graft within the bone tunnels in the anatomic position restores normal ACL function and knee kinematics.[1-3] However, a greater number of surgeons have been adopting the transtibial tunnel approach to drill bone tunnels at isometric points in the femur and tibia,[4] with a risk of placing the graft in a nonanatomic position.[5-8] It is important to recognize that an intact ACL does not behave in a so-called isometric fashion. If the femoral tunnel is prepared for an isometric graft placement, the graft becomes more vertical in orientation than the native ACL. This less favorable angle of the graft brings reduction of its potential to resist against an applied anterior tibial force or to control rotation, leading to the necessity for greater initial tension of the graft at the

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time of reconstruction.[9-11] On the other hand, anatomic double-bundle ACL reconstruction techniques with hamstring tendon grafts have been performed for over 10 years by a medial portal or outside-in drilling technique to place grafts more obliquely, whereas the procedure with a bone—patellar tendon—bone (BPTB) graft has been performed to aim at achieving a single-bundle reconstruction. Shino et al.[12,13] proposed a novel ACL reconstruction procedure with the BPTB graft to mimic the fiber arrangement of the native ACL, as well as to follow the concept of double-bundle reconstruction and to maximize the graft-tunnel contact area by an independent drilling method.

The objectives of this cadaveric study were as follows: First, we sought to determine the initial graft tension required to restore normal anteroposterior (AP) laxity after the 2 ACL reconstruction techniques with BPTB grafts using the anatomic rectangular tunnel (RET) or isometric round tunnel (ROT). Second, we sought to biomechanically compare the knees after the 2 reconstruction techniques with a clinically feasible initial tension based on each determined laxity match tension. We hypothesized that the RET reconstruction technique would produce more biomechanically efficient results than the conventional ROT reconstruction technique in controlling both anterior and rotational instability after loss of the ACL.

Methods

Specimen Preparation

Fifteen fresh-frozen human cadaveric knees were selected. The mean age of the sample knees was 77.4 years, ranging from 65 to 90 years. Each specimen was manually tested for stability and inspected visually for intra-articular pathology. Knees with ligamentous injury or significant degenerative joint disease were excluded from the study. The knees were thawed at room temperature for 24 hours before the experiment. The femur and tibia were cut 15 cm from the joint line, and any soft tissues including muscles and tendons were removed, leaving the joint capsule, ligaments, and menisci intact. BPTB grafts were harvested from the sample knees for use in this study. Both ends of the tibia and femur were potted and fixed in cylindrical molds of acrylic resin (Ostron II; GC, Tokyo, Japan). The fibula was cut 5 cm distally from the tibiofibular joint junction and then set and fixed in its anatomic position with acrylic resin. Both ends of the cylinders were fixed by a specifically designed aluminum clamp to the manipulator arms of a robotic testing apparatus developed by Fujie et al.[14-17] (Fig 1).

Apparatus

A 6-*df* robotic simulator composed of a 6-axis manipulator fitted with a universal force-moment sensor (IFS-40 15A100-I63-EX; JR3, Woodland, CA) was used. The 6-axis manipulator consisted of a linear upper mechanism that moved in 3 translational axes (SGMP series; Yasukawa, Fukuoka, Japan) and 3 rotational axes (FHA series; Harmonic Drive Systems, Tokyo, Japan) and a complementary lower mechanism that moved in a single translational axis, all of which were powered by an AC servomotor.[14-17]

The manipulator has a positional accuracy of 120 μm when 500 N of load is applied. The apparatus enables manipulation of positional displacement in all degrees of freedom, as well as the force-moment, making it possible to conduct the biomechanical experiment without impeding the knee in any way. The control mechanism works by calculating the force and moment acting on the knee from the output on the 6-*df* axial force sensor attached to the end of the upper mechanism and calculating the amount of displacement of the knee in 6 *df* from the position of the robotic instrument. By use of the data collected, it is possible to calculate the motion necessary in the robotic arm to attain the intended knee kinematics. By repeating this process at high speeds, it is possible to smoothly and effectively control the movement of the knee and the loads acting on it.

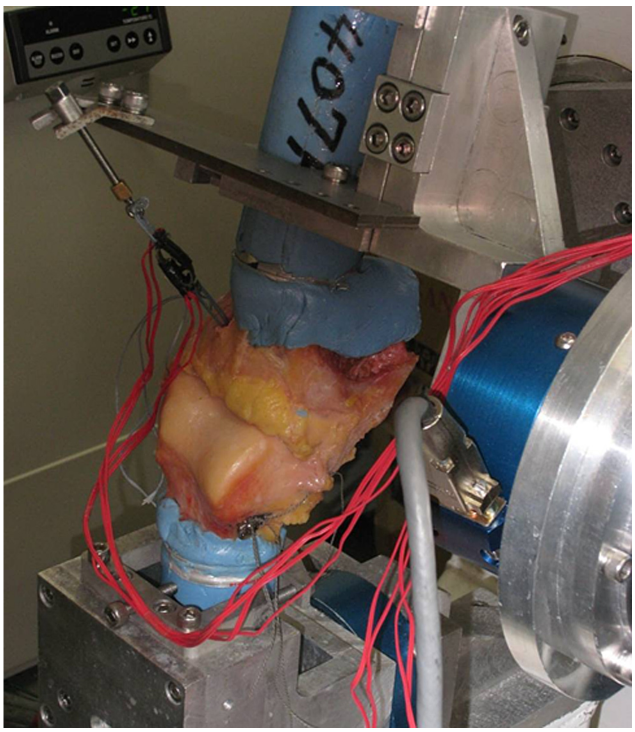

Fig 1. Right knee, after removal of extensor mechanism, mounted on robot system. Because the robotic arm fitted with the universal force-moment sensor comprises the upper part of the system, the femur is fixed to the bottom and the tibia is held on top. The custom-made force gauge is fixed on the tibia.