[Orthopaedics]

Transepiphyseal Anterior Cruciate Ligament Reconstruction in Pediatric Patients: Surgical Technique

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The prevalence of anterior cruciate ligament (ACL) tears in children and adolescents is relatively low due to anatomic and biomechanical factors that predispose skeletally immature knees to bone injury rather than ligament tears.¹⁷ Nevertheless, ACL tears in this age group appear to be increasing.^{1,7,8,12,14-16,18} Management of these injuries presents a unique challenge; evidence in the literature indicates that the outcome of nonoperative treatment of ACL tears in skeletally immature patients is poor.^{1,9,11,14,15} Conversely, surgical intervention may cause iatrogenic physeal injury, which can result in leg-length discrepancy or angular deformity.^{6,11,13,14} Management decisions are complicated by deficiency in the basic science on physeal response to injury and by the limitations of the clinical studies that document surgical treatment for ACL insufficiency in children and adolescents.

Despite these uncertainties, a rational approach based on current understanding of normal growth and development can be implemented.²⁻⁵ This article describes a technique for transepiphyseal reconstruction of the ACL using autogenous hamstring tendon grafts. The procedure adheres to the generally accepted principles of ACL replacement in adults, but theoretically minimizes the risk of physeal injury by not transgressing either the tibial or femoral physis. The decision as to whether to use this procedure to treat an ACL tear in a child or adolescent can be based on estimates of the relative risk of physeal injury (high, intermediate, or low), which can be determined by assessing the patient's skeletal and physiological age.

The consequences of iatrogenic physeal injury may be severe in children who have a great deal of growth remaining and insignificant in teenagers who have minimal growth remaining in the distal femur and proximal tibial physes. The central

issue in treatment of ACL tears in the pediatric age group is the patient's skeletal age, which determines the potential risk of injurious consequences. The most common method of estimating skeletal age is by comparing an anteroposterior radiograph of the patient's left hand and wrist with the age-specific radiographs in the Greulich and Pyle Atlas.¹⁰ Physiological age can be classified according to Tanner's staging of sexual maturation.¹⁹ Prepubescent patients are categorized in Tanner stages I and II of development, pubescent patients are in Tanner stage III, late pubescent in Tanner stage IV, and postpubescent patients are in Tanner stage V.³⁻⁵

The success of transepiphyseal ACL reconstruction, with meniscal repair, without evidence of growth disturbance, supports a recommendation for aggressive treatment of these injuries.²⁻⁵ Transepiphyseal replacement is recommended for prepubescent patients in Tanner stage I or II of development, including boys younger than 12 years and girls younger than 11 years; these patients are at high risk of growth disturbance if physeal injury occurs. Pubescent Tanner stage III patients, including boys 13 to 16 years of age and girls 12 to 14 years of age, are at intermediate risk. Transepiphyseal replacement is also recommended in early Tanner stage III patients because the threshold of safety for transphyseal drilling is currently unknown.

Surgical Setup

The injured lower limb is placed in an arthroscopic leg holder with the hip flexed 20° to facilitate C-arm fluoroscopic visualization of the knee in the lateral plane. The C-arm is positioned on the side of the table opposite the injured knee, and the monitor is placed at the head of the table.

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Figure 1. Graphically enhanced anteroposterior (A) and lateral (B) views demonstrating the position of the guide wire in the femoral epiphysis. Lateral view from the C-arm monitor after drilling the femoral hole (C).

The tibial and femoral growth plates are visualized in both the anteroposterior and the lateral plane before the limb is prepared and draped. When the distal part of the femur is viewed, the C-arm is adjusted so that the medial and lateral femoral condyles line up perfectly in the lateral plane (Figure 1A). The C-arm is then rotated to visualize the extension of the tibial physis into the tibial tubercle on the lateral view of the tibia (Figure 1C).

Surgical Technique

An oblique, 4-cm incision is made over the semitendinosus and gracilis tendons, which are dissected free, transected at the musculotendinous junction with a standard tendon stripper, and detached distally. The tendons are doubled, and then a No. 2 Fiberwire suture (Arthrex, Naples, Florida) is inserted in the ends of the tendons with a locking whipstitch. The doubled tendons are then placed under 4.5 kg (10 pounds) of tension on the back table with use of the Graftmaster device (Acufex-Smith Nephew, Andover, Maryland). Intra-articular examination is systematically performed in the usual manner. Debris in the intercondylar notch is removed, and a minimal notchplasty is performed to visualize the anatomical footprint of the ACL on the femur. If an unstable, longitudinal-vertical meniscal tear is found, it should be repaired if possible.

