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# Pediatric ACL in Sports, Prognosis, Decision Making and Outcomes of Management

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## Abstract

Anterior cruciate ligament (ACL) injuries in pediatric & adolescent patients may occur as tibial eminence fractures, mid-substance ligament injuries and peel-off injuries of the femoral insertion site. ACL injuries in adolescents nearing skeletal maturity may be treated as adults without risk of deformity or leg length discrepancy. Treatment of ACL injuries children with wide open physes and substantial remaining growth are controversial. Disappointing functional results and an increased prevalence of secondary meniscal and cartilage damage with conservative management have led to an increased utilization of surgical treatment in these children. ACL reconstruction with soft tissue grafts and physeal sparing techniques are considered the gold standard of surgical management. Primary repair combined with healing enhancement techniques for femoral peel-off injuries with minimal damage to the body of the ACL can be used in select cases. The rates of growth disturbance after ACL surgery remain low with modern techniques and are usually clinically insignificant. However, a higher rate of failure and need for revision has been reported in pediatric & adolescent ACL injuries compared to adults. The risk of failure increases in patients with allografts and who return to high risk impact sports.

Keywords: Paediatric ACL tEAR, Physeal sparing techniques, repair

## Introduction

Mid-substance (ACL) injuries have become more prevalent in recent years due to Increase and earlier participation in contact sports, increased prevalence of girls in sports activities and increased awareness of this injury. Mc Conkey et al., have reported that pediatric & adolescent ACL injuries constitute 0,5-3% of all ACL injuries (1). Werner et al., using national databases, have reported an increased prevalence of ACL injuries in pediatric ACL injuries throughout the years compared to adults (2). The prevalence of ACL injury in adolescents has been reported to be 60.9 per 100.000 person/year (3).The injury is rare before 9 years and is associated with sports in more than ¾ of the cases (4). Boys are more frequently injured than girls up to 13 years, then the trend reverses and girls are more prone to injury due to changes in leg alignment, landing techniques and hormonal changes (5). Several factors such as a narrow intercondylar notch") (6) and increased lateral tibial slope (7) have been associated with an increased risk of ACL injury. Adolescent girls have also been shown to have decreased hamstring strength and increased valgus landing patterns predisposing to ACL injury (8).

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## Diagnosis

The injury mechanism is similar to adults, which is usually a non-contact injury during landing resulting in valgus and external rotation forces. Direct antero-posterior forces during falls usually result in a tibial eminence fracture. Severe pain and a popping sensation followed by an acute hemarthrosis is typical. Pain and muscle spasm preclude an accurate clinical exam during the acute stage, however, Lachman, anterior drawer and pivot shift tests become positive in the chronic stage. Children with an intact ACL may have a positive anterior drawer test of 3-4 mm until the end of adolescence. This physiological laxity is symmetrical and should not be confused with ACL rupture. In a study of 232 children analyzed with instrumented laxity testers, Baxter et al. have shown that this laxity decreases gradually over time and reaches normal adult values in boys at 13 and girls at 12 years of age (9). Similarly, Moksneshas shown that bilateral symmetrical positive pivot-shift test may be present in 85% of the normal children (10). Examination of both knees of children with suspected ACL injury is critical to avoid unnecessary surgery. Plain radiographs are the first step in all


**Figure 1:** a,b,c: Floroscopic guidance during hybrid ACL reconstruction using an intra-physeal femoral tunnel and a trans-physeal tibial tunnel.

children with acute hemarthrosis. Tibial eminence fracture and patellar dislocation can be ruled out and status of the growth plate can be assessed. Magnetic resonance imaging (MRI) is the most useful tool for the diagnosis of ACL injury. In addition to the ACL, accompanying injuries to the menisci and cartilage can be assessed. Dumont has shown the rate of medial and lateral meniscal injuries accompanying ACL injury to be 38% & 56% (11). Other series have shown a similar trend for increased lateral meniscal tears(12).

