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Anterior Cruciate Ligament Re-tear and Revision Reconstruction in the Skeletally Immature Athlete

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Abstract

Purpose of Review With an increase in high-demand sporting activity, the rate of pediatric and adolescent anterior cruciate ligament (ACL) reconstruction is increasing. Yet, the failure rates after reconstruction are much higher than the adult population. The purpose of this paper is to understand failure rates, reasons for graft failure, and strategies for successful revision surgery.

Recent Findings A complete understanding of the failure etiology is essential for the clinician treating this population prior to revision. This begins with an assessment of post-operative patient compliance and sporting activity. Surgical technique must then be scrutinized for non-anatomic tunnel placement and poor graft size/type. Concurrent bony deformity must also be addressed including lower extremity valgus alignment and tibial slope abnormalities. Meniscus and chondral injury must be aggressively treated. Furthermore, imaging must be examined to look for missed posterolateral corner injury. Lateral extra-articular tenodesis (in the setting of ligamentous laxity or rotational instability) may be also indicated as well. The surgeon can then choose a graft type and surgical technique that optimizes outcome and respects skeletal growth. Prior to surgical intervention, the clinician must also counsel patients in regard to the guarded prognosis and outcomes in this setting. Prolonged rehabilitation protocols/return-to-play timing as well as sporting activity modification in the post-operative period after revision are critical.

Summary There is limited literature on revision ACL reconstruction in the skeletally immature athlete. An understanding of all the risk factors for failure is essential in order to achieve treatment success.

Keywords Anterior cruciate ligament · Pediatrics · Anterior cruciate ligament reconstruction · Re-rupture · Revision · Revision outcome

Introduction

Youth sports culture has shifted from non-structured play to organized, single-sport specialization. This change in sports participation patterns has been linked to an increase in lower extremity injury risk [1, 2••]. Concurrent with this change has been a rise in pediatric and adolescent anterior cruciate ligament (ACL) reconstruction. Tepolt et al. examined the Pediatric Health Information System database and found that ACL reconstructions in patients under age 18 increased 3 times relative to other orthopedic procedures during a 10-year period [3••]. Similarly, Dodwell et al. found an increase in pediatric ACL reconstruction in NY state from 17.6 per 100,000 (ages 3 to 20) to 50.9 per 100,000 over a 20-year period [4]. The reasons for this are multifactorial and can be postulated to be due to change in sports participation patterns, increased injury recognition as well as the development of new surgical techniques.

Yet, unlike the adult population, the skeletally immature patient who suffers an ACL injury must balance the benefits of providing stability to the pediatric knee (and decreasing chondral injury) via surgery with the risk of growth disturbance [5]. Although multiple techniques have been described in the literature in order to minimize growth disturbance [6••, 7•], the more difficult aspect of care of the pediatric athlete who undergoes reconstruction may be dealing with the return to high-risk sporting activity and subsequent risk of re-injury.

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Incidence of Complications: Growth Disturbance vs. Graft Tear

Traditionally, ACL reconstruction for a skeletally immature patient was delayed until skeletal maturity due to the risk of growth disturbance. Yet, the risk of chondral damage with delayed surgery (combined with validation of new surgical techniques) has played a large role in an increase in reconstruction [8, 9•]. A recent meta-analysis reviewed 1392 pediatric ACL reconstructions from 45 total studies and found a 4.1% rate of growth disturbances, with only a smaller proportion of these patients (27.6%) requiring corrective surgery [6••]. The re-tear rate was noted to be 8.7%, with 94.6% of these patients requiring revision surgery. Thus, the risk of re-tear is perhaps a larger risk to the immature population than growth disturbance.

Dekker et al. retrospectively reviewed 85 pediatric patients who underwent ACL reconstruction (ACLR) and found a 32% incidence of a second ACL injury (19% ipsilateral, 13% contralateral) [10••]. DeFrancesco et al. examined 419 pediatric ACLR’s and found a graft failure rate of 10.3%, with almost half of all patients suffering a re-tear prior to return to full activities [11]. Finally, Ho et al. examined 561 ACLR’s and found a re-tear rate of 9.6% [12••]. These re-tear rates cited in for the pediatric and adolescent population are much higher than the graft re-tear rate of 4.4% cited in the adult population [13].

