Technical Note

Meniscal Circumferential Fiber Augmentation: A Biomechanical Arthroscopic Meniscal Repair Technique

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Abstract: Radial tears of the human knee meniscus result in the loss of circumferential hoop stress and are highly correlated with knee degeneration. Although a variety of surgical techniques are available to repair radial meniscal tears, including inside-out, outside-in, and all-inside techniques, conventional repair techniques focus only on stabilizing the damaged portion. This Technical Note describes a biomechanical meniscus repair technique of meniscal circumferential fiber augmentation, concomitant with conventional repair, to promote meniscal healing from a biomechanical perspective.

The knee meniscus is a C-shaped fibrocartilaginous structure that plays critical roles in load transmission, stabilization, lubrication, and shock absorption.[1] The collagen fibers of the meniscus consist of superficial randomly oriented fibers, circumferential fibers, and radial tie fibers.[2] Of these, the circumferential fiber plays a role in transferring a vertical compressive load into circumferential hoop stress. The tear of the meniscus is the most common intra-articular knee injury, and tear pattern of meniscal injuries is classified generally into 3 types, including vertical/longitudinal, radial/transverse, and horizontal/complex. The radial tear of the midbody of the lateral meniscus is more common in young athletes, whereas the radial tear of the posterior root of the medial meniscus is more common in older patients. This condition disrupts the circumferential fibers of the meniscus; as a result, the contact area of the knee joint decreases and the contact pressure increases.[3] Consequently, the incidence of degenerative and osteoarthritic changes increases. Numerous techniques have been reported for repairing meniscal radial tears.[4] However, healing of the meniscus after surgery is sometimes insufficient because injured meniscal tissue has limited healing ability due to its poor vascularity. This Technical Note describes a technique for meniscal repair with meniscal circumferential fiber augmentation using an artificial ligament tape, concomitant with conventional repair, to promote meniscal healing from a biomechanical perspective.

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Indications

This technique is indicated for all patients with radial meniscal tears assessed using magnetic resonance imaging. In this Technical Note, a meniscal circumferential fiber augmentation technique for a radial tear of the midbody of the lateral meniscus of right knee is presented.

Surgical Technique (With Video Illustration)

The surgical technique is demonstrated in Video 1.

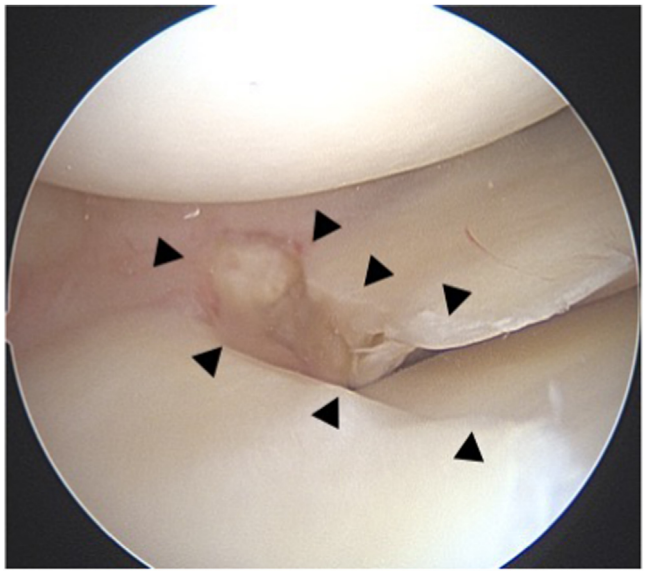

Fig 1. Arthroscopic views of right knee via anterolateral portal showing complete radial tear of the mid body of the lateral meniscus.

Step 1: Incisions and Approaches

The patient is placed in the supine position under general anesthesia with the arms on arm boards. After an air tourniquet is applied to the patient's proximal thigh, the affected lower limb is placed with a side support on the lateral side of the thigh and an attachable footrest beneath the foot to allow the knee to be placed at a 90° angle.

The procedure is initiated by knee arthroscopy through the conventional anteromedial and anterolateral portals to diagnose associated injuries (Fig 1). Subsequently, a far anteromedial (FAM) portal and an 8-cm skin incision are made on the lateral side of the knee joint (Fig 2). The iliotibial band is identified through an incision. Then, the interval between the biceps tendon insertion and iliotibial band is identified and incised. The space between the posterolateral capsule and lateral gastrocnemius tendon is bluntly developed, and a Henning retractor is inserted into the space to approach the posterior part of the capsule.

