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. 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. 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. 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. If the to-be-fabricated grafts are too thin, the anterior half of the peroneus longus tendon is harvested 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...
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 accessory AM portal is made, and the ligating sutures are pulled through this portal.

### Femoral Notch Plasty

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

Creating the Tibial Tunnels
The tibial tunnels are created as in anatomical double-bundle transtibial ACL reconstruction without remnant preservation. 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, Tuttingen, 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).
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
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).
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. Therefore, variety exists in the structural properties of the remnant and preservation...
methods, which may explain the variety of remnant preservation results. 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 procedure 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 non-standardized 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.

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.

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

PCL, posterior cruciate ligament.
References

1. Kosy JD, Mandalia VI. Anterior cruciate ligament mechanoreceptors and their potential importance in remnant-preserving reconstruction: A review of basic science and clinical findings. J Knee Surg 2018;31:736-746.

2. Wang H, Liu Z, Li Y, Peng Y, Xu W, Hu N, Huang W. Is remnant preservation in anterior cruciate ligament reconstruction superior to the standard technique? A systematic review and meta-analysis. Biomed Res Int 2019;2019:1652901.

3. Wang HD, Wang FS, Gao SJ, Zhang YZ. Remnant preservation technique versus standard technique for anterior cruciate ligament reconstruction: A meta-analysis of randomized controlled trials. J Orthop Surg Res 2018;13:231.

4. Kim SJ, Choi CH, Chun YM, et al. Anterior cruciate ligament reconstruction using bone-patellar tendon-bone autograft with remnant preservation: Comparison of outcomes according to the amount of remnant tissue. J Knee Surg 2019;32:847-859.

5. Nakayama H, Kambara S, Iseki T, Kanto R, Kurosaka K, Yoshiya S. Double-bundle anterior cruciate ligament reconstruction with and without remnant preservation—Comparison of early postoperative outcomes and complications. Knee 2017;24:1039-1046.

6. Zhao J. Anatomical double bundle transtibial anterior cruciate ligament reconstruction. Arthrosc Tech. February 2, 2021.

7. Zhao J, Huangfu X. The biomechanical and clinical application of using the anterior half of the peroneus longus tendon as an autograft source. Am J Sports Med 2012;40:662-671.

8. Adachi N, Ochi M, Takazawa K, et al. Morphologic evaluation of remnant anterior cruciate ligament bundles after injury with three-dimensional computed tomography. Knee Surg Sports Traumatol Arthrosc 2016;24:148-153.

9. Haviv B, Shemesh S, Kittani M, Yassin M, Yaari L. The reliability of classifying the morphology of anterior cruciate ligament remnants during surgery [published online November 4, 2019]. J Knee Surg. https://doi.org/10.1055/s-0039-1700810.

10. Yanagisawa S, Kimura M, Hagiwara K, et al. The relationship between the clinical results and the remnant type following anterior cruciate ligament reconstruction using a hamstring tendon. J Orthop Surg (Hong Kong) 2019;27. 2309499019837653.

11. Kim JH, Oh E, Yoon YC, Lee DK, Lee SS, Wang JH. Remnant-tensioning single-bundle ACL reconstruction provides comparable stability to and better graft-vascularity than double-bundle ACL reconstruction in acute or subacute injury: A prospective randomized controlled study using DCE-MRI. Arthroscopy 2021;37:209-221.