



Operative Technique: Pediatric All-Epiphyseal Anterior Cruciate Ligament Reconstruction with Quadrupled Semitendinosus Autograft

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Introduction

Anterior cruciate ligament (ACL) tears in skeletally immature patients are more prevalent today than ever before.¹⁻⁴ The management of ACL injury in this patient population is challenging and controversial. Employing non-operative measures with bracing and activity modification or delaying surgical intervention to skeletal maturity raises concerns from a compliance standpoint and risks further intra-articular damage.⁵⁻⁸ Although prompt surgical reconstruction provides functional knee stability, risk for disruption of the physis and growth disturbance is present, potentially resulting in limb length inequality or angular deformity.⁹⁻¹¹

For partial tears of the ACL, non-operative treatment has been shown to be successful in children and adolescents less than fourteen years of skeletal age.¹² A recent systematic review of current evidence found overwhelming support for surgical stabilization as the preferred treatment in skeletally immature patients with complete ACL tears.¹³

Background

For pediatric ACL reconstruction, several principles guide treatment to reduce the risk of growth disturbance: avoid fixation across the physis, refrain from disrupting the perichondrial ring and surrounding tissues, make drill holes small and centrally located when crossing the physis, and be wary of tensioning a soft tissue graft across the physis if significant growth remains.^{9,14-16}

Various physal-sparing techniques have been previously described.¹⁷⁻²¹ However, there are limitations to these techniques, such as tensioning of the graft across the tibial physis¹⁷⁻¹⁹ or nonanatomic positioning of the ACL graft.^{20,21} We developed and previously described an all-epiphyseal ACL reconstruction technique using a socket in the tibia to place the graft at the native footprint of the ACL.¹⁵ Subsequent to that study, recent refinements to the instrumentation have allowed for the all-epiphyseal ACL reconstruction to be less invasive and less disruptive to the anatomy of prepubescent patients. For more skeletally mature patients, partial transphyseal and traditional transphyseal techniques may be considered.

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Preoperative Evaluation and Surgical Indications

The anterior drawer, Lachman, and pivot shift tests may reveal pathologic laxity in the ACL-deficient knee. Radiographs of the knee are performed, including AP, lateral, notch and patellar views, to assess for other potential injuries common in pediatric and adolescent patients, such as tibial spine avulsion fractures or osteochondritis dissecans. Knee magnetic resonance imaging (MRI) can confirm the presence of an intra-substance ACL tear as well as meniscal or chondral pathology.

The severity of the ACL tear is important to characterize. Incomplete ACL tears may be treated nonoperatively if the patient and family's are willing to adhere to a strict activity restriction protocol. For complete tears of the ACL, surgical reconstruction is recommended after a thorough discussion with the patient and family about the risks and benefits. Preoperative wrist radiographs are taken to determine bone age using the Greulich and Pyle atlas.²²

Procedure

Standard anteromedial working and anterolateral viewing arthroscopy portals are established. Arthroscopic confirmation of a complete intra-substance tear of the ACL is first accomplished. Any residual ACL stump is removed, and the femoral and tibial footprints are identified. Associated meniscal pathology, if present, is also addressed.

For all-epiphyseal reconstruction, pilot tracks are created by guide pins in the tibial and femoral epiphyses centered in the ACL footprint in a trajectory that also avoids the physes. Confirmation of positioning is accomplished with either O-arm 3-D CT scanner (Medtronic, Inc., Minneapolis, MN) or C-arm imaging. A stepped guide pin sleeve is placed over the pins and is malleted into tibial and femoral cortical bone to its depth stop. A FlipCutter (Arthrex, Naples, FL) allows "inside-out" drilling of tibial and femoral sockets without violation of the exterior cortices and periosteum.

Two ACL TightRope RT implants (Arthrex, Naples, FL) are placed on opposite ends of

a quadrupled semitendinosus autograft. Alternatively, a TightRope ABS Implant and Button (Arthrex, Naples, FL) may be used on the tibial side of the graft. A total graft length of at least five millimeters shorter than the combined total measured femoral and tibial bone socket lengths and intra-articular distance allows for proper graft tensioning to be achieved during fixation.

