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. 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, with a risk of placing the graft in a nonanatomic position. 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
time of reconstruction. 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. 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. (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.

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.](image-url)
Coordinate System

A laser digitizer was aimed at the femoral attachment points of the medial collateral ligament and lateral collateral ligament from both directions to record the position, and this was used as the reference axis for the flexion and extension of the femur.\textsuperscript{18}

The femoral and tibial coordination points were fixed to each bone structure, with the internal-external rotation axis of the tibia set at the long axis.\textsuperscript{18}

The coordination points were set according to the knee joint coordination system proposed by Grood and Suntay,\textsuperscript{19} and a computer program developed by use of LabVIEW (version 8.6.1; National Instruments, Austin, TX) was executed to control the displacement and force-moment working on the knee.\textsuperscript{18}

Part I: Laxity Match Tension

A preliminary experiment was undertaken to determine the desirable graft tension in both anatomic RET reconstruction independent of the tibial tunnel and isometric ROT reconstruction through the transtibial tunnel. Nine fresh-frozen human cadaveric knees were selected. The mean age of the sample knees was 81 years, ranging from 73 to 90 years.

The normal knee was placed in a position that permitted normal kinematics, and an extension moment of 0.5 Nm was applied. At this point, the flexion-extension coordinate of the knee was defined as 0\textdegree/C14 of flexion.

A passive knee extension moment of 5 Nm was applied to the joint from its hyperextended position to 120\textdegree of flexion; this was applied at a rate of 0.5\textdegree/s and repeated a total of 3 times. Next, at 30\textdegree of knee flexion, an AP force of ±120 N was applied, and the AP displacement of the tibia in relation to the femur was recorded to determine the normal anterior laxity: anterior displacement of the tibia at a 100-N anterior tibial load.\textsuperscript{20,21}

First, RET ACL reconstruction was performed after the removal of the normal ACL (Fig 2). A BPTB graft of 10 mm in width was harvested from the index knee. The bone plugs of the graft were cut into parallelepiped rectangles with a cross-sectional thickness of 5 mm and 10 mm in width and 15 mm in length. The rectangular femoral tunnel was prepared as follows: The upper and posterior articular cartilage margins and the resident’s ridge of the lateral condyle of the femur were exposed with a radiofrequency device to identify the native ACL femoral attachment area.\textsuperscript{22-25} After the center of the crescent shape of the area was identified, 2 guide pins at a spacing of 5 mm were inserted proximally and distally to the center in parallel to the ridge or the long axis of the attachment area with a 3-hole in-line parallel pin guide. The center of the crescent shape of the area was identified, 2 guide pins at a spacing of 5 mm were inserted proximally and distally to the center in parallel to the ridge or the long axis of the attachment area with a 3-hole in-line parallel pin guide. After overdrilling of the pins with a 5-mm cannulated drill, a rectangular 5 × 10–mm dilator (model 72200555; Smith & Nephew Endoscopy, Andover, MA) was used to create a rectangular socket in an inside-out manner.\textsuperscript{12} The rectangular tibial tunnel was prepared as follows: The tibial attachment area and its center were identified. A guide pin was drilled from the point just medial to the tibial tubercle to the center with a drill guide. Two guide pins at a spacing of 5 mm were inserted anteriorly and posteriorly to the center, parallel to the long axis of the attachment area, with a 3-hole in-line parallel pin guide. After overdrilling of the pins with a 5-mm cannulated drill, the rectangular 5 × 10–mm dilator was then used to create an RET in an outside-in manner.\textsuperscript{12} The graft was introduced into the joint through the tibial tunnel to the femoral socket by pulling its tibial bone plug. The graft was inserted into the joint through the tibial tunnel. The tibial bone plug was fixed by inserting a 6-mm interference screw (model 6901106; Smith & Nephew Endoscopy) in the anteroproximal area of the socket in an outside-in manner (Fig 2). The No. 5 sutures placed on the patellar bone plug on the tibia were passed through the
tibial tunnel and fixed to the custom-made clamp with a tension-adjustable force gauge installed on the anterior tibial cortex (Fig 1).20,21 The graft was tensioned at an optimal amount of initial tension at 15° of flexion. At the time of tensioning the graft, the planned amount of tension was sustained for 300 seconds, and the robotic arm with the tibia was able to move freely under universal force-moment sensor control, allowing 5 df except for the flexion angle. Then, the anterior laxity at 100 N was measured by an AP drawer test with 120 N of tibial force at a knee flexion angle of 30°. The repeated measurements made it possible to determine the laxity match tension in each ACL-reconstructed knee.26-28 The laxity match tension is the amount of graft tension that is required so that the reconstructed knee displays the same amount of AP laxity as the intact knee at a specified angle of knee flexion.26-28