Although the reasons for the high graft failure are likely multi-factorial (i.e., compliance, post-operative activity, gender, graft choice, surgical technique, neuromuscular control), the surgeon must not only be prepared to counsel patients both of the risk of re-tear but also be ready to deal with revision reconstruction.

Strategies for Revision

Recognition of High-Risk Populations

Pre-operative identification of high-risk populations is the first step in preparation for revision surgery. Patients who suffer re-tear due to non-compliance with post-operative protocols, limited post-operative participation in physical therapy, deficient family support, and lack of socio-emotional maturity should give clinicians pause prior to performance of revision surgery. The optimization of the post-operative environment must be achieved prior to a secondary intervention due to the risk of surgical failure.

Age at time of reconstruction may also play a large role in graft failure as well. Cordasco et al. examined a cohort of 324 pediatric and adolescent ACLR and divided them into 3 groups (mean ages 12, 14.3, and 16.2 years, respectively) [14••]. The authors found that athletes with a mean skeletal age of 14.3 years had a significantly higher revision rate after ACL reconstruction (20%) compared with not only]the group of patients athletes with mean age of 12 years (6%) but also the older skeletal age athletes with mean age of 16.2 years (6%). Thus, patients who are in their late middle school/early high-school years (and are still undergoing skeletal growth) at the time of increasing sports intensity may need different clinical strategies to decrease risk of re-tear.

Graft choice also plays a significant role in the rate of ACL reconstruction failure. In their review of 561 ACL reconstructions, Ho et al. also found that soft tissue grafts were over twice as likely to fail compared to bone-patellar tendon-bone grafts (13% vs. 6%) [12••]. In addition, the utilization of allograft tissue in the young population (ages 10–19) leads to a failure rate that is 4 times higher than autograft tissue [15]. This trend holds true even when allograft augmentation occurs with autografts, with a recent study demonstrating a 30% re-tear rate [16••].

Initial Assessment of Failure: Surgical Technique

Multiple non-modifiable risk factors for ACL injury exist including gender, ligamentous laxity, knee recurvatum, lateral tibial slope, decreased notch width, valgus deformity, limb length discrepancy, and contralateral knee surgery [17]. Although attention will be paid to those factors below, a critical analysis of surgical technique is important during the planning for revision surgery.

The first step is an examination femoral and tibial tunnel in regard to anatomic vs. non-anatomic positioning (Fig. 1). Although tibial tunnel positions should not vary substantially in regard to intra-articular placement (with the exception of the risk of anterior tibial tunnel placement with intra-epiphyseal techniques), there can be a great degree of

Fig. 1 AP and lateral radiographs of a 12-year-old male s/p partial transphyseal ACL reconstruction with vertical tunnel placement resulting in rotational instability

variability in femoral tunnel position. Traditional transphyseal reconstructions were performed with vertical tunnels in order to minimize the cross-sectional area of the physis affected [18]. Yet, vertical tunnels in this setting can lead to continued rotational laxity in both the pediatric [19] and adult population [20, 21]. This increase in rotational laxity can place additional strain on the secondary stabilizers of the knee, particularly the posterior horn of the medial meniscus.

As a result, patients who present with graft re-tears on MRI (Fig. 2) who demonstrate medial meniscus pathology in the absence of lateral hemi-joint bone bruising may have suffered from chronic graft failure with a higher likelihood of non-anatomic tunnel position. In contrast, re-tear in patients who demonstrate more typical lateral hemi-joint bone-bruise patterns (Fig. 3) or more likely to be due to traumatic event unrelated to tunnel placement.

Patients who have had graft rupture after transphyseal reconstruction performed should have a very close examination of tunnel position. Non-anatomic tunnels cannot be reused however, skeletal growth remaining can preclude placement of new tunnels across the physis. If anatomic tunnels cannot be placed due to open physes in patients with greater than 2 years of growth remaining, delayed reconstruction may be indicated such that an anatomic reconstruction can be obtained.

