Technical Note

Sandwich-Style Anterior Cruciate Ligament Reconstruction: Double-Bundle Anterior Cruciate Ligament Reconstruction With In-Between Remnant Preservation

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Abstract: Various degree of remnant tissues exists following anterior cruciate ligament (ACL) injury. Making use of these tissues may be helpful for the reconstructed ACL from many aspects. There are many methods of remnant preservation and use, as well as many types of combined ACL reconstruction. However, the most effective methods of remnant reuse as well as ACL reconstruction are still being pursued. We introduce an anatomical double-bundle transtibial ACL reconstruction with in-between remnant preservation technique named sandwich-style ACL reconstruction. The indication of this technique is complete ACL tear with a large volume of connectable remnant. The main tricks of this technique are proper ligation of the remnant, proper location of the anteromedial-bundle tibial tunnels, and passing the anteromedial bundle through the shallow side of the remnant. We believe the introduction of this technique will provide more options for remnant preservation and ACL reconstruction.

Anterior cruciate ligament (ACL) injury always leave remnant tissue, especially in acute cases.[1] During ACL reconstruction, whether to preserve the remnant is controversial. Recent studies have indicated that ACL reconstruction with remnant preservation promotes similar graft synovial coverage and revascularization, in addition to better sealing of the tibial tunnel, that results in equivalent or superior results regarding postoperative knee stability and clinical scores, better proprioception restoration, and similar total complication rate when compared with ACL reconstruction with remnant removal.[2,3] In our clinical practice, the remnant is always preserved when there is enough room for the graft and the remnant in the femoral notch. There are many types of ACL remnant, and many methods of remnant preservation and ACL reconstruction, which results in many method combinations of ACL reconstruction with remnant preservation.[4,5] We would like to introduce an anatomical double-bundle transtibial ACL reconstruction technique with in-between remnant preservation named sandwich-style ACL reconstruction. The indication of this technique is complete ACL tear at the femoral side with remnant that can be reconnected to the femur.

Surgical Procedure (With Video Illustration)

Tendon Harvesting and Graft Preparation

The semitendinosus tendon (ST) and gracilis tendon (GT) are harvested to make two 4-stranded grafts as in anatomical double-bundle transtibial ACL reconstruction without remnant preservation.[6] If the to-be-fabricated grafts are too thin, the anterior half of the peroneus longus tendon is harvested[7] along with the ST and GT to make a 6-stranded graft from the GT and anterior half of the peroneus longus tendon and a 4-stranded graft from the ST. The longer graft is used for the anteromedial (AM) bundle reconstruction and

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Table 1. Step-by-Step Procedure of Sandwich-Style ACL Reconstruction

1.	The ST and GT are harvested. A 4-stranded graft is made from each tendon.
2.	The ACL remnant is ligated with 2 PDS sutures.
3.	Femoral notch plasty is performed. The femoral tunnels are located and marked with a radiofrequency probe.
4.	The tibial tunnels are located and marked with a radiofrequency probe.
5.	The projection of the AM-bundle tibial tunnel is defined. The AM-bundle tibial tunnel is created.
7.	The projection of the PL-bundle tibial tunnel is defined. The PL-bundle tibial tunnel is created.
9.	A K wire is drilled to the marked point of the PL-bundle femoral tunnel through the PL-bundle tibial tunnel.
10.	The PL-bundle femoral tunnel is created.
11.	A K wire is drilled to the marked point of the AM-bundle femoral tunnel through the AM-bundle tibial tunnel.
12.	The AM-bundle femoral tunnel is created.
13.	An incision is made on the lateral midline of the thigh to reach the anterolateral femur through the underside of the quadriceps.
14.	The ligating sutures and the remnant are pulled into the AM-bundle femoral tunnel.
15.	The fixation sutures on the PL-bundle graft are pulled into the femoral tunnels through the PL-bundle tibial tunnels.
16.	The fixation sutures on the AM-bundle graft are pulled into the femoral tunnels through the AM-bundle tibial tunnels and the superior side of the remnant.
17.	The AM-bundle graft is placed in.
18.	The PL-bundle graft is placed in.
19.	Proximal suspension fixation is completed by tying the sutures on a mini-plate over each orifice.
20.	The sutures from the distal graft ends are tied at an adjustable loop, which is set through a transtibial ridge tunnel.

