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Original Article

# Biomechanical characteristics of the anatomic rectangular tunnel anterior cruciate ligament reconstruction with a bone-patellar tendon-bone graft

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ABSTRACT

*Purpose:* To clarify 1) the force sharing between two portions of BTB graft in anatomic rectangular tunnel (ART) reconstruction and 2) the knee stability in ART technique under anterior tibial load.

*Methods:* Eleven fresh cadaveric knees were used. First, anterior-posterior (A-P) laxity was measured with Knee Laxity Tester® in response to 134 N of A-P tibial load at 20° on the normal knees. Then ART ACL reconstruction was performed with a BTB graft. For graft, the patellar bone plug and tendon portion was longitudinally cut into half as AM and PL portions. After the tibial bone plug was fixed at femoral aperture, AM/PL portions were connected to the tension-adjustable force gauges at tibial tubercle, and were fixed with 10 N to each portion at 20°. Then the tension was measured 1) under anterior tibial load of 134 N at 0, 30, 60, and 90°, and 2) during passive knee extension from 120 to 0°. Next the graft tension was set at 0, 10, 20, 30, or 40 N at 20°, and the A-P laxity was measured by applying A-P load of 134 N. By comparing the laxity for the normal knee, the tension to restore the normal A-P laxity (LMP) was estimated.

*Results:* The AM force was significantly smaller at 0° and larger at 90° than the PL force under anterior load, while the force sharing showed a reciprocal pattern. During knee extension motion, the tension of both portions gradually increased from around 5 N to 20–30 N with knee extended. And the LMP was 1.6 ± 1.0 N with a range from 0.3 to 3.5 N.

*Conclusion:* The pattern of force sharing was similar to that in the normal ACL in response to anterior tibial load and during passive knee extension motion. LMP in this procedure was close to the tension in the normal ACL.

*Level of evidence:* Level IV, a controlled-laboratory study.



## 1. Introduction

Thanks to recent progress in anatomic studies and improvement of surgical instruments, anatomic double-bundle ACL reconstruction with hamstring tendon grafts fixed with suspensory fixation devices is widely performed with successful outcomes [1–5]. However, some problems such as tunnel enlargement which might be due to bungee cord effect or to wind-shield wiper motion were reported [6–8]. A bone-patellar tendon-bone (BTB) graft is also used for anatomic single-tunnel ACL reconstruction. The BTB graft fixed with interference screw can shorten the inter-fixation distance of graft and reduce the bungee cord effect in the femoral tunnel. It is our belief that the tunnel apertures should be kept inside the attachment areas of greater cortical thickness to reduce postoperative tunnel enlargement [9]. However, a single round tunnel of 10-mm in diameter could not be created within the anatomical ACL footprints, as the width of femoral or tibial attachment is 7–9 mm [10,11]. Shino et al. reported the anatomic rectangular tunnel (ART) ACL reconstruction with BTB graft to mimic fiber arrangement inside the native ACL like the double-bundle ACL reconstructions [12,13]. In this technique, the rectangular single tunnel of 5-mm width and 10-mm length can be created inside the attachment areas, in contrast to the single round

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tunnel ACL reconstruction. Anterior portion of the BTB graft runs from proximal femoral attachment to anterior tibial footprint, while its posterior portion runs from distal femoral attachment to posterior tibial footprint. This fiber arrangement is quite similar to that of the normal ACL which can be generally divided into anteromedial (AM) bundle and posterolateral (PL) bundle [14–16]. The ART ACL reconstruction with a BTB graft also has the following advantages: 1) the rectangular parallelepiped bone plug in the parallelepiped tunnel of rectangular cross section minimize the futile space, resulting in earlier bone plug-tunnel integration; 2) interference screw fixation at femoral tunnel aperture shortens the graft fixation distance to reduce bungee cord motion; 3) adverse effect due to windshield wiper motion at the femoral tunnel aperture can be minimized, as bone–tendon junction of a BTB graft locates just at the femoral tunnel aperture. However biomechanical behavior of this technique is still unclear.

It is well known that each bundle of the native ACL shares its function in response to an anterior tibial load, and that PL bundle functions more than AM bundle in extension whereas AM bundle functions mainly in flexion, and that the two bundles effectively collaborate to stabilize the knee against anterior tibial load [17,18]. The BTB graft in ART technique can morphologically mimic the fiber arrangement of the normal ACL with two main bundles. However, the force sharing between two portions of the BTB graft in the ART technique remains unclear, while there were a few biomechanical studies [19,20]. Therefore, our purposes of this study were (1) to clarify the force sharing between two portions of the BTB graft in the ART technique, and (2) to clarify the knee stability in ART technique with a BTB graft in response to anterior tibial load. Our hypotheses were as follows: (1) the force sharing between two portions of the BTB graft in the ART technique was close to that between the two ACL bundles; (2) the BTB graft in the ART technique stabilized the knee as effectively as the native ACL under anterior tibial load.

