Technical Note

All-Epiphyseal Anterior Cruciate Ligament Repair Using Suture Ring Device in the Skeletally Immature Patient

Katie Smeltzer, D.O., Amy Meyers, D.O., and Ryan Nelson, D.O.

Abstract: Anterior cruciate ligament (ACL) tears in pediatric patients pose distinct challenges in management, especially in patients with open distal femoral and proximal tibial physes. There are a variety of contemporary reconstruction techniques that attempt to address these challenges. However, with the resurgence of ACL repair in the adult population, it has become apparent that the pediatric patient may also benefit from primary ACL repair rather than reconstruction. ACL repair is a procedure performed to treat ACL tears that avoids the donor-site morbidity seen with ACL reconstruction using autograft. We describe a surgical technique involving FiberRing sutures (Arthrex, Naples, FL) and TightRope—internal brace fixation (Arthrex) for ACL repair with all-epiphyseal fixation in the pediatric patient. The FiberRing is a knotless, tensionable suture device that can be used to stitch the torn ACL and coupled with the TightRope and internal brace to fix the ACL.

In the athletic population, anterior cruciate ligament (ACL) injuries are very common injuries. ACL injury has become more prevalent in the pediatric population with increased participation and specialization in sporting activities.[1] The rate of ACL reconstruction in patients younger than 15 years has increased 924% since 1994.[2]

The management of ACL injuries in the skeletally immature population presents unique challenges that differ from those presented by ACL treatment in adults. Historically, the risk of physeal damage in skeletally immature patients, with potential for growth disturbance, angular deformity, or limb length discrepancy, led surgeons to favor nonoperative management of these injuries.[2-4] However, unaddressed instability is associated with further meniscal and cartilage damage.[1] This finding led to the development of physeal-sparing (extraphyseal or all-epiphyseal) ACL reconstruction techniques aimed at minimizing the risk of growth arrest in skeletally immature patients, and reconstruction with autograft is currently the gold-standard treatment in this population.[4,5]

Typically, in the pediatric population, autograft reconstruction is the treatment of choice for ACL injuries. ACL repair was first introduced in 1895 by Robson.[1] The appeal of performing ACL repair is avoiding donor-site graft morbidity and, in the pediatric population, avoiding the placement of transphyseal tunnels. Unfortunately, early reports showed that ACL repair was associated with high failure rates.[1] Sherman et al.[3] looked into this with a subgroup analysis of their research and found that patients who had type 1 ACL tears (tears of the proximal aspect of the ACL off the femur) had better outcomes than patients who had type 3 or 4 tears (midsubstance tears and areas of the ligament with poor blood supply and healing potential).

ACL repair is becoming a more popular procedure for proximal ACL tears off the femoral attachment of the ACL owing to the higher healing potential and advances in anchors and arthroscopic instrumentation. Good results have been reported in the adult population after ACL repair for proximal femoral avulsion. However, a study by Gagliardi et al.[4] looking at 22

From Ascension Genesys Hospital, Grand Blanc, Michigan, U.S.A. (K.S., A.M.); and Greater Michigan Orthopedics, Grand Blanc, Michigan, U.S.A. (R.N.).

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Address correspondence to Amy Meyers, D.O., Ascension Genesys Hospital, One Genesys Pkwy, Grand Blanc, MI 48439, U.S.A. E-mail: Meyersal12@gmail.com

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Table 1. Advantages and Disadvantages of Technique

Advantages	Disadvantages
All-epiphyseal technique, avoiding growth disturbance and damage to physes	Potential for accidental drilling into physis if fluoroscopy is inadequate
No need for autograft preparation	Technique of passing FiberRing suture through ACL may be difficult for some surgeons
Avoidance of autograft donor-site morbidity	Reliance on intraoperative fluoroscopy to remain extraphyseal
Retention of natural ACL tissue	Failure to differentiate type 1 vs type 2 ACL tear
Less invasive nature with smaller incisions	

ACL, anterior cruciate ligament.

patients at 2.5 years of follow-up showed a 10 times higher association with failure after ACL repair compared with quadriceps autograft reconstruction in adolescent patients. The authors believed this higher risk of retear was due to an increase in the patients' level of play during sport and possible fatigue failure of the suture augmentation at around 18 months. Other studies have shown more promising results. Bigoni et al.[4] performed a review of 5 patients after ACL repair with sutures and observed no evidence of retear or growth disturbance at 43 months. Dabis et al.[5] found similar results in a study following up 20 patients at 2 years postoperatively: Patients who underwent suture repair of proximal ACL tears did not have any retears or growth disturbance postoperatively.[2] These studies have shown that ACL tears involving the proximal aspect can be successfully treated with ACL repair using suture augmentation.[6] The benefits of primary repair include the less invasive nature of the procedure, avoidance of graft donor-site morbidity, retention of the native ACL anatomy and proprioceptive function, and preservation of the biomechanical properties of the ligament (Table 1).[6,7] We describe a technique for arthroscopic ACL repair using FiberRing sutures (Arthrex, Naples, FL) and TightRope—internal brace fixation (Arthrex) in an all-epiphyseal manner in the pediatric population.

