Review Article
Anterior Cruciate Ligament injuries in Growing Skeleton - Review article

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Abstract

Anterior cruciate ligament (ACL) injuries in the adult patients are thoroughly studied and published in orthopedic literature. Until recently, little was known about similar injuries in skeletally growing patients. The more frequent involvement of this age group in various athletic activities and the improved diagnostic modalities have increased the awareness and interest of ACL injuries in skeletally immature patients. ACL reconstruction in growing skeleton is controversial and carries some risks to the tibial and femoral growth plate. A guarded approach to ACL reconstruction is recommended in skeletally immature patients. Modification of activity of ACL injured young patient, proper rehabilitation and prudent planning of adolescent age ACL reconstruction carries the least risks of growth plate violation.

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Introduction

By definition the skeletally immature individual is one in whom the growth plates are open and significant axial growth is expected.[1,2] The explanation for underestimation of ACL injuries in skeletally immature patients in the past could be attributed to the less involvement of this group of patients in athletic sports and the inclusion of the adolescent injuries in the adult series. However, the increased awareness of ACL injuries in growing skeleton could be explained by more involvement of the younger age group in sports activity and the assistance of the new diagnostic modalities.[1-19] Previous belief that most ACL injuries in growing skeleton were predominantly avulsion fractures of the tibial spine has changed.[20-23] Recent studies have reported midsubstance ACL tears more frequently than previously thought in skeletally immature patients.[24-29] This paper reviews the epidemiology, anatomy, natural history of ACL injuries in growing skeleton, as well as, the options for conservative and operative treatment. The possible complications and risks are also discussed.

Epidemiology

The incidence of ACL injuries in skeletally immature patients is growing due to the increased popularity of competitive athletic activities among adolescents. Further, greater awareness of this injury has improved the diagnostic modalities.[4, 26-27, 30-31] Incidence of ACL injuries in skeletally immature patients has been reported between 0.5-3 % in several studies. [8, 30, 32] Females are more frequently affected than males and numerous factors have been identified as possible causes for this difference in ACL injury rate between males and females.[28, 33, 34] The athletic involvement, muscular strength, skill level, joint laxity, limb alignment, femoral notch dimension, hormonal/ menstrual factors and ligament size are some of the factors cited.[35-41]

Anatomy of ACL

The knee joint develops as a cleft between mesenchymal rudiments of the femur and the tibia. The cruciate ligaments appear as condensations of vascular synovial mesenchyme at eight weeks of fetal development. The blood supply is derived mainly from the middle geniculate artery and it receives the nerve supply from the posterior branch of the posterior tibial nerve. It is believed to be mainly proprioception, providing the afferent arc for postural changes during motion and ligament deformation. The ACL is an intracapsular and extrasynovial structure. Congenital deficiency of the ACL, narrow femoral notch and differences in the proximal tibial sloping are known anatomic variations in the knee.[42] The immature ACL has its origin and insertion at the chondroepiphyseal junctions of the proximal tibia and distal femur (Fig1). These attachments mature to become a fibrocartilagenous-bone interface in the adult.[43-45] These attachments are susceptible to avulsion injuries in the growing skeleton.[46]

Natural history of ACL injuries

A skeletally immature patient who suffers acute knee injury and haemarthrosis may have one of the many injuries that involve the knee structures.[13,18,20,22] The differential diagnosis includes intrasubstance ACL rupture, tibial spine avulsