



# Primary Anterior Cruciate Ligament Repair With Hyaluronic Scaffold and Autogenous Bone Marrow Aspirate Augmentation in Adolescents With Open Physes

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**Abstract:** It is well known that the anterior cruciate ligament (ACL) is the main stabilizer to the anterior tibial translation in the knee. The current gold standard of treatment for such lesions is ACL reconstruction. However, there are notable disadvantages to ACL reconstruction that include loss of proprioception, donor site morbidity, incomplete return to high-demand sports, and the inability to restore normal kinematics of the knee joint. Additionally, in adolescents who have open physes, there is a risk of potential iatrogenic growth plate injury. Tibial-sided soft-tissue avulsion is a rare subtype of ACL injuries. This Technical Note presents a method for primary anatomic ACL repair with a bioabsorbable scaffold and bone marrow concentrate augmentation for an acute distal ACL injury. Our technique is an alternative to reconstruction as it allows the preservation of the native insertion site and has the potential to reduce the risk of posttraumatic osteoarthritis.

The anterior cruciate ligament (ACL) is the main stabilizer of the knee joint because it controls anteroposterior and rotatory knee laxity. ACL injuries have been on the rise in the past 3 decades because of an increased participation in recreational and competitive sporting activities. Injury to the ACL often leads to functional instability, damage to meniscus and articular cartilage, and an increased risk for osteoarthritis.<sup>1-3</sup> Because the ACL has limited healing potential, the surgical procedure of choice is ACL reconstruction (ACLR). Recent advances in tissue engineering and regenerative medicine have resulted in a renewed interest in ACL repair. Using hyaluronic scaffolds and

concentrated bone marrow aspirate (BMAC) is well known in cartilage lesions repair.<sup>4,5</sup> Encouraged by these results, we decided to use similar biologic enhancement for ACL repair.

## Diagnosis

The diagnosis of ACL tears depends on a thorough clinical examination and magnetic resonance imaging (MRI). The Lachman test should be assessed to determine whether there is an increase in instability compared with the contralateral normal knee, with the knee flexed to 30°. Concurrent with this, a pivot-shift test can be performed to check the rotational stability of the knee joint. In addition to the clinical examination, radiographs are important to assess for ACL tears in adolescents. MRI scan is performed to confirm the diagnosis and assess concomitant injuries.

## Indications

The main indication for this technique is acute (less than 2 weeks from injury), complete, distal ACL tear in adolescents. Patients are advised to undergo arthroscopy based on a history of knee strain with pain, buckling, and giving way. The examination demonstrates increased laxity and the Lachman test is positive. The diagnosis is confirmed with magnetic resonance imaging (Fig 1 A and B).

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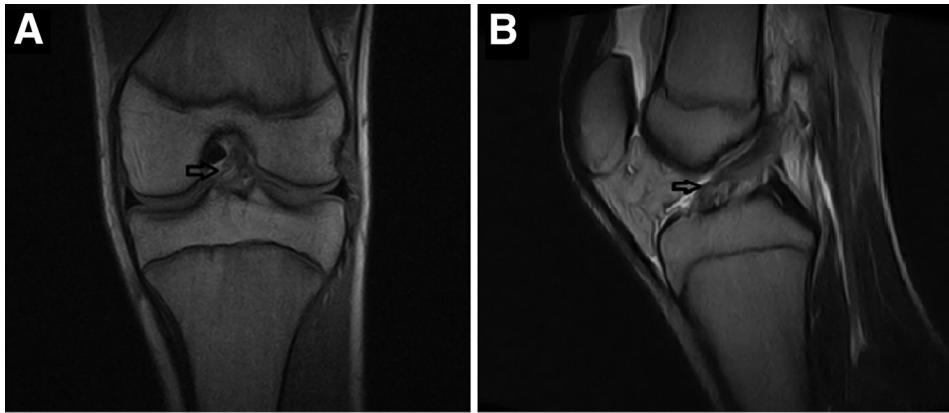
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**Fig 1.** The MRI images of the left knee of a 15-year-old male with open physes 1 week after ACL injury. The (A) coronal view and (B) sagittal view revealed tibial-sided peel-off tear of the ACL (arrows). (ACL, anterior cruciate ligament.)