ACL, anterior cruciate ligament; AM, anteromedial; GT, gracilis tendon; PDS, polydioxanone; PL, posterolateral; ST, semitendinosus tendon.

the shorter graft is used for the posterolateral (PL) bundle reconstruction (Table 1 and Video 1).

Ligating the Remnant

Two polydioxanone II sutures are used to ligate the middle and proximal part of the ACL remnant with a suture passing instrument (Viper; Arthrex, Naples, FL) (Fig 1). An accessary AM portal is made, and the ligating sutures are pulled through this portal.

Femoral Notch Plasty

Because that the overall space that the grafts occupy is large and remnant fibers are retained, it is usually necessary to perform femoral notch plasty. A motorized

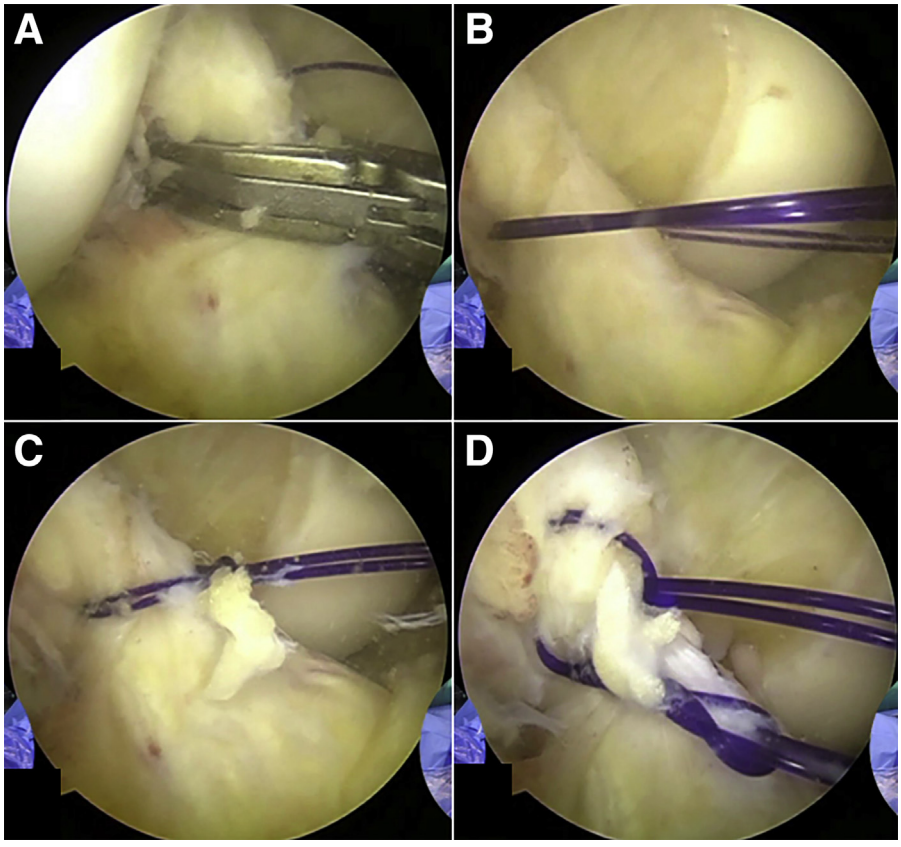

Fig 1. Ligating the remnant with a suture passer (Viper; Arthrex, Naples, FL). (A) A suture passer is used to bite at the middle part of the remnant. (B) One folded polydioxanone suture is passed through the remnant. (C) The remnant is ligated. (D) Another suture is used to ligate the remnant at the proximal part of the remnant.

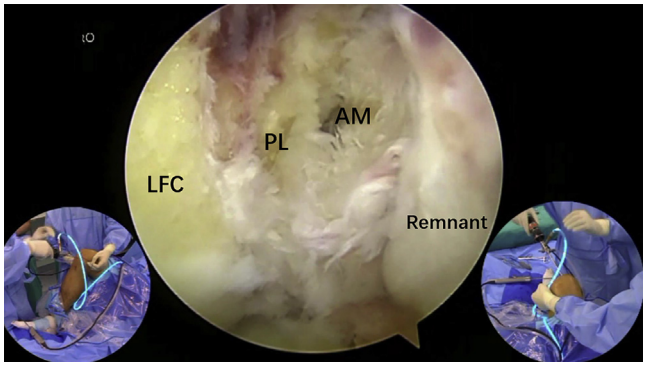

Fig 2. The femoral tunnels are located with reference to the remnant (Arthroscopic view of right knee through the anterolateral portal). (AM, location of the AM-bundle femoral tunnel; LFC, lateral femoral condyle; PL, location of the PL bundle femoral tunnel.)

