Review Article

Anatomical rectangular tunnel ACL reconstruction with a bone-patellar tendon-bone graft: its concept, indication and efficacy

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Abstract: The anatomical rectangular tunnel (ART) ACL reconstruction (ART ACLR) with a single bone-patellar tendon-bone (BTB) graft was developed under the concept of closely replicating the normal ACL. This technique makes it possible (I) to mimic internal fiber orientation inside the ACL, (II) to maximize the graft-tunnel wall contact. Our follow-up study showed that 95% of the patients restored satisfactory stability of the knee with normal motion maintained without extra-articular tenodesis or reconstruction of the anterolateral structures. ART ACLR with a BTB graft can stabilize the knee without loss of motion by closely mimicking the native ACL.

Keywords: ACL reconstruction (ACLR); bone-patellar tendon-bone (BTB) graft; anatomical rectangular tunnel (ART); notchplasty

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Concept

For achieving the goal of ACL reconstruction (ACLR) to restore stability of the knee without loss of motion, we believe that the implanted graft should closely resemble the native ACL in macroscopic morphology, orientation, alignment of internal fibers and tension. Thus, it is mandatory to select a suitable graft, to create the tunnel apertures inside the native ACL attachment areas, to place it properly, and to fix it under adequate tension.

A bone-patellar tendon-bone (BTB) autograft is one of the most suitable tissues for ACLR (1), while the graft of 10-mm width has been widely used via 10-mm round tunnels to reconstruct a single bundle (SB). In this SB ACLR procedure with the graft, the following issues had been concerned: (I) the graft could not mimic the internal fiber arrangement of the native ACL; (II) there is futile space between the trapezoid/triangular pillar bone plugs and the round/cylindrical tunnels; (III) there is unfavorable space between the proximal portion of the round tibial tunnel and tendinous portion of the graft of rectangular cross section.

In order to resolve these issues, the anatomical rectangular tunnel (ART) ACLR with a single BTB graft was developed (*Figures 1*,*2*), as we found it possible to arrange the graft to mimic not only the orientation of the native ACL but its internal fiber arrangement (2). In this procedure (3,4), the BTB graft with rectangular cross section could fairly resemble the normal ACL in internal fiber arrangement (4), as well as contact with tunnel wall without little futile space. In other words, this technique could realize the concept of double bundle ACLR with a single BTB graft. Biomechanically, ART ACLR has been proven superior to the conventional trans-tibial SB ACLR based on the isometric grafting concept (5).

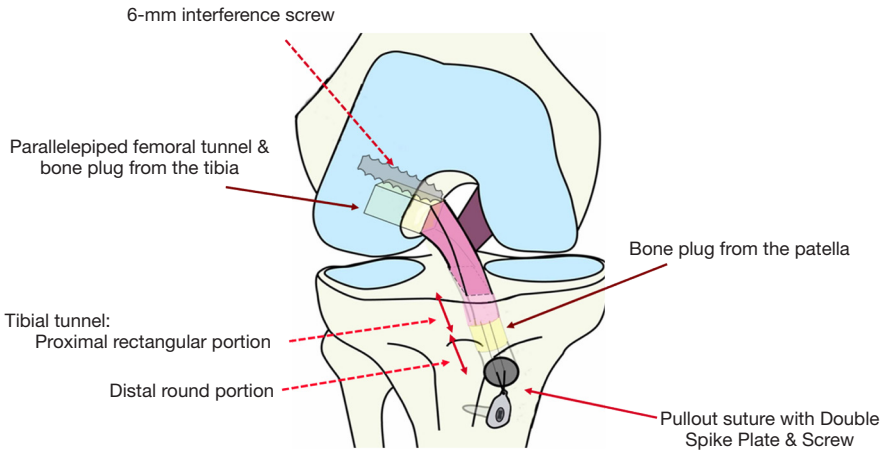

Figure 1 Schema of the anatomical rectangular tunnel (ART) BTB ACL Reconstruction via rectangular femoral and partially rectangular/round tibial tunnels. It is our policy to place the graft as posteroproximally as possible in the femoral attachment area, and to locate it as anteromedially as possible in the tibial attachment area. This makes it possible for the graft to not only morphologically but biomechanically mimic the normal ACL. For femoral side fixation, 6-mm interference screw or, pull out suture technique is applied. For tibial side fixation, pull out suture technique using the double spike plate (DSP) and a screw to adjust the tension to the graft, is used. Adopted with permission from J Orthop Sci 2015;20:457-68.