### Patient Setup and Arthroscopic Evaluation

The patient is placed supine on a standard operating table. A tourniquet is placed around the proximal thigh for safety in the case of excessive blood loss and to maximize visualization. The operative leg as well as the skin over the iliac crest for bone marrow aspiration is prepared with preoperative skin preparation and then draped in the usual sterile fashion (Fig 2A and B).

A 30° 4.0-mm arthroscope (Smith & Nephew) is used to perform a comprehensive arthroscopic examination of the knee. The anterolateral and antemedial portal are created with a No. 11 blade to make a vertical incision adjacent to the lateral border of the patellar tendon at the level of the joint line. A diagnostic arthroscopy is performed and any concurrent intraarticular pathology addressed. One additional portal is made positioned 1 cm lateral and 1 cm proximal to the standard anterolateral portal (Fig 3). The tibial-sided soft-tissue avulsion ACL injury is found (Fig 4). Arthroscopy-assisted anterior drawer test and Lachman test are performed to assess the possibility of reattaching the ACL. An arthroscopic shaver (Smith & Nephew) is initially used to debride any scar tissue.

### Sutures of ACL

Two parallel polydioxanone No. 1 sutures (PDS II, Ethicon) are passed through the distal part of ACL using a suture passer (Accu-Pass Suture Shuttle, Right 45 Curve, Smith & Nephew). First, using the medial portal,

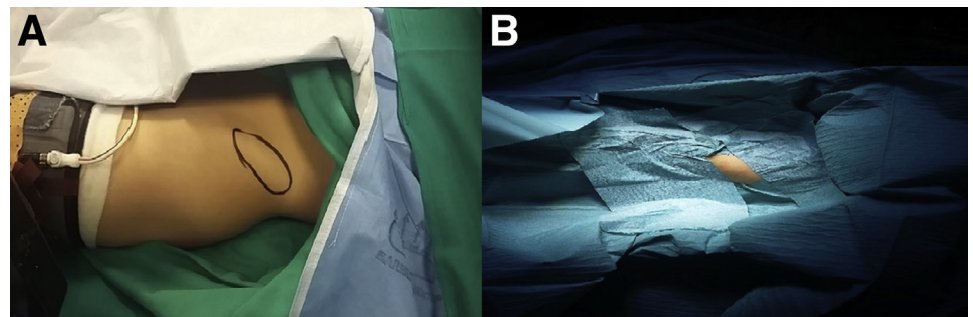
take a bite through the posterolateral bundle. This suture is then converted to nonabsorbable ultra-high-molecular-weight polyethylene sutures (FiberWire, Arthrex). Similarly, another suture can be passed through the anteromedial bundle, using the same portal (Fig 5 A-C). The loop-stitch taken is temporarily passed outside the lateral portal using an arthroscopic grasper (Smith & Nephew). It is necessary to avoid shaving to have a dry arthroscopic area in the latter steps of the surgery.

Two tibial tunnels are drilled using an elbow-aiming ACL tibial tunnel guide (Acufex Director Elbow Aimer, Smith & Nephew), medially and laterally on both sides of the ACL footprint (Fig 6 A and B). We recommend parallel drilling of these 2 tunnels with minimum 5 mm distance between them (Fig 7). By means of the suture passer (Accu-Pass Suture Shuttle, Big Curve, Smith & Nephew) the sutures are taken outside (Figs 8 and 9). Sutures from the medial side of ACL were passed through the medial tunnel and lateral sutures through the lateral tunnel, respectively. After tensioning the sutures are tied over the bone-bridge medially to the tibial tuberosity. The stability of this reattachment is checked under arthroscopy (Fig 10).

### Scaffold Preparation and Fixation

The bioabsorbable, hyaluronic scaffold Hyalonect (Anika Therapeutics) should be rolled to form a cylinder. Two sutures at both ends are prepared and then

**Fig 2.** (A) The patient is in the supine position, with the left iliac crest shown. (B) The area described before is draped in the usual sterile fashion for the bone marrow aspiration.