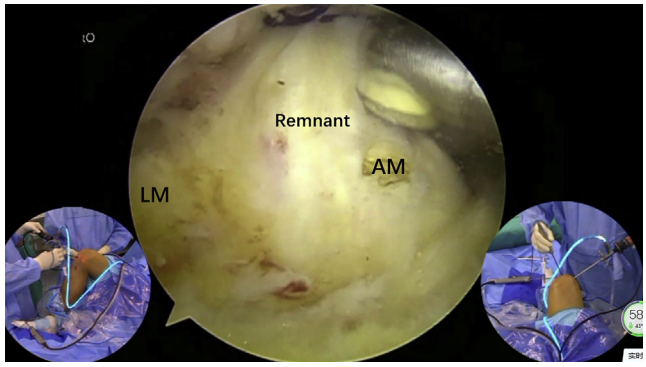

Fig 4. The tibial tunnels are located with reference to the remnant (Arthroscopic view of right knee through the anterolateral portal). (AM, location of the AM-bundle femoral tunnel; LM, lateral meniscus.)

burr is used to perform the notch plasty. The lateral wall of the femoral notch should be moved laterally to a place 5-mm lateral to the tip of the lateral tibial eminence. Then, the sponge bone at the distal edge of the femoral notch is devitalized with a radiofrequency probe.

Locating the Femoral and the Tibial Tunnels

The femoral tunnels of the 2 bundles are located respectively at the middle of the proximal and distal halves of the footprint (Fig 2). When there is no ligament remnant left in the footprint area for tunnel location, a low reference point is located at the lowest point of the lateral wall of the femoral notch, and a high reference point is located at the over-the-top point. The PL bundle is located at a point (PLP) 5 mm anterior to the low reference point. The AM bundle is located a point 10 mm proximal to the PLP on the line passing through the PLP and the high reference point (Fig 3).

The tibial tunnels of the 2 bundles are in the middle of the anterior and posterior halves of the ACL tibial footprints (Fig 4).

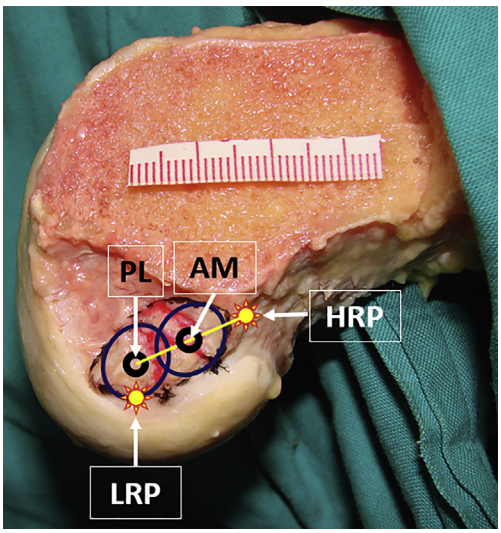

Fig 3. Illustration of the locations of the femoral tunnels in the right knee. An LRP is located at the lowest point of the lateral wall of the femoral notch, and an HRP is located at the over-the-top point. The posterolateral bundle is located at a point (PLP) 5 mm anterior to the LRP. The anteromedial bundle is located a point 10 mm proximal to the PLP on the line passing through the PLP and the HRP. (AM, anteromedial bundle; HRP, high reference point; LRP, low reference point; PL, the posterolateral bundle.)

Creating the Tibial Tunnels

The tibial tunnels are created as in anatomical double-bundle transtibial ACL reconstruction without remnant preservation.[6] In the construction of the AM bundle tibia tunnel, the tunnel positioning should not be too close to the anterior side, Otherwise, the main part of the ACL attachment may be damaged when the tunnel is drilled, which may affect the effect of remnant preservation.

For the creation of each tibial tunnel, an ACL tibial tunnel locating device (Aesculap, Tuttlingen, Germany) is used, and a K wire is first drilled through the tibia into the joint to evaluate the projection of the tibial tunnel. When the desired projection of the tibial tunnel to the corresponding location of the femoral tunnel is obtained, the tibial tunnel is created (Figs 5 and 6).

