Technical Note

Remnant Tensioning Through Pullout Sutures From the Femoral Tunnel During Anatomic Anterior Cruciate Ligament Reconstruction

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Abstract: Even after anterior cruciate ligament (ACL) tear, its remnant retains the vascularized synovial sheets, fibroblasts, myofibroblasts, and various mechanoreceptors within it. The aim of preserving the remnant is to retain these components during ACL reconstruction. In the recent past, there has been an increasing trend towards preserving remnants during ACL reconstruction. Although preserving remnants have physiological advantages, cyclops lesion and extension loss were among the most feared complications. Cyclops and loss of extension are due to the fallback of the remnant into the notch. Moreover, the mechanoreceptors present in the remnant are not active when the remnant is lax. These mechanoreceptors are active when the remnant is in tension. Thus, rather than merely preserving the remnant, it is essential to tension it for more physiological functions. Although there are various techniques of remnant tensioning described in the literature, these techniques require tampering of the fixation devices or an extra fixation device adding to the cost of surgery. We describe our modification of the remnant-tensioning method during anatomic ACL reconstruction. In this technique, the sutures holding the remnant are pulled out through the anatomic femoral tunnel and fixed with an interference screw along with the hamstring graft. This technique is cost-effective, reproducible, and does not require tampering with the fixation devices. Moreover, the direction of remnant pull will be the same as that of the reconstructed graft making both the graft and remnant anatomical in orientation. Suture management and visibility of the intraarticular structures during this procedure are a few downsides of this technique. The only prerequisite of this technique is a good quality remnant to hold the sutures.

The anterior cruciate ligament (ACL) is considered an organ with nerves and blood vessels and is much more than a mere mechanical structure.[1] Torn remnants of ACL are rich in mechanoreceptors and vascular synovial sheaths and fibroblasts. These are presumed to be crucial in obtaining good functional and subjective satisfaction and mechanical stability.[2] Therefore, remnant-preserving ACL reconstruction has been noted to have better healing and functional results compared with remnant-sacrificing ACL reconstruction.[3] Most of these ACL tears are from femoral sides, so the remnant tends to fall anteriorly into the notch and may lead to loss of extension and cyclops lesion if preserved.[4] One of the techniques to avoid the fallback of remnants is to tension this remnant with sutures. Tensioning also makes the mechanoreceptors work more effectively and relieves the kinking within the blood vessels of the remnant.[5]

Various techniques of remnant tensioning are described in the literature, but they are technically demanding and difficult to replicate.[6-8] Some of these techniques need separate fixation devices for the remnant, making those techniques costly and nonanatomical.[6] Some require a sizeable outside incision to secure remnant sutures, whereas some require tampering with a primary suspensory fixation device for graft. Most of these techniques vary in femoral fixation methods.[7] Aperture fixation with interference screw on femoral side is a straightforward technique and found to have similar clinical or radiographic

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outcome compared with cortical suspensory button fixation.[9] In our technique, we pulled the sutures holding the remnant through the femoral tunnel along with the hamstring graft and fixed it with an interference screw. The remaining steps are similar to the anatomic ACL reconstruction. The purpose of this paper is to describe a technique of remnant tensioning during anatomic ACL reconstruction by aperture fixation using an interference screw.

Surgical Technique (With Video Illustration)

Patient Positioning

After the appropriate anesthesia is administered, the patient is placed in the supine position, and a tourniquet is applied to the upper thigh. The operative knee is painted and draped. The patient is positioned with the knee flexed to 90° and held with lateral side post and foot support. Diagnostic arthroscopy is performed. Associated injuries are identified and adequately managed by making additional portals. Carefully, the fat pad is debrided to visualize anatomical landmarks. Fat pad removal through an anteromedial portal.

Steps of Surgery

For ease of understanding, we have divided this technique into 6 different steps.

1. Remnant assessment and graft harvest.
2. Suture passage through the remnant.
3. Femoral tunnel preparation and pulling fiber tape out through the femoral tunnel.
4. Tibial tunnel preparation.
5. Graft passage and remnant tensioning.
6. Fixation of the femoral and tibial side.

Step 1. Remnant Assessment and Graft Harvest

ACL tear is confirmed arthroscopically, and remnant quality is evaluated for the possible execution of the remnant-tensioning technique (Fig 1A-C). If the remnant is lacerated, friable, and fibrillated, the remnant tensioning is not performed as the remnant will not hold sutures. The synovial lining also is assessed. A good synovial cover is indicative of good vascularity. After assuring the quality of the remnant (Fig 1A-C) and deciding to execute remnant tensioning, a semitendinosus graft is harvested and prepared for ACL reconstruction.