Step 2: Introduction of Meniscal Suture Tape Along the Circumferential Fiber of the Meniscus

The Henning system of inside-out meniscal repair is used throughout the entire process (Fig 3).[5] A high-strength (composed of ultrahigh-molecular-weight polyethylene) 1.5-mm wide artificial ligament tape with needles on each end (M Braid, Stryker Japan, Tokyo, Japan) (Fig 4) is adopted for the circumferential augmentation. From the medial side of the knee, a long needle is inserted toward the anterior horn of the meniscus. The direction of the needle is confirmed, and a FAM portal is created. Through a metal cannula inserted into the FAM portal, the outer rim of the anterior horn of the lateral meniscus is penetrated by the needle of the artificial ligament tape. The needle is pushed forward and pulled out from outside the anterolateral aspect of the capsule, placing the artificial ligament tape from the anterior horn to the anterolateral aspect of the meniscus (Fig 5A). Then, the needles attached to the artificial ligament tape are cut off. If the artificial ligament tape is penetrating the iliotibial band, it is pulled out from under the iliotibial band.

An 8-cm long needle attached to a conventional Henning meniscal suture (Stryker Japan, Tokyo, Japan) is inserted from the anterolateral to the posterolateral aspect of the capsule (Fig 5B). Through this process, the needle is ensured to be inside the circumferential fiber

Fig 2. Preoperative markings on right knee.

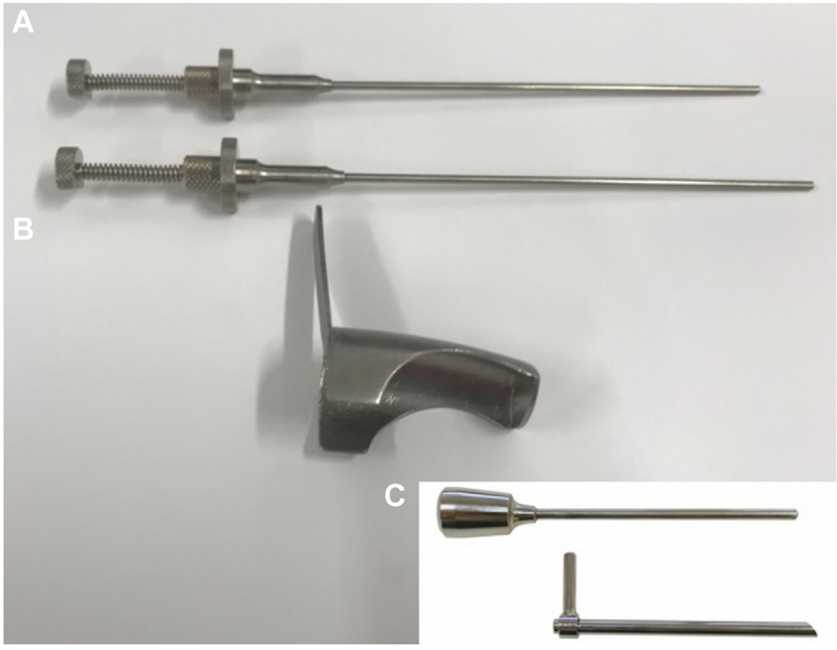

Fig 3. The Henning system of inside-out meniscal repair (Stryker Japan, Tokyo, Japan). (A) Needle holder, (B) retractor, (C) cannula.

of the meniscus. Occasionally, arthroscopy identified the needle at the injury site of the meniscus. The needle is then pulled out from the Henning retractor, and a loop for the suture relay is prepared by tying the suture on the anterolateral side. The artificial ligament tape is passed from the anterolateral to the posterolateral capsule through the midbody of the meniscus (Fig 6).

A conventional Henning meniscal suture (Stryker Japan, Tokyo, Japan) is inserted beneath the posterior horn of the meniscus into the posterolateral capsule and pulled out of the retractor, similar to the conventional inside-out technique. The needle is cut off and a loop for relay is created by tying the suture. Then, the artificial ligament tape is passed from the posterior capsule to the posterior horn of the meniscus. The artificial ligament tape is positioned around the circumferential fiber hanging both the anterolateral and posterolateral capsules.