Next, an ROT procedure was conducted on the same knee. The graft bone used in the RET procedure was left in the rectangular femoral socket, whereas the tendon portion of the graft was removed. To create an ROT in the center of the tibial attachment area, a 10-mm cannulated drill was used to overdrill the RET. A guide pin was inserted through the tibial tunnel to the so-called isometric point 7 mm anterior to the “over-the-top” position of the lateral femoral condyle or to the upper posterior cartilage margin at 90° of knee flexion. A 10-mm-diameter ROT was drilled around the isometric point in an inside-out manner, just anterior and proximal to the anatomic RET aperture. Care was taken to avoid overlapping between the previous RET and the new ROT. A BPTB graft from the contralateral knee was harvested, and the bone plugs were shaped into triangular prisms so that it would pass through a 10-mm-diameter cylindrical sizing tube. For fixation of the tibial bone plug to the femoral socket, an 8-mm interference screw was used in an inside-out manner (Fig 3).29,30 The No. 5 sutures placed on the patellar bone plug on the tibial side were passed through the tibial tunnel and fixed to the custom-made clamp with the tension-adjustable force gauge on the anterior tibial cortex (Fig 1). Care was taken to keep the posterior aspect of the tendinous portion of the graft in front. The laxity match tension was measured in the same manner as described previously.

The preliminary experiment found that the mean laxity match tension for the RET-reconstructed knees was $8.6 \pm 4.8$ N whereas that of the ROT-reconstructed knees was $34.8 \pm 9.3$ N at 15° of flexion, showing a statistically significant difference (Table 1). On the basis of this evidence, the graft initial tension for the RET-reconstructed knee was set at 10 N whereas that of the ROT-reconstructed knee was set at 40 N in experiment 2 because clinicians always try to create a slightly tighter knee by over-tensioning the graft at the time of performing ACL reconstruction, taking into account load relaxation and remodeling of the graft.

### Table 1. Test Results for Part I

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<th>ROT</th>
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<tr>
<td>Laxity match tension (N)*</td>
<td>8.6</td>
<td>4.8</td>
<td>34.8$^1$</td>
<td>9.3</td>
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</table>

*Initial graft tension required to restore normal AP laxity after the 2 ACL reconstruction techniques.

$^1$Significant difference ($P < .05$).
The normal knee was placed in a position that permitted normal kinematics, and an extension moment of 0.5 Nm was applied. At this point, the flexion-extension coordinate of the knee was defined as 0° of flexion.

A passive knee extension moment of 5 Nm was applied to the joint from its hyperextended position to 120° of flexion; this was applied at a rate of 0.5°C/s and repeated a total of 3 times. Next, an AP force of ±120 N was applied at each of the following knee flexion angles: 0°, 15°, 30°, 60°, and 90°. At 15° and 30° of flexion, 5 Nm of internal rotation plus 10 Nm of valgus force were added as combined loads to the knee. During these tests, the trajectory on the knee in 6 df was recorded. After the ACL was removed, the RET ACL reconstruction was performed as described previously on the same knee (Fig 2). The amount of initial tension was set at 10 N, which was slightly higher than the laxity match tension obtained in experiment 1. Graft tension was sustained for 300 seconds at 15° of flexion while leaving the knee free to move in the remaining 5 df. A passive flexion-extension test, anterior drawer test, and combined load test were conducted, and the 3-dimensional paths were recorded.

Next, an ROT ACL reconstruction was performed on the same knee, as described previously. The amount of initial tension was set at 40 N, based on the results of experiment 1. Graft tension was maintained for 300 seconds at 15° of flexion while leaving the knee free to move in the remaining 5 df. The same test sequences were undertaken as for the RET ACL-reconstructed knees.

The kinematics of the normal knee was regarded as the point of reference (i.e., 0), and the motion kinematics of the RET ACL—reconstructed knee and the ROT ACL—reconstructed knee were compared. The relative position between the femur and tibia on the normal knee during the passive flexion-extension test at 0°, 15°, 30°, 60°, and 90° was set at 0, and the positional displacement between the femur and tibia after RET/ROT ACL reconstruction was pursued. The displacements were measured in the 5 df other than flexion-extension: (1) anterior displacement, (2) external rotation, (3) varus rotation, (4) lateral shift, and (5) proximal displacement. Statistical analyses were performed using 2-way repeated-measures analysis of variance and the paired t test, and P < .05 was regarded as statistically significant.