Creating the Femoral Tunnels

A K wire is drilled through the PL bundle tibial tunnel to the location of the PL bundle femoral tunnel free-handed. The PL bundle femoral tunnel is created to the expected length and size (Fig 7). Then, a K wire is drilled through the AM bundle tibial tunnel and the inferior side of the ACL remnant to the location of the AM bundle femoral tunnel free-handed. The AM bundle femoral tunnel is created to the expected length and size (Figs 8 and 9).

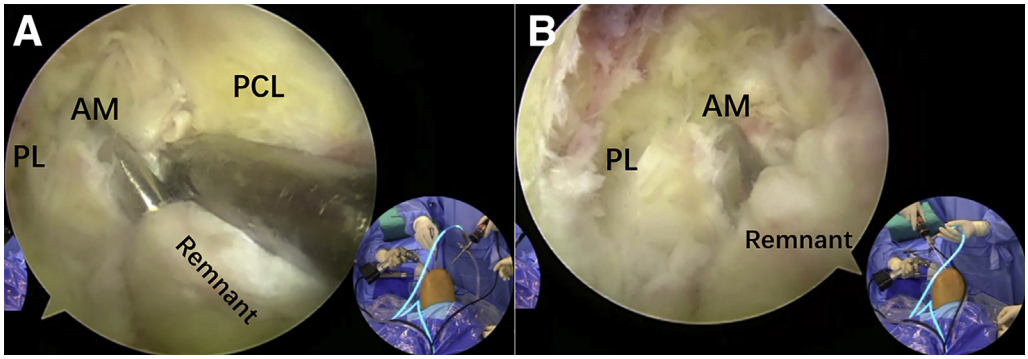

Fig 5. Adjusting the projection of the AM bundle tibial tunnel to the AM bundle femoral tunnel. (A) Arthroscopic view of right knee through the anterolateral portal. (B) Arthroscopic view of right knee through the anteromedial portal. (AM, location of the AM-bundle femoral tunnel; PCL, posterior cruciate ligament; PL, location of the PL-bundle femoral tunnel.)

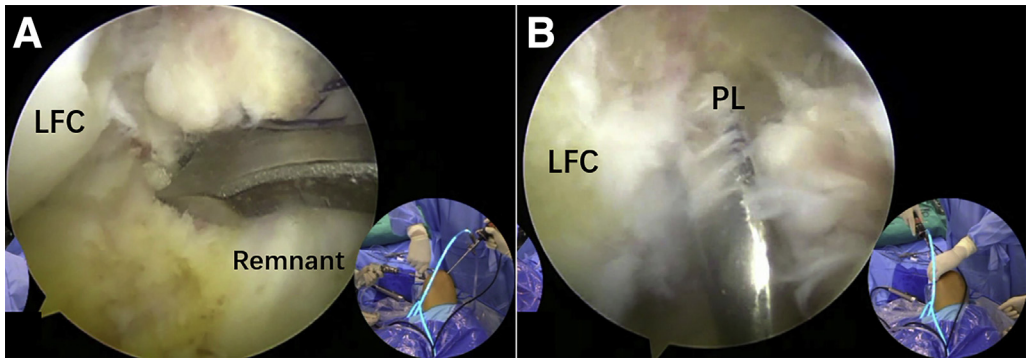

Fig 6. Creating the PL bundle tibial tunnel. (A) Arthroscopic view of right knee through the anterolateral portal) with the projection to the PL bundle femoral tunnel. (B) Arthroscopic view of right knee through the anteromedial portal. (LFC, lateral femoral condyle; PL, location of the PL bundle femoral tunnel.)