Surgical Technique

Indications

This technique is performed in the skeletally immature patient with a femoral-sided avulsion tear (Sherman type 1 tear) of the ACL.[7] Contraindications to this procedure include ACL tears involving the midsubstance of the ligament and ACL tears with inadequate tissue for repair or poor tissue quality that would affect stitch integrity within the ligament (Table 2). Our technique involves all-epiphyseal ACL repair, which limits the performance of this technique to the pediatric population with open physes.

Patient Setup and Positioning

The patient is placed supine on the operating table. Clinical examination with the patient under anesthesia is performed as described later. A thigh tourniquet is placed on the affected extremity, which is then secured in an arthroscopic leg holder, and the foot of the table is brought down. The contralateral limb is padded and abducted 30° with the hip at 10° of flexion over an arthroscopy pad. The well leg is secured in a padded well-leg holder, which ensures that the hip is flexed to 10°. The leg is prepared and draped in the usual sterile fashion. The patient is given weight-based antibiotics prior to the procedure start.

Preoperative examination is performed after adequate anesthesia is achieved. Testing of the affected knee through its range of motion is performed. The collateral ligaments are tested with varus and valgus stress at full knee extension as well as 30° of knee flexion. With the knee at 90° of flexion, the patient is evaluated to determine whether the sag sign is present. The anterior and posterior drawer tests are performed, and the findings are compared with the contralateral limb. The Lachman, pivot-shift, and dial tests are also performed, and the results are recorded.

Arthroscopy

Prior to incision, standard anterolateral and anteromedial arthroscopic portal sites are marked. The leg is

Table 2. Pearls and Pitfalls to Consider while Performing Technique

Pearls	Pitfalls
The quality of remaining ACL tissue and location of ACL tear should be thoroughly evaluated.	Failure to recognize poor tissue quality or more distal tears may result in failure of the repair technique.
The surgeon should ensure that the patient is moved down on the bed enough to allow for adequate intraoperative fluoroscopy.	Patient positioning may affect the ability to obtain appropriate intraoperative fluoroscopic imaging to confirm that drilling is all epiphyseal.
The surgeon should make sure to resect enough fat pad and ligamentum mucosum to avoid issues with visualization during the case.	Poor suture management may require the stitches to be re-passed through the tunnels.
Hemostats should be used to help with suture management and to help secure passed stitches to avoid stitch pullout.	

ACL, anterior cruciate ligament.

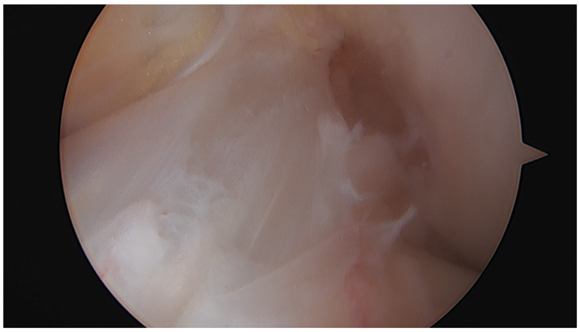

Fig 1. Left knee, patient positioned supine. Intraoperative photograph, taken from anterolateral portal, showing anterior cruciate ligament proximal femoral-sided avulsion tear.

exsanguinated, and the tourniquet is brought up to 250 mm Hg. The anterolateral portal incision is made, and a diagnostic arthroscopy is performed to identify the femoral-sided ACL avulsion and any concurrent pathology (Fig 1). The anteromedial portal is made under spinal localization. The ligamentum mucosum and infrapatellar fat pad are resected as needed for visualization of the notch and ACL.

Femoral Preparation

A motorized shaver is used to prepare the femoral side of the ACL footprint at the lateral and posterolateral aspects of the notch, keeping as many ACL fibers intact as possible. The camera is then switched to the anteromedial portal, allowing placement of a femoral guide (Arthrex) through the anterolateral portal. The placement of the femoral guide is confirmed under fluoroscopy using a mini C-arm to ensure that it is located within the epiphysis (Fig 2, Video 1, Table 2).