**Fig 3.** The patient is in the supine position, with the left knee shown. The tourniquet is placed on the thigh. The arthroscope is inserted into the anterolateral portal for viewing with an arthroscopic probe inserted into the additional anterolateral portal, positioned 1 cm lateral and 1 cm proximal to the standard anterolateral portal (white arrow).

the scaffold is double-folded (Fig 11). The anteromedial portal has been used to drill a 4.5-mm-diameter femoral tunnel. After changing the knee flexion, a 4.5-mm-wide tunnel is drilled through the tibia (Fig 12). The prepared scaffold is pulled through a 1.5-cm-deep



**Fig 4.** A 30° arthroscope is in the anterolateral portal of the left knee. The torn tibia attachment of the anterior cruciate ligament is visualized.

tunnel in the femur for the good press-fit fixation under arthroscopic guidance with additional suturing to the iliotibial band (Fig 13 A and B).

### **BMAC Aspiration and Concentration**

A dedicated aspiration kit is used to harvest approximately 60 mL of bone marrow from the ipsilateral iliac crest (Fig 14). A commercially available system is used to centrifuge the aspirate and concentrate the bone marrow cells (Angel, Cytomedix, Gaithersburg, MD) (Fig 15).

### **BMAC Application During dry Arthroscopy**

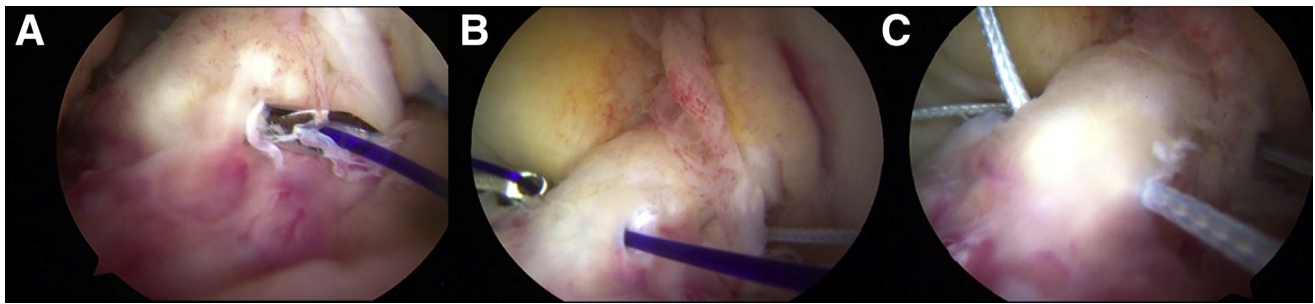
Arthroscopic fluid is drained from the working articular space. The BMAC is applied to the Hyalonect scaffold by arthroscopically-assisted injection (Figs 16 and 17). The Lachman test is performed postoperatively to check the stability of the ACL and the scaffold. After the whole procedure, a knee brace blocked in 10° of flexion is applied. Arthroscopic primary repair of ACL is shown in Video 1.

### **Postoperative Treatment**

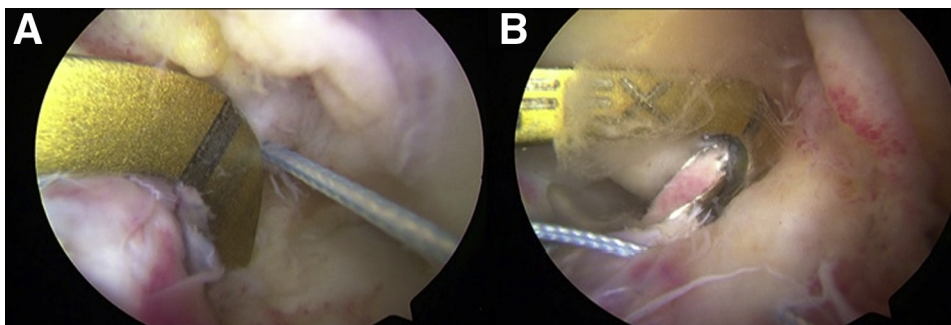
A long-knee brace in 10° of flexion was applied for the first week. Touch-toe weight-bearing was allowed for the first 2 weeks. Isometric muscle activation was started on the first postoperative day. From the 8th day after the surgery, knee range-of motion exercises were started. Full knee extension and up to 50° flexion was achieved at week 4. About 6 weeks postsurgery, closed-chain exercises in a hinged knee brace started under therapist guidance. MRI was performed 6 months after the surgery.