## Natural History

The natural history of pediatric ACL injuries is unfavorable. Repeated episodes of instability and secondary damage to the menisci and cartilage occurs in time. Newman has reported a 4.8 fold increase in cartilage and meniscal injury if treatment is delayed more than 3 months. (13). Anderson has shown that every episode of instability results in 4.8 fold risk of medial meniscal tear and 3 fold increase in a lateral meniscal tear (14).Reporting on a series of 112 children, Guenther has found that delayed surgery results in 5.7 fold increase in medial meniscal tears and the risk of bucket handle tears increases after one year in untreated patients (15). These and many earlier studies indicate that the risk of secondary injury to menisci and cartilage increase in time if these children are left untreated.

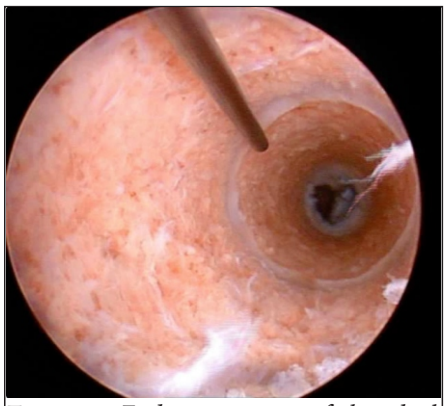

**Figure 2:** Endoscopic view of the tibial tunnel crossing the physis vertically, probe demonstrates the physeal line.

## Conservative treatment

Very little evidence exists for conservative treatment of ACL injury in children. Woods, in an older study suggested that with absolute activity restrictions, surgery could be delayed until skeletal maturity. However, a 69% rate of meniscal injury was found in patients with surgery delayed for more than 6 months (16). The recent consensus statement of the International Olympic Committee suggests "high quality rehabilitation" as a treatment option in ACL injuries, however the clinical data supporting this option is scarce (17). Moksneshas reported an 88-90% return to pivoting sports with a structured rehabilitation program in two studies (18,19). The rate of patients requiring late ACL reconstruction was 22-32%, meniscal surgery was performed in 19.5%. However, 38% of the child athletes had to decrease their sports level. Vavken performed a meta-analysis of 12 level II, III and IV studies on conservative treatment of ACL injuries and found disappointing results. Of the 476 children followed for 52 months, a significant proportion were unstable and 50% had serious meniscus or cartilage damage that needed to be addressed surgically (20). Strict activity modification and bracing is unrealistic in children & adolescents. Compliance with a long rehabilitation program is a serious problem. A small subset of patients who can decrease their activity

**Figure 3:** A 12 year old patient multiply operated for ACL deficiency. Permanent implant in the tibial tunnel crossing the physis is a risk for growth disturbance and should be avoided.

level and do not have symptomatic instability may be treated conservatively, however, surgery is a better option for active children with symptomatic instability. Ramski, in a recent meta-analysisof 6 studies comparing non-operative and operative treatment, found significantly lower IKDC scores and pathological laxity in 75% of the non-operatively treated patients (21). A 12 fold increase in medial meniscal tears was reported with conservative treatment, and none of the patients in this group could return to their previous activity level.

## Surgical treatment

Surgical treatment is advocated for patients with symptomatic instability and accompanying meniscal or chondral damage. Several meta-analyses have shown that early surgery results in better outcomes than delayed surgery (21, 22). Kay in a meta-analysis of 20 studies, reported a 92% rate of return to sports after surgical treatment in 1156 children & adolescents (23). Return to pre-injury level of ports was found to be 78.6%. However, 13% of the children sustained a re-rupture and a contra-lateral ACL injury was observed in 14% of the children.

## Physeal injury in experimental studies

All surgical interventions around the physis carry a risk of injury. In an excellent review, Seilhas outlined the findingsof current experimental studies concerning surgery around the physis (24). It is generally accepted that, drill holes in the growth plate do not regenerate and if left empty, carry the risk of bone bridge formation tethering growth. Completely filling the tunnel with a soft tissue graft decreases the risk of bone bridge formation. Permanent implants crossing the physis in tunnels cause growth disturbances and should be avoided. Tunnels near the periphery of the physis cause more damage than centrally placed tunnels. The critical threshold for physeal damage causing growth disturbance is 7-9% of the total area for central and 3-5% for peripherally placed tunnels. Oblique tunnels cause more injury to the physis than vertical tunnels. The risk of growth disturbance is correlated with the amount of remaining growth. Over tensioning the grafts may cause growth disturbance due to a teno-epiphysiodesis effect. These principles should guide the surgeon to perform safe surgery with minimal growth plate damage.