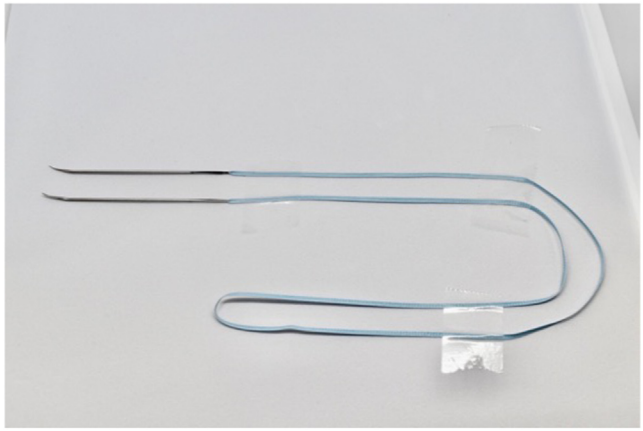

Fig 4. A high-strength (composed of ultrahigh-molecular-weight polyethylene) 1.5-mm wide artificial ligament tape (M Braid, Stryker Japan, Tokyo, Japan).

Step 3: Fixation of the Artificial Ligament Tape

A 5-mm diameter silicone cannula is placed in the anterolateral portal. A tiny part of the anterior horn of the meniscus is abraded to expose the tibial bone. The anterior part of the artificial ligament tape is attached to the self-punching all-PEEK knotless anchor (Omega, Stryker Endoscopy, San Jose, CA) and fixed into the tibial bone.

A 1-cm longitudinal skin incision is made proximal to the pes anserinus. From this incision, a 2.4-mm K-wire is placed from anterior aspect of the tibia to the posterior attachment of the lateral meniscus using ACUFEX Director ACL Tibial Aimer (Smith & Nephew Endoscopy, Andover, MA). Through the drill hole, the artificial ligament tape on the posterior horn is retrieved from the anterior aspect of the tibia using a Suture Retriever (Smith & Nephew Endoscopy). The tape is confirmed to be placed inside the meniscus, and the displaced meniscus is reduced by pulling the tape on the anterior tibia. On arthroscopically visualizing each stump of the torn meniscus close to each other while pulling the artificial ligament tape (Fig 7), the suture tape is fixed into the tibial using a similar anchor (Omega, Stryker Endoscopy).

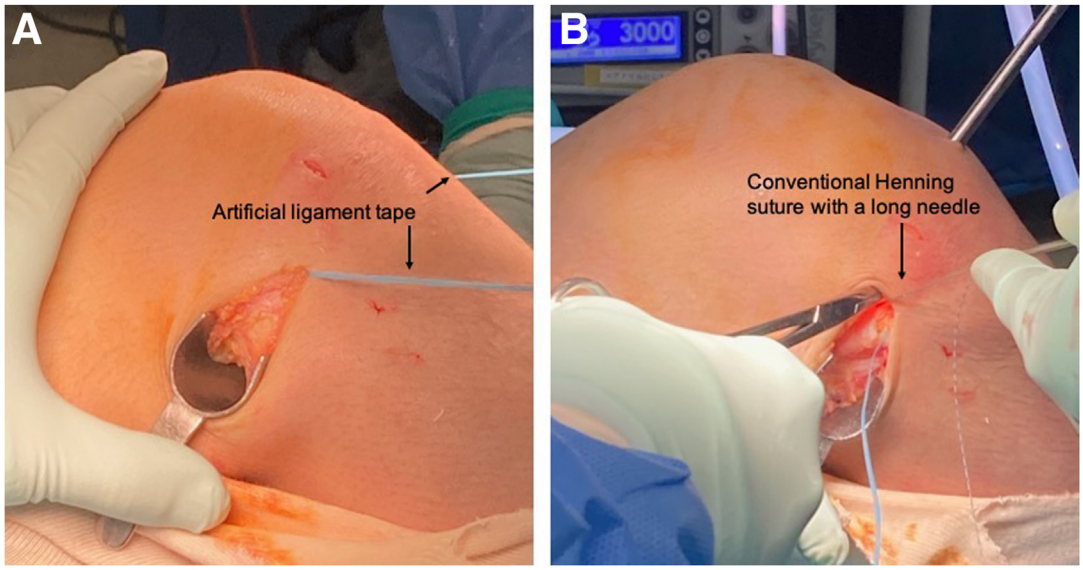

Fig 5. The artificial ligament tape is passed from FAM portal to anterolateral aspect of the capsule (A). An 8-cm long needle attached to a conventional Henning meniscal suture is inserted from the anterolateral to the posterolateral aspect of the capsule (B). (FAM, far anteromedial.)