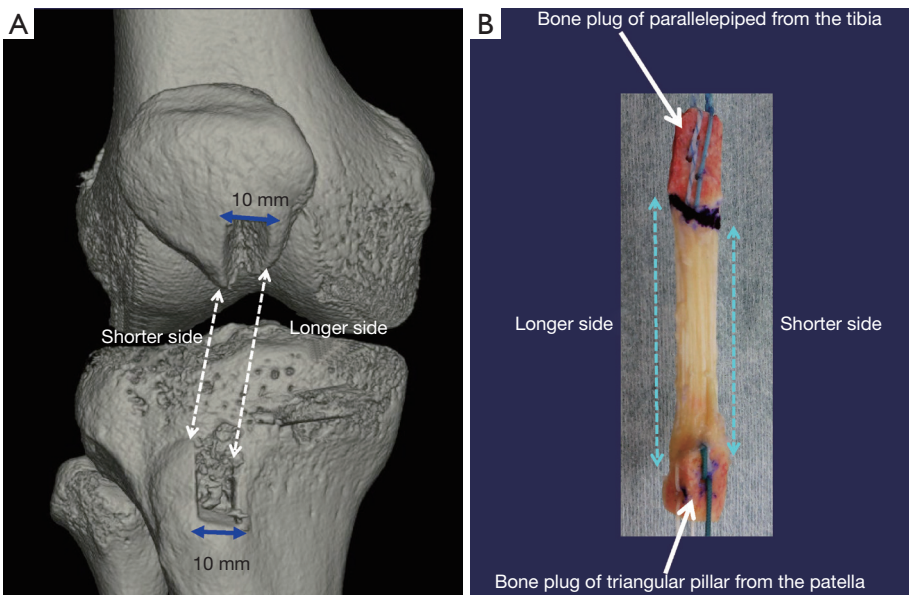

Figure 2 Graft harvest and preparation. It is our policy to minimize the BTB graft harvest site morbidity. Therefore, we consistently harvest the predilection site for patellar tendinitis: the central portion of the medial half of the patellar tendon. As the longer side of the tendon is assigned anteriorly, the bone plug of triangular pillar from the patella is located into the tibial tunnel, while the one of parallelepiped from the tibia is situated into the femur. (A) BTB graft harvest site of the central portion of the medial half of the patellar tendon of the right knee. The longer tendinous portion is assigned for the anterior portion of the graft, while the shorter side is placed posteriorly. (B) A prepared 10-mm wide graft. The tibial parallelepiped bone plug of 5 mm in thickness ×10 mm in width ×15 mm in length is for the rectangular femoral tunnel, while the patellar bone block of a triangular pillar is for the distal round portion of the tibial tunnel. BTB, bone-patellar tendon-bone.