## **Discussion**

The ACL is a critical stabilizer of the knee joint, helping to control rotational tibiofemoral motion and motion in the anteroposterior plane. ACL injuries are an often-cited cause of functional limitation with respect to a wide range of activities, from recreational to elite sporting competition. ACL reconstruction is the current gold standard treatment for ACL insufficiency, with high success rates for return-to-play typically reported.<sup>6,7</sup> The main objective of all surgical techniques in adolescents is to avoid potential iatrogenic growth plate injury. “Physeal-sparing” techniques such as over-the-top reconstructions of the femur and tibia and iliotibial band reconstructions, all-epiphyseal, and transphyseal reconstruction were developed.<sup>8-12</sup> There are notable disadvantages of ACLR that include loss of proprioception, donor side morbidity, incomplete return to high-demand sports, and the inability to restore normal kinematics of the knee joint.<sup>13-15</sup> Considering that ACL injuries most commonly affect a younger demographic, leading to substantial morbidity and lifestyle modification, therapeutic



**Fig 5.** Left knee, viewing from anterolateral portal. (A) Two parallel polydioxanone No. 1 sutures (PDS II, Ethicon) are passed through the distal part of the anterior cruciate ligament using a suture passer (Accu-Pass Suture Shuttle). First, using the medial portal, take a bite through the posterolateral bundle. (B) First suture is converted to nonabsorbable ultra-high-molecular-weight polyethylene sutures (FiberWire). (C) A second suture can be passed through the anteromedial bundle using the same portal.



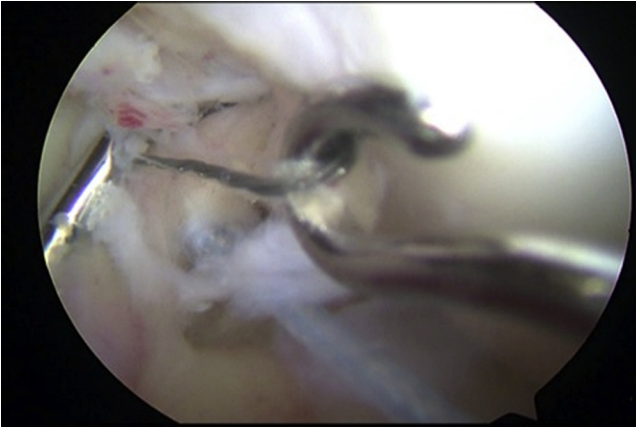
**Fig 6.** Left knee, viewing from anterolateral portal. (A) The ACL tibial tunnel guide (Acufex Director Elbow Aimer) is inserted into the anterolateral portal. (B) The first tibial tunnel is drilled using an elbow-aiming ACL tibia tunnel guide (Acufex Director Elbow Aimer), medial to the ACL footprint. (ACL, anterior cruciate ligament.)



**Fig 7.** The arthroscope is inserted into the anterolateral portal of the left knee and a nonabsorbable ultra-high-molecular-weight polyethylene suture (FiberWire) is going into the knee joint through the anteromedial portal. A minimum of 5-mm distance between tunnels is recommended for tibial tunnels' parallel drilling.



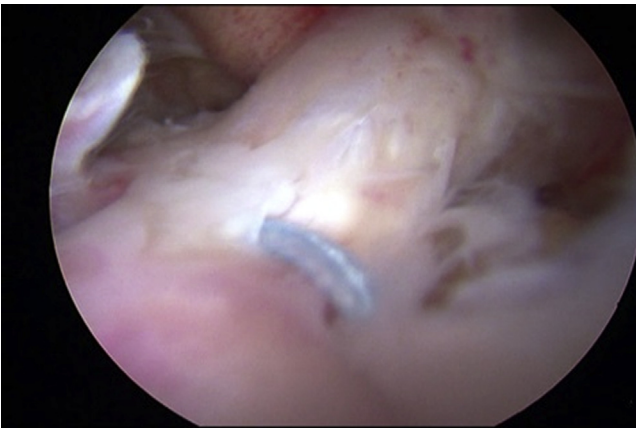
**Fig 8.** A metal loop-stitch taken temporarily is passed outside the medial portal using an arthroscopic hook (Smith & Nephew).



**Fig 9.** Left knee, viewing from anterolateral portal. The view from the inside of left knee joint through the anterolateral portal. The metal loop-stitch is taken outside through the medial portal by an arthroscopic hook (Smith & Nephew).



**Fig 11.** Hyaluronic scaffold is rolled to form a cylinder. Both ends are then sutured and the graft is double-folded.

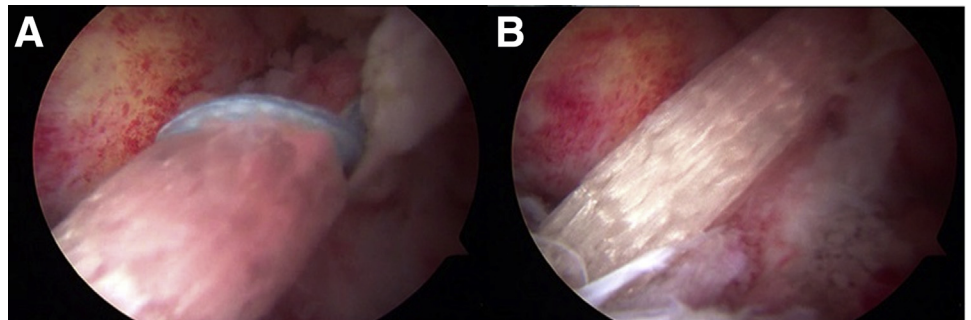


**Fig 10.** Left knee, anterolateral portal view of the sutures from the medial side of anterior cruciate ligament that are then passed through the medial tunnel and lateral sutures through the lateral tunnel, respectively. After tensioning, the sutures are tied over the bone bridge medially to the tibial tuberosity. The stability of this reattachment is checked under arthroscopy.



**Fig 12.** The anteromedial portal is used to drill a 4.5-mm diameter femoral tunnel. After changing the knee flexion, a 4.5-mm wide tunnel is drilled through the tibia using elbow aimer (Acufex Director Elbow Aimer). An arthroscope is inserted through the anterolateral portal to visualize the entry point of the drill near the anterior cruciate ligament femoral attachment.

**Fig 13.** View from the anterolateral portal. (A) The scaffold, rolled and folded in half, is passed through previously drilled 4.5-mm tibial tunnel into the knee joint. (B) Then the scaffold is pulled 1.5 cm deep into the femoral tunnel and sutured onto the iliotibial band. The fixed scaffold is checked for stability.





**Fig 14.** The patient is in the supine position, and the left iliac crest is shown. A dedicated aspiration kit is used to harvest approximately 60 mL of bone marrow from the iliac crest.

options that are capable of restoring near-anatomic function of this ligament have the potential to overcome a number of the disadvantages associated with current ACLR techniques. Theoretically, preserving the native ACL will minimize loss of proprioception and



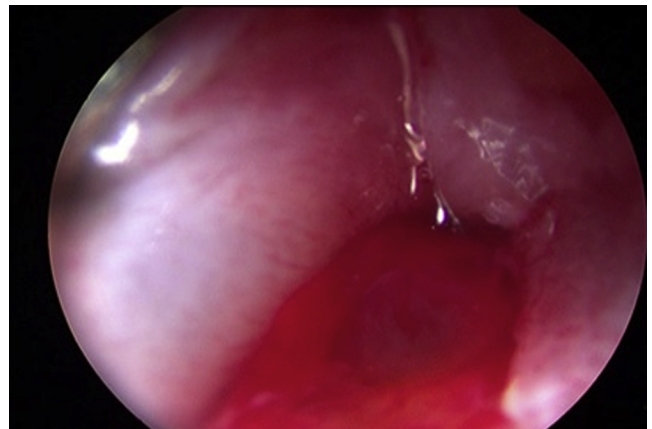
**Fig 15.** The syringe is filled with bone marrow aspirate concentrate, which is prepared in a commercially available system centrifuge.



