Technical Note

Arthroscopic Repair of the "Tibial Avulsion Triad"—ACL Posterolateral Bundle, PCL, and Lateral Meniscus Posterior Root: The Triple Tunnel Technique

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Abstract: Tibial avulsion fractures of the posterior cruciate ligament (PCL) are rare injuries that can be fixed either via and open or arthroscopic approach to restore native knee biomechanics. The advantage of arthroscopic fixation is the ability to treat concomitant intra-articular pathologies that are otherwise difficult to identify and manage via an open approach, such as medial meniscal root tears and avulsions. This technical note describes an all-arthroscopic technique of treating a rare and previously undescribed injury pattern consisting of PCL tibial and lateral meniscus posterior root bony avulsions and ACL posterolateral bundle tibial peel-off, termed the "tibial avulsion triad".

Introduction

Injuries to the posterior cruciate ligament (PCL) occur in up to 38% of acute knee injuries that present with hemarthrosis, and most of the time in the setting of a combined multiligament knee injury.[1] Isolated ligamentous injuries involving the PCL are rare, and even rarer are bony avulsions. PCL tibial bony avulsions are particularly uncommon in North America given their high association with motorcycle accidents, which are far more prevalent in countries such as India and China.[2,3] Meniscal tears are present in 16.8% of PCL tibial bony avulsions, most commonly involving the medial meniscus.[3] Given the high rate of associated intra-articular injuries, many authors recommend arthroscopic fixation of PCL tibial bony avulsions in order to best identify and treat these concomitant injuries.

Because of the proximity of attachment of the posterior root of the medial meniscus to the PCL tibial facet, medial meniscal posterior root tears have been described, albeit infrequently, in the setting of PCL tibial bony avulsions.[3,4] However, lateral meniscus posterior root avulsions (LMRAs), which comprise less than 1% of lateral meniscal tears and are often associated with anterior cruciate ligament (ACL) tears, have not been reported in this context.[5-7] When present, root tears are best treated with reinsertion in order to restore the meniscus' hoop tension and reduce the risk of arthritis progression and subsequent knee arthroplasty.[8]

The purpose of this technical note is to describe a rare injury triad of PCL tibial and lateral meniscus posterior root bony avulsions and ACL posterolateral bundle (PLB) tibial peel-off injury treated with arthroscopic triple tunnel suspensory fixation using a dual posteromedial (PM) portal technique. This technique allows for treatment of all associated intra-articular pathology and minimizes the risk of arthrofibrosis and iatrogenic nerve injury (Table 1).

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Table 1. Pearls and Pitfalls of the Arthroscopic Triple Tunnel Technique for Repair of ACL Posterolateral Bundle Tibial Peel-Off, Lateral Meniscal Root Bony Avulsion, and Tibial PCL Avulsion Fracture

Pearls	Pitfalls
Anterior compartment procedures should be performed prior to posterior compartment procedures.	Access to the posterior compartment can be restricted by a high PM portal placed too close to the femur, insufficient contralateral leg abducted in a small patient, and insufficient release of the intercruciate septum.
The posterior compartment can safely be accessed by 3 portals: one low and one high PM portal, and a trans-septal portal.	The posterior root of the MM is at risk of injury during PCL fracture bed preparation.
The ACL tibial tunnel is the most anterior tunnel and should be created first, followed by the LM posterior root tunnel and the PCL tibial tunnel.	Tunnel convergence can occur if tunnels are performed in the improper sequence, with posterior tunnels placed more laterally than anterior tunnels.
Tunnel convergence can be avoided by starting each subsequent tunnel more proximally and medially on the anterior tibia.	Malreduction of the PCL fragment may occur with this technique if the tibial tunnel isn't placed distal to the fracture bed and repair sutures aren't carefully positioned over top of the fragment before tensioning.

ACL, anterior cruciate ligament; LM, lateral meniscus; MM, medial meniscus; PCL, posterior cruciate ligament; PM, posteromedial.

Surgical Technique (With Video Illustration)

The procedure is performed with the patient under general anesthesia in the supine position on a flat table, with a side-post and a bump at the foot of the table to allow for 90° of unassisted knee flexion (Video 1). We recommend tourniquet use in order to improve visualization, especially when working in the posterior compartment of the knee. Before draping, the patient is examined under anesthesia for detection of associated ligamentous injuries. Intraoperative lateral fluoroscopy of the contralateral knee can be performed prior to draping in order to confirm the resting position of the tibial plateau relative to the femoral condyles. Anatomic landmarks are identified and marked on the skin.