## Assesment of skeletal maturity

The amount of remaining growth is critical for the choice of surgical technique in pediatric & adolescent ACL injuries. Chronological age, Tanner stage, menarche, X-ray appearance of the physes are important factors in the decision making process. Tanner stage 4-5 adolescents with nearly closed physes can be treated as adults. These children (boys older than 16, girls older than 14.5 years) typically have less than 1.5 cm expected limb growth and can be treated with trans-physeal techniques without concern for angular deformity or leg length discrepancy. Tanner stage 1-3 children with wide open physes and significant remaining growth are a challenge to treat. Guzzanti has reported that Tanner stage 1 children (boys 12 years, girls 11 years) have 7-15 cm remaining growth and are most at risk for growth disturbance after surgery. Tanner stage 2-3 adolescents (boys 15, girls 13) have 1.5-7 cm remaining limb growth. Physeal sparing techniques should be employed in Tanner 1-3 patients to minimize the risk of growth disturbance (25).

## Surgical treatment

The aims of surgical treatment in pediatric & adolescent patients are to provide a stable knee that allows return to sports and activities, prevent or repair meniscal & chondral damage and minimize growth disturbance. Several different ACL reconstruction techniques can be used in Tanner stage 1-3 children. Whichever technique is chosen, common principles should be adhered to minimize damage to the physis. Surgery should be performed under fluoroscopic guidance to accurately place the tunnels (Figure1). Tunnels crossing the physis should be oriented vertically and placed in the central part of the growth plate. This is easy on the tibial side (Figure2 ), however, anatomically placed femoral tunnels using trans-portal techniques cross the physis in an oblique fashion in the peripheral part of the growth plate. Consideration should be given to using outside-in intra-epiphyseal tunnels or over-the-top techniques in Tanner stage 1-2 patients. A more verticalfemoral tunnel orientation can be achieved with trans-tibial drilling, however these tunnel locations are non-anatomical and compromise stability, therefore should be avoided. The metaphyseal exits of tunnels should be placed far from the physes and care should be taken to avoid damaging the perichondrial ring during dissection. No periosteal elevation should be performed during hamstring tendon harvest and the tibial apophysis should be preserved. Tunnels should be drilled in one step with a sharp reamer and lavage to prevent thermal damage. The tunnel diameter should be as small as possible, achieving a tight fit of the graft in the tunnel.Shea et al., have analyzed the amount of physeal damage created by 7-9 mm diameter tunnels in children using MRI. The percentage of physeal damage was 1.6-3.8% in the proximal tibial physisand 2.4-5.4 % in the distal femoral physis (26). These amounts are much smaller than the 7-9% critical threshold for growth disturbance found in animal studies. The effects of all intra-epihyseal tunnels are less studied.

Nabawi et al, have analyzed the physeal damage produced by intra-epiphyseal tunnels in 23 adolescents with a mean age of 12.6. No damage to the femoral physis could be observed at one year follow-up, while 2% surface area damage was seen on the proximal tibial physis (27). No permanent implants or bone blocks should be placed crossing the growth plate (Figure 3 ). Fixation in trans-physeal techniques should be performed extra-cortically away from the growth plate. The optimal amount of graft tension is not clear, 80N graft tensioning has been shown to create a tether effect in animal studies, while 40N seems to be safe. However, this has not been validated in human trails (24). Several techniques have been defined for pediatric & adolescent ACL reconstruction (ACLR) (Figure 4). Tanner stage 4-5 children can be managed with trans-physeal techniques, tunnels can be drilled across the physis without concern for growth disturbance. Tanner stage 1-3 patients can be reconstructed with intra-epiphyseal techniques with radiological verification. No tunnels are drilled across the growth plate. Non-anatomical techniques without drilling tunnels in bone have been utilized in the past. The graft may be passed under the intermeniscal ligament on the tibia and placed in the "over-the top" position of the femur. Although they avoid the physes, these non-anatomical techniques do not restore stability of the knee throughout the range of motion and have fallen out of favor. The surgeon can combine any of these techniques (ie. trans-physeal in the tibia, over the top in the femur) to suit the patient's needs (Figure5 ).

