Anterior Cruciate Ligament Injuries in Skeletally Immature Patients

Douglas R. Johnston
Theodore J. Ganley, MD
John M. Flynn, MD
John R. Gregg, MD

The past decade has seen a marked increase in medical literature addressing anterior cruciate ligament (ACL) injuries in young athletes. This increase is related to the following factors: 1) increased participation of young males and females in sports, 2) increased participation in sports of a higher competition level, and 3) increased awareness and improved techniques of the examiner.1 2

A few reports in the literature have sought to determine the incidence of ACL tears in the young athlete. Souryal and Freeman3 previously studied 902 high school athletes for a 2-year period and found a 3% ACL injury rate in those athletes with knee injuries. In 1983, DeLee and Curtis4 reported an ACL injury incidence of 1% (3 of 338) in children aged <14 years with knee injuries. Additional incidence reports include values of 3.4% and 3.3% presented by Lipscomb and Anderson5 and McCarroll et al.,6 respectively.

Anterior cruciate ligament injuries in adults have been reviewed extensively7-10; however, children with ACL injuries constitute a unique patient population due to continuing growth and differing ligamentous and bone strength. Damage to a child’s open physes could potentially cause angular deformity, limb-length inequality, and condylar dysplasia, which could lead to significant functional limitations. It also is important to remember that differences exist within the pediatric population, as some children are prepubescent with significant growth remaining and others are nearing skeletal maturity. Thus, the physiological differences amongst children of different ages prohibit orthopedists from making generalizations regarding ACL injuries in the pediatric population.

Nonoperative management has been associated with persistent instability and meniscal tears,5-11-15 which is why extra-articular surgical options now receive more attention. Additionally, because children may not comply with activity restrictions or because of a lack of understanding of the severity and nature of their injury, nonoperative management is less likely to be a success.

Despite the recent surge in literature addressing ACL injuries in young patients, the risks in the surgical treatment to the pediatric knee are not as well documented as in the adult population. To assess the potential damage of surgical intervention for ACL injury, future studies must also focus on the reconstructed knee long after maturity has been reached. In this way, long-

---

Educational Objectives

As a result of reading this article, physicians will be able to:

1. Define the diagnostic principles in evaluating an anterior cruciate ligament (ACL) tear in the pediatric population based on presentation and physical examination.

2. Identify what age-related factors influence the appropriate treatment of ACL tears in the pediatric population.

3. State the reasons for the relative abandonment of certain treatment options and the acceptance of others in addressing ACL tears in skeletally immature patients.

4. Recognize that certain principles must be followed to safely treat pediatric patients with ACL tears with transphyseal surgical techniques.

---

Drs. Johnston, Ganley, Flynn, and Gregg have not declared any industry relationships.

www.orthobluemagazine.com
term results can help enumerate additional surgical risks, such as graft failure and early arthritis. Because limitations are inherent in each study, future investigations must attempt to limit the problems that have potentially led to inaccuracy in past reports. These problems include, but are not limited to: categorizing all pediatric patients with ACL deficiencies into one group; failing to report accurate age, accurate skeletal maturity, and gender; and not reporting specific descriptions of successful and unsuccessful outcomes.

This article reviews the biomechanics, clinical history, physical examination, radiographic evaluation, and treatment options for ACL injuries in the pediatric population.

**TIBIAL EMINENCE FRACTURES**

In younger children, bone is weaker under tensile/shear forces than the ligaments,\(^1\,^2\,^9\,^10\) which explains why ACL injuries in younger children more frequently involve a breach in the bone at the tibial eminence, as opposed to the ACL. Kellenberger and von Laer,\(^16\) in a study of 62 patients with ACL injuries, reported an 80% incidence of tibial spine avulsions in children aged <12 years in comparison to a 90% incidence of midsubstance ACL tears in children aged >12 years.

In 1970, Meyers and McKeever\(^17\) classified fractures of the intercondylar eminence into three types: type I fractures have minimal or no displacement, type II fractures display a partially attached portion of the tibial eminence, and type III fractures are characterized by complete displacement of a bony fragment. A type III+ fracture has rotational malalignment. A tibial eminence fracture, recognized by Zaricznyj\(^18\) in 1977, is type IV and represents a comminuted fracture.