Step 2. Suture Passage Through the Remnant

A suture-passing device (FIRSTPASS MINI; Smith & Nephew, Andover, MA), a high-strength ultra-high molecular weight polyethylene suture (BioFiber; Biotek - Chetan Meditech Pvt. Ltd., Gujarat, India), and tape (BioFiber tape No. 2; Biotek - Chetan Meditech Pvt. Ltd.) is prepared at the back table. First, a loop of suture is passed at the mid-point of the ACL remnant with the help of a suture passing device (Fig 2 A and B). Caution is taken to take bites through the whole circumference of the remnant. The suture loop is retrieved out through the anteromedial portal, and the same loop is used to shuttle back the tape replacing the suture (Fig 2 C and D). A cinch knot is made using the 2 limbs of tape and cinched at the remnant of ACL (Fig 2 E and F). Each limb of tape is again passed through the remnant such that, the tails of the tape ae delivered through the core of the remnant and out of the proximal stump (Fig 2 G and H). Both ends of the tape are parked in the anteromedial portal.

Step 3. Femoral Tunnel Preparation and Pulling Fiber Tape Out Through the Femoral Tunnel

A far anteromedial portal is created by the outside-in technique. At 90° of knee flexion, the femoral remnant of torn ACL is debrided (Fig 3A), the center point of the footprint is marked using a radiofrequency ablator (Fig 3B). A femoral offset aimer is introduced and

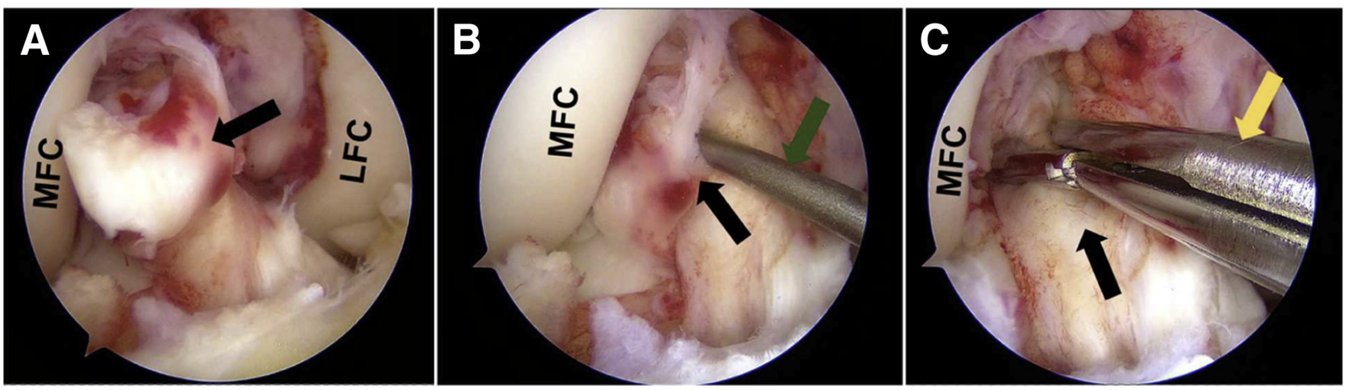

Fig 1. Arthroscopic view of the right knee with the knee in 90° of flexion and 30° arthroscope introduced through anterolateral portal. (A) Anterior cruciate ligament tear from its femoral attachment and the remnant flipped anteriorly (black arrow). (B) Arthroscopy probe introduced from the anteromedial portal (green arrow) and the remnant (black arrow) inspected for its quality. (C) An arthroscopy grasper is introduced from the anteromedial portal (yellow arrow), the remnant (black arrow) is grasped, and the ability to bring it to the femoral wall is confirmed.