## Trans-physeal techniques

Trans-physeal techniques are usually indicated for Tanner stage 4-5 patients nearing skeletal maturity. However, these techniques can safely be used in Tanner 1-3 patients with wide open physes with good outcomes and low complication rates. The graft should be fixed on the metaphysis, avoiding implants and bone blocks crossing the growth plate (Fig. 6). Domzalski et al., performed transphyseal ACL reconstruction in 22 pre-adolescent(Tannerstage 1 & 2) athletes, and reported a mean IKDC score of 95 at 77 months follow-up (28). None of the children had a clinically detectable growth disturbance, and the results were independent from the amount of remaining growth. Calvo et al., reported on 27 children with a mean age of 13 during transphyseal hamstring ACLR with a 10 year follow-up(29). Mean IKDC score was 94, 2 patients had residual instability and 3 had a re-rupture of the graft. No growth disturbance was observed. Although the risk of growth disturbance is low, pediatric & adolescent patients have higher rates of residual laxity or re-rupture compared to adults. Redler et al., reported good clinical outcomes in 18 children undergoing trans-physeal ACLR, however, contra-lateral ACL rupture was observed in 4 children(30). Larson at al., reported on 29 Tanner stage 1-3 children undergoing transphyseal ACLR(31). Five children had a re-rupture, and although not statistically significant, failure was more frequent in allografts. Five kids had contra-lateral ACL injuries during follow-up. Growth disturbance was clinically insignificant with a mean of 1° (0°-4°) angular deviation and 2 mm (0-10) leg length discrepancy. The high rate of re-rupture and contra-lateral ACL injuries in children in these series and meta-analyses suggest that other anatomical/hormonal factors (tibial slope, notch width ect.) may play a role in the higher failure rates in children. In an interesting study on graft maturation, Astur et al. have measured the diameter of hamstring grafts used in trans-physeal ACLR in children (32). The authors observed a 25% decrease in graft diameter with growth. This might be one of the factors associated with higher failure rats in children.

## Intra-epiphyseal ACL reconstruction

Intra-epiphyseal ACLR is performed with tunnels drilled under image intensification without crossing the physis. This usually involves outside-in drilling for both the femur and tibia. Since the risk of growth disturbance is more important on the femoral side, a combination of trans-physeal tibial and intra-epiphyseal femur drilling can be performed. Pennock et al., reported on 30 children undergoing all-epiphyseal ACL reconstruction. Mean age at surgery was 11 years, 89% returned to sport and there were 4 failures. One child had a 12 mm leg length discrepancy (33).

## Growth disturbance after ACLR

A meta-analysis of 55 series with 935 children has reported a 1.8% angular deformity of leg length discrepancy after pediatric ACL (34). These deformities occurred mostly due to technical errors. (34). A more recent review of 21 studies found a total of 39 children with growth disturbance (35). The most frequent problem was genu valgum (mean 6 degrees), followed by lengthening the extremity (mean 1.3 cm). Interestingly, 25% of the angular deformities and 47% of the leg length discrepancies occurred in children undergoing physeal sparing techniques. Pierce compared the rates of growth disturbance in 21 series with trans-physeal techniques to 6 studies with physeal sparing techniques (36). The rates of angular deformity and length discrepancy were similar and less than 1%. In conclusion, growth disturbance following pediatric ACLR is rare and usually asymptomatic. It usually occurs as femoral valgus, probably due to the tethering effect of the graft. Genu recurvatum may occur in the tibia (37). Shortening is rare, some lengthening

may occur due to stimulation of growth and may require temporary epiphysiodesis(38). Children undergoing ACLR should be followed yearly until skeletal maturity and interventions to guide growth should be planned in cases of impending deformity.

## Conclusions

The natural history of pediatric ACL injuries is episodes of instability and secondary chondral and meniscal damage in most of the cases. These children should undergo ACL reconstruction before secondary damage occurs. Modern surgical techniques are safe; the risk of growth disturbance is very low and usually clinically insignificant. The risk of re-rupture after ACLR is higher than adults and contra-lateral ACL injury is a real risk.

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