### Results

#### Knee Joint Kinematics

The positional displacement between the femur and tibia after RET/ROT ACL reconstruction is shown in Figure 4. With the RET reconstruction method, a 1.8 ± 0.9—mm displacement in the posterior direction was observed at 0° of flexion. However, the amount of displacement when compared with the normal knees was less than 1 mm beyond 15° of flexion. On the other hand, the ROT-reconstructed knees exhibited 3.9 ± 1.9 mm of posterior displacement at 0° of flexion (P = .01) and 3.0 ± 2.6 mm at 15° of flexion (P = .003), showing a statistically significant difference in comparison with the normal or RET-reconstructed knees (P < .05) (Fig 4A). Regarding external rotation of the tibia, when compared with the normal knees, the RET-reconstructed knees exhibited less than 5° of external rotation through all angles of flexion. Conversely, the ROT-reconstructed knees exhibited external rotation through all angles of flexion, the greatest of which was found at 90° of flexion, when the difference in external rotation compared with the normal knees was 14.1° ± 14.8° (Fig 4B). In the ROT-reconstructed knees, the tibia was in a varus position throughout all flexion angles, and at 60° of flexion, there was a maximum of 2.3° ± 2.4° of valgus rotation (Fig 4C).

Regarding mediolateral shift, the RET-reconstructed knees showed a mean of less than 1.3 mm of lateral shift whereas the ROT-reconstructed knees showed a mean of 2 mm of medial shift (Fig 4D). Regarding proximal displacement, it was confirmed that the RET-reconstructed knees and ROT-reconstructed knees had a mean of less than 1 mm of proximal displacement, showing no statistically significant difference (P > .05) (Fig 4E).

#### AP Drawer Test

Overall, the amount of displacement in the RET-reconstructed knees was found to be less than 1 mm compared with the normal knees through all angles of flexion, showing a slight over-tightness approaching extension and slight looseness during flexion. On
the contrary, the ROT-reconstructed knees showed a looseness approaching extension and an over-tightness during flexion.

The mean anterior laxity of the RET-reconstructed knees was 0.6 mm less at $0^\circ$ and 0.8 mm greater at $90^\circ$, $-0.4 \pm 1.3$ mm at $15^\circ$ of flexion, $-0.1 \pm 1.3$ mm at $30^\circ$ of flexion, $0.3 \pm 1.7$ mm at $60^\circ$ of flexion, and $0.8 \pm 1.5$ mm at $90^\circ$ of flexion, whereas that of the ROT-reconstructed knees was $1.0$ mm less at $0^\circ$ of flexion and $1.3$ mm greater at $90^\circ$ of flexion when compared with the intact knee (Table 3).

The mean anterior laxity of the RET-reconstructed knees with 5 Nm of internal rotation and 10 Nm of valgus moment load was $0.1$ mm greater than that of the normal knees, and the mean anterior laxity of the ROT-reconstructed knees was $0.7$ mm greater than that of the normal knees. These values were not significantly different between the groups. On the other hand, at $30^\circ$ of flexion, the values were $0.4$ mm greater for the RET-reconstructed knees and $0.7$ mm greater for the ROT-reconstructed knees (Table 3). The ROT-reconstructed knees showed significant looseness in comparison with the normal knees ($P < .05$).

**Fig 4.** Relative position of tibia in ACL-reconstructed knees compared with that in normal knees during flexion-extension test: (A) anterior translation, (B) external rotation, (C) varus rotation, (D) lateral shift, and (E) proximal displacement. Asterisks indicate $P < .05$ for RET versus ROT. The error bars indicate 1 SD of the sample mean. One should note that RET-reconstructed knees are closer in position to normal knees in the AP, external-internal rotation, or varus-valgus rotation direction.

**Table 3. Test Results**

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<th>RET</th>
<th>ROT</th>
<th>Intact</th>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
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<tr>
<td><strong>AP laxity (mm) at 100-N anterior load</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$0^\circ$ flexion angle</td>
<td>10.2</td>
<td>0.9</td>
<td>11.8</td>
</tr>
<tr>
<td>$15^\circ$ flexion angle</td>
<td>12.5</td>
<td>1.3</td>
<td>13.5</td>
</tr>
<tr>
<td>$30^\circ$ flexion angle</td>
<td>11.1</td>
<td>1.3</td>
<td>11.1</td>
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<tr>
<td>$60^\circ$ flexion angle</td>
<td>9.4</td>
<td>1.7</td>
<td>8.3</td>
</tr>
<tr>
<td>$90^\circ$ flexion angle</td>
<td>9.6</td>
<td>1.5</td>
<td>7.5</td>
</tr>
<tr>
<td><strong>AP laxity (mm) at 5 Nm of internal rotation plus 10 Nm of valgus</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$15^\circ$ flexion angle</td>
<td>3.5</td>
<td>1.0</td>
<td>4.1</td>
</tr>
<tr>
<td>$30^\circ$ flexion angle</td>
<td>6.7</td>
<td>0.8</td>
<td>7.1*</td>
</tr>
</tbody>
</table>

*Significant difference ($P < .05$) for normal versus ROT-reconstructed knees.