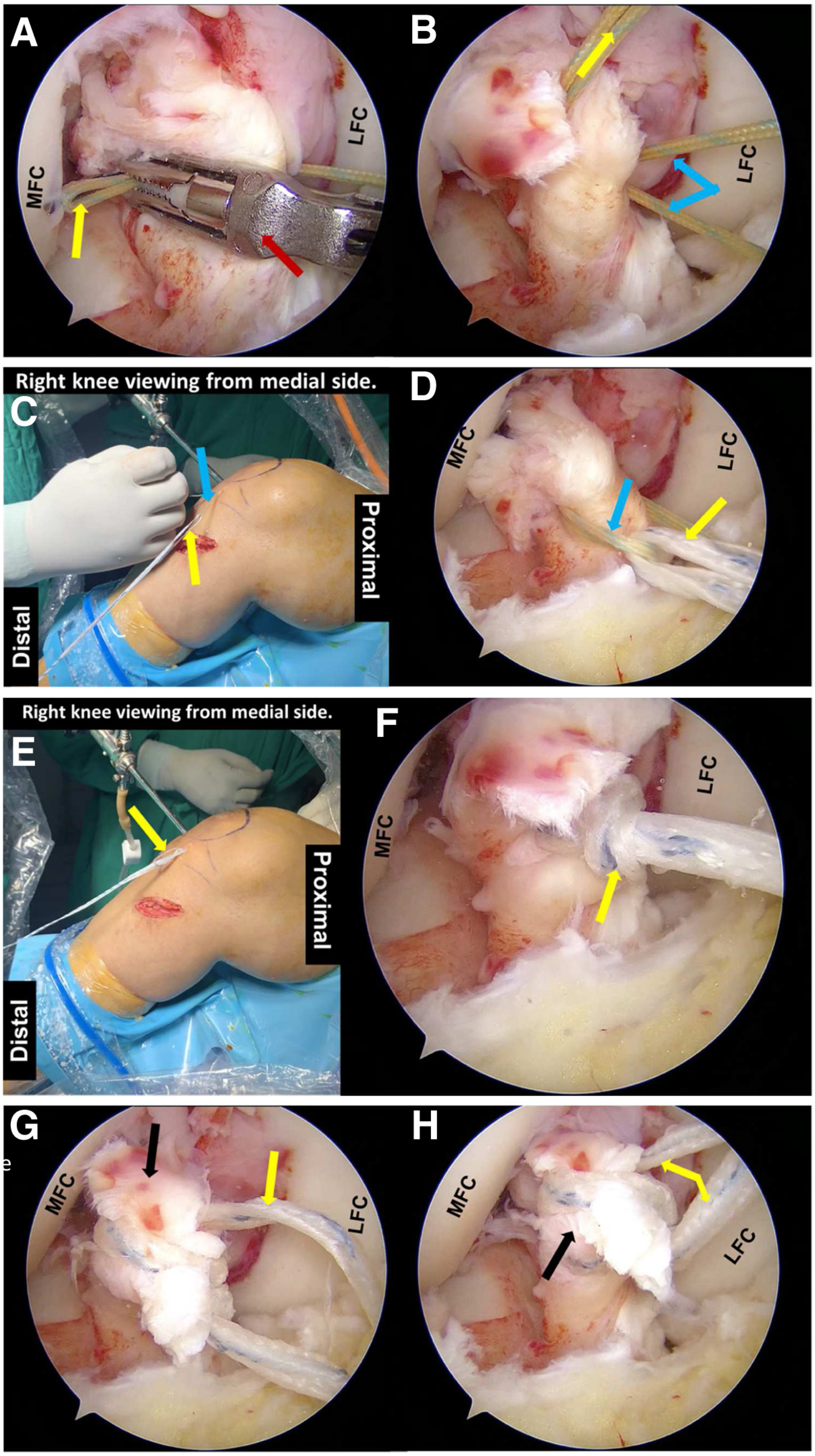

Fig 2. Arthroscopic view of the right knee with the knee in 90° of flexion and 30° arthroscope introduced through anterolateral portal. (A) A loop of suture (yellow arrow) is passed from the middle of the ACL remnant with the help of a suture passing device (red arrow). (B) Photograph depicting the suture loop passing through the ACL stump (blue arrows) and exiting from the anteromedial portal (yellow arrow). (C) Outside view showing the medial aspect of the right knee. The suture loop (blue arrow) is used to shuttle the no. 2 tape (yellow arrow). (D) Arthroscopy view of the right knee showing the tape (yellow arrow) is being shuttled back through the ACL remnant using the suture (blue arrow). (E) Outside view showing the medial aspect of right knee depicting cinching of the fiber tape (yellow arrow). (F) Arthroscopy view of the right knee showing a cinch knot is being applied in the ACL remnant (yellow arrow). (G-H) Each limb of tape is again passed through the remnant such that it exits from the edge of the remnant.

aimed at the previously marked point (Fig 3C). The knee is then flexed to 120°, and the offset aimer is readjusted to point towards the marking (Fig 3D). A 1.8-mm Beath pin is introduced through the lumen of the aimer and drilled through the marked point to deliver out from the lateral cortex and anterolateral thigh (Fig 3E). The offset aimer is removed, and a 4.5-mm flower tip reamer is used to create a tunnel over