In addition, if either a significant amount of bone loss is present precluding new tunnel placement and/or tunnel widening is present with anatomic tunnels, staged bone grafting may be necessary [22, 23] prior to reconstruction. In our experience, this is done for tunnels that are typically greater than 11 mm. If open physes preclude bone grafting, delaying revision surgery until bone grafting can be performed (prior to reconstruction) may be necessary. There are limited reports in the literature in regard to tunnel widening in the young population although Kopf et al. noted no tunnel widening at mean follow-up of 7 years who underwent transphyseal reconstruction [24].

In addition, to tunnel placement, small soft-tissue graft size may be the culprit for graft re-tear. Conte et al. performed a systematic review and found that graft sizes greater than 8 mm decreased graft failure rates in patients under the 20 [25•]. Similarly, Magnussen et al. found that graft sizes below 8 mm in patients under 20 increased revision rates [26•]. Care should be taken in the revision (and primary setting) to achieve a graft of adequate size with via various soft tissue preparation techniques.

Secondary Issues to Address: Bony Deformity

After assessment of surgical technique, angular deformities that can contribute to increased graft strain must be identified. Patients should obtain a standing bone length radiograph to assess for deformity and leg length discrepancy. This deformities may be due to growth disturbance which may arise from the procedure itself (i.e., valgus, Fig. 4) or may be preexisting (i.e., valgus or increased tibial slope, Fig. 5). Correction of deformity may need to occur either as a staged procedure or at the time of revision surgery. The type of correction will also vary based on the amount of growth remaining. Patients with significant growth remaining may achieve deformity correction via guided growth procedures whereas patients who are nearing and/or skeletal mature may benefit from single stage osteotomies (Fig. 6). This is particularly important as both static [27] and dynamic [28] knee valgus has been associated with ACL tear risk.

In addition, abnormalities in tibial slope have been associated with an increased risk of ACL injury. Dare et al. performed an MRI review of 76 skeletally immature ACL-injured knees versus 76 normal knees and found that increased slope of the lateral tibial plateau was found in ACL deficient knees (5.7° vs. 3.4°) [29•]. Similarly, O'Malley et al. compared 32 skeletally immature patients with ACL injuries versus normal knees [30•]. The authors found an increased posterior tibial slope (10° vs. 8.5°) in the ACL injured population. Finally, Vyas et al. examined a cohort of 39 adolescent patients with open physes and found that an increased medial tibial slope (12.1° vs. 8.9°) was present in ACL injured patients versus controls [31].

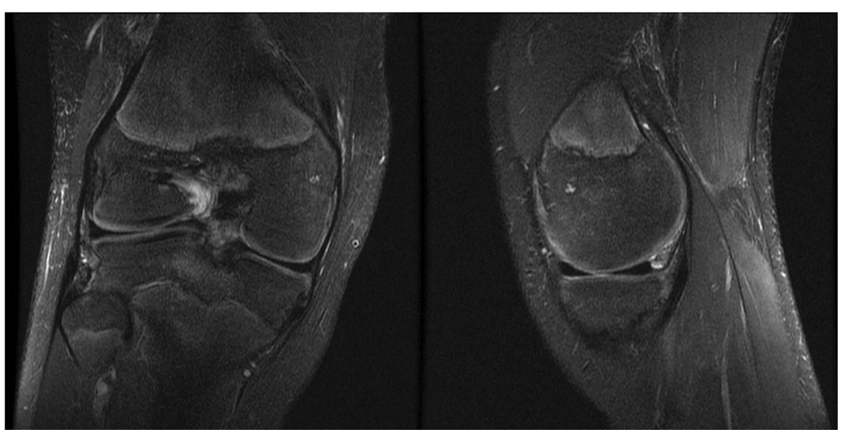

Fig. 2 T2 sagittal and coronal MRI images of a 14-year-old male 2 years s/p partial transphyseal ACL reconstruction with graft re-tear. MRI images demonstrate absence of lateral hemi-joint bone bruising with posterior horn medial meniscus tear

Fig. 3 T2 sagittal and coronal MRI images of a 16-year-old female 2 years s/p transphyseal ACL reconstruction with graft retear. MRI images demonstrate presence of lateral hemi-joint bone bruising

As a result, when tibial slope values are high (greater than 12°) in the revision setting, the surgeon should consider proximal tibial osteotomy (Fig. 7). Dejour et al. examined nine patients who underwent combined tibial dorsiflexion osteotomy with revision ACL surgery [32]. Tibial osteotomy was performed in patients with slopes greater than 12° via an anterior closing wedge technique without patellar tendon detachment. All patients healed their osteotomies, had stable knees, and no complications. Similarly, Sonnery-Cottet et al. reported on five cases of revision ACL with anterior closing wedge proximal tibial osteotomy, all of whom had restoration of knee function and stability [33].

Secondary Issues: Meniscus and Chondral Injury

It is also essential to analyze the injured knee for other pathology beyond those that may predispose the patient to rupture their graft. Clinical success is not simply be a function of knee stability but also resolution of pain from meniscus/chondral pathology.

In the setting of non-anatomic reconstructions, the medial meniscus (particularly the meniscal root, Fig. 8) should be aggressively treated. Wilson et al. examined 314 pediatric and adolescent patients who underwent meniscus surgery [34••]. In their series, 18.5% of patients had meniscal root

Fig. 4 Bone length radiograph of a 15-year-old male s/p transphyseal ACL reconstruction with resultant valgus deformity

Fig. 5 Bone length radiographs of a 14-year-old male with pre-existing bilateral valgus deformity with ACL tear s/p guided growth to correct deformity

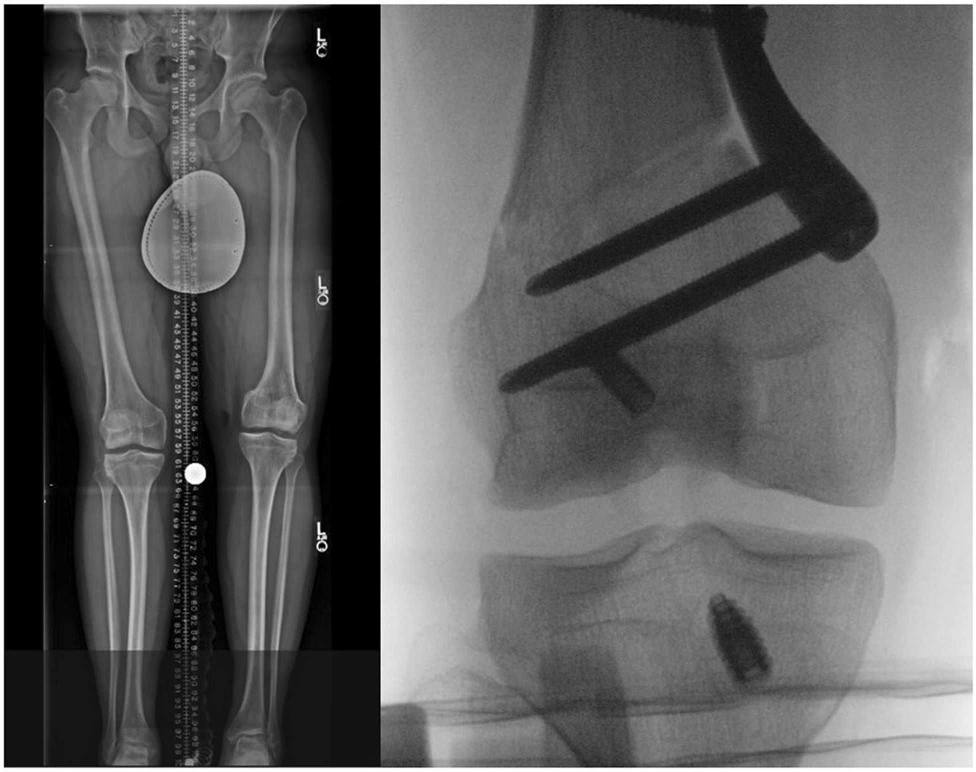

Fig. 6 Pre-operative bone length radiographs and intra-op fluoroscopy images of a 17-year-old male with valgus deformity and ACL tear s/p medial closing wedge osteotomy performed at time of bone tendon bone ACL reconstruction to treat valgus deformity