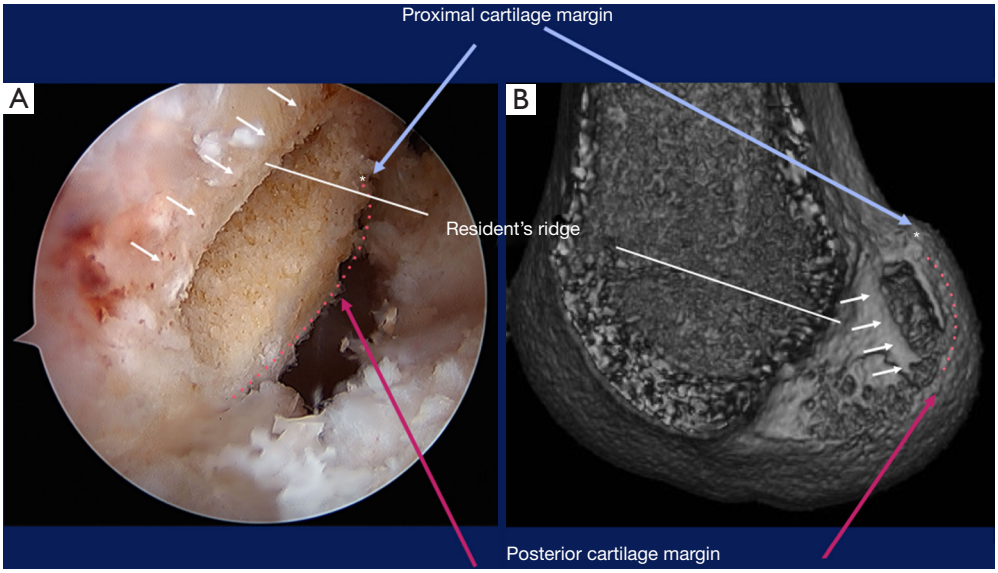

Figure 3 A rectangular femoral tunnel aperture of the right knee. (A) Arthroscopic view via the anteromedial portal with a 45° arthroscope; (B) 3D CT view. There are 3 landmarks to identify the attachment area: Resident's ridge (white arrows), proximal cartilage margin (*) , posterior cartilage margin (dotted pink line).

Indications for BTB grafting

One of the advantages for ART ACLR with a BTB graft is earlier integration of bone plug to bone tunnel wall (6), while the graft harvest site morbidity is relatively high in autografting. Therefore, the autogenous BTB graft may be indicated for young athletes with high motivation for returning strenuous/contact sports including football or judo. On the contrary, this graft may not be suitable for aged patients with weaker bone plug due to osteoporosis or less active female patients with higher risk of arthrofibrosis.

Operative procedure

A BTB autograft of 10 to 13 mm width is harvested from the central portion of the medial half of the patellar tendon. A rectangular parallelepiped femoral tunnel in accordance with the rectangular cross section of the graft is created inside the femoral attachment area (*Figure 3*) (7,8). The tibial tunnel of proximal rectangular parallelepiped and of distal round cylinder is made inside the tibial attachment area (*Figure 4*) (9-11). The graft is passed through the tibial tunnel to the femoral one. Femoral fixation is achieved with 6 to 7 mm interference screw or pull out sutures to the femoral cortex. Then tibial fixation is performed as the following special pull out suture technique: (I) the sutures tied to the bone plug are connected to the top hole of Double Spike Plate® (DSP, Meira, Nagoya, Japan); (II) the tensioning suture passed through the bottom hole of DSP is connected to a tensioner mounted to the tensioning boot fixed to the tibia with a bandage; (III) the graft is *in situ* pretensioned by repetitive strong manual pulls of 10 times; (IV) an initial tension of 10–20N is applied to the graft at 20 degree of flexion; (V) the final graft fixation is achieved with the DSP and a screw installed.

In this procedure the notchplasty is not required to avoid the graft impingement to the notch in extension (*Figure 5*).

Postoperative rehabilitation

After brace immobilization for one week, ROM exercise is begun. Partial weight bearing is allowed at two weeks, followed by full weight bearing at four weeks. Jogging is recommended at three months, followed by return to sports activities at 7–9 months.