With the C-arm in the lateral position, the limb is adjusted to provide a true lateral view. The point of the guide wire is placed on the skin over the lateral femoral condyle corresponding with the location of the footprint of the ACL on the femur. This point is approximately one fourth of the

distance from posterior to anterior along the Blumensaat line and one-fourth of the distance down from the Blumensaat line (Figure 1A). A 2-cm lateral incision is made at this point, the iliotibial tract is incised longitudinally, and the periosteum is stripped from a small area of the lateral femoral condyle. The C-arm is used to visualize the entry point of the guide wire in both the anteroposterior plane and the lateral plane. With the C-arm in the lateral plane, the point of the guide wire is introduced freehand 2 mm to 3 mm into the femoral epiphysis. The pin is not angled anteriorly or posteriorly but is kept perpendicular to the femur in the coronal plane. The C-arm is then rotated to the anteroposterior plane to ensure that the guide wire is not angled superiorly or inferiorly. The guide wire is then driven across the femoral epiphysis perpendicular to the femur and distal to the physis (Figures 1A and 1B). The entrance of the guide wire into the intercondylar notch is subsequently visualized arthroscopically. The guide wire should enter at the center of the anatomical footprint of the ACL on the femur.

The femoral guide wire is left in place, and a second guide wire is inserted into the anteromedial aspect of the tibia through the epiphysis with the aid of a tibial drill guide. From the direct lateral position, the C-arm is rotated externally approximately 30° to provide a clear view of the physis extending into the tibial tubercle. The guide wire is then drilled into the tibial epiphysis under real-time fluoroscopic imaging (Figure 2). The handle of the drill guide must be lifted for the pin to clear the anterior part of the tibial physis. The pin should enter the joint at the level of the free edge of the lateral meniscus and in the posterior footprint of the ACL on the tibia. The obliquity of the tibial drill hole will result in a more anterior position of the ACL graft than would normally occur with a tibial drill hole that is more vertical, allowing the graft will lie in a more anatomic position. The positions of both guide wires should be confirmed arthroscopically at this point to ensure they are appropriate.

Tendon sizers are used to measure the diameter of the quadruple tendon grafts, which typically ranges from 6 mm to 8 mm. Because a tight fit is important, the smallest appropriate drill is used to ream over both guide wires. The edge of the femoral hole (Figure 1C) is chamfered intra-articularly and the width of the lateral femoral condyle is measured. The appropriate EndoButton CL (Smith & Nephew, Memphis, Tennessee) is chosen so that approximately 2 cm of the quadruple hamstring tendon grafts will remain within the lateral femoral condyle. The EndoButton is then passed around the middle of the double tendons and is looped inside of itself to secure the tendons proximally (Figure 3). When looped around the tendons in this way, a 2.5-cm continuous loop will be approximately 1 cm to 1.5 cm long, depending upon the diameter of the tendons. Alternatively, the tendons can be placed through the continuous loop before the tendon ends are sutured together. If this method is chosen, a 1.5-cm continuous loop will probably be the appropriate size.

Figure 2. Lateral view of the tibia demonstrating position of the tibial guide wire. Although the guide wire appears to enter the tibial tubercle in this view, it enters the epiphysis medial to the tibial tubercle.

A No. 5 Fiberwire suture is inserted in one end of the EndoButton, and a suture passer is used to pass it from anterior to posterior through the tibia and out the lateral femoral condyle (Figure 3). The EndoButton and tendons are then pulled up through the tibia and out of the femoral tunnel with the use of the No. 5 suture. An EndoButton or AO washer (Smith & Nephew), 3 mm to 4 mm larger than the femoral tunnel, is placed over the EndoButton (Figure 4). The washer is necessary to anchor the graft proximally because the tunnel in the lateral femoral condyle is larger than the EndoButton. Tension is then applied to the tendons distally, which pulls the EndoButton and washer to the surface of the lateral femoral condyle. The grafts are placed under tension, and the knee is extended to determine arthroscopically whether there is impingement of the grafts on the intercondylar notch. Although an anterior notchplasty is usually unnecessary when this technique is used, if the anterior outlet of the intercondylar notch touches or indents the grafts in terminal extension, a small portion of the anterior outlet may be removed. With the knee in 10° of flexion, the quadruple hamstring grafts are secured distally by tying the No. 2 Fiberwire sutures over a tibial screw and post that is placed medial to the tibial tubercle apophysis and distal to the proximal tibial physis (Figure 5). If the tendon grafts extend through the tibial tunnel, figure-8 stitches are used to secure them to the periosteum of the anterior tibia with multiple No. 1 Ethibond sutures (Figure 6). The subcutaneous tissue and skin are closed in a routine fashion, and a hinged brace is applied.