Arthroscopy

A standard anterolateral (AL) portal (1 cm lateral and 2 cm distal to the junction of the lateral patellar tendon border and the inferior pole of the patella) is first created and a diagnostic arthroscopy is performed. After evacuation of the hemarthrosis, a high anteromedial (AM) portal is created using 18-G spinal needle localization. This portal is positioned more centrally and superiorly in order to have unopposed access to the femoral notch and posterior horn of the lateral meniscus.

Anterior Compartment

The procedure involves an anterior and posterior component. The anterior component is the most rapid and should be performed first prior to proceeding to the posterior compartment. Any associated intra-articular anterior compartment pathologies should be identified at this stage. The LMRA fracture site is debrided of interposed hematoma, and the fragment is provisionally reduced with an arthroscopic probe. Next, a self-retrieving suture-passing device (Knee Scorpion Suture Passer, Arthrex, Naples, FL) is used to pass a high-strength suture tape (Broadband Loop, Zimmer, Warsaw, IN) in a cinch-loop configuration through the posterior horn of the lateral meniscus in close proximity to the root (Fig 1). The same steps are repeated for the ACL PLB tibial peel-off (Fig 2).

The tibial footprint of the ACL PLB is then lightly decorticated with an arthroscopic shaver (Smith & Nephew, Andover, MA), and a universal ACL tibial guide (Arthrex) is used to target the passage of a 2.4-mm Kirschner wire out the ACL PLB's tibial footprint via a percutaneous incision approximately 4 cm distal

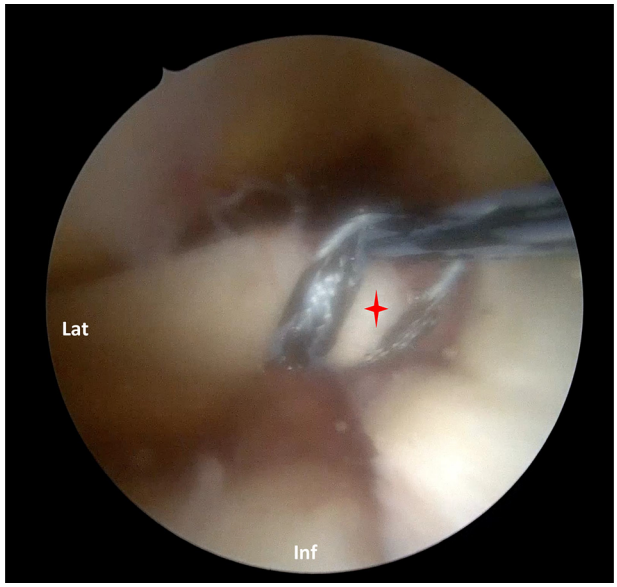

Fig 1. The patient is in the supine position. Arthroscopic view of the right knee through the anterolateral portal demonstrating a suture tape passed in a cinch loop configuration through the posterior horn (star) of the lateral meniscus adjacent to the root using a self-retrieving suture passing instrument.

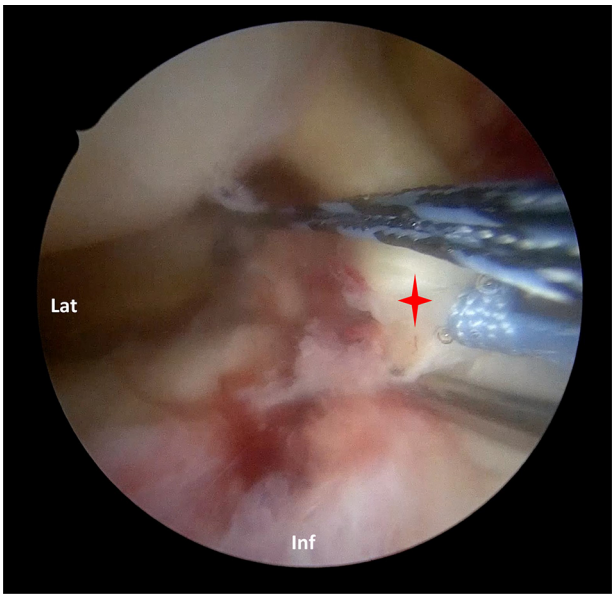

Fig 2. The patient is in the supine position. Arthroscopic view of the right knee through the anterolateral portal demonstrating a suture tape passed in a cinch loop configuration through the anterior cruciate ligament posterolateral bundle (star) proximal to the peel-off injury, similar to the lateral meniscus root repair.

to the medial joint line (MJL) and 2 cm medial to the tibial tuberosity. A suture shuttling device (25-G metallic wire folded on itself to create a loop) is then used to retrieve the repair sutures out the tibial tunnel. The same steps are repeated for the LMRA repair, with tunnel placement approximately 2 cm medial and 1 cm proximal to the ACL tunnel in order to avoid tunnel convergence.

The repair sutures are then tensioned provisionally to assess the ACL PLB, and lateral meniscus (LM) root reduction and clamped (Fig 3). Any other associated intra-articular pathology is then addressed at this stage prior to proceeding with posterior compartment arthroscopy.

Posterior Compartment

In order to access the posterior compartment, the fracture hematoma between the PCL and the medial femoral condyle (MFC) is debrided, thus allowing access via the modified Gillquist maneuver.[9] Once in the posterior compartment, the camera lens is turned to face the PM capsule, and a low PM portal is created in the safe zone (Fig 4).[10] A partially threaded 8.5-mm instrument cannula is then inserted (Arthrex). The arthroscope is then withdrawn back into the anterior compartment, and a trans-septal portal is created by releasing the posterior septum off of the femur with a radio frequency (RF) device (Fig 5). This allows for the knee capsule to fall posteriorly, thereby increasing the working space in the posterior compartment.

The PCL fracture surfaces are then debrided of soft tissue using an arthroscopic shaver from the low PM working portal. Once completed, the camera is repositioned into the posterior compartment via the Gillquist maneuver, and a high PM portal is created in the safe zone. A second cannula is inserted into this portal. The arthroscope is then placed into the high posteromedial portal, and the tibial PCL fracture bed is further prepared via the low PM portal (Fig 6). Blunt dissection can be performed to mobilize the PCL fragment from the posterior capsule, if needed, in order to reduce the risk of injury to the popliteal neurovascular bundle. The arthroscope is then moved to the low PM portal, and the high PM portal is used to pass two suture tapes in a cinch-loop configuration through the PCL approximately 3 mm proximal to its tibial fragment. The fragment is then provisionally reduced with a probe to ensure anatomic reduction.

Fig 3. Patient is in the supine position. Repair sutures from the lateral meniscal root and anterior cruciate ligament posterolateral bundle are shuttled through their respective tunnels and secured over metallic buttons with the knee in a reduced position.

Fig 4. The patient is in the supine position. The knee is flexed at 90°. The figure shows the outside-in creation of high and low posteromedial portals used for posterior compartment arthroscopy. They are created while viewing through the modified Gillquist portal using spinal needle localization in the safe zone (bordered by the semimembranosus and medial head of gastrocnemius folds).

The final step involves creation of the tibial PCL tunnel. The tibial PCL guide (Arthrex) is inserted via the AM and trans-septal portals and positioned onto the distal aspect of the tibial PCL footprint (Fig 7). The angle of the guide is adjusted to allow for placement on the anteromedial tibia approximately 2 cm medial and 1 cm proximal to the previous tunnel (LM root), once again to avoid tunnel convergence, and a percutaneous incision is created in this location. The PCL repair sutures are then shuttled through the PCL tibial tunnel, and a probe is used to reduce the fracture and place the sutures over the top of the fragment for maximal compression.

Repair Tensioning

The repair sutures for each structure (ACL PLM, LM root, PCL) are passed over cortical buttons (Endobutton, Arthrex) prior to final tensioning. The ACL is tensioned at 10° ensuring reduction of the tibial sag, the LM root is tensioned in full extension, and the PCL is tensioned with the knee at 90° of flexion under direct

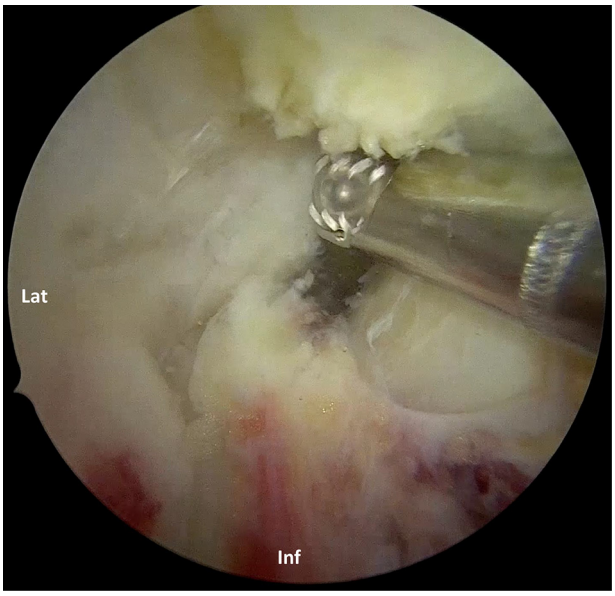

Fig 5. The patient is in the supine position. Arthroscopic view of the right knee through the anterolateral portal. Debridement of the intercruciate septum between the anterior cruciate ligament (green star) and posterior cruciate ligament (red star) for creation of the trans-septal portal, used for PCL tibial guide passage.

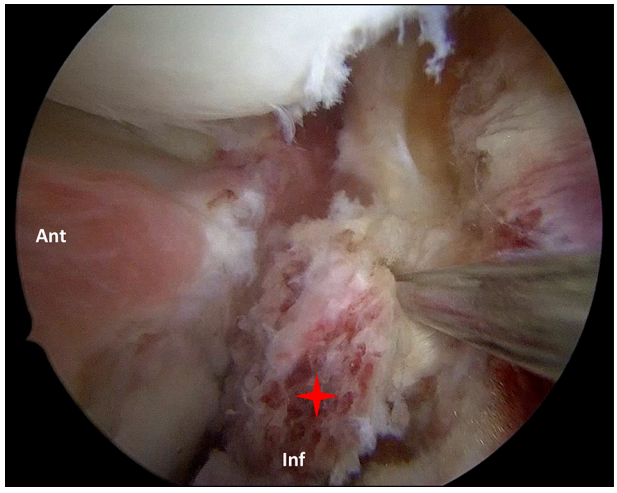

Fig 6. The patient is in the supine position. Arthroscopic view of the right knee through the low posteromedial portal. The PCL tibial bony fragment (star) is visualized and mobilized from the high posteromedial portal.

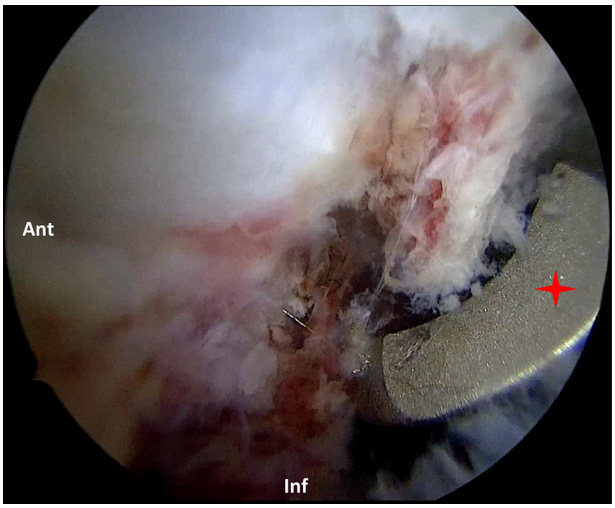

Fig 7. The patient is in the supine position. Arthroscopic view of the right knee through the low posteromedial portal showing creation of the PCL tibial tunnel with the PCL tibial aiming guide (star) inserted through the trans-septal portal.

arthroscopic visualization to confirm reduction of the tibial sag (Fig 8).

Postoperative Rehabilitation

Patients are placed into a standard hinged knee brace, which is changed to a PCL brace at 2-3 weeks once swelling subsides. A PCL-protective rehabilitation protocol is begun immediately, which generally consists of early quadriceps activation, avoidance of hamstring contraction, non-weight bearing, and passive prone 0-90° knee range-of-motion (ROM) for 6 weeks. The protocol is advanced in a systematic fashion, with resumption of normal weight bearing at 8 weeks and institution of a strengthening program at 3 months.

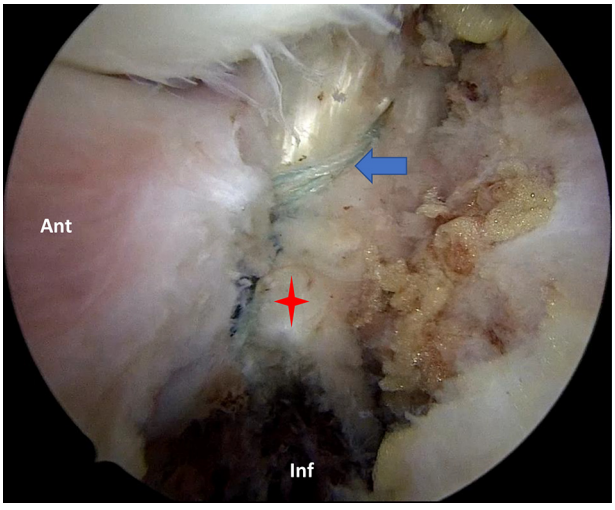

Fig 8. The patient is in the supine position. Arthroscopic view of the right knee through the low posteromedial portal. Posterior cruciate ligament repair sutures (arrow) are placed over the fracture fragment, allowing for anatomic reduction of the tibial posterior cruciate ligament bony avulsion (star) and reduction of the tibial sag once tensioned and tied over a metallic button.