**Fig 16.** The knee is drained of arthroscopic fluid. The arthroscope is inserted into the anterolateral for viewing with a needle and syringe into the additional anterolateral portal for bone marrow aspirate concentrate injection.

avoid morbidity associated with autologous graft harvesting.<sup>16</sup> However, the intra-articular nature of the ACL is 1 of the biggest problems with ACL repair efficacy.<sup>17,18</sup> There are specific deficiencies of cellular repair that impact healing of injured ACL tissue, and mesenchymal stem cell therapies have the capacity to influence reparative processes at the cellular and molecular level.<sup>19,20</sup> Bone marrow–delivered mesenchymal stem cells possess ACL healing-promoting potential, as demonstrated in our previous study about primary repair of partial ACL tears.<sup>21,22</sup> Additionally, the use of scaffolds has been shown to be effective because ACL fibroblasts attach, proliferate, and express collagen on them.<sup>23,24</sup> Another study demonstrated significantly improved ACL repair outcomes and superior tissue mechanical properties using primary repair augmented with biologic treatment compared with suture repair alone.<sup>25,26</sup>

Biologic augmentation of reparative methods to treat ACL injuries will continue to evolve, and work will continue to determine the ideal constituents of scaffold



**Fig 17.** The view from the anterolateral portal of the left knee joint during dry arthroscopy. The hyaluronic scaffold is filled with bone marrow aspirate concentrate.

**Table 1.** Advantages and Disadvantages

Advantages	Disadvantages
The native ACL is spared, providing proprioceptive properties and enhancing the revalidation	There is a time limit of 2 weeks postrupture for the surgery
This technique is less invasive than ACL reconstruction and the risk of growth plate injury is much lower	The ACL stump has to be of good tissue quality and not retracted
Augmentation with BMAC and hyaluronic scaffold increases the healing potential of ACL	There is still the risk of growth plate injury during the tibial tunnel drilling
In the case of rerupture, a standard ACL reconstruction can be performed.	
No donor harvesting morbidity	

ACL, bone marrow aspirate concentrate; BMAC, bone marrow aspirate concentrate.

**Table 2.** Pearls and Pitfalls

Surgical Step	Pearls	Pitfall
ACL suturing	Place the sutures in both bundles to ensure proper tensioning of the ligament	Sutures placed too peripheral may increase the risk of ligament rupture at the suture site
Drilling tibial tunnel for sutures	The tunnels should be parallel and at a minimum distance of 5 mm	Tunnels placed too close together can result in fracturing of the bone bridge
Drilling tibial tunnel for scaffold	Place the drill at a safe distance from previously drilled tunnels	Placing this tunnel too close may damage the repair
BMAC application during dry arthroscopy	Drain the fluid completely before applying BMAC. Ensure that applied concentrate is well absorbed into the scaffold	Applying BMAC quickly results in an incomplete absorption of the concentrate not the scaffold

ACL, bone marrow aspirate concentrate; BMAC, bone marrow aspirate concentrate.

and mesenchymal stem cell preparations that will optimize tissue healing.<sup>27</sup> To emphasizing the importance of focusing the Technical Note of ACL repair on acute tears, these findings may provide important information to develop treatment algorithms for ACL injuries in adolescents.

### Limitations

Our technique has some limitations. It is reserved for acute injuries and has to be performed within 2 weeks from the time of injury. The morphology of the injury is also a limiting factor because this technique can only be used for ACL tibial insertion injury. Similar technique can also be considered in femoral attachment avulsion, but complete tears of the middle part of ACL may not be suitable for this kind of surgery. Although the risk is much lower than using standard ACL reconstruction technique, there still is risk of growth plate injury during the tibial tunnel drilling.

Advantages/disadvantages and pearls/pitfalls of the technique are highlighted in [Table 1](#) and [Table 2](#), respectively.

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