Solid and striped high-strength sutures are utilized to assist in passing the graft into the femoral and tibial sockets. After button flipping is confirmed, cinching suture limbs are pulled to draw the graft into the sockets. Additional tibial fixation may be achieved, if desired, by securing the tensioning suture limbs into epiphyseal bone using a PushLock anchor (Arthrex, Naples, FL).

The partial transphyseal technique combines the all-epiphyseal femoral tunnel with a traditional transphyseal tibial tunnel.

Postoperative Protocol

Cryotherapy and continuous passive motion are used for the first three weeks postoperatively. For the initial four weeks, weight-bearing is restricted to toe-touching with a brace locked in extension during ambulation. Physical therapy following a standard ACL protocol is initiated five days postoperatively and continued until strength and functional testing are equal to the contralateral, unaffected limb. Routine follow-up visits and radiographs are conducted to monitor progress and signs of growth disturbance. Patients return to sports at nine months postoperatively and are followed on a yearly basis thereafter until skeletal maturity.

Discussion

For the skeletally immature patient with a complete ACL tear, the potential sequelae of growth disturbance of the physis are significant. Therefore, the appropriate technique based on bone age and remaining growth should be employed. We advocate stratifying ACL reconstruction techniques based on bone age determined by wrist radiographs, similar to a previously described treatment algorithm.¹⁶

For patients with bone ages between ten and twelve, the refined all-epiphyseal technique with cortical button fixation is advised (Fig. 1A). The senior author has observed good functional outcomes with this technique without evidence of growth disturbance.

A partial transphyseal technique is recommended for patients with bone ages ranging from twelve to fourteen, where a moderate amount of growth remains (Fig. 1B). Previous clinical studies of a partial transphyseal technique have documented good results. Andrews *et al* followed eight patients with a mean age of 13.5 years status post partial transphyseal reconstruction to skeletal maturity and found excellent stability and no difference in lower limb lengths.²³ Similarly, Lo *et al* reported on five consecutive patients with a mean age of 12.9 years and a minimum follow-up of 4.5 years and found no evidence for leg length discrepancy.²⁴

Seven of the nine patients (mean age of thirteen years) in the report by Bisson *et al* had excellent results with no signs of growth disturbance and full return to sports.²⁵ Two grafts ruptured and were considered failures. Guzzanti *et al* performed their reconstruction with a transphyseal femoral tunnel.²⁶ Ten adolescents in Tanner stages two and three



Figure 1A-B. Postoperative ACL reconstruction radiographs revealing tunnel locations (black) and course of soft tissue graft (gray). A) Patient with a bone age of 10 having undergone the all-epiphyseal technique with cortical button fixation. In summary: 1. Tunnels avoid physes. 2. The senior author prefers hamstring autograft; however, surgeons may elect graft of choice. 3. Fixation avoids the physes. B) Patient with a bone age of 12 having undergone a partial transphyseal procedure. In summary: 1. Femoral tunnel is below physis 2. Tibial soft tissue graft only traverses physis 3. Fixation again avoids physes.

reached skeletal maturity with no evidence for growth disturbance and returned to sports with no restrictions.

A traditional transphyseal reconstruction, as conducted in adults, is preferred for patients with bone ages above fourteen, where the risk for growth disturbance is minimal. Prior reports of the transphyseal technique have also documented satisfactory results. Aronowitz *et al* showed satisfactory patient results and no growth disturbance in nineteen adolescents with a skeletal age of at least fourteen years.²⁷ Kocher *et al* reported excellent functional results and a low revision rate and minimal growth disturbance on fifty-nine skeletally immature adolescents in Tanner stages three with mean chronological age of 14.7 years.²⁸ Sankar *et al* conducted a survivorship analysis of girls with bone ages greater than 13 years and boys with bone ages greater than 14 years undergoing transphyseal ACL reconstruction.²⁹ At one year and five years, 96.4% and 93.1% of patients, respectively, had no reports of knee instability or required revision surgery.

By using bone age as a guide for ACL reconstruction in the skeletally immature patient with a complete ACL tear, the benefits of operative intervention are provided while the risks for growth disturbance across the distal femoral and proximal tibial physes are minimized.

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