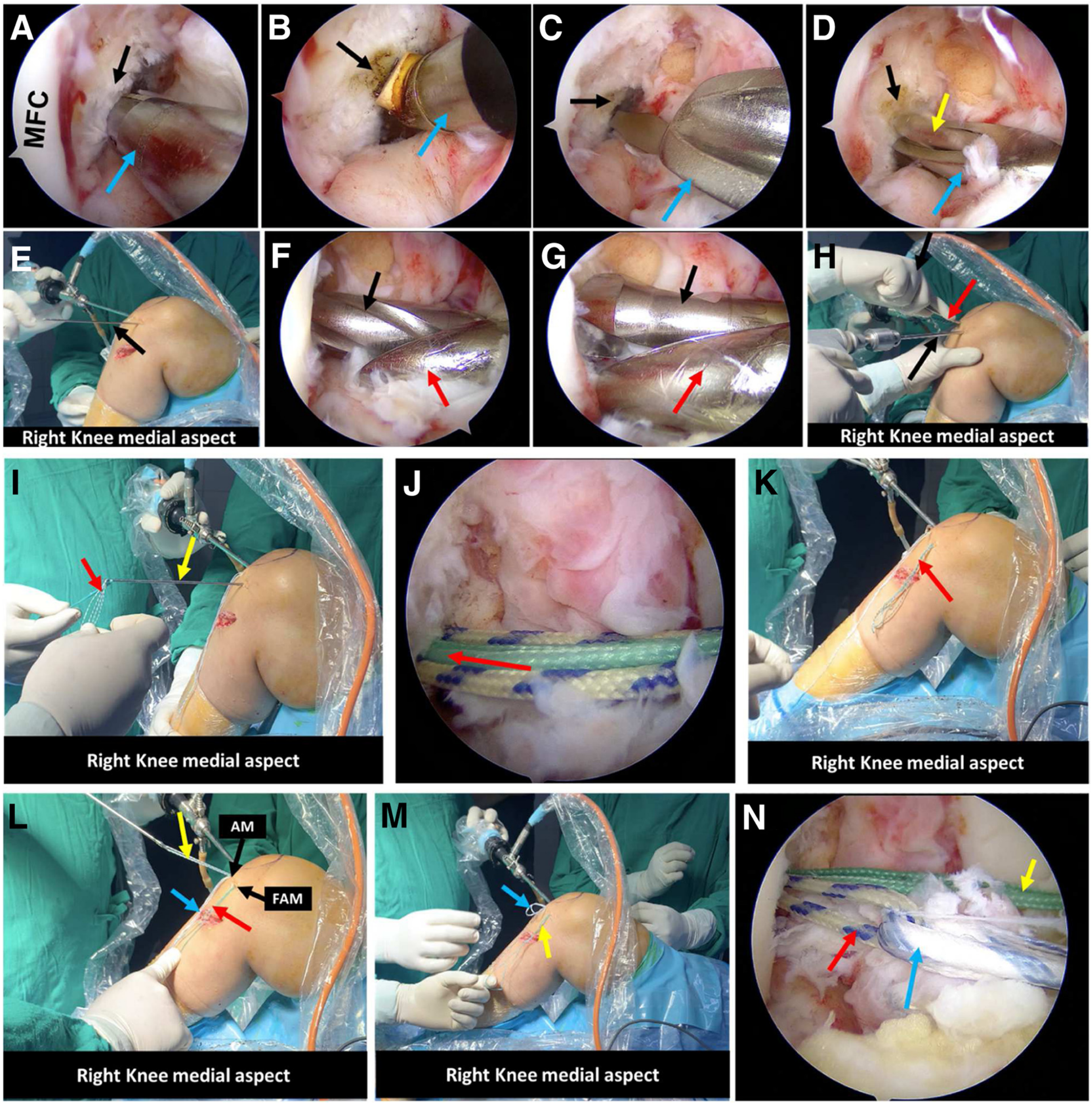

Fig 3. Arthroscopy pictures of the right knee with 30° arthroscope in the anterolateral portal, depicting steps of femoral tunnel preparation and pulling fiber tape through the tunnel. (A) Clearing footprint (black arrow) with arthroscopic shaver (blue arrow). (B) Marking the center of the femoral footprint (black arrow) with a radiofrequency ablator (blue arrow). (C) A 6-mm femoral offset aimer is introduced through the far anteromedial portal (blue arrow) and aimed towards the marked area at the footprint (black arrow). (D) A 1.8-mm Beath pin (yellow arrow) is passed through the lumen of the offset aimer (blue arrow) and drilled through the marked point (black arrow) at the femoral condyle out of the anterolateral thigh. (E) Outside view of medial aspect of knee depicting beath pin inserted through the far anteromedial portal. (F) A 4.5-mm ENDOBUTTON reamer (black arrow) is introduced over the beath pin to make the femoral tunnel. A cannulated arthroscopic suction tube (red arrow) is used to protect the tape and remnant from being tangled and damaged during reaming. (G) After removing the endo button reamer, an 8-mm flower-tip endoscopic reamer (black arrow) is introduced over the beath pin to make a socket of 25 mm in length. (H) Outside view of medial aspect of the knee showing an arthroscopic suction (red arrow) tube introduced from anteromedial portal to protect tissues and threads from reamer (black arrow). (I) Two different-colored sutures (red arrow) were passed through the eyelet of the beath pin (yellow arrow). (J) Arthroscopic view of right knee depicting two different colored sutures being passed through the far anteromedial portal to the femoral tunnel. (K) Outside picture of right knee depicting two suture loops in the far anteromedial portal (red arrow). (L) One suture loop (yellow arrow) is pulled from the far anteromedial (FAM) to the anteromedial (AM) portal where the limbs of fiber tape were parked (blue arrow). (M) The limb of suture tape (blue arrow) is pulled inside the femoral tunnel leaving one suture loop (yellow arrow) in the far anteromedial portal for pulling the graft. (N) Arthroscopic picture of right knee depicting the process of pulling of fiber tape limb (blue arrow) into the femoral tunnel using one suture loop (red arrow) and leaving another suture loop (yellow arrow) in the far anteromedial portal.