Efficacy

Our 2-year follow-up study has just been published (12). We prospectively enrolled 71 patients in this study from the total number of 242 patients undergoing the ART ACLR for primary unilateral ACL injury from January 2009 to

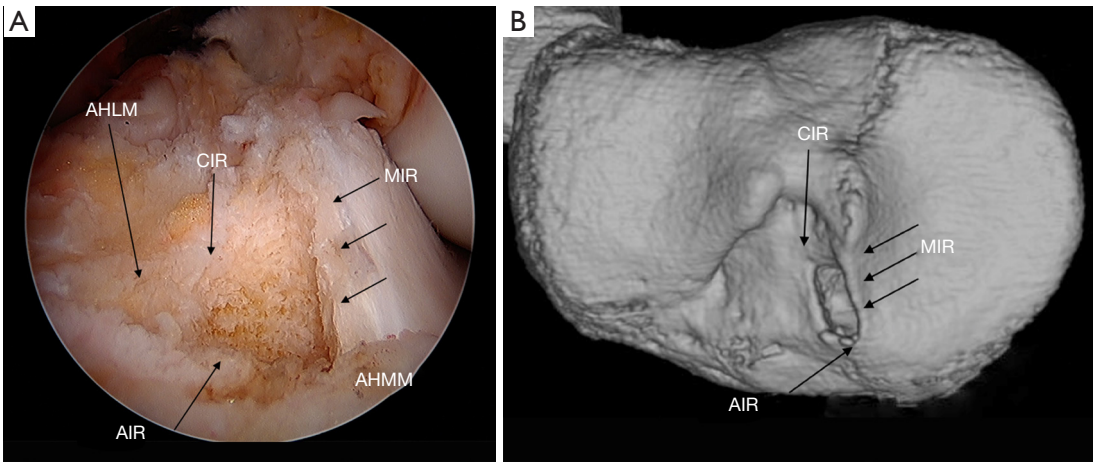

Figure 4 A rectangular tibial tunnel aperture of the right knee. (A) Arthroscopic view via the anteromedial portal with a 45° arthroscope; (B) 3D CT view. The landmarks to identify the attachment area are the medial intercondylar ridge (MIR): medial margin, the anterior intercondylar ridge (AIR): anterior margin, the anterior horn of the lateral meniscus (AHLM), the anterior horn of the medial meniscus (AHMM) and the central intercondylar ridge (CIR): lateral border of the posterior 2/3 of the attachment area.

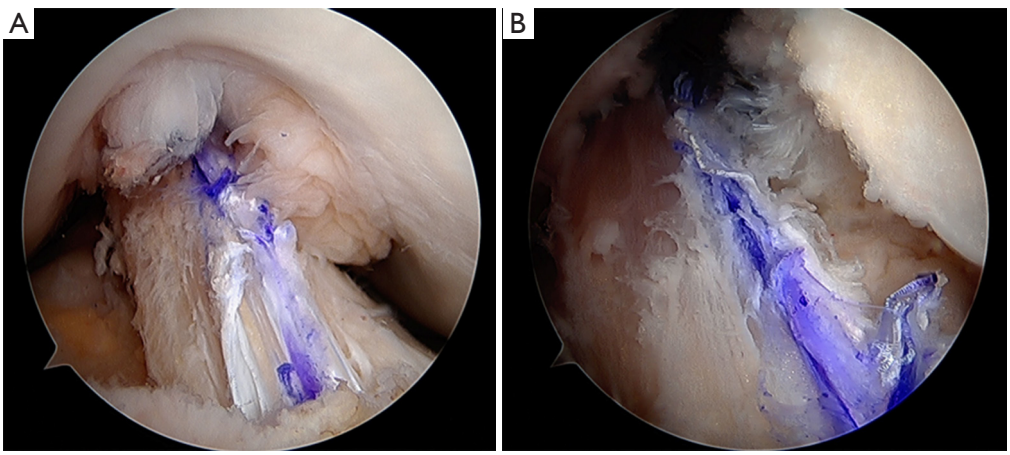

Figure 5 BTB graft of the right knee in ART ACLR viewed through the anterolateral portal: (A) in extension; (B) in flexion. The anteromedial border of the graft is marked with blue dye. Note no graft impingement to the notch or PCL, while the notch is preserved. BTB, bone-patellar tendon-bone; ART, anatomical rectangular tunnel; ACLR, ACL reconstruction.