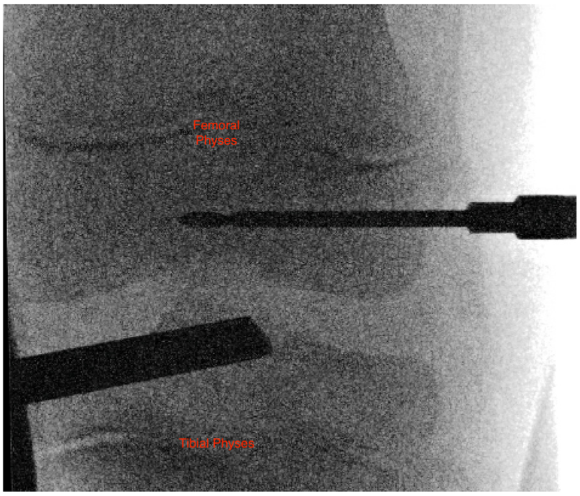

Fig 2. Left knee, patient positioned supine. On an intraoperative radiographic image of the knee (anteroposterior view), all-epiphyseal femoral tunnel placement is confirmed. The scope is visualized in the anteromedial portal. The drill is drilled in an all-epiphyseal manner from lateral to medial into the notch.

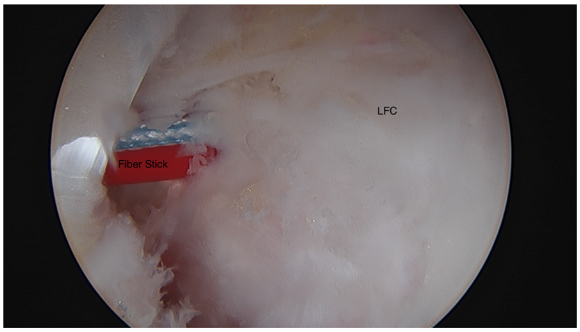

Fig 3. Left knee, patient positioned supine. With the scope in the anteromedial portal, an intraoperative photograph shows passage of the FiberStick being placed through the femoral tunnel, positioned to then be grabbed with the surgeon's preferred instrument. LFC, lateral femoral condyle.

Subsequently, a 3.5-mm drill is drilled distally through the guide from the anterolateral aspect of the femur and into the notch. The placement is again confirmed with orthogonal fluoroscopic imaging to ensure that the drill tract remains all epiphyseal. After the drill is removed, the looped end of a FiberStick (Arthrex) is passed through the femoral guide (Fig 3). The looped end is retrieved through the anterolateral portal, and a hemostat is used to secure the ends of the loop for later use (Table 2).

ACL Preparation

Attention is turned to preparation of the ACL (Video 1). A PassPort cannula (Arthrex) is placed through the anteromedial portal. At this point, 2 FiberRing sutures are placed through the retracted ACL stump: 1 from medial to lateral and 1 from lateral to medial. These are then secured at the end of the stitches with a hemostat for later use.

Tibial Preparation

A tibial guide (Arthrex) is now used to drill the tibial side (Fig 4, Video 1). Biplanar fluoroscopic imaging is used to ensure placement in the epiphysis, as well as to achieve adequate bone penetration to the center of the ACL. A 3.5-mm cannulated pin is passed. After confirmation of anatomic placement, a nitinol wire with loop is passed through this, and the cannulated pin is removed. The nitinol wire with loop is secured with a hemostat for later use.

ACL Repair, Femoral Fixation, and Button Deployment

Next, the FiberRing is attached through the TightRope button with an internal brace (Arthrex) and pulled through the previously drilled femoral tunnel from inside out (Video 1). The button is flipped on the lateral cortex. The ACL is then tensioned in full extension. Once adequate tension is achieved, the internal brace is shuttled down on the anterior medial tibia.