**Discussion**

This study on ACL reconstruction techniques with a BPTB graft showed that initial graft tension required to restore normal AP laxity for the anatomic RET reconstruction was smaller than that for the isometric ROT reconstruction. Furthermore, in the ROT-reconstructed knees with a higher initial graft tension, the tibia moved...
posterolaterally with external and valgus rotation, suggesting that it produced abnormal joint kinematics. Thus the study has clearly supported our hypotheses.

In recent years, the clinical performance of anatomic double-bundle ACL reconstruction that mimicked the fiber arrangement of the ACL using hamstring graft was reported to have improved as a result of a better understanding of the functional anatomy of the ACL.\textsuperscript{12,13} This suggests that the more anatomically the graft is placed, the better it performs in the clinical setting. Shino et al.\textsuperscript{25} proposed a procedure whereby the resident’s ridge on the femoral lateral condyle was identified as the bony landmark of the anterior border of the anatomic femoral attachment during arthroscopic surgery. Furthermore, they also proposed an ACL reconstruction method using the patellar tendon to mimic the fiber arrangement of the native ACL or to pursue the concept of double-bundle reconstruction.\textsuperscript{12,13} According to the previous studies on the ACL attachment site,\textsuperscript{22-24} placing a BPTB graft posteriorly to the ridge through a 10-mm ROT would be impossible without blowout of the tunnel. With the RET procedure, a BPTB graft could be placed in the tunnel within the anatomic attachment area behind the ridge.\textsuperscript{12,13} Thus the RET procedure is a more rational method to anatomically create a femoral tunnel at the center of the original ACL footprint.

One of the key factors for a successful ACL reconstruction is initial graft tension.\textsuperscript{9-11} There is a close relation between the initial tension required to control abnormal anterior laxity and tunnel position.\textsuperscript{9-11} In part I of this study, we found that the initial tension required to simulate the anterior displacement of a normal knee at 100 N of anterior drawer load (laxity match tension) was 38.1 ± 4.9 N for the ROT-reconstructed knee and 8.8 ± 3.6 N for the RET-reconstructed knee. This finding suggests that the RET grafts could control anterior instability more efficiently than the ROT grafts. In other words, the RET grafts behave more closely biomechanically to the normal ACL than the ROT grafts if it is taken into account that the resultant force of the normal ACL is nearly 0 N at 15°.\textsuperscript{32} This suggests that an ACL reconstruction such as the ROT procedure through a bone tunnel drilled around the isometric point, away from the center of the normal ACL attachment area, would require greater initial graft tension to restore normal stability.

In part II of this study, both the ROT-reconstructed knee with an initial graft tension of 40 N and the RET-reconstructed knee with 10 N of initial graft tension were shown to have less than 1 mm of difference in anterior laxity at a 100-N anterior force compared with the normal knee. However, the positional difference during passive flexion-extension between the ROT-reconstructed knees and the normal knees was significantly greater than that between the RET-reconstructed knees and the normal knees in internal-external rotation, in varus-valgus rotation, or with mediolateral shift. Under the same experimental conditions, Mae et al.\textsuperscript{20,21} also found that reconstructions with greater initial graft tension could not adequately restore the positional relation between the tibia and femur of a normal knee. Although it is not obvious whether this observed difference in kinematics between the 2 groups was because of the difference in graft placement, because of the difference in graft tension, or both, a combination of anatomic placement and less initial graft tension did lead to superior performance of the graft in controlling anterior instability without compromising the knee kinematics or the positional relations between the femur and the tibia.

Consequently, this biomechanical study transmits the following important, clinically relevant message: A graft placed through the femoral tunnel aiming at the isometric graft positioning in ROT reconstruction, that is, some way off the center of the anatomic attachment area, appears at first sight to restore normal AP stability if initial graft tension is increased. However, the increased initial graft tension to reduce anterior translation impairs the normal positional relation between the tibia and the femur, resulting in abnormal knee kinematics. This, in turn, alters the normal surface contact among the femur, tibia, and patella and raises the potential of acceleration of joint degeneration. In contrast to that in ROT reconstruction, the graft in RET reconstruction provides normal knee joint stability with less initial graft tension while maintaining the knee kinematics much closer to that of the normal knee.

**Limitations**

Our study has the following limitations: (1) Regarding study design, this is an in vitro, cadaveric study and therefore does not consider the effects of variables such as weight and muscle load that might be observed within in vivo knee kinematics; thus its applicability to clinical practice may be limited. (2) Regarding specimen age, the cadavers were much older than the typical athlete who sustains an ACL injury during sporting activities; the results may not be representative of a sample frame containing younger subjects. (3) The sample size was small. (4) Regarding study methodology, the study group differed in 3 main variables (graft placement, shape of tunnel, and graft tension). The specimens were clearly grouped according to the variable of graft placement, which allowed us to use the same knee specimens. Although this method holds advantages in statistically analyzing results, it did not permit us to compare differences pertaining to the proximity of the tunnels.
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.

References