Step 4: Conventional Inside-Out Repair

Although circumferential fiber augmentation brought the torn stumps close, conventional repair sutures are added to stabilize the torn site because it remained unstable. On visualizing the reduced tear site from anterolateral portal, 3 conventional inside-out horizontal sutures for the mid to outer rim and an artificial ligament tape for inner rim were performed using Zone Specific II Meniscal Repair System (ConMed Linvatec, Largo, FL) through anterolateral portal for the patient (Fig 8). The split between the biceps and iliotibial bands is repaired using absorbable sutures, and the incisions are closed in a standard fashion (Fig 9; Tables 1 and 2).

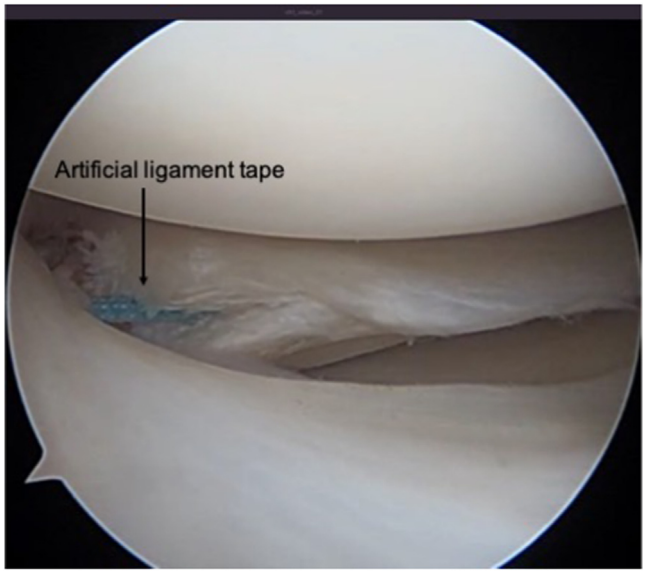

Fig 6. Arthroscopic views of right knee via anterolateral portal showing the artificial ligament tape in torn meniscus.

Postoperative Rehabilitation

The knee is immobilized using a soft brace for 2 weeks following range of motion exercises. Partial weight-bearing with crutches is initiated at 3 weeks. Full weight-bearing is initiated after 4 weeks. Closed kinetic chain exercises are prohibited until 4 months after surgery. Sports participation is permitted 6 months after surgery.

Discussion

Various techniques have been reported for the surgical management of radial tear of the meniscus.[4] Most techniques focus only on the degree to which a torn site is stabilized. Although Branch et al.[6] reported in their cadaveric study that figure-of-8 plus horizontal construct was the strongest compared with all-inside horizontal, inside-out horizontal, and Mason−Allen construct, maximum failure load of the figure-of-8 plus horizontal construct was approximately a quarter of that of the control. Buckley et al.[7] performed a cadaveric study and concluded that "hybrid tunnel" repair technique, wherein 2 tunnels in the tibia were created just under the torn lesion and the meniscal tear was fixed with pulling out the sutures on the anterior of the tibia using metal buttons, was more efficient than the technique previously reported. However, it is not an

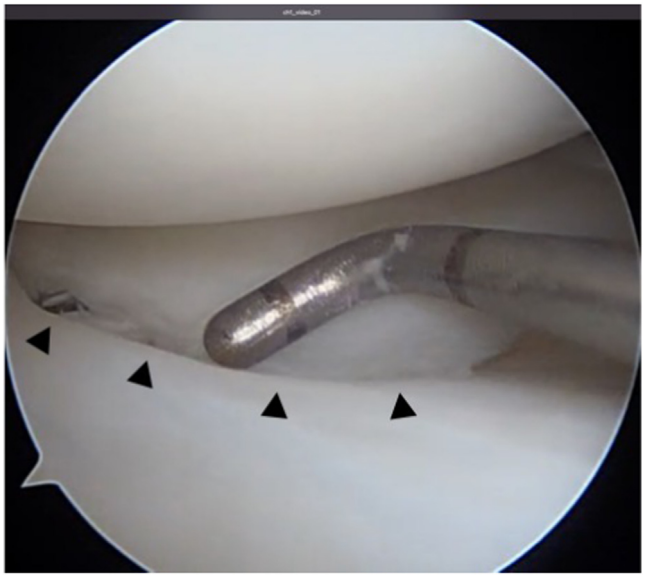

Fig 7. Arthroscopic views of right knee via anterolateral portal showing the torn meniscus being reduced by pulling the ligament tape on the anterior aspect of the tibia.