Figure 3. The semitendinosus and gracilis tendons are pulled up through the tibia and out of the lateral femoral condyle with the No. 5 suture tied to the EndoButton. (Reprinted with permission from Delilah Cohn.)

Postoperative Rehabilitation

The patient's knee is placed in a hinged brace postoperatively. Phase I of rehabilitation is started as soon as the patient awakes after surgery. The patient is encouraged to perform quadriceps muscle contraction and straight-leg raises. Cryotherapy is used for 5 to 10 minutes every hour. Range of motion exercises and hamstring muscle stretches while the patient is prone are started the day after surgery. Patients who did not require a meniscal repair are allowed to walk with crutches with weightbearing as tolerated. Patients who underwent a meniscal repair are allowed only toe-touch weightbearing for 6 weeks.

At 1 week after surgery, the goal is a range of motion from 0° of extension to 90° of flexion. Phase II of rehabilitation, the strengthening phase, lasts from 2 to 11 weeks postoperatively. Active range of motion exercises along with patella mobilization and electrical muscle stimulation are begun. Patients progress through the exercises at their own pace. They are fitted with a Neoprene brace (DonJoy, Los Angeles, California) with hinges 2 weeks after surgery, and full weightbearing is encouraged. Exercises are introduced into the rehabilitation program in order of increasing difficulty. These include hamstring and quadriceps muscle stretching and strengthening, proprioception exercises, functional strengthening, and aquatic strengthening exercises. The goal is a full range of motion equal to that of the contralateral normal knee at 6 weeks after surgery.

Figure 4. The EndoButton washer is placed over the EndoButton, and the washer is pulled back to the surface of the lateral femoral condyle. (Reprinted with permission from Delilah Cohn.)

Figure 5. The quadruple hamstring grafts are secured distally by tying the No. 2 Fiberwire suture over a screw and post. (Reprinted with permission from Delilah Cohn.)

Figure 6. Anteroposterior (A) and lateral (B) radiographs made 4 months after transepiphyseal anterior cruciate reconstruction in a 10-year, 8-month-old boy in Tanner stage I of development.

Phase III of rehabilitation lasts from 12 to 20 weeks postoperatively. This phase includes functional strengthening, straight-line jogging, plyometric exercises, Sport Cord exercises for jogging, lateral movement, and foot agility exercises. At 16 to 20 weeks postoperatively, patients are permitted to perform functional activities, including full-speed running, while wearing a brace. They are allowed to advance to full activity, including competitive sports, 28 weeks after surgery.

CONCLUSION

The literature on ACL reconstruction in adults indicates that anatomic intra-articular ACL replacements are superior to extra-articular and modified ACL replacement procedures. Hypothetically, this would hold true for children and adolescents as well. Because of the risk of physeal injury and its potential consequences on normal development, the surgical technique used for intra-articular ACL replacements should be modified depending upon the patient's skeletal maturity. High-risk prepubescent patients in Tanner stages I and II of development and intermediate-risk pubescent patients in early Tanner stage III can be treated with efficacy and relative safety using a transepiphyseal ACL replacement. Lower-risk Tanner stage IV patients who are nearing skeletal maturity can be treated safely with a transphyseal reconstruction using small, centrally placed, perpendicular drill holes and quadruple hamstring grafts. Postpubescent Tanner stage V patients may be treated as adults.

Clinical Recommendations

SORT: Strength of Recommendation Taxonomy

A: consistent, good-quality patient-oriented evidence

B: inconsistent or limited-quality patient-oriented evidence

C: consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
For behavioral or other reasons the outcome of nonoperative treatment of ACL tears in children and adolescents is poor.	A
The success of ACL reconstruction in this age group supports a recommendation for aggressive treatment in this age group.	A
The type of ACL reconstruction is influenced by the patient's skeletal age and sexual maturity.	C
Transepiphyseal replacement is recommended for prepubescent patients in Tanner stages I or II of development, including boys younger than 12 years or girls younger than 11 years of age.	C

For more information about the SORT evidence rating system, see www.aafp.org/afpsort.xml and Ebell MH, Siwek J, Weiss BD, et al. Strength of Recommendation Taxonomy (SORT): a patient-centered approach to grading evidence in the medical literature. *Am Fam Physician*. 2004;69:549-557.

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