Anatomic reduction of intercondylar tibial eminence fractures is achieved with closed reduction and casting for type I and II fractures. Some believe, however, that type II fractures should be addressed arthroscopically and fixed with sutures to remove bony debris and view potential soft-tissue damage.\(^19\)

Closed reduction of tibial eminence fractures can be complicated by entrapment of the meniscus ligament beneath the fracture fragment, resulting in improper reduction.\(^20\,^20\) Type III and IV fractures are primarily treated with reduction and fixation with sutures and drill holes using open or arthroscopic techniques.\(^21\,^22\)

Fixation with cannulated screws has been described\(^23\) and, in some instances, may be a technical challenge due to the proximity of the avulsion to the growth plate. The association of tibial eminence avulsion with collateral ligament and meniscal damage\(^17\,^18\,^22\,^24\) underscores the importance of a thorough examination and evaluation of all imaging studies. It should also be noted that, on rare occasions, it is possible for a femoral avulsion fracture to occur at the femoral ACL attachment site, which can be corrected with open reduction using suture fixation.\(^25\,^26\)

**BIOMECHANICS**

In the skeletally immature knee, longitudinal growth occurs at the distal femoral and proximal tibial physis. Widening of the bone occurs at the periphery, which includes the zone of Ranvier and the ring of Lacroix, and the growing ossific nucleus develops the condyles and tibial plateau.\(^27\,^28\)

Surgical considerations in the pediatric knee involve the effects of compression and tension on physeal bone growth. The Heuter-Volkmann principles (originally proposed by Delpoch\(^29\)) dictate that whereas certain amounts of compression and tension can stimulate physeal bone growth, forces outside of the physiological limits can stunt bone growth, producing progressive deformity. The formation of a bone bridge across a physis also can cause supra-physiologic compression and lead to deformity. It also is important to note that growth inhibition can occur with supraphysiologic ACL tension loads in the absence of bone bridge formation across the physis.\(^30\) These growth concerns are important considerations for surgical ACL reconstructions in children in which tension is placed across the physes, or in which transphyseal tunnels are drilled.

**CLINICAL HISTORY**

Anterior cruciate ligament injuries usually are caused by knee twisting, a blow to the knee, or knee hyperextension, during which the foot remains fixed on the ground. These injuries commonly result in knee hemarthroses and the tear often can be heard as a “popping” sound. Children with chronic ACL injuries may sustain recurrent effusions and instability, which is characterized by repeated “giving way.” Some children may present with congenital ACL deficiencies, which may represent the absence of the ACL or constitutional laxity.

Absence of the ACL is associated with other congenital abnormalities, such as proximal focal femoral deficiency, congenital knee dislocation, and leg-length discrepancy.\(^31\,^33\) Additionally, physiologic laxity often is seen in the pre-pubescent knee, which can lead to a misdiagnosis of ACL injury.\(^20\) For these reasons, it is essential that the uninjured knee is examined in all children presenting with ACL instability. Based on the child’s accounts of which motions and positions are responsible for giving way, along with a physical examination of both knees, the examiner can determine if an ACL deficiency exists.

**Physical Examination**

Physical examination of the injured knee should be accompanied by the examination of the contralateral knee to rule out generalized ligamentous laxity and anatomic deformity. Patients often present a few days after injury with knee effusion, lack of knee extension, and an antalgic gait with a shortened stance phase in the affected extremity. Passive motion often is painful, and the patient may exhibit guarding, which can limit ligamentous stress testing.

When the swelling and discomfort...
improve, usually after several weeks, complete ligamentous stress testing can be performed. A firm endpoint with the Lachman's test signals the presence of the ACL. The amount of increased excursion with the Lachman test quantifies existing pathologic laxity. Positive results with other familiar orthopedic tests, such as the anterior drawer, pivot shift, and flexion-rotation tests, also indicate ACL insufficiency. Patella stability also should be tested to rule out patella subluxation or dislocation. Symmetry of hip range of motion should be checked to uncover potential pathologic hip conditions that may refer pain to the knee, such as a slipped capital femoral epiphysis.

Radiographic Evaluation
Anteroposterior, lateral, tunnel, and patella radiographs should be obtained to preclude tibial eminence fractures, osteochondral damage, and periarticular fractures. Magnetic resonance imaging (MRI) is a valuable tool in determining occult fractures and the extent of soft-tissue damage of the ACL and other supporting structures, including the menisci (Figure 1).

TREATMENT OF MIDSUBSTANCE ACL TEARS
Skeletal Age
The treatment of ACL tears in the pediatric population revolves around the skeletal age and how to address the open physis. The knee is a vital growth center, where approximately 65% of lower extremity growth occurs. To select a treatment plan within the pediatric population, accurate evaluation of the child's skeletal age and remaining growth is necessary to avoid physeal and epiphyseal growth disturbances leading to angular deformity, leg-length discrepancy, and condylar dysplasia.

Wester et al. created a series of graphs that help predict leg-length discrepancies and angular deformities of the distal femoral and proximal tibial physes after transphyseal surgical reconstruction in skeletally immature patients. Several factors are helpful in determining skeletal age, including bone age evaluation by wrist radiographs according to Greulich and Pyle. Secondary sex characteristics, patient and familial height, and recent foot growth. Based on these factors, an informed decision regarding risk to the growth plates can be made.

Nonsurgical Treatment
As in the adult population, nonsurgical treatment of ACL tears in skeletally immature patients has led to recurrent instability, with a poor outlook for patients returning to previous athletic levels. The recurrent instability associated with nonoperative treatment can lead to further episodes of giving way, which not only increases meniscal damage, but also leads to undue trauma to the articular cartilage. Nonoperative options include bracing, quadriceps and hamstring strengthening, activity modification, and counseling.

In a review of 32 adolescent patients treated by cast immobilization, Kannus and Jarvinen reported good to excellent results for partial ACL tears, as diagnosed by clinical testing (25 of 32), but poor long-term functional results with continuous symptoms and some osteoarthritis in those with complete ACL tears (7 of 25).

Angel and Hall reported 22 patients treated conservatively at average 51-month follow-up. They found that no patients with complete ACL tears were capable of returning to sports and 41% of patients had associated meniscal pathology.

Graf et al had similar results with 12 patients with open physes. Eight patients experienced recurrent episodes of “giving way” after treatment with hamstring and quadriceps strengthening and returning to sports with a brace. Seven patients also sustained further meniscal damage within 7-27 months.

Primary Repair Procedures
Primary repair procedures in the pediatric population have been relatively unsuccessful in the limited existing literature. In 1983, DeLee and Curtis reported three children who underwent primary ACL repair. All three patients later reported clinical laxity. Engelbrecht et al reported eight patients treated with surgical repair. Similarly, all were restricted to limited
activity and five reported gross instability.

The failure of primary repair procedures is related to the anatomic position of the ACL, in that it is intra-articular and extrasympathetic. Because the ACL exists outside of the bone, it has a unique blood supply that derives from the ligamentous branches of the middle genicular artery and the terminal branches of the medial and lateral inferior genicular arteries. Additionally, the ACL is compartmentalized from the synovium by a synovial fold, which is richly vascularized, predominantly by vessels from the ligamentous branches of the middle genicular artery. When the ACL tears, it not only severs its blood supply, but also tears the synovial sheath, exposing it to the synovium, which does not offer the healing factors that facilitate repair. Combined with the intrinsic changes that naturally occur with a midsubstance tear, the loss of blood supply and exposure to the synovium results in insufficient repair abilities, a handicap that limits the efficacy of primary repair techniques.

**Extrashyal Surgical Intervention**

Extra-articular procedures for ACL insufficiencies in skeletally immature patients have achieved mixed results. The goal of these surgeries is to provide increased stability and refrain from drilling across open physes. In 1988, McCarron et al.\(^4\) reported 10 patients who received either an AO tenodesis of the iliotibial band (3 patients) or a modified Andrews iliotibial band tenodesis. Of these 10 patients, 5 returned to sports without problems, 4 experienced one episode of giving way without further problems, and 1 experienced a re-injury. In a separate study by Graf et al.\(^3\), 2 patients were treated with medial meniscal repair and the modified Andrews iliotibial band technique. Both patients reportedly developed symptomatic instability.

Extra-articular augmentation serves a role in providing temporary stability to young patients until they reach skeletal maturity.\(^2\)\(^,\)\(^4\)\(^,\)\(^3\) And some authors report favorable results beyond skeletal maturity.\(^3\)

DeLee\(^2\) recommends treating pediatric patients with chronic ACL instability of a mild degree with extra-articular repair. After detaching the proximal origin of the iliotibial band, DeLee favors passing it behind the lateral collateral ligament, through an osteoperiosteal tunnel that lies superior to the distal femoral physis and then back under the lateral collateral ligament to be attached by a screw into Gerdy's tubercle. This procedure avoids passing the iliotibial band around the lateral collateral ligament, thus, avoiding placing unneeded stress at the distal femoral physeal plate during rehabilitation and sports activities.\(^2\)

Bergfeld's technique,\(^2\) also called the tomato stake repair, involves taking a portion of the infrapatellar tendon, which is left attached to the tibial tubercle, and passing it over the front of the tibia, beneath the transverse ligament, and then over the lateral condyle of the femur, where it is attached above the physis (Figure 2).