anatomical approach from the point of view that the meniscus is fixed on the middle part of the tibial surface. In contrast, the meniscal circumferential augmentation technique is thought to be a highly anatomical reconstruction, creating resistance to hoop stresses by augmenting the circumferential fiber of the meniscus without disturbing the natural movement of the meniscus with knee flexion and extension. From a novel perspective, this technique may promote meniscal healing.

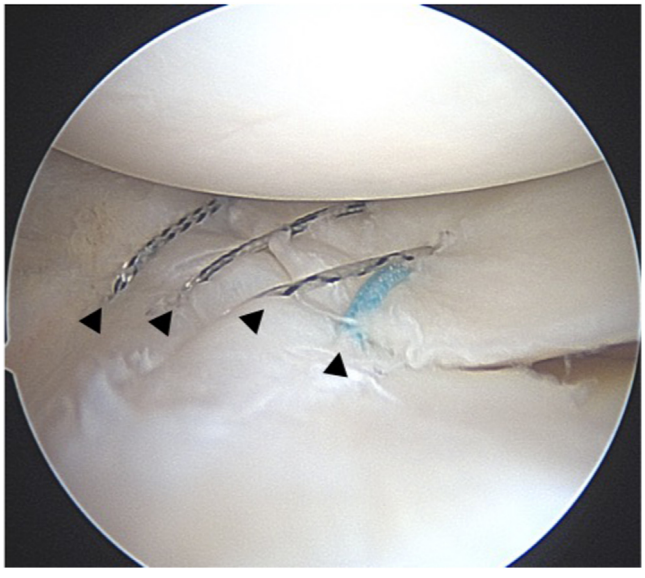

Fig 8. Arthroscopic views of right knee via anterolateral portal showing the torn site being stabilized by 4 conventional inside-out sutures.

Table 1. Advantages and Disadvantages

Advantages
Provides more rigid fixation of the torn meniscus
Anatomical reconstruction of the circumferential fiber of the meniscus
Creates resistance to hoop stresses with capsules
Preservation of the natural meniscus
No need to use specific instruments
Applicable to all meniscus tears that induce extrusion
Disadvantages
No consensus on appropriate tensioning
Durability of the artificial ligament tape
More invasive compared with conventional meniscal suture techniques

Meniscal extrusion is a serious issue that requires treatment because it is significantly associated with knee osteoarthritis. Meniscal tears, such as a radial tear of the posterior root of the medial meniscus, torn discoid lateral meniscus, radial tear of midbody of the lateral meniscus on stable knee, radial tear of the post horn of the lateral meniscus with anterior cruciate ligament injury, and degenerated meniscus, might be the causes of the meniscal extrusion. The pathology of these tears is the failure of the circumferential fiber of the meniscus. Our technique can be applied to all meniscal tears that induce extrusion.

However, the technique has some limitations. No biomechanical study has verified that this technique is sufficient to endure circumferential hoop stress; however, an optimal result can be expected in our ongoing study. Park et al.[8] created a posterior and anterior root tear in rabbit and porcine menisci, and their perimeniscal circumferential augmentation, similar to our technique, reduced the degree of meniscal extrusion and prevented the progression of arthritis. The durability of the high-strength (ultrahigh-molecular-weight polyethylene) 1.5-mm wide artificial ligament tape used in the technical note is unknown. Although the artificial ligament tape will wear out some day, we believe that this technique can enhance meniscal healing by supporting the meniscal circumferential fibers. The tensioning of the tape is another issue. Overtightening could be a cause of adverse events, and undertensioning could be a cause of surgical failure.