the beath pin (Fig 3F). Since the size of the graft is 8 mm, a socket of 25 mm is drilled over the Beath pin using an 8 mm flower-tipped reamer (Fig 3G). Care should be taken not to damage the remnant during reaming. An arthroscopy suction tube can be inserted through the anteromedial portal to protect the remnant and sutures (Fig 3H). Gentle traction given to the remnant through the threads also may protect the remnant during drilling. Two different-colored sutures were shuttled through the femoral tunnel out of the anterolateral thigh with the help of the eyelet of the beath pin (Fig 3 I-K). One loop of suture from the far anteromedial portal is brought to the anteromedial portal where the limbs of fiber tape were parked. Using the same loop, the limbs of fiber tape from the remnants were shuttled into the femoral tunnel (Fig 3 L-N).

Step 4. Tibial Tunnel Preparation

With the 30° arthroscope in the anterolateral portal, a radiofrequency probe is introduced through the anteromedial portal, and the tibial tunnel is marked (Fig 4A). A point just posterior to the posterior border of the anterior horn of the lateral meniscus (Fig 4A) is taken as a reference for the tibial tunnel. A Smith & Nephew (ACUFEX) tip aimer ACL zig is introduced from the anteromedial portal and fixed at a previously marked point (Fig 4B). A Beath pin is introduced through the zig and its intraarticular position is confirmed (Fig 4C). ACL zig is removed and an 8-mm cannulated tibial reamer is used to make the tibial tunnel (Fig 4D). Care must be taken to prevent iatrogenic injury to the remnant while the tibial reamer penetrates the joint. Once the reamer reaches the second cortex, the drilling should be very gentle and

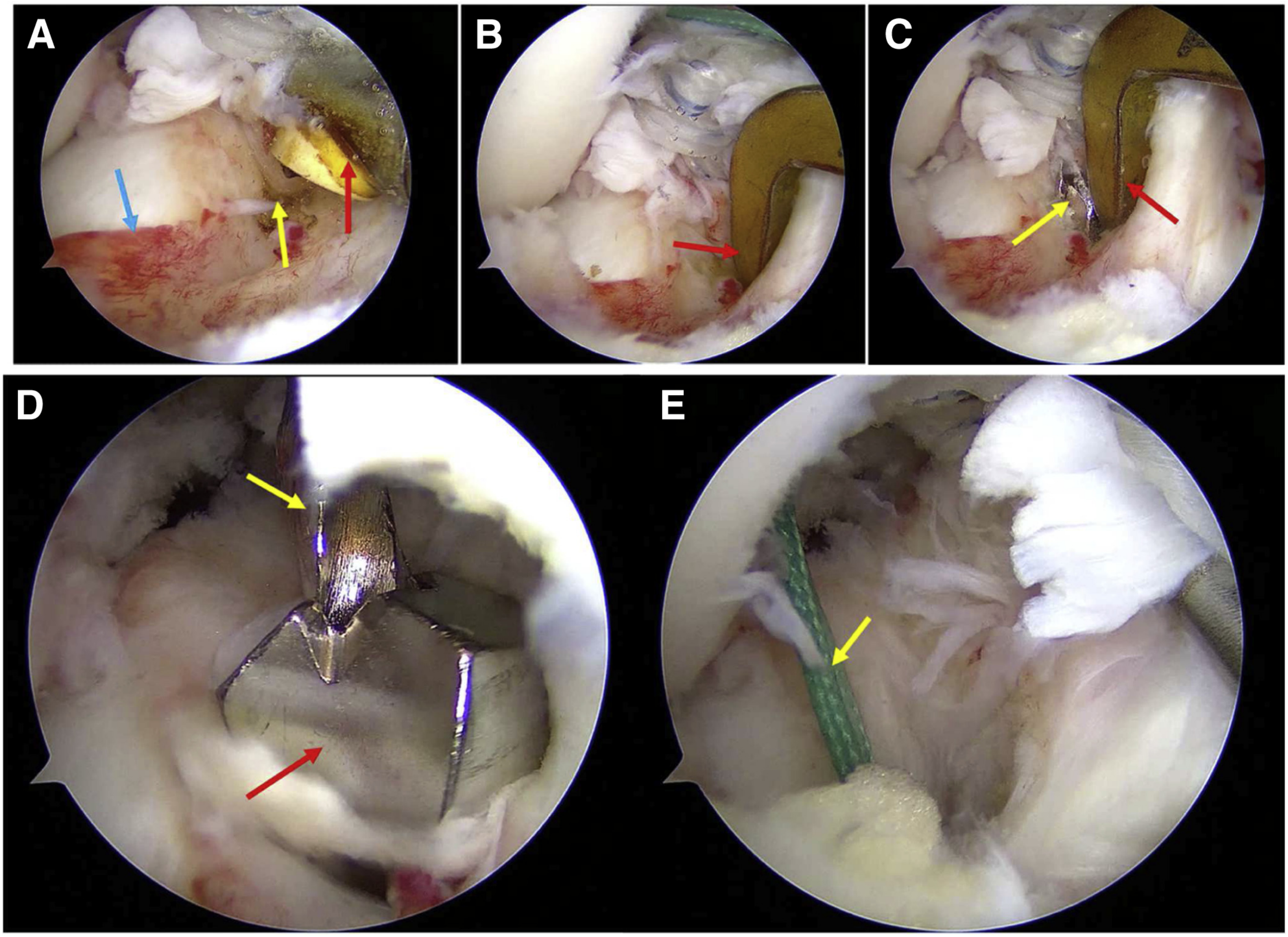

Fig 4. Arthroscopy pictures of the right knee with 30° arthroscope in the anterolateral portal, depicting steps of tibial tunnel preparation and pulling fiber tape through the tunnel. (A) A point posterior to the posterior border of the anterior horn of the lateral meniscus (blue arrow) is marked (yellow arrow) with a radiofrequency ablator probe (red arrow). (B) Arthroscopy view of right knee depicting placement of tip aimer (red arrow) at the previously marked point. (C) A Beath pin is inserted through the zig (red arrow), exiting at the anatomical point (yellow arrow). (D) An 8-mm tibial reamer (red arrow) is used to make the tibial tunnel over the beath pin (yellow arrow). (E) The suture (yellow arrow) that remained in the far anteromedial portal is retrieved through the tibial tunnel.

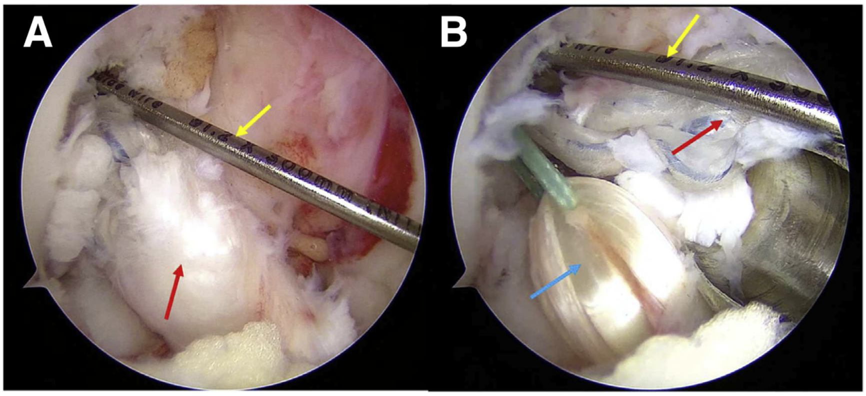

Fig 5. Arthroscopic view of right knee depicting the process of graft passage and remnant tensioning. (A) The final inspection of the remnant position (red arrow) is checked by pulling the tape. A nitinol wire (yellow arrow) is inserted into the femoral tunnel through the far anteromedial portal. (B) While retracting the remnant (red arrow), the hamstring graft (blue arrow) is pulled into the femoral tunnel keeping the nitinol wire (yellow arrow) in the femoral tunnel.

controlled; the final penetration of the intra-articular part of the tibial tunnel is done by manual reaming. The suture left at the far anteromedial portal is delivered through the tibial tunnel with the help of a suture retriever (Fig 4E).

Step 5. Graft Passage and Remnant Tensioning

Before pulling the graft to the tunnel, a nitinol wire (Fig 5A) is passed from the far anteromedial portal to the femoral tunnel. The prepared ACL graft is pulled using the suture across the femoral and tibial tunnel. Once the graft is inside the joint, the remnant is retracted to clear the passage of the graft using an arthroscopy probe (Fig 5B). Once the graft is pulled into the tunnel to the desired marking, adequate traction is given on tape from the remnant. The tension within the remnant and graft position is checked.

Step 6. Fixation of the Femoral and Tibial Side

Once the graft and remnant were pulled on either side of the tunnel**,** sustained traction is maintained on the graft sutures and remnant sutures. The knee is flexed to 120° and a 7 × 25-mm PEEK (polyether ether ketone) screw is passed over the nitinol wire to fix the graft and remnant sutures in the femoral tunnel (Fig 6A).

The knee is then cycled through the full range of motion. Sustained traction is maintained over the graft and the graft is secured in the tibial tunnel with an interference screw at 30° of knee flexion (Fig 6B). A 10 × 30-mm PEEK screw is used to fix the graft in the tibial tunnel.

Final arthroscopic examination of the joint is done, and the proper tensioning of graft and the remnant is confirmed with the probe (Fig 7 A and B). The new graft can be seen well surrounded by good-quality remnants after this technique (Fig 7B). The knee is extended fully to see any notch impingement with graft or remnant (Fig 7C). Finally, sutures are cut and the wound closed in layers. The incision at graft harvest site is closed in layers with a routine technique. Skin and portal closure are done with PROLENE 2/0 sutures.

Discussion

If tissue has to be replaced, similar tissue would be the best choice for replacement.[10] However, when ACL is torn, a ligament has to be replaced by a tendon as donor ligaments are not available. When an ACL is reconstructed with a tendon graft, the graft must undergo ligamentization, which may take 9 to 18 months.[11] The remnant of native ACL does not need to undergo ligamentization. So, if preserved, it acts as a scaffold with

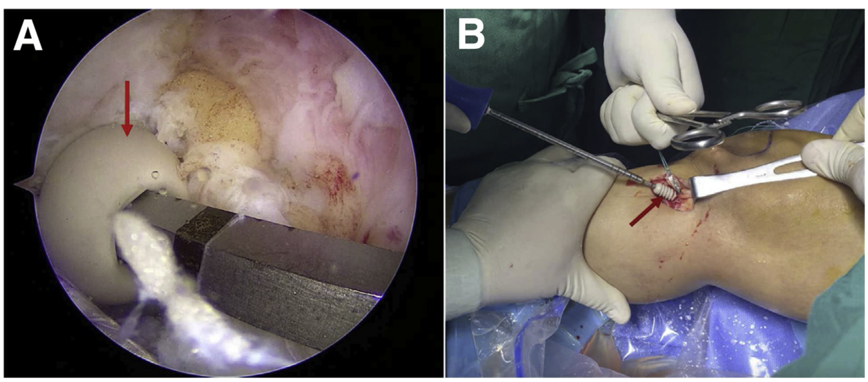

Fig 6. Figures depicting femoral and tibial fixation. (A) Femoral fixation with one size small (7 mm) PEEK interference screw (red arrow). (B) Tibial fixation is done with a bigger (10 mm) PEEK interference screw (red arrow) than the tibial tunnel with the knee at 30° flexion.

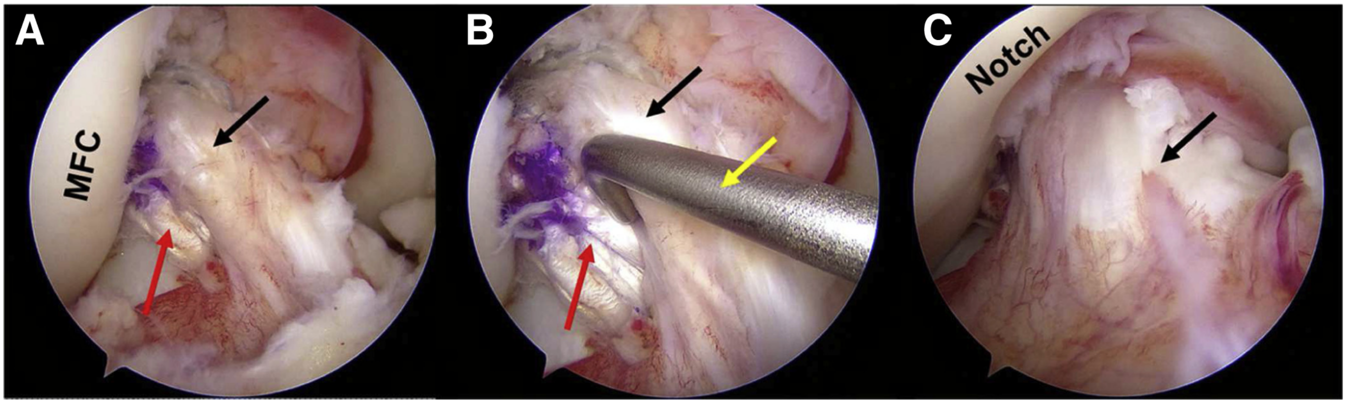

Fig 7. Arthroscopy view of the right knee. (A) Final reconstructed ACL (red arrow) and tensioned remnant (black arrow). (B) Structures were probed (yellow arrow), and adequate tension is observed both on the remnant (black arrow) and ACL graft (red arrow). (C) The knee is fully extended to visualize any impingement or overstuffing of the notch.

