

# Anatomical Remnant-Preserving Double-Bundle ACL Reconstruction With a New Remnant Augmentation Technique



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**Abstract:** Anterior cruciate ligament (ACL) remnant preservation techniques have been recently introduced for covering the graft with remnant to improve the clinical results of ACL reconstruction. Several theoretical advantages exist for this technique; however, clinical results remain inconsistent and controversial. We have focused on the biomechanical function of the remnant and have been performing a new remnant-preserving reconstruction procedure that augments the graft with residual remnant. Preserving the structure and continuity of good-quality remnants may help maintain the early postoperative stress on the tendon graft, thereby providing a positive effect on remodeling. Although our concept is significantly different from previously reported remnant preservation techniques and has several pitfalls, the surgical technique that we outline in this report is simple and does not require specialized equipment. The procedure will also work more advantageously in preserving the residual mechanoreceptors in the remnant. We believe that this method can be a procedure with better results for patients with remnants that are in good condition.

Although satisfactory results have been reported for current anterior cruciate ligament (ACL) procedures, a review article reported poor outcomes and symptomatic instability in a considerable subset of patients. Several new approaches have been proposed to stabilize and improve these postoperative results.

One approach for improving results after ACL reconstruction is the preservation of the ACL remnant. Mesenchymal cells are known to remain in the

remnant, and the remnant envelops the reconstructed ligament that works favorably in the remodeling process of the grafted tendon. Although there are clinical reports that good results have been obtained with this approach, some have stated that there was no difference between remnant preservation and conventional methods.<sup>1</sup> Problems with this method include the condition of the remnant that vary by case, the reduced size of the remnant becoming smaller than that of a normal ACL, and the varying position of the attachment site. Because of these issues, even if the tendon graft is passed through and appears to be surrounded by remnant tissues under the anterior arthroscopic view, the actual coverage may be a small part of the whole (Fig 1).

In addition to the biological functions described, remnants are also known to contribute to the stabilization of the knee. Crain et al.<sup>2</sup> classified ACL remnant tissues into 4 types, and reported that the roof type (type II) and wall type (type III) changes the anteroposterior laxity before and after resection.<sup>2</sup> We have placed our focus on the biomechanical function of the remnant—its residual stabilizing function for the knee joint—and have been performing a new remnant-preserving reconstruction procedure that retains as much continuity as possible without damaging the

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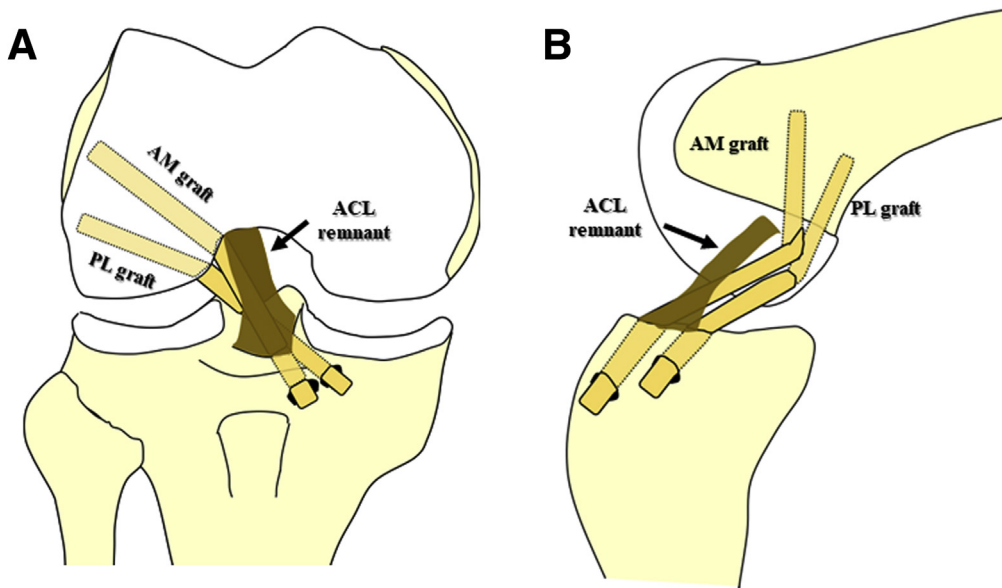
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**Fig 1.** Illustration of double-bundle ACL reconstruction with conventional remnant preservation. A reconstruction method that allows the passage of the graft within the remnant. (A) From the anterior view, the graft appears to be covered by the remnant. (B) Only the lower part of the graft may actually be covered. (ACL, anterior cruciate ligament; AM, anteromedial; PL, posteromedial.)

remnant to improve postoperative results (Fig 2). In this report, we will describe our surgical technique.

## Surgical Technique

### Patient Setup

All techniques are shown in Figs 3-7 and Video 1. The patient is placed in the supine position, with the affected side hanging down to the knee joint level. An oblique skin incision extending 3 to 4 cm in the posteromedial direction is made while using a tourniquet. Following tendon harvesting, double-looped autografts are prepared from semitendinosus and gracilis tendons (diameter, 5-6 mm). A TightRope (Arthrex) fixation system is used to fix the proximal end of the graft, and

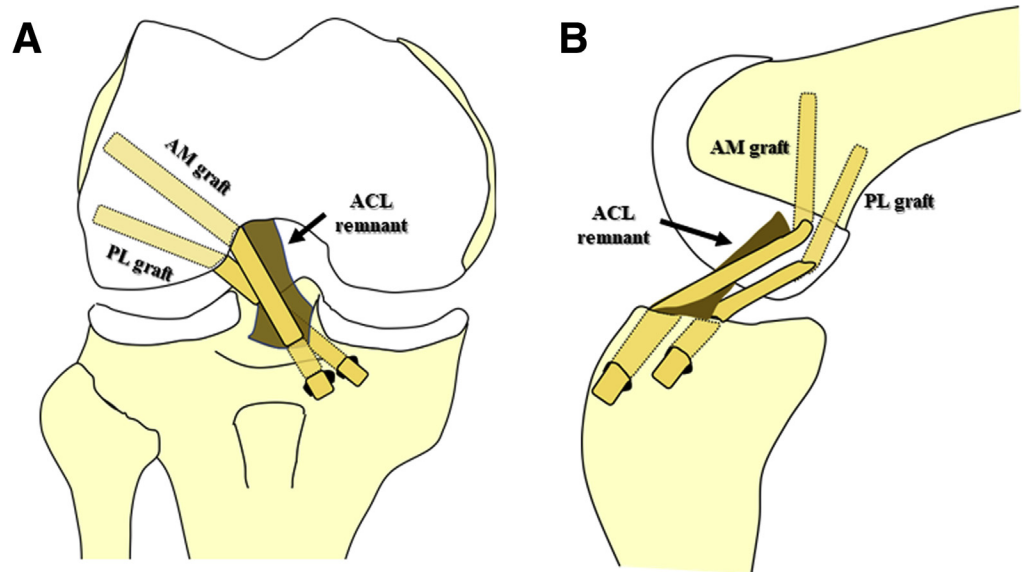
baseball glove sutures are used to prepare the distal ends. We examine the knee joint arthroscopically. Additional treatment is performed if meniscus tears or articular cartilage lesions are observed.

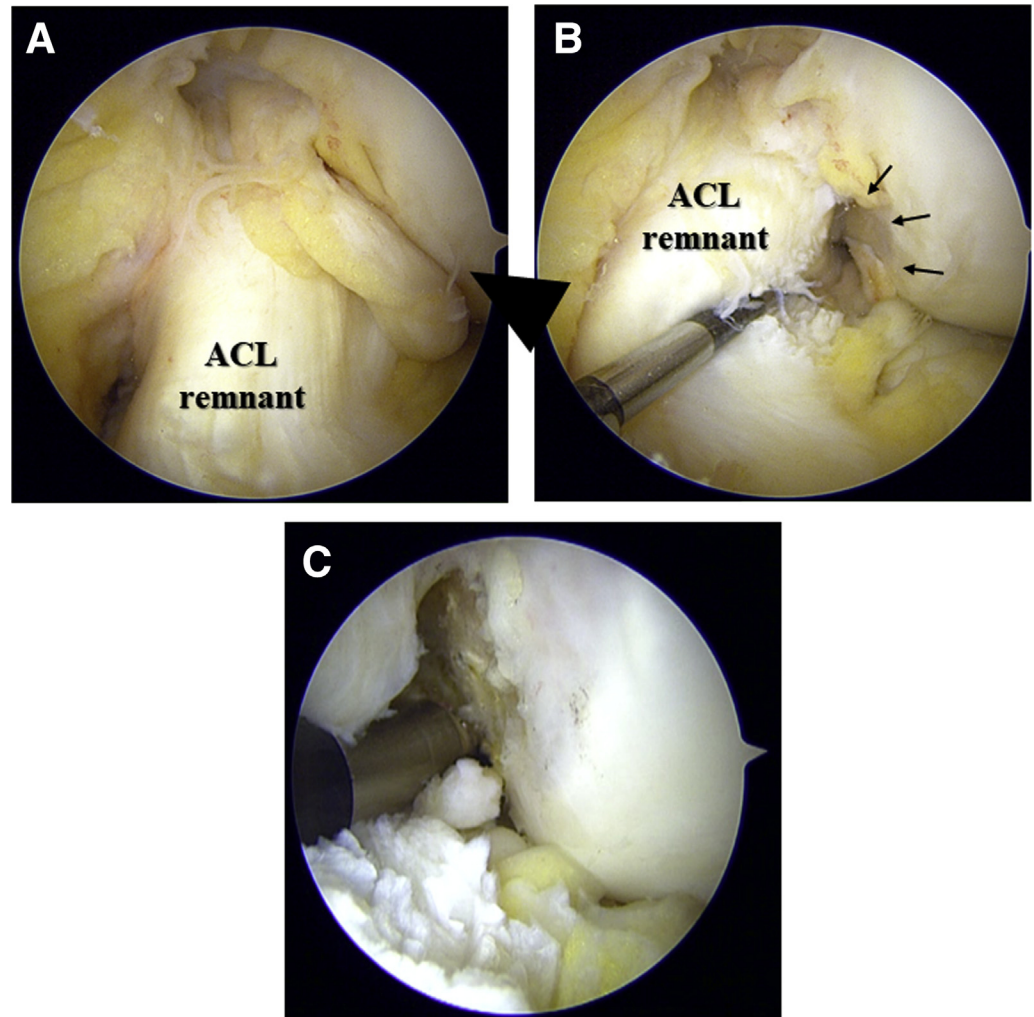
The ACL remnant injury site, volume, quality, and tension are carefully assessed and classified with a probe to 4 types described by Crain et al.<sup>2</sup> (Fig 3 A and B). When the remnant cannot be preserved, a conventional procedure is performed. While preserving the ACL remnant, femoral tunnels are constructed first.

### Preparing and Drilling of the Femoral Tunnel

With the knee in 90° flexion, ACL remnant and scar tissue are partially peeled off from the anterolateral (AL) portal with an arthroscope and the anteromedial

**Fig 2.** (A) Illustration of remnant-preserving ACL reconstruction with our remnant augmentation technique. (B) Our reconstruction method, which allows the passage of the graft outside of the remnant. (ACL, anterior cruciate ligament; AM, anteromedial; PL, posteromedial.)



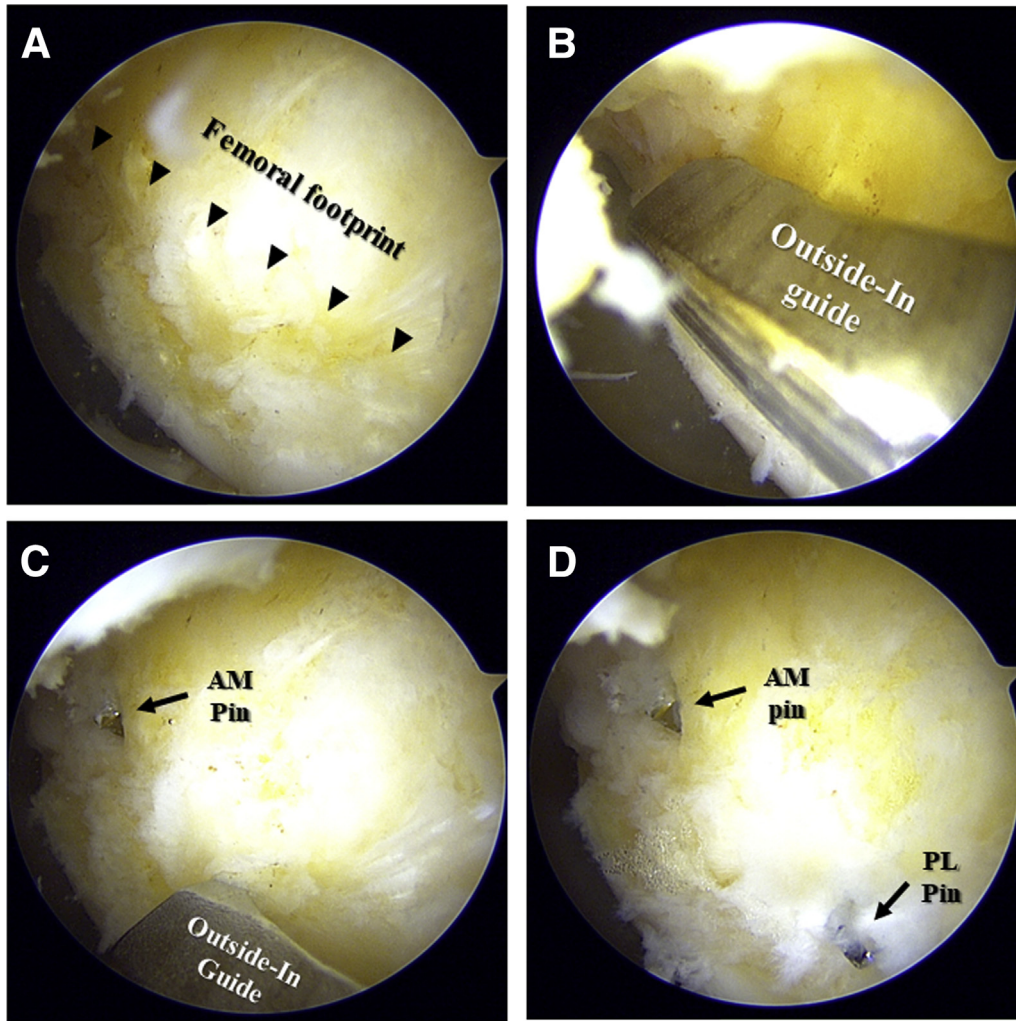


**Fig 3.** Arthroscopic view of intercondylar notch of left knee from the anterolateral portal. (A) The remnant is well preserved and is attached to the wall from the roof of the intercondylar notch. (B) Probing shows that the ligament is not attached to the anatomical femoral attachment (black arrow). (C) Using a thermal device/shaver, the femoral attachment site of the remnant is peeled as much as possible to obtain enough space to insert the arthroscope and outside-in guide. (AM, anteromedial; PL, posteromedial.)

(AM) portal with a thermal device (Fig 3C). If the remnant is too voluminous to secure a visualization of the surgical field, a suture passer or meniscal scorpion (Arthrex) is used to suture and retract the remnant in the superolateral direction. Once the remnant has been peeled to some extent, change the arthroscope into the AM portal and confirm that the anatomical footprint of the femur can be sufficiently visualized, and that an anterolateral entry femoral aimer (Smith & Nephew Endoscopy) can be inserted (Fig 4). If adequate access for maneuvering the arthroscope cannot be attained, the remnant should be peeled further. In the event that there is still not enough working space, abstain from further pursuing the preservation and remove the remnant, switching over to the conventional procedure. The pin for the bone tunnel of anteromedial bundle (AMB) is inserted first. If the AMB pin is in an adequate position, then insert the posterolateral bundle (PLB) pin. Once each pin is in an adequate position, drilling is performed to the actual diameter of the graft.

#### Preparing and Drilling of the Tibial Tunnel

The tibial tunnel is created using our previously described method.<sup>3-5</sup> Even if the remnant is preserved, the tibial attachment site can be confirmed by referencing its surrounding landmarks. The 4 landmarks are easily identified by using a probe, including the Parsons' knob to the anterior side, medial intercondylar ridge to the medial side, anterior horn of the lateral meniscus to the lateral side, anterior borders of the medial, and lateral tubercle to the posterior side (Fig 5). A quadrilateral surrounding these landmarks is better visualized and established when the remnant is preserved. The Parsons' knob can be confirmed with a probe by sharply splitting the anterior margin of the remnant longitudinally. The bone tunnel of AMB is created at the anteromedial side of the attachment to minimize the damage to the remnant, at which point the L-shaped ridge—a combination of the medial intercondylar ridge and Parson's knob—is used as an indicator. An



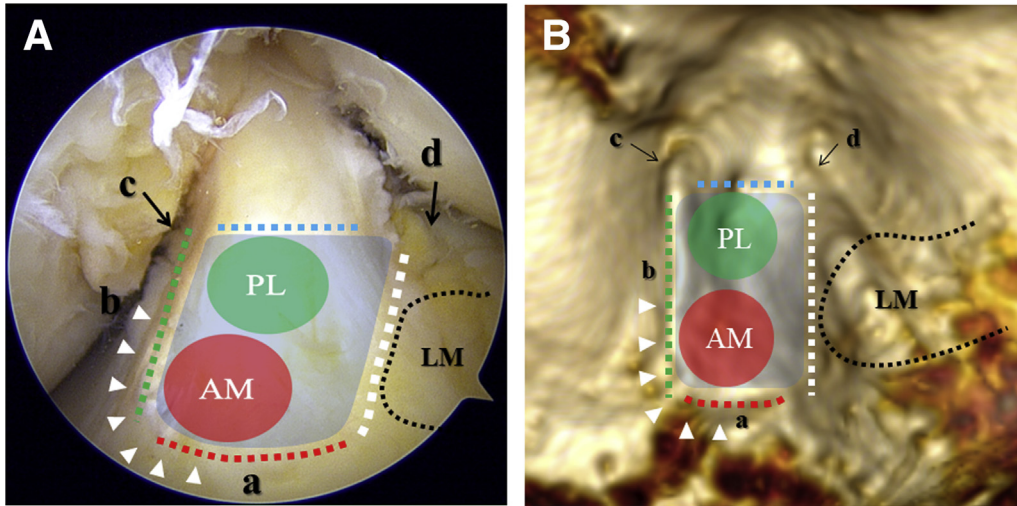
**Fig 4.** Arthroscopic view of the anatomical footprint (arrowheads) of the left knee from the anteromedial portal. (A) Even when the remnant is preserved, the anatomical footprint of the femur can be sufficiently visualized by arthroscopy. (B) Tip of the outside-in guide from the anterolateral portal is positioned at the AM attachment site. (C) Tip of the outside-in guide is positioned at the PL attachment site. (D) The AM/PL pin is inserted at a suitable position. (AM, anteromedial; PL, posteromedial.)

Acuflex Director Drill Guide (Smith & Nephew Endoscopy) is used as a guide for pin insertion (Fig 6). If the pin penetrates the articular surface, a curette is used to prevent the tip of the pin from damaging the remnant. In terms of creating the bone tunnel of PLB, the tip aimer is positioned posterior to the AMB guide pin and toward the back of the remnant. When inserting the PLB guide pin, the remnant is anteromedially retracted with a probe to confirm the tip of the pin. Although the exit of the bony surface cannot be confirmed when the remnant is preserved on the PLB side, it is possible to infer its position on the articular surface from the trajectory of the tip of the pin that is placed at a slightly anterior position from the lateral intercondylar tubercle. If both pins are placed in appropriate positions, drill and create the bone tunnel. The tibial side is drilled 0.5 mm smaller than the diameter of the tendon graft. When drilling, attention must be paid so as not to damage the fibers

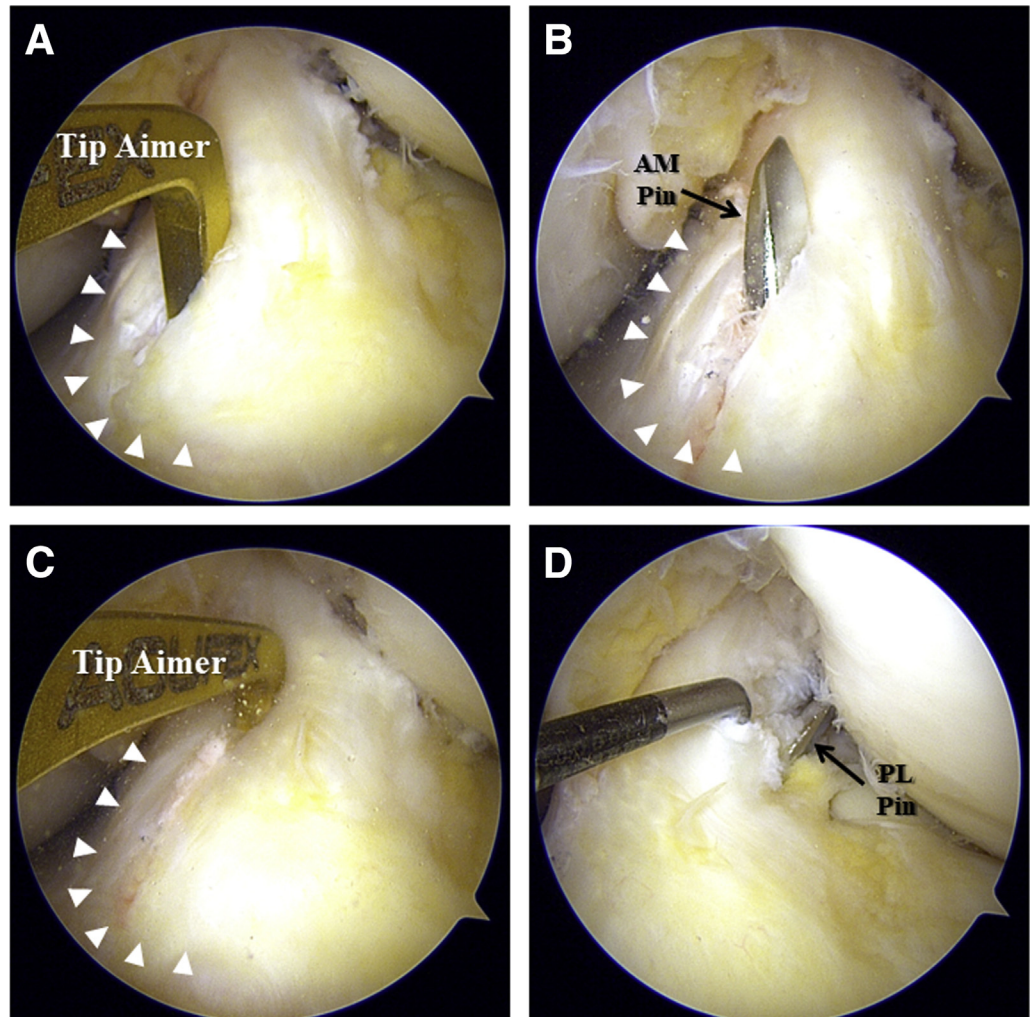
of the attachment site. After drilling, the tibial tunnel is enlarged to the same diameter with a dilator.

#### Graft Passage, Tensioning, and Fixation

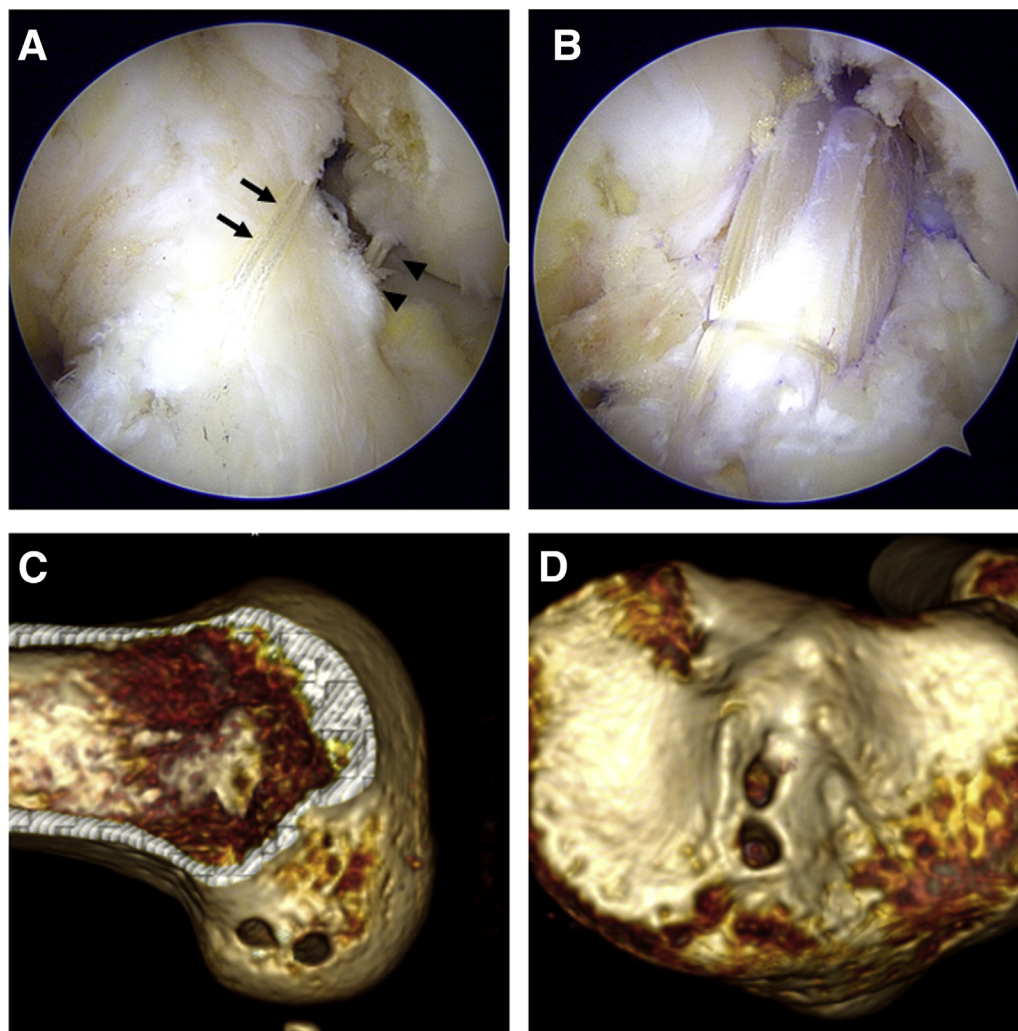
Following the creation of the bone tunnels, guide sutures are passed from the femoral tunnel to the tibial tunnel. Ensure that the guide sutures are passed over the anterior and under the posterior aspect of the remnant (Fig 7). Pull the guide suture proximally for graft passage and lead the graft tendon in the order of PLB and AMB sides. After flipping and fixing the tightrope on the femoral surface, introduce each graft in adequate depth and fix with a Double Spike Plate (Meira) on the tibial surface after applying 10N of tension with the tensioning boot system (Meira). After tensioning, make sure to check for any impingement with the surrounding tissues by flexing and extending the knee. The frayed edges of the remnant that sometimes occur in the drilling process may impinge



**Fig 5.** (A) Arthroscopic view of intercondylar notch of left knee from the anterolateral portal. (B) Axial 3-dimensional computed tomography image of left knee tibial plateau. AM/PL bone tunnels are positioned anteroposteriorly to a square that is formed from the 4 landmarks (anterior side: Parsons' knob; medial side: medial intercondylar ridge; lateral side: anterior horn of lateral meniscus; posterior side: anterior border of medial/lateral intercondylar tubercle). (a) Dotted red line: Parsons' knob; (b) dotted green line: medial intercondylar ridge; (c) medial intercondylar tubercle; (d) lateral intercondylar tubercle; (e) dotted white line: attachment of anterior root of lateral meniscus; dotted blue line: anterior edge of medial and lateral intercondylar tubercle; dotted black line; white arrowheads, Parsons' knob and medial intercondylar ridge are joined at their anteromedial edge to form the L-shaped ridge. (AM, anteromedial; LM, anterior horn of lateral meniscus; PL, posteromedial.)



**Fig 6.** Arthroscopic view of intercondylar notch of left knee from the anterolateral portal. (A) Make a slit in the remnant, place the tip of aimer in AM center, and refer to the L-shaped ridge (white arrowheads), which is a combination of the medial intercondylar ridge and Parson 's Knob. (B) AM guide pin is inserted at an adequate position within the remnant. (C) The tip of the aimer is positioned posteriorly to the AM pin in the PL center within the quadrilateral. (D) PL guide pin is inserted posteriorly to the remnant. (AM, anteromedial; PL, posteromedial.)



**Fig 7.** (A) Arthroscopic view of intercondylar notch of left knee from the anterolateral portal. After the creation of femoral and tibial tunnels, the ACL remnant was well-preserved. The guide suture (AM, black arrow; PL, arrowheads) is passed over the anterior and under the posterior side of the remnant. (B) The AM graft is positioned anteriorly to the remnant after fixation of the tendon graft. (C) Post-operative 3-dimensional computed tomography sagittal images of lateral femoral condyle; (D) axial image of the tibial plateau. Two tunnels of femur and tibia were successfully created. (AM, anteromedial; PL, posteromedial.)

between the condyles during knee flexion-extension. In this case, only parts that could potentially get caught is carefully removed with a shaver.

### Rehabilitation

Postoperatively, after the knee is immobilized for a week, range of motion exercises and partial weight bearing with crutches are allowed. Full weight bearing is initiated at 4 weeks postoperatively. Running is allowed at 3 months postoperatively. Athletes are allowed to return to play at 8 to 9 months after surgery.

### Discussion

Although various methods and procedures for remnant-preserving ACL reconstruction are reported in the literature, most have relied on the concept of revascularizing/remodeling the reconstructed ligament by passing the graft through the remnant and covering the graft surface with remnant tissues. However, the actual quality of the remnant is not uniform, and much of the remnant may be replaced by scar tissue.

Furthermore, it is unknown how many cells can invade the graft and contribute to graft remodeling in humans. In addition, because the attachment of the remnant is positioned significantly differently from that of a normal attachment, it is highly probable that only partial coverage is achieved when the graft is anatomically reconstructed. Considering these points, many questions remain as to how much residual remnant

### Table 1. Advantages and Disadvantages

#### Advantages

- Easy, straightforward technique.
- No need for specialized equipment.
- Preservation is also possible with a single-bundle procedure.
- Greater preservation of mechanoreceptors within the remnant.

#### Disadvantages

- Sometimes cannot be performed because of the large amount of residual remnant.
- The biomechanical property of the remnant may depend on its condition.

**Table 2.** Tips and Pearls

- The bone tunnels are created with the outside-in technique for both the tibia and femur.
- When pinning the femur, insert the camera from the AM portal and the guide from the AL portal.
- For the tibia, use the anatomical/bony landmarks as indicators for creating a bone tunnel.
- Care should be taken to avoid damaging the remnant during pinning and drilling on the tibial side.
- Use a dilator on the tibial side.
- Remove as much of the impinging residual tissues as possible around the graft.

AM, anteromedial; PL, posteromedial.

tissue will benefit the remodeling process of the graft tendon.

Our focus was placed on the biomechanical rather than biological properties of the remnant. Crain et al.<sup>2</sup> reported that there were no changes in the anteroposterior laxity of the knee after remnant debridement for cases with absent or PCL-adhering remnants, whereas cases with roof- or wall-adhering remnants showed increased instability after debridement. Nakase et al.<sup>6</sup> reported that cases with the remnant attached to the lateral wall affects not only the anteroposterior laxity but also the rotational stability of the knee. In addition, Nakamae et al.<sup>7</sup> reported that there was increased laxity for those who underwent remnant removal within 1 year of injury. These findings suggest that the ACL remnant contributes to the stability of the knee joint to some extent, depending on the position of reattachment and the duration after injury. Thus, preserving the structure and continuity of good-quality remnants may help maintain the early postoperative stress on the tendon graft, thereby providing a positive effect on remodeling.

An important point of our reconstruction technique is how to prevent damage to the remnant during the drilling process. Because there is a high possibility of

damaging the remnant during drilling using the trans-tibial and far anteromedial techniques, it is important to use the outside-in technique for the tibial side as well as the femoral side. Because the remnant does not adhere to the normal attachment, part of the remnant is therefore removed from the femoral side, and it is not too difficult to obtain the minimum space that is required to insert the outside-in guide and arthroscope under the remnant. If visualization of femoral attachment cannot be sufficiently secured, a better working space can be obtained by retracting the suture over the remnant and retracting medially. On the other hand, if sufficient visualization still cannot be secured, there is a possibility that the position of the bone tunnel may be less than ideal; in this case, the surgeon should switch to a conventional procedure.

On the tibial side, the remnant is often preserved in almost all cases. However, by using our previously described quadrant method for creating tibial tunnels, it is easy to create a bone tunnel in the correct position.<sup>3,4</sup> Even if the remnant is preserved, these landmarks can be visualized, and it is easy to create the tibial tunnels within a square that is formed from the 4 boundaries of these landmarks. This method enables bone tunnels to be created with the same accuracy and reproducibility as when the remnant is removed.<sup>5</sup>

To minimize damage to the remnant, the AM bone tunnel is positioned more anteromedially to the attachment, wherein the L-shaped ridge—a combination of the medial intercondylar ridge and Parson's knob—are used as a reference. The tunnel is drilled smaller than the diameter of the tendon graft, and by enlarging it with a dilator, damage at the attachment can be minimized. Although drilling can cause damage to the tibial attachment, the ACL tibial attachment covers a wide range of the intercondylar area, and the structural properties and continuity of the remnant are sufficiently maintained after drilling. The passage of the

**Table 3.** Risks and Limitations

	Precaution	Risk	Limitation
General	Some familiarity of standard ACL reconstruction technique is necessary. Must be familiar with anatomy of the attachment site.	May result in poor bone tunnel positioning.	Results depend on the condition of the original residual remnant.
Femoral tunnel	Peel off enough of the attachment site to allow arthroscopic visualization. Care must be taken to prevent peeling too much of the remnant attachment.	Continuity may be lost with excessive peeling. Arthroscopic visualization of the femoral attachment site may not be obtainable without an adequate amount of peeling.	Preservation of continuity may not be possible when there is a considerable amount of residual remnant.
Tibial tunnel	Must be familiar with landmarks around the tibial attachment site. Care must be taken when drilling through articular surface.	Remnants are preserved on the tibial side in most cases. Position of guide pin is difficult to confirm on the PL side.	Some damage to the remnant from drilling is inevitable on the tibial side.

ACL, anterior cruciate ligament; PL, posteromedial.

tendon graft after creating the bone tunnel is easier than the method of passing the graft through the remnant and is not too different from the conventional method.

The advantages and disadvantages, tips and pearls, risks, and limitations of our technique are described in Tables 1-3. Although our concept is significantly different from previously reported remnant preservation techniques, the surgical technique we have outlined in this report is a new method that focuses on the different functions of the remnant. Nakamae et al.<sup>8</sup> reported an ACL augmentation technique in which the tendon graft is fixed as an additional reinforcement when there is a partial ACL tear or a lot of residual tissues. Our concept is an extension of their concept, and we expect a better remodeling of the reconstructed ligament by augmenting the residual remnant and reducing the direct load. The surgical technique is simple and does not require specialized equipment, and it can be applied to single bundle reconstruction techniques. The procedure will also work more advantageously in preserving the residual mechanoreceptor in the remnant. We believe that this method can be a procedure with better results for patients with remnants that are in good condition.

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