Discussion

Repair of PCL tibial avulsion injuries is well described in the literature.[3,10-13] Classically, this involves open reduction and internal fixation using a screw-washer construct via a modified posterior approach to the knee.[3] However, given the morbidity and risks associated with this procedure, all-arthroscopic techniques have been described. Two recent systematic reviews have compared the outcomes following open versus arthroscopic repair of tibial PCL avulsions. Hooper et al. showed better International Knee Documentation Committee (IKDC) grade A scores (78.9% vs 65.9%) and a higher rate of return to preinjury level of activity (100% vs 86.2%), but a slightly higher rate of arthrofibrosis in the arthroscopic group (0-35% vs 0-25%).[3] Song et al. yielded similar results, demonstrating similar Lysholm scores (85-100 vs 80-100), normal or nearly normal knees on IKDC rating (92-100% vs 90-100%), and differences in side-to-side ROM (<5°) in patients with displaced PCL avulsion fractures treated with either open or arthroscopic suture fixation.[14] These findings prompted the authors to conclude that both approaches have a similar outcomes and complications profile, but that the arthroscopic approach has the advantage of identifying and addressing concomitant intra-articular pathology.

Arthroscopic access to the posterior compartment of the knee can be achieved via posteromedial, posterolateral, and trans-septal portals, or a combination of the three.[11,13,15] Recently, Vishwakarma et al. described a dual-posteromedial portal technique for fixation of PCL tibial avulsion fractures.[10] The primary advantage of this technique is the avoidance of the need to create a posterolateral portal, which places the common peroneal nerve at risk of injury, and trans-septal portal, which places the posterior tibial neurovascular bundle at risk. However, we have found that if the posterior capsule is carefully released directly off bone through the intercruciate window, not only is the capsule safe from injury, but it falls posteriorly, thereby increasing the working space in the posterior compartment. Furthermore, an additional access is created to improve the trajectory of PCL tibial guide placement.

PCL avulsion fractures are often associated with other intra-articular ligamentous or meniscal injuries. Pardiwala et al. showed a 28% rate of intra-articular pathology in their randomized controlled-trial (RCT) comparing open to arthroscopic fixation of PCL tibial bony avulsions.[16] The ability to treat associated intra-articular injuries in the same setting has increased the popularity of the arthroscopic approach to fixing these fractures. The medial and lateral menisci are injured

relatively frequently in the context of PCL tibial avulsion fractures, and rarer avulsions of the posterior root of the medial meniscus have also been described.[4] There has been one case report of a bony avulsion of the posterior root of the lateral meniscus in conjunction with a tear of the ACL, and none, to our knowledge, in the context of a PCL tibial avulsion fracture.[17] The additional ACL PLB tibial peel-off injury described in this technique note thus presents an extremely rare variant of PCL avulsion injuries that we termed the "tibial avulsion triad".

The triple tunnel technique described here employs suspensory fixation of each avulsed structure via cortical buttons. Zhao et al. compared two-tunnel suture fixation over a cortical bridge to Endobutton fixation of acute displaced PCL tibial avulsion fractures and found no difference in terms of the Lysholm score, IKDC subjective knee rating, KT-1000 arthrometry, or radiographic healing rate between the two groups at 2-year follow-up.[13] Similarly, Zheng et al. showed that arthroscopic suspensory fixation using an Endobutton resulted in excellent outcomes at an average follow-up of 32 months.[11] The major caveat to this technique is avoiding tunnel convergence, which has been shown to be a significant concern when multiple tibial tunnels are being used, such as in the case of multiligament knee reconstruction. However, by placing the first tunnel in close proximity to the distal aspect of the tibial tuberosity and each subsequent one, proximal and medial to the prior, the risk of convergence can be mostly mitigated. Additionally, each tunnel is only 2.4 mm in diameter, thereby further reducing this risk.

In conclusion, avulsion fractures of the lateral meniscus posterior root can rarely occur in the context of PCL tibial bony avulsions, as well as partial tibial ACL peel-off injuries. When present, this "tibial avulsion triad" can be fixed using the arthroscopic triple-tunnel technique that provides a minimally invasive approach to stable fixation.

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