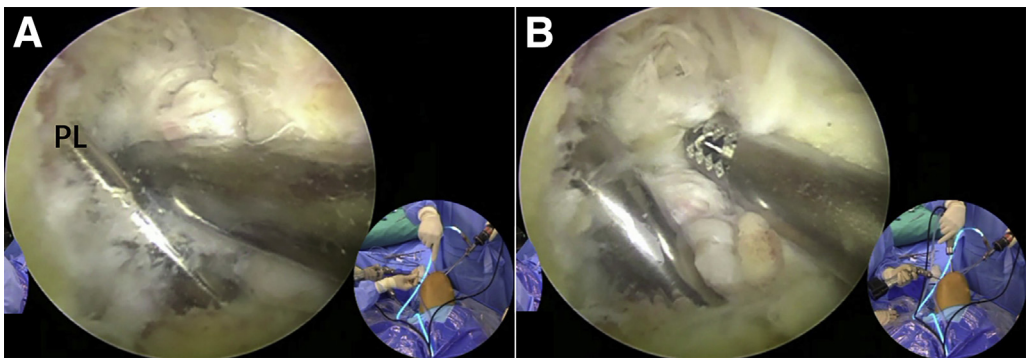

Fig 7. Creating the PL bundle femoral tunnel (Arthroscopic view of right knee through the anterolateral portal). (A) A K wire is drilled first through the PL bundle tibial tunnel free-handedly to the location of the PL bundle femoral tunnel. (B) The PL bundle femoral tunnel is created through the PL bundle tibial tunnel. (PL, location of the PL bundle femoral tunnel.)

Pulling the Remnant to the Femoral Tunnel

An incision is made on the lateral midline of the thigh to reach the anterolateral femur through the underside of the quadriceps. A guide pin with a tailed guide suture loop is placed through the AM bundle tibial and femoral tunnels to leave the guide suture loop within the joint. The ligating suture are passed through the guide suture loop. The connection of the remnant to the femur is restored by pulling the ligating suture into the AM-bundle femoral tunnel using the guide suture loop (Fig 10).

Graft Implantation

The proximal fixation suture on the PL bundle graft is first pulled through the PL bundle tibial tunnel to the PL bundle femoral tunnel. Then, a guide pin is passed through the AM bundle tibial tunnel to the superior side of the remnant, adjusted and passed through the

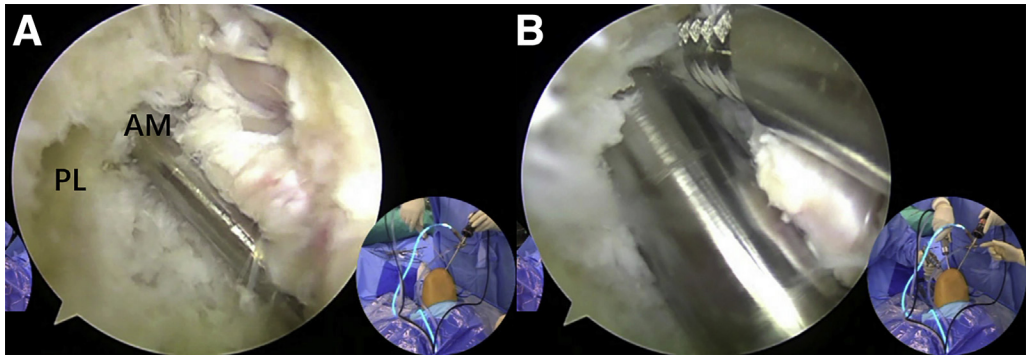

Fig 8. Creating the AM bundle femoral tunnel (Arthroscopic view of right knee through the anterolateral portal). (A) A K wire is drilled first through the AM bundle tibial tunnel and the inferior side of the remnant free-handedly to the location of the AM bundle femoral tunnel. (B) The AM bundle femoral tunnel is created through the AM bundle tibial tunnel. (AM, location of the AM-bundle femoral tunnel; PL, location of the PL-bundle femoral tunnel.)

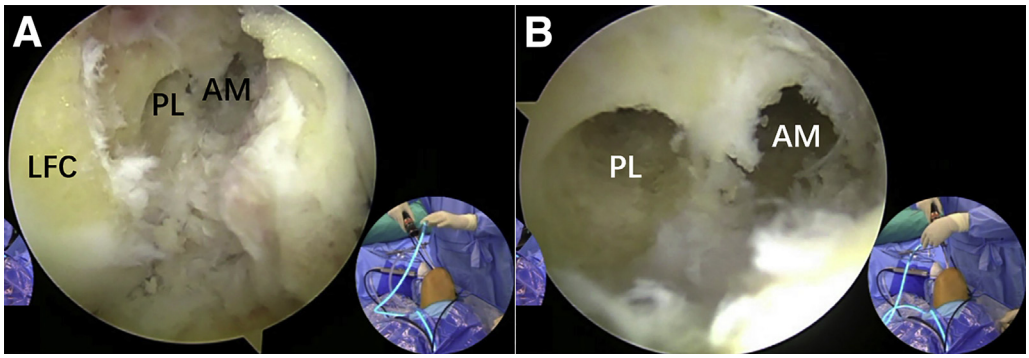

Fig 9. The 2 created femoral tunnels (Arthroscopic view of right knee through the anteromedial portal). (A) Distant view. (B) Close view. (AM, the femoral tunnel for the anteromedial bundle; LFC, lateral femoral condyle; PL, the femoral tunnel for the posterolateral bundle.)

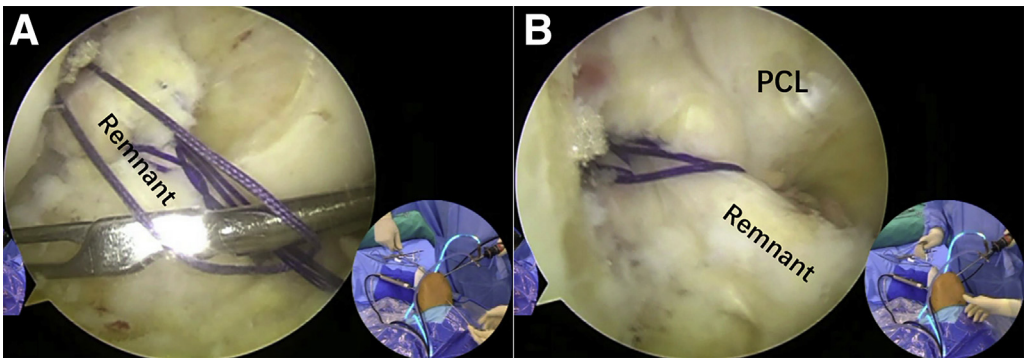

Fig 10. Pulling the remnant to the AM bundle femoral tunnel (Arthroscopic view of right knee through the anterolateral portal). (A) A looped guide suture is passed through the AM bundle femoral tunnel and the ligating sutures on the remnant are passed through the guide suture loop. (B) The ligating sutures, and the remnant are pulled to the femoral side. (PCL, posterior cruciate ligament.)

AM bundle femoral tunnel. The proximal fixation suture on the AM bundle graft is pulled through the AM bundle tibial tunnel to the AM bundle femoral tunnel (Fig 11).

The AM and PL bundle grafts are placed in sequentially. Finally, the remnant fibers are placed between the 2 bundles of graft to realize double-bundle ACL reconstruction with in-between remnant preservation (Fig 12).