Table. 2. Pearls and Pitfalls

Pearls
A far anteromedial portal positioning is confirmed by a long needle
The suture needles are ensured to be inside the circumferential fiber of the meniscus
If the direction of the needle is lost, an additional reference needle is inserted into the joint
The space between the capsules and gastrocnemius tendon is secured by a Henning retractor
Pitfalls
Do not penetrate the ligament, the tendon, and the nerve
Overtightening of the tape could be a cause of knee contracture

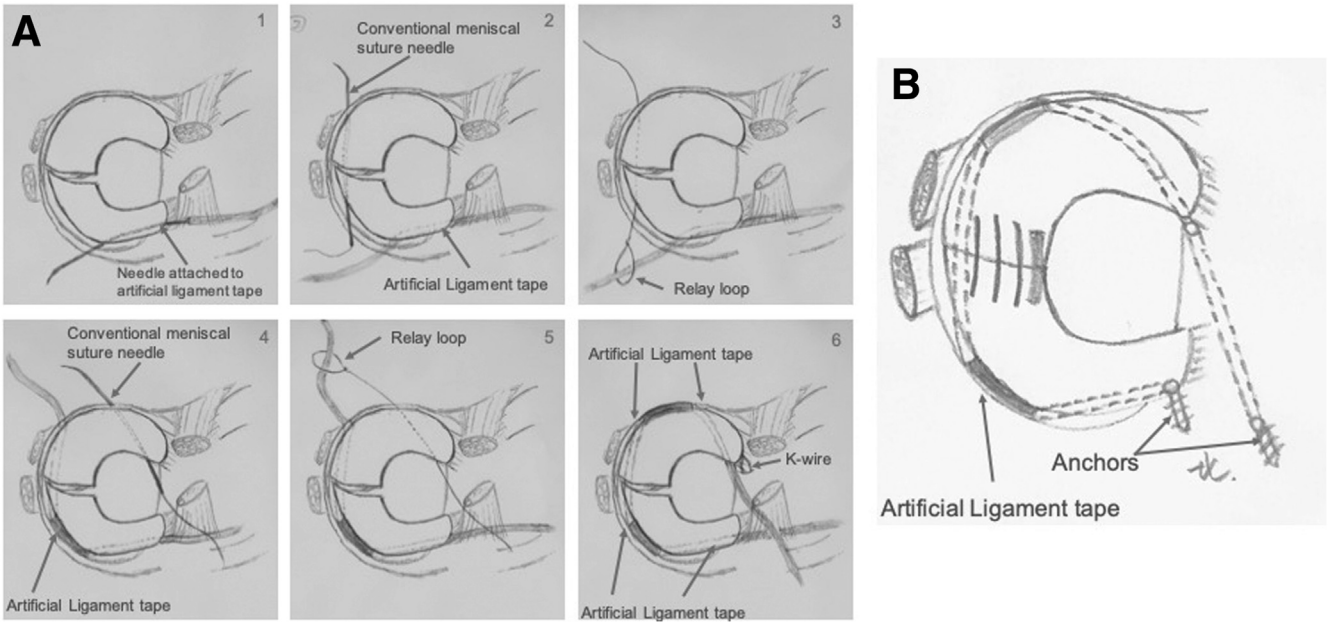

Fig 9. Schemes of this technique. The needle of the artificial ligament tape is passed through the outer rim of the meniscus from the anterior horn to the anterolateral aspect of the capsule (A1). A long needle attached to a conventional Henning meniscal suture is inserted from the anterolateral to the posterolateral aspect of the capsule (A2). The artificial ligament tape is passed from the anterolateral to the posterolateral capsule through the midbody of the meniscus by suture relay (A3). A conventional Henning meniscal suture is inserted beneath the posterior horn of the meniscus into the posterolateral capsule (A4). The artificial ligament tape is passed from the posterior capsule to the posterior horn of the meniscus (A5). Through the drill hole created by a 2.4-mm K-wire, the artificial ligament tape on the posterior horn is brought to the anterior aspect of the distal tibia (A6) (B) Completion drawing of the circumferential fiber augmentation technique.

Appropriate tensioning remains to be achieved; however, we believe that the condition in which the torn stumps of the meniscus are properly reduced is the best. Finally, it is unclear which technique should be used to add conventional sutures after augmentation. Arthroscopically, the torn site was rigidly reduced, and a conventional horizontal suture was sufficient to stabilize the torn meniscus. Future studies from different perspectives are warranted.

Acknowledgments

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