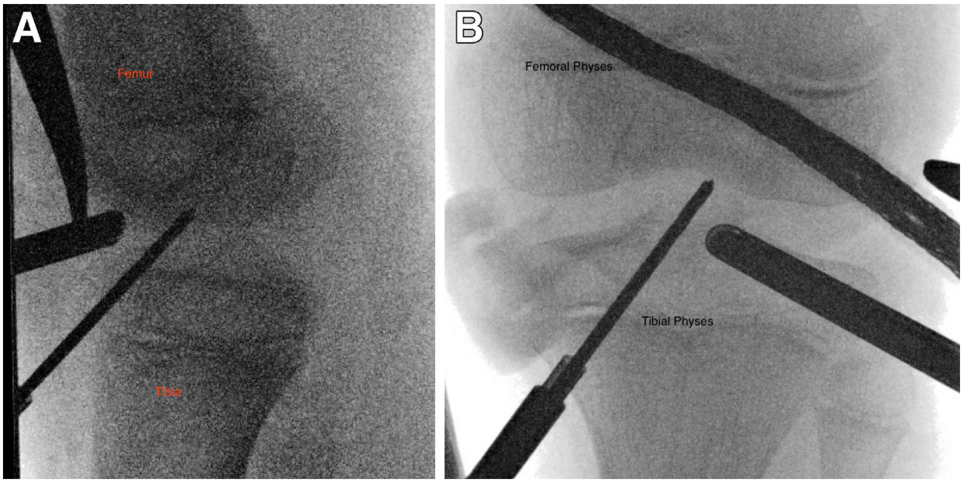

Fig 4. Left knee, patient positioned supine. Biplanar fluoroscopic imaging of the knee is used to ensure placement in the tibial epiphysis, as well as to achieve adequate bone penetration to the center of the anterior cruciate ligament: lateral (A) and anteroposterior (B) radiographs.

Tibial Fixation

Under biplanar fluoroscopy, a 2.5-mm guide pin is drilled for tibial fixation (Video 1). The 2.5 mm guide pin is then overdrilled with a 4.0 Bio-Tenodesis drill (Arthrex), allowing for subsequent placement of a 4.75-mm SwiveLock (Arthrex) (Fig 5).

Final Testing

After placement of the SwiveLock anchor, adequate tension of the ACL is visualized through the arthroscope and confirmed by probing (Fig 6). Range of motion is tested, and if it is satisfactory, the suture ends on the tibial side are cut. The remaining sutures from the TightRope button are then tied over the button with 6 half-hitches and then cut. After irrigation of all wounds, closure is performed and a sterile dressing is applied.

Postoperative Rehabilitation

Immediately after surgery, the patient is placed in a hinged knee brace and is permitted 0° to 90° of motion when seated; the patient is instructed to start motion within the first 3 days postoperatively under the direction of a physical therapist. The patient is restricted to touch-down weight bearing with crutches for the first 6 weeks postoperatively but is instructed to lock the hinged knee brace in full extension when ambulatory. The patient then follows our standard soft-tissue ACL protocol.

Discussion

Primary ACL repair was largely abandoned in the 1970s and 1980s, after several reports showed inconsistent outcomes and high failure rates of open repair.[8] In search of an explanation for the poor outcomes, Sherman et al.[9] performed an extensive subgroup analysis of open ACL repairs. They classified ACL tears based on tear location and found that patients with type 1 tears (proximal ligament avulsion without a major bony fragment) with excellent tissue quality had much

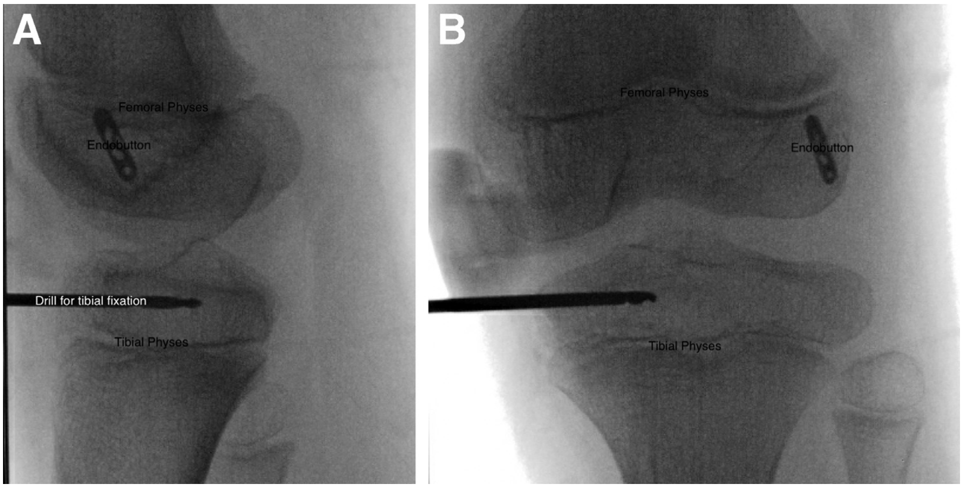

Fig 5. Left knee, patient positioned supine. (A, B) Radiographic views of knee allowing visualization of previously placed TightRope button. The FiberRing sutures are attached to the TightRope button with an internal brace and pulled through the previously drilled femoral tunnel. Under biplanar fluoroscopy, a 2.5-mm guide pin is drilled for tibial fixation. This is then overdrilled with a 4.0 Bio-Tenodesis drill, allowing for subsequent placement of a 4.75-mm SwiveLock.