June 2014. The inclusion criteria were as follows: (I) contralateral healthy knee; (II) no radiological osteoarthritic change; (III) consent of undergoing postoperative CT scans and outpatient follow-up evaluation at 2 years. During the postoperative follow-up term, 10 patients were excluded due to secondary ACL injury: 6 patients, graft rupture; 4 patients, contralateral ACL injury. Then 61 patients were finally included. They were 40 males and 21 females with a mean age of 22.7±8.0 [14–48] years at the time of ACLR. None of the patients sustained secondary meniscal injuries.

The International Knee Documentation Committee (IKDC) subjective assessment showed that all the 61 patients who had not sustained traumatic graft rupture were classified as 'normal' or 'nearly normal'. The Lachman and pivot-shift test were negative in 98.4% and 95.1% of them, respectively. The mean side-to-side difference of the anterior laxity at the maximum manual force with KT-1000 Knee Arthrometer was 0.2±0.9 mm, with 95.1% of patients ranging from −1 to +2 mm (*Figure 6*) (12). Furthermore, tunnel expansion following the current procedure is much

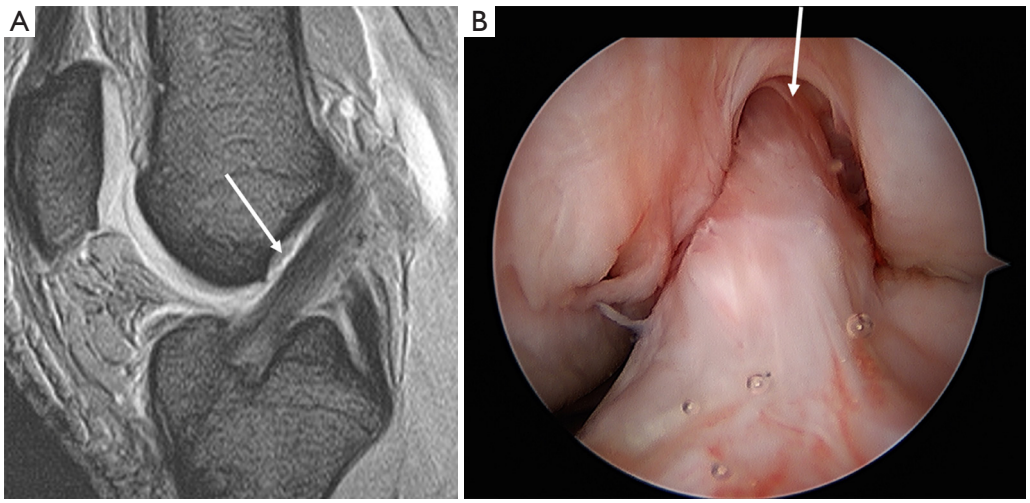

Figure 6 An example of the BTB ACL graft of a patient who further sustained injury to the lateral meniscus at 3.5 years after ART BTB ACLR. (A) An oblique-sagittal slice of T2*-weighted MR image (arrow). The graft is running along the Blumensaadt's line/the notch roof like the native ACL, while the positional relationship between the femur and the tibia is normally maintained. (B) Arthroscopic view. Note the graft is taut, thick and well synovialized (arrow). BTB, bone-patellar tendon-bone; ART, anatomical rectangular tunnel; ACLR, ACL reconstruction.

less than that after the reconstruction using hamstring tendons (13).

Discussion

There is a concern on higher graft rupture rate following the anatomical ACLRs including ART procedure compared to that after non-anatomical ACLRs which had been frequently performed in the last century (14). One of the reasons for the higher graft rupture rate could be full return to pre-injury strenuous sports without fear of instability. However, it should be noted that subsequent meniscal tears after the anatomical ACLRs are much fewer compared to those following the non-anatomical ACLRs. This suggests that the anatomical ACLRs are more effective to stabilize the knee or to preserve the menisci.

Improved rehabilitation, proprioceptive training and adequate education may be required to prevent secondary ACL injury.

Conclusions

ART ACLR with a single BTB graft is an effective procedure to stabilize the knee without loss of motion by closely mimicking the native ACL. No lateral extra-articular tenodesis is required.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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