injuries. These were seen more frequently in association with ACL injuries, contact injuries, multi-ligament injuries, and meniscal extrusion. In addition, there is limited literature in regard to outcomes after revision meniscus surgery in this population. Shieh et al. examined 324 pediatric and adolescent patients who underwent meniscal surgery and found a 13% rate of revision of which 44% underwent debridement, and 56% underwent repair [35•]. The revision rate was higher in patients who had an index repair performed, particularly with open physes and bucket handle tear patterns. Most tears occurred due to an acute injury within 1 year of surgery. If deficient meniscal tissue is found based on pre-operative MRI and/or during arthroscopy, meniscal transplantation should be performed and has been found to be safe in the pediatric and adolescent population with good outcomes although further study is needed [36, 37].

In addition, osteochondral injuries should be aggressively treated as well, particularly in the revision setting. There is data to suggest that traditional microfracture techniques in this population have inferior outcomes [38] although the literature continues to be mixed as to the appropriate cartilage restoration technique in this population [30•]. Procedures such as autologous chondrocyte implantation [40] or OATS [39] have been shown to be safe in this age group (Fig. 9).

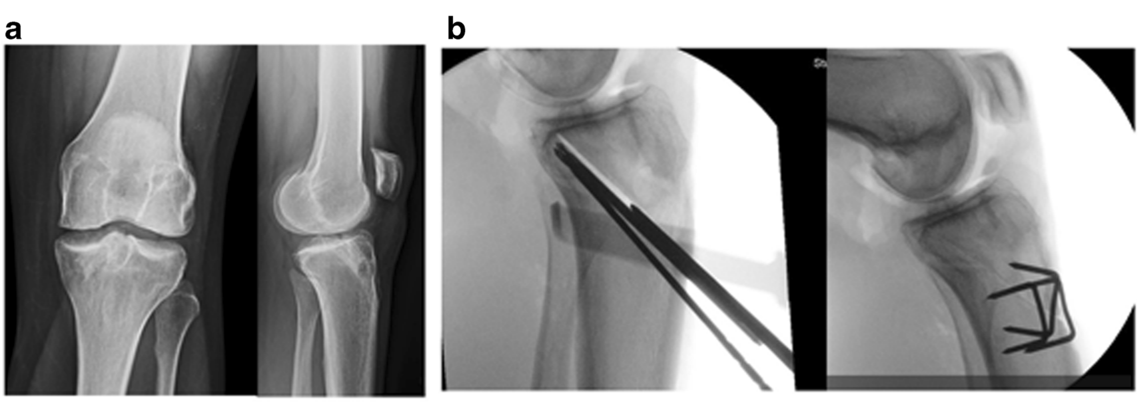

Fig. 7 **a** Pre-operative AP and lateral radiographs of a young adult patient with ACL graft re-tear, medial meniscus deficiency, and increased tibial slope. **b** Intra-operative fluoroscopy images demonstrating proximal tibial slope correcting osteotomy at the time of ACL revision surgery and medial meniscus transplant (courtesy of Dr. Christina Allen)

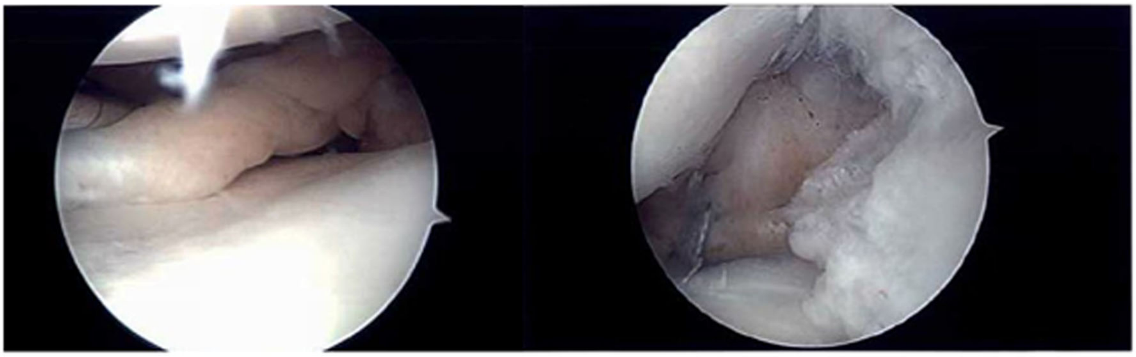

Fig. 8 Intra-operative arthroscopy pictures of a left knee in a 14-year-old male s/p prior knee procedure with missed posterior horn meniscus injury. Patient underwent meniscus root repair at time of revision surgery

Secondary Issues: Missed Ligamentous Injury

Careful attention must be paid to posterolateral corner (PLC) injuries in this patient cohort as well (Fig. 10), particularly as missed PLC injuries are a known cause of ACL reconstruction failure in the adult population. Kinsella et al. examined 50 skeletally immature patients with a mean age of 13.3 years at injury who underwent ACL reconstruction without PLC surgery [41••]. Fifty-two percent of patients had posterolateral corner injuries with 14% having complete tears. The risk of PLC injury increased with age. As a result, even in the skeletally immature population, care must be taken to examine for posterolateral corner injury as a risk factor for graft failure and physeal sparing reconstruction [42] can be performed as needed.

Secondary Issues: Laxity

At the time of revision reconstruction, if patients demonstrate generalized ligamentous laxity [43] and/or have persistent grade 2 pivot shift after revision [43, 44] then anterolateral ligament procedures (i.e., lateral extra-articular tenodesis) may be indicated. It is important to note that the anatomy is variable in the pediatric population for the anterolateral ligament and further data is necessary as to the appropriate procedure and long-term outcomes [45••, 46].

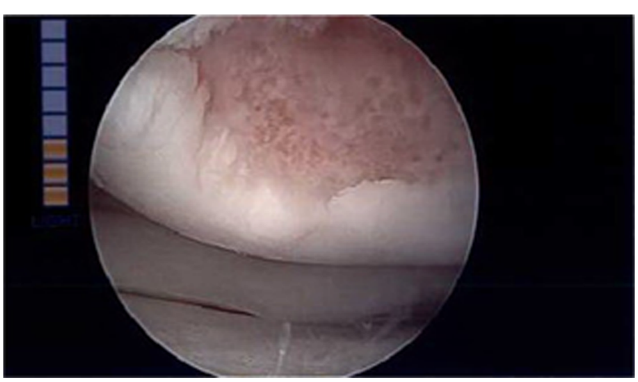

Fig. 9 Intra-operative arthroscopy pictures of a 17-year-old male 3 years s/p transphyseal ACL reconstruction with large osteochondral defect of the medial femoral condyle at the time of revision surgery

Graft Choice

In the pediatric and adolescent patient undergoing revision reconstruction, avoidance of allograft (as in the primary setting) is key. The choice of revision graft choice is then dependent on physeal status (avoidance of bone across the growth plates), and prior graft utilized. In the adult population, the utilization of soft tissue or bone-patellar tendon bone grafts in the revision setting have not shown differences in re-rupture or patients reported outcomes [47]. A recent study of five pediatric cadaver specimens examined the mechanical properties of pediatric ACL autograft tendons commonly used for reconstruction including patellar tendons, quadriceps tendons, semitendinosus tendons, and iliotibial bands (ITBs) [48••]. The authors found that the mechanical properties of the patellar tendon were close to native properties of the ACL tendon (ultimate stress (5.2 ± 3.1 MPa), ultimate strain (35.3% ± 12.5%), and the Young modulus (27.0 ± 8.8 MPa) comparted to native ACLs (5.2 ± 2.2 MPa, 31.4% ± 9.9%, and 23.6 ± 15.5 MPa, respectively)). Semitendinosus tendons and ITBs were stronger but less compliant than the quadriceps or patellar tendons. The quadriceps tendon autograft provides a promising alternative in the revision setting and techniques have been described for its use in the skeletally immature population [49].

We recommend that surgeons utilize an autograft in the revision setting that they are comfortable using in a manner that respects the physeal status of the patient.

Post-operative Rehabilitation

Preventing a third ACL graft rupture is paramount following revision surgery. Young athletes are at considerable risk of having multiple re-ruptures due to participation in high-risk sporting activities. The clinician must have a frank discussion

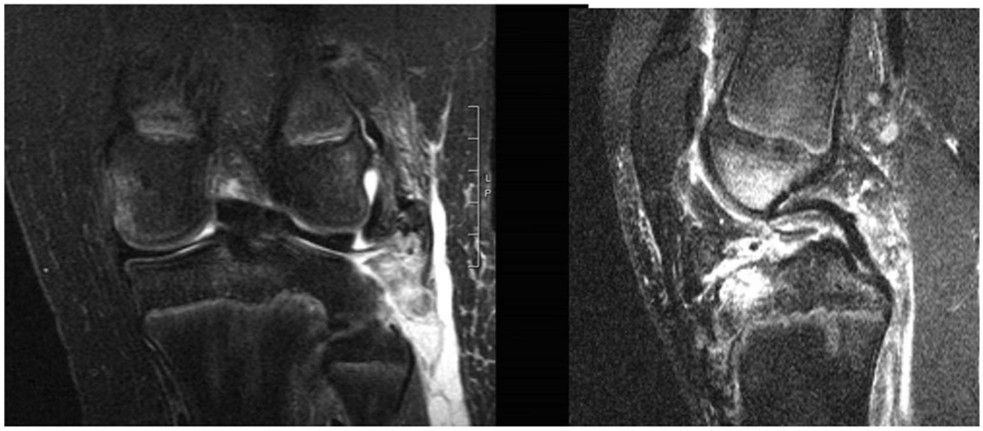

Fig. 10 T2 coronal and sagittal MRI images of a 14-year-old male diagnosed at an outside hospital with an ACL tear who presented with a chronic postero-lateral corner injury

with the patient and family in regard to guarded prognosis, risk of degeneration, and change in sporting activity.

Wiggins et al. performed a systematic review of secondary injury in ACL reconstruction in younger athletes [50•]. The authors found that 25% of young athletic patients would sustain a repeat ACL injury in their career, particularly in the early return to play period. This risk is 30 to 40 times greater for an ACL injury than uninjured adolescents per the authors. Furthermore, they conclude that activity modification, improved rehabilitation/return to play guidelines, and neuromuscular training are essential. In addition, Webster et al. examined 151 patients who underwent revision ACL reconstruction [51••]. Sixteen percent of patients suffered graft re-rupture, with medial meniscus injury and return to preinjury sport associated with graft re-rupture in the revision setting.

As a result, the surgeon must ensure the patient has addressed all neuromuscular deficits prior to return to sport in the revision setting as well consider change in activity along with later return to sport; perhaps even 18–24 months after surgery.

Outcomes After Revision Surgery

There is limited literature on the outcomes of young patients after revision reconstruction. Ouillette et al. examined a cohort of 60 revision ACL reconstructions in adolescent patients in comparison to an institutional database of primary reconstructions [52••]. The graft failure rate was higher in the revision cohort (21% vs. 9%) with autograft tissue tending towards a lower failure rate than allograft (11% vs. 27%). A greater incidence of meniscus and cartilage pathology was encountered as well in the revision setting. Only 27% percent of revision patients returned to the same level of sport. Patient outcomes scores were noted to be low.

Similarly, Christino et al. reported on 90 revision ACL reconstructions with a mean age of 16.6 years [53••]. . Twenty percent of patients re-injured their graft with only 69 % of patients being able to return to play (with 55.2% returning to the same level of play). Furthermore, 20 % of revision reconstructions had contralateral ACL injuries with 33% of those who injured their revision graft suffering a contralateral injury as well. As with the prior study, patient outcome scores were low.

Conclusions

Pediatric and adolescent sports participation has led to an increase in ACL reconstruction with subsequent failure rates that are higher than the adult population. ACL revision reconstruction is a complex orthopedic endeavor in this cohort. A complete understanding of the reasons for failure with a comprehensive treatment plan addressing all factors is critical. Patients and families must be prepared for complex revision surgery with guarded outcomes.

Compliance with Ethical Standards

Conflict of Interest Steven Garcia declares that he has no conflict of interest.

Nirav Pandya is a consultant for Orthopediatrics.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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