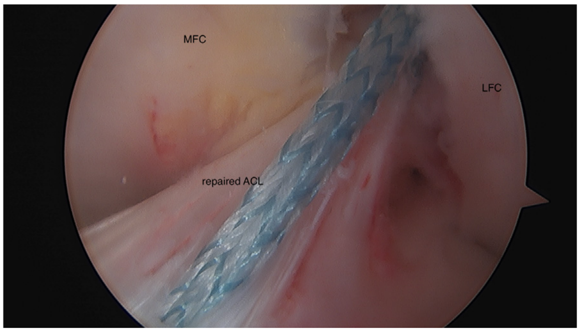

Fig 6. Left knee, patient positioned supine. Intraoperative photograph from anterolateral portal showing repaired anterior cruciate ligament (ACL) tear with internal brace sutures in place. LFC, lateral femoral condyle, MFC, medial femoral condyle.

better outcomes than those with midsubstance tears or tears of poor tissue quality.[9] Their discoveries in patient selection form the basis of many contemporary ACL repair protocols. Advances in magnetic resonance imaging, which allows surgeons to preoperatively assess tear location and tissue quality, have further contributed to the re-emergence of ACL repair as a promising option in both children and adults over the past several decades.[7]

Primary repair, such as the technique described in this article, is an appealing option in the skeletally immature patient for several reasons. When compared with nonoperative management, a successful repair directly addresses instability, with the goals of re-establishing a stable, functional knee and preventing further damage to the cartilage and menisci, and it allows for a quicker return to normal gait patterns, daily activities, and sporting activities.[5,10] In contrast to reconstruction techniques, there is no donor-site morbidity with ACL repair, the proprioceptive nerve endings are preserved, and the technique allows for anatomic restoration of the ligament, which is not achieved in some extraphyseal and physeal-sparing reconstruction techniques.[3,5,10-12] ACL repair can be performed without drilling tunnels or with the drilling of only very small tunnels that do not need to accommodate a graft,[7,11] addressing the concern that larger tunnels result in a greater risk of damage to the physis.[6] Finally, because of the less aggressive nature of ACL repair surgery, it does not preclude the patient from future ACL reconstruction.[12] A summary of the advantages and disadvantages of our technique can be found in Table 1.

Several other techniques for ACL repair have previously been described with promising results. DiFelice et al.[11] described a successful technique in adults that used two 4.5-mm biocomposite suture anchors to secure the proximal ACL to the femoral insertion, with no tibial drilling or fixation. For the pediatric patient, Bigoni et al.[12] modified this technique and used a single, smaller 3.5-mm bioabsorbable knotless suture anchor. This technique allowed all drilling to remain in the epiphysis and avoided disruption of the open physis. At 2-year follow-up, there were no reports of reinjury, leg length discrepancy, or articular lesions on repeated magnetic resonance imaging. Moreover, all 5 patients returned to normal sporting activity.[12] Smith et al.[10] described an all-epiphyseal technique using a transosseous femoral suspension button reinforced with a temporary internal brace. Their technique used a calibrated pediatric drill guide to ensure no violation of the physis and performed a suture shuttling technique to avoid passing the button through the femur, allowing the use of a 2.4-mm tunnel. All 3 patients had stable knees at 3 months and had returned to activity without limitations at 4 months. There were no cases of leg growth disturbance, malalignment, or leg length discrepancy at 2 years.[10] Of note, the technique of Smith et al. did include a second surgical procedure to remove the temporary internal brace at 3 months.[10] Dabis et al.[6] described a transphyseal approach with small-diameter tunnels on both the femoral and tibial sides in 20 pediatric patients. They used a modified, smaller transphyseal tunnel in Tanner stage I patients. They found reliable healing with no growth disturbance, leg length discrepancy, or growth arrest despite the transphyseal drilling.

Our technique uses all-epiphyseal transosseous fixation with the addition of an internal brace. The femoral attachment is secured using a suspensory button, which requires only a small drill tunnel in the epiphysis. A suture button technique is preferred because it is unlikely that the small epiphysis in a preadolescent child could accommodate larger or multiple suture anchors. The addition of an internal brace requires additional tibial fixation but provides increased reinforcement to the ligament repair. All tunnels are drilled using biplanar fluoroscopic imaging to ensure that the tunnels remain in the epiphysis and to prevent violation of the open physis. This technique minimizes the risk of growth disturbance in the skeletally immature patient while providing secure anatomic fixation and internal brace suture tape reinforcement of the ACL repair. We have described an all-epiphyseal technique for ACL repair using FiberRing sutures that can be used in pediatric patients with type 1 ACL tears.

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