storage of the mechanoreceptors and other cellular components of native ACL. This concept has led to increased interest in studies of remnant preservation, proven by the recent surge in publications in the field of repair and remnant preservation.[2,3,6-8,12] Because of newer information about the remnant, ACL is now considered as an organ with neural and vascular tissues and not merely a stabilizing structure.[11] Many histologic studies have confirmed that remnants of torn ACL retain vascularized synovial sheets, numerous fibroblasts and myofibroblasts, and various mechanoreceptors.[2,3,12] Because of these components, preserving remnants while doing ACL reconstruction has been shown to promote early vascularization, synovialisation, and ligamentization. As these remnants are rich with mechanoreceptors, remnant preserved ACL reconstruction are also found to be regaining early proprioceptive control. These added advantages of remnant preservation led to better functional results than remnant sacrificing ACL reconstruction despite comparable mechanical stability.[1,6,11,13]

Although remnant-preservation techniques have shown promising results, this technique is reported to have complications like cyclops formation, loss of extension, and painful extension. These complications result from remnants falling anteriorly as most of the ACL tear occurs from the femoral side.[44] This can be addressed if the remnant is tightened and fixed to a structure. Remnant tensioning with pullout sutures during the reconstruction will preserve proprioception and facilitate revascularization and graft healing. The primary purpose is to keep the remnant relatively taut during the healing process. With tensioning, it is expected that the blood flow will increase in residual vascular channels by relieving the kinking in lax remnants, increasing its healing potential. The remnant will also act as a scaffold for good graft healing.[5] There are various methods of remnant tensioning, but this requires an extra procedure or manipulation with fixation devices.[6]

Our technique is an easy and reproducible technique of remnant tensioning with no added costs or incisions. The prerequisite of remnant tensioning is a good-quality remnant. Remnants that are serrated, multilacerated, and friable are not amenable to suture passage, so they are not ideal for the execution of our technique.

The main concept behind our technique is tensioning of the remnant, which will protect from the fallback of the remnant into the notch area. Our technique also ensures the remnant is attached at the anatomical location of the ACL. Since graft and remnant are pulled in the same direction and tensioned simultaneously, it will not create any stress shielding effect in the reconstructed ACL.

Table 1. Advantages and Disadvantages of the Remnant Tensioning Technique

Advantages	Disadvantages
1. Easy, economical, and can be done with usual arthroscopy instruments.	1. Possibility of tensioning depends upon the quality of the remnant.
2. No risk of future cyclops lesion.	2. This technique is not possible with the poor quality multilacerated remnant.
3. Tensioning of the remnant will make sensory tissues more receptive to stimulus so that proprioception will be better.	3. May have iatrogenic remnant injury while making femoral and tibial tunnels.
4. Early synovialization and ligamentization.	4. Extra cost of fiber tape that is used as a remnant-tensioning suture.
5. Improved vascularity because of stretching of kinked vessels.	
6. No need for an extra fixation device or incision for remnant fixation.	

Table 2. Risks of Remnant Tensioning Technique and Tips to Avoid

Risks	Tips to Avoid
1. Iatrogenic injury to remnant while making tunnels 2. Wrong tunnel placement	1. (a) While making a femoral tunnel, a flower-tip reamer should be used. The remnant has to be visualized while introducing and taking out the reamer. A probe or arthroscopy suction tube can be used to protect the remnant. (b) While making a tibial tunnel, the intra-articular cortex is drilled manually, retracting the stump away from the drill direction. 2. Because of a preserved remnant, intra-articular visibility may be obstructed, especially on the femoral side. Identification of femoral footprint and marking of future tunnel site is made at 90° of flexion. Then the knee is flexed. If the marked site is not visible, minimal debridement of the footprint from the femoral wall is done to ensure correct tunnel placement.

Our technique has the advantages of both remnant preservation and tensioning with low cost and ease. This technique is easy, economical, reproducible, and can be performed with the usual arthroscopy instruments. We do not need the complex extra-articular maneuvers, extra incisions, and different fixation devices described in other remnant-tensioning techniques. The advantages and disadvantages of this technique are summarized in Table 1. The risks of this technique and tips to avoid are summarized in Table 2.

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