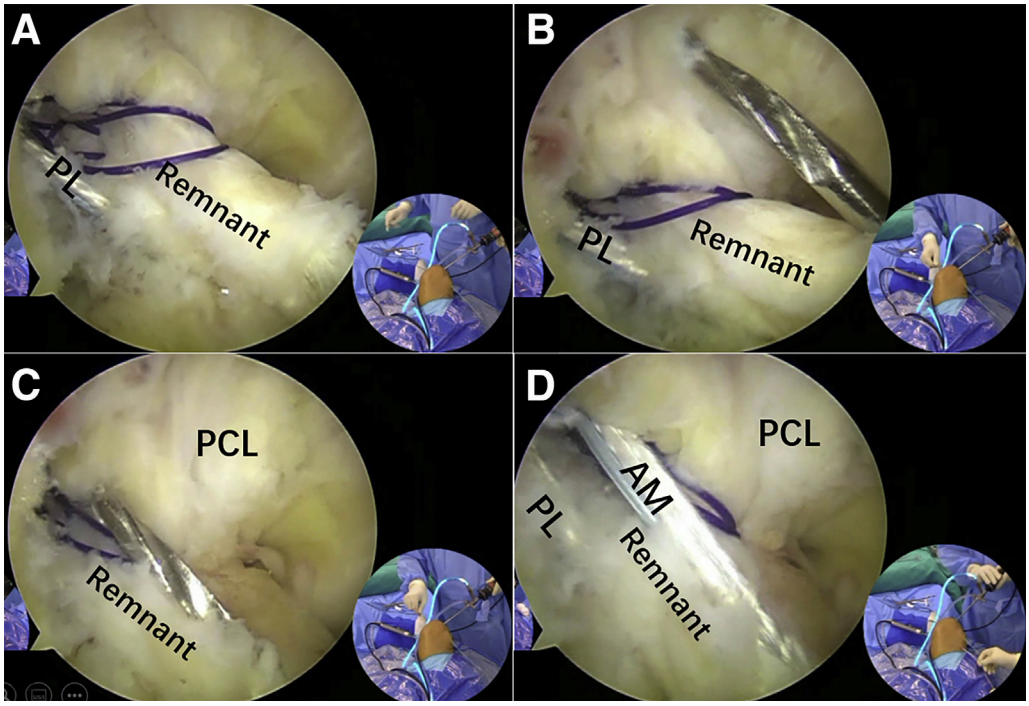

Fig 11. Placement of the proximal fixation sutures of the graft (Arthroscopic view of right knee through the anterolateral portal). (A) The proximal fixation suture on the PL-bundle graft is pulled through corresponding femoral tunnel. (B) A guide pin is passed through the AM-bundle tibial tunnel to the superior side of the remnant. (C) The guide pin is passed through the AM bundle femoral tunnel. (D) The proximal fixation suture on the AM bundle graft is pulled to the AM bundle femoral tunnel. (AM, fixation future on the AM bundle graft; PCL, posterior cruciate ligament; PL, fixation suture for the PL bundle graft.)

Graft Fixation

Through the lateral incision, proximal fixation is performed by tying the proximal fixation sutures from the grafts on mini-plates over the outer orifices of the femoral tunnels. The knee is extended to preclude femoral notch impingement (Fig 13). Further notch plasty is conducted in case of impingement. The knee is placed in full extension. One interference screw is placed into the AM bundle tibial tunnel just behind the graft for fixation.

A 4.5-mm transtibial ridge tunnel is created. A set of mini-plates with an adjustable loop (Arthrex) is pulled through this tunnel from the medial to the lateral side. Half of the sutures from the graft ends are passed through the adjustable loop. The mini-plate is pulled through the transverse tibial tunnel and flipped over the lateral orifice. The sutures limbs passing through the adjustable loop are tied to their counterparts to fix the graft at the adjustable loop. The adjustable loop is reduced to tension the graft finally.

Discussion

There are many kinds of ACL remnants in both acute and chronic stages of ACL tear with respect to length, width, reconnection potential, or adhesion site of the remnant.[8,9] Thus, variety exists in the structural properties of the remnant and preservation

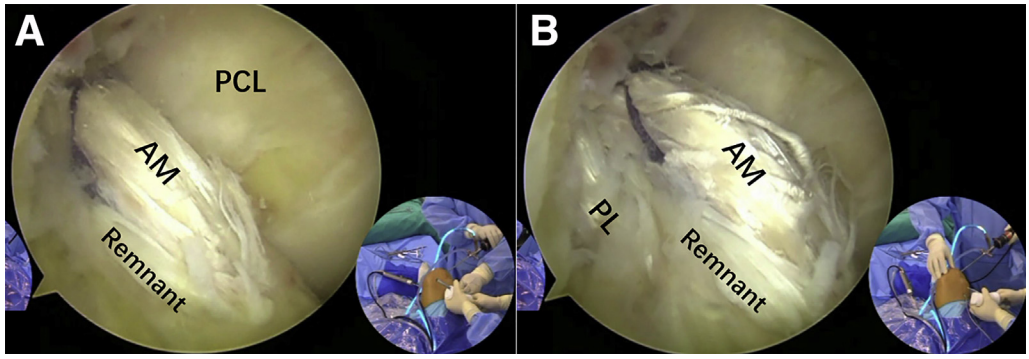

Fig 12. Placement of the grafts (Arthroscopic view of right knee through the anterolateral portal). (A) The AM bundle graft is first placed in. (B) The PL bundle graft is placed in. (AM, the graft of the anteromedial bundle; PCL, posterior cruciate ligament; PL, fixation suture for the PL bundle graft.)

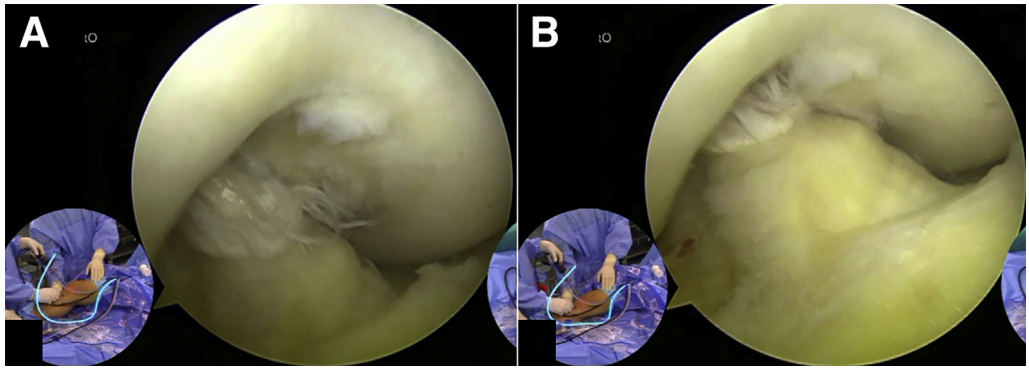

Fig 13. The knee is extended from 15° (A) to full extension (B) to preclude femoral notch impingement.