Drez modified Bergfeld's technique by passing the graft through a groove in the tibial physis that allows for more posterior positioning. The graft is then placed in the over-the-top position of the femur through a second groove below the femoral physis, which places the graft more anteriorly. The combination of posterior positioning at the proximal tibia and anterior positioning at the distal more closely approximates the position of the ACL.

Micheli et al.\(^4\) advocate a combination of intra- and extra-articular surgical intervention that avoids the growth plates. A modification of the MacIntosh and Darby\(^4\) combined intra- and extra-articular procedure, Micheli's technique passes the iliotibial band around the lateral femoral notch, through a notchplasty, and attaches it in an over-the-top position on the proximal tibia. The graft is sutured to the periosteum medial to
TABLE

<table>
<thead>
<tr>
<th>Study</th>
<th>Technique</th>
<th>No. Patients</th>
<th>Average Patient Age</th>
<th>Average Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipscomb &amp; Anderson(^5)</td>
<td>Semitendinosus and gracilis tendons across physis; often supplemented with Ellison or Losee extra-articular reconstruction</td>
<td>24</td>
<td>11—completely open physis, 13—partially open physis</td>
<td>35 mos</td>
</tr>
<tr>
<td>McCarroll et al(^6)</td>
<td>Patellar tendon across physis</td>
<td>14</td>
<td>13 y</td>
<td>26 mos</td>
</tr>
<tr>
<td>McCarroll et al(^3,4)</td>
<td>Patellar tendon across physis</td>
<td>60</td>
<td>14.2 y</td>
<td>4 y</td>
</tr>
<tr>
<td>Andrews et al(^11)</td>
<td>Achilles allograft through tibial physis and over-the-top position on femur</td>
<td>8</td>
<td>13.5 y</td>
<td>58 mos</td>
</tr>
<tr>
<td>Lo et al(^45)</td>
<td>Hamstring or patellar tendon through PT physis and over-the-top position on femur</td>
<td>5</td>
<td>12.9 y†</td>
<td>7 y</td>
</tr>
<tr>
<td>Matava &amp; Siegel(^46)</td>
<td>Hamstring autograft through physis</td>
<td>8</td>
<td>14 y 9 mos</td>
<td>32 mos</td>
</tr>
<tr>
<td>Aronowitz et al(^1)</td>
<td>Achilles allograft through physis</td>
<td>19</td>
<td>13.4 y</td>
<td>25 mos</td>
</tr>
</tbody>
</table>

*Includes data from McCarroll et al\(^6\) 1988 study.
†All patients had wide open physis.

the tibial tubercle and proximally at the lateral femoral condyle (Figure 3). All 17 children with ACL insufficiency in the study by Micheli et al\(^43\) were prepubescent at surgery and no patient received intra-articular surgical intervention during average 66-month follow-up.

**Transphyseal Surgical Intervention**

Although transphyseal ACL reconstructions are the treatment of choice in adults, procedures that drill across the physis of the distal femur or proximal tibia are controversial in skeletally immature patients. For the most part, these transphyseal procedures have been used in children at or nearing skeletal maturity (Figure 4).\(^1,2,11,45,46\) A synopsis of transphyseal ACL reconstruction studies is provided in the Table. The debate remains amongst orthopedists regarding the age and maturity level at which it is safe to drill across open physis. Although young athletes frequently wish to return to sports as soon as possible, transphyseal surgery is not always the safest solution.

In 1995, Stadelmaier et al\(^47\) determined whether placing a soft-tissue graft across an open physis would result in bony bridge formation. The study was comprised of two groups of skeletally immature dogs that received drill holes across the distal femur and proximal tibia. One group had fascia lata autograft placed through the tunnels in a manner duplicating ACL reconstruction. The other group received the same drill holes, but had nothing placed through the tunnels. All dogs in the soft-tissue group had no bony bridge formation and all dogs with empty tunnels had bony bridge formation. These results demonstrate that soft-tissue grafts can possibly be used in ACL reconstruction of skeletally immature patients without the formation of bony bridges across the open growth plate.

Guzzanti et al\(^48\) performed intra-articular ACL reconstructions in skeletally immature rabbits by placing the semitendinosus tendon across the physis of the distal femur and proximal tibia. They noted damage to 11% of the frontal plane of the femoral physis and 12% damage to the frontal plane of the tibial physis. Additionally, they found 3% damage to the cross-sectional area of the femoral physis and 4% to the cross-sectional area of the tibial physis. No alteration of growth or axial deviation of the femora was noted, but two tibiae developed valgus deformities and one shortened. Because of mixed results, they suggested careful evaluation of the potential damage to the growth plate before using transphyseal reconstruction methods for ACL-deficient children.

Edwards et al\(^30\) reported results of a study examining the effect of an excessively tensioned graft across the physis of skeletally immature beagles. In their study, 10-week-old beagles underwent ACL reconstruction with 1-cm fascia lata autografts through the distal femoral and proximal tibial physis using 4-mm diameter drill holes. The grafts were tensioned at 80 N (the amount advocated by Yasuda et al\(^49\) in adult patients) and fixed with screws and washers. The contralateral limbs served as controls. Significant valgus deformities of the distal femur
<table>
<thead>
<tr>
<th>Results</th>
<th>Adverse Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent (n=16), good (n=7), fair (n=1); none reported giving way; 1.8-mm side-to-side difference</td>
<td>2-cm leg-length discrepancy (n=1); moderately severe anterior drawer sign (n=2)</td>
</tr>
<tr>
<td>Returned to previous athletic levels without reinjury (n=13); 1.7-mm side-to-side difference</td>
<td>Meniscal reinjury (n=1)</td>
</tr>
<tr>
<td>Returned to previous athletic levels without reinjury (n=51); ≤3-mm side-to-side difference (n=51)</td>
<td>≥4-mm side-to-side difference (n=9), late ACL graft tears (n=3), late meniscal tear (n=1)</td>
</tr>
<tr>
<td>Excellent (n=6), good (n=1), fair (n=1); ≤3-mm side-to-side difference (n=5)</td>
<td>Deterioration of femoral sulcus region (n=1)</td>
</tr>
<tr>
<td>Returned to previous athletic levels without reinjury (n=4); ≤3-mm side-to-side difference (n=5)</td>
<td>Late patellar osteochondral fracture (n=1)</td>
</tr>
<tr>
<td>Returned to previous athletic level without reinjury (n=7); ≤3-mm side-to-side difference (n=7)</td>
<td>8-mm side-to-side difference (n=1); late reinjury (n=1)</td>
</tr>
<tr>
<td>Returned to previous athletic levels without reinjury (n=16); 1.7-mm side-to-side difference</td>
<td>Late meniscal tear (n=1)</td>
</tr>
</tbody>
</table>

and significant varus deformities of the proximal femur were found, therefore, significant growth disturbances could occur with excessively tensioned transphyseal reconstruction techniques. The 80 N of tension used on the beagle knee and the ratio of tunnel and graft size may be disproportionate to the appropriate tension and graft and tunnel size for ACL reconstruction in the pediatric knee. These results, however, remind orthopedists that transphyseal repair of ACL tears may result in growth disturbances in the skeletally immature population.

In 1986, Lipscomb and Anderson reported their results of transphyseal ACL reconstruction in 24 adolescents from 1977-1983. Their technique used the semitendinosus and gracilis tendons and drilled across the proximal tibial physis and the distal femoral epiphysis. Eleven patients had completely open physes at the time of surgery, and 13 had partially open physes. At average 35-month follow-up, 16 patients reported having a normal knee and 8 stated it was improved. Patients reported no swelling or giving way, but 3 had occasional clicking, 6 had occasional discomfort, and 9 experienced postoperative crepitus. The side-to-side laxity difference was reported at a mean of 1.8 mm. Six patients had a leg-length discrepancy between 6 and 10 mm, while one patient had a 1.3-cm difference and another a 2-cm difference.

In 1988, McCarron et al reported 14 patients who underwent transphyseal ACL reconstruction with patellar tendon autografts. To meet the requirements for transphyseal surgery, patients had to be at least 14 years old, not have a bone age ≤6 months than the chronological age, no growth potential remaining (as evaluated by family history), and complete maturity according to Tanner's classification. The patellar tendon was passed through drill holes in the distal femoral and proximal tibial physes. Six patients had dynamic biceps tendon transfer and 8 underwent iliotibial band reinforcement. At an average 26-month follow-up, all 14 patients returned to their previous athletic level. The average passive anterior drawer sign was 1.7 mm on KT-1000 arthrome-

ter examination, and there were no growth aberrations.

In 1994, McCarron et al reported 60 patients who underwent patellar tendon graft reconstruction across the distal femoral and proximal tibial physes. At surgery, 57 of 60 patients were at least 14 years old. The following criteria were required for surgical intervention: unwillingness to modify activity levels, clinical and radiographic evidence of skeletal maturity, positive Lachman and pivot shift tests, or evidence of a repairable meniscal tear. At minimum 2-year follow-up, 56 of 60 patients were able to return to their original sport with no incidence of abnormal growth, episodes of giving way, or leg-length discrepancy. One patient sustained a meniscal tear after the surgical repair. Although McCarron et al treated some 13-year-old patients, they advised against using transphyseal techniques in any patient with significant growth remaining.

Andrews et al reported eight adolescent patients who underwent ACL reconstruction using a fascia lata or Achilles tendon allograft placed across the proximal tibial physis and in an over-the-top position on the femur (Figure 5). Seven of eight patients had good to excellent ratings and one had a fair rating. At average 58-month follow-up, no patient had a clinically significant leg-length discrepancy, and KT-1000 arthrometer revealed <3-mm discrepancy between knee laxity in five patients, and a 3-5 mm difference in the remaining 3 patients.

Lo et al reported using a technique in which a graft was placed through a 6-mm transphyseal tibial tunnel and in the over-the-top position on the femur. They reported five patients with “wide open” physes, with an average age of 12.9 years. Three reconstructions were performed with hamstring tendons and two with quadriceps prepatellar fascia-patellar tendons. At average 7-year follow-up, no significant leg-length discrepancies were noted, and no patient had positive anterior drawer, Lachman, or pivot shift tests. The mean instrumented side-
to-side laxity difference was 1 ± 1.6 mm. One patient sustained a patellar osteochondral fracture. Subsequent height growth by the patients averaged 14.3 cm and was consistent with the age-based predictions.

Matava and Siegel reported the results of semitendinosus-gracilis autograft use on eight skeletally immature patients. Grafts were placed through the distal femoral and proximal tibial physeal plate defects in 7- to 9-mm tunnels. All eight patients returned to their pre-injury sport and none had a clinically significant leg-length discrepancy. One patient had a repeat injury and an 8-mm side-to-side difference.

Aronowitz et al. reported the results of ACL reconstruction by placing an Achilles tendon allograft across the distal femoral and proximal tibial physeal plate in patients nearing skeletal maturity (Figure 6). This study included 19 patients with an average age of 13 years, all of whom were satisfied with their results. Sixteen of 19 patients returned to the same sport after reconstruction, and those who elected not to return to their previous sport stated that their decision was not based on symptoms in the reconstructed knee. Of the 15 patients who returned for follow-up, the mean side-to-side KT 1000 arthometer difference was 1.7 mm. Scanograms and long leg radiographs were obtained and no significant leg-length discrepancies or angular deformities were reported. Aronowitz et al. suggest patients obtain a bone age of at least 14 years in males and at least 13 years in females before undergoing this procedure to allow sufficient development of the physeal plate.

**CONCLUSION**

The treatment of skeletally immature patients with midsubstance ACL tears has eluded a general consensus amongst treating physicians. However, nonoperative treatment in children who do not significantly modify their activities has been unsuccessful and has led to increased ACL instability and potential meniscal damage.

Primary ACL repair in skeletally immature children also has produced poor functional results and increased laxity. The use of intra-articular surgical repair has achieved mixed results, but is, perhaps, a valuable method of providing stability to skeletally immature patients until skeletal maturity is near and transphyseal procedures are less risky to the physis. Several successful techniques for transphyseal ACL reconstruction in adolescents at or nearing skeletal maturity have been reported in the literature.

In choosing a management protocol, growth plate considerations should continue to shape the treating physician's decision. Further basic science research may elucidate when transphyseal drilling is appropriate in skeletally immature patients. Similarly, determining which techniques best address the deficient ACL in the adolescent population depends on continued reports of relative success and failure and on an increase in prospective and long-term evaluations.

**REFERENCES**


2. Lo IK, Bell DM, Fowler PJ. Anterior cruciate ligament injuries in the skeletally immature patient.