## 2. Materials and methods

Eleven intact human cadaveric knee joints were used. The mean age of the specimens was 63 years (range, 48–70). After the femur was horizontally fixed with a clamp, arthroscopy was performed in order to confirm that there were no ligamentous injury or significant degenerative cartilage/meniscus change. Then the anterior-posterior (A-P) displacement of the tibia was measured for the intact knees with Knee Laxity Tester® (Stryker, USA) when the A-P load of 134 N was applied at 20° of knee flexion. After resection of the ACL, the A-P displacement of the tibia for the ACL-injured knees was measured in the same manner. We got IRB approval of our institute.

### 2.1. Operative procedure

Anatomic rectangular tunnel (ART) ACL reconstruction was performed with BTB graft [12,13]. First, the ACL remnant was arthroscopically cleaned up around the femoral attachment area. A femoral tunnel with a 5 × 10 mm rectangular aperture was created behind the ridge and just anterior to the cartilage margin, while a parallelepiped tibial tunnel with a 5 × 10 mm aperture was made in the ACL attachment. A 10-mm wide BTB graft was harvested from the medial portion of the patellar tendon with 15-mm long bone plugs on both ends. These bone plugs were shaped into a rectangular parallelepiped, 5-mm thick × 10-mm wide × 15-mm long shape to snugly fit the tunnels. Two holes of 1.5-mm diameter were created in the tibial bone plug, and two #2 Ultrabrade sutures (Smith&Nephew, Andover, MA, USA) were respectively passed through the holes and bone–tendon junction. For the patellar bone plug, the plug and tendon portion were longitudinally cut into half and two #2 Ultrabrade threads were sutured with Krackow technique respectively (Fig. 1). Those two portions were treated as AM and PL portions. The graft was introduced into knee joint through the tibial tunnel with the bone plug from tibia in the lead. Femoral graft fixation with a 6 × 20 mm interference screw (Cannu-flex Silk Screw; Smith & Nephew, Andover, MA, USA) was achieved, while keeping the bone–tendon junction of the graft matched the aperture of femoral tunnel carefully. Then, the graft sutures were tied to custom-made and tension-adjustable force gauges (Kyowa, Japan) fixed on the tibial cortex around the exit of the tunnel (Fig. 2).

### 2.2. Force distribution under anterior tibial load

A total of 20 N of initial tension, 10 N to each portion, was settled at 20° of knee flexion after pre-tensioning for 5 min. Pre-tensioning was repeated at every trial. At 0, 30, 60, and 90° of flexion, an anterior tibial load of 134 N was applied with Knee Laxity Tester® (Stryker, USA), and the tension exerted on the AM portion and the PL portion was simultaneously measured using the force gauges on the tibial cortex (Fig. 3).

### 2.3. Force distribution during passive extension motion

A total of 20 N of initial tension (10 N to each graft) was again applied at 20° of flexion, and the tension to the AM portion and the PL portion was continuously measured with permitting tibial rotation during passive knee extension from 120 to 0° of flexion. Next, a total of 40 N of initial tension (20 N to each graft) was set using the force gauge at 20° of knee flexion in the same manner, and the tension to each portion was measured again during passive knee extension from 120 to 0° of flexion.

### 2.4. Measurement of laxity match pretension

We focused on the laxity match pretension (LMP): the graft tension required to restore the normal laxity as the parameter of effectiveness to stabilize the knee under anterior tibial load. The smaller LMP, the more effective in restoring stability, as the tension in the native ACL is nearly zero at 20° of flexion [21].

A total initial tension of 10 N was applied using the force gauges on the tibial cortex at 20° of knee flexion after pre-tension for 5 min. Then the A-P displacement of the tibia was again measured with Knee Laxity Tester® (Stryker, USA) when the A-P load of 134 N was applied at the same knee position. Similarly, the tension on the graft was set at 20, 30, and 40 N, and the A-P displacement measurement was repeated. All measurements were completed by the same examiner for all tests to reduce variability. The A-P displacement for each initial tension was plotted on a graph to approximate to an exponential curve for estimation of the LMP. The

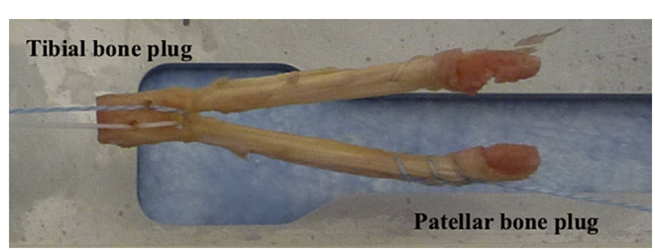


**Fig. 1.** BTB graft. Patellar bone plug and tendon were divided into two portions: anteromedial (AM) and posterolateral (PL) portions.

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