methods, which may explain the variety of remnant preservation results.[10,11] Clinically, we classify the ACL remnant into 3 types, namely connected remnant, disconnected but connectable remnant, and disconnected and unconnectable remnant. The current technique is suitable for acute or chronic ACL tear with disconnected but connectable remnant. For those with unconnectable remnant or remnant in ectopic adhesion, other methods of remnant preservation should be considered.

Technically, anatomical double-bundle transtibial ACL reconstruction may be challenging, but the combined remnant preservation part in this procedure is neither challenging nor time-consuming. So long as there is no harmful effect to the reconstructed ACL when the remnant is preserved, ACL reconstruction with remnant preservation should be considered.

The crucial point in this procure is first how to preserve the remnant (Tables 2 and 3). Because most of the ACL fibers insert at the anterior and medial site of the ACL tibial footprint, avoiding direct tunnel penetration at the anterior and medial edges of the ACL footprint is crucial. The second point is how to make full use of the remnant. To incorporate the remnant in the force chain, the remnant should be tensioned, and an attempt should be made to reattach it to the femur. The third crucial point is that one should not choose nonstandardized ACL reconstruction due to the preservation of the remnant from the aspects of graft choices and tunnel location.

Table 2. Pearls and Pitfalls of Sandwich-Style ACL Reconstruction

1. Because the reliability and final strength of the connection of the remnant to the femur cannot be relied on, enough total graft size is needed for ensure final tibial–femur connection strength. Thus, a total graft size larger than that of a 10-mm graft is the best choice, as in double bundle ACL reconstruction without remnant preservation.
2. Because of the use of 8- or 10-stranded hamstring tendons to perform double-bundle ACL reconstruction, the grafts will occupy relatively large space in the femoral notch. Ultimately, regarding whether to retain the ACL remnant fiber, one needs to refer to total size of the graft. If both bundles of the grafts are larger, especially if the ST graft diameter is more than 9 mm, either the remnant fiber needs to be removed to avoid femoral notch crowdedness or single-bundle ACL reconstruction with remnant preservation but less graft tissue is performed.
3. During location and creation of the AM-bundle tibial tunnel, the trick to preserve the tibial attachment of the remnant is to set the tunnel just posterior to the anterior curtain-like compact fiber part.
4. During creation of the AM-bundle femoral tunnel, the drill is passed through the inferior side of the anterior curtain-like compact fiber part in a manually reverse manner to protect the remnant.
5. When the remnant is long enough, it is pulled to the AM-bundle femoral tunnel. Otherwise, it is pulled to the PL-bundle femoral tunnel.
6. This special sandwich-style ACL reconstruction can be realized when the AM-bundle tibial tunnel is located anteriorly enough, although the less disturbance of the remnant, the better. When the AM bundle tibial tunnel is located too posteriorly, the remnant cannot be placed between the 2 reconstructed bundles and can just be placed at the shallow side of the 2 bundles in a cloak-style.
7. Proximal fixation of the ligating and traction sutures from the remnant rely on the compression and friction in the tendon–tunnel interface and the fitness of the graft in the tunnel. When the graft doesn't fit the tunnel well, namely it is too loose in the tunnel, the compression and friction effect cannot be relied on. It is suggested to fix the ligating sutures on the same mini-plate for graft fixation at knee extension.

ACL, anterior cruciate ligament; AM, anteromedial; GT, gracilis tendon; PL, posterolateral; ST, semitendinosus tendon.

Table 3. Disadvantages of Sandwich-Style ACL Reconstruction

The biggest disadvantage of retaining remnant fibers is that it may cause crowding in the femoral notch.
It is necessary to increase the capacity of the femoral notch by notch plasty and remove the synovium over the PCL.
It is also necessary to plan before and during surgery to adjust the number of grafts in a timely manner. If the implant is implanted and the femoral notch is relatively small, the remnant fiber needs to be removed.

PCL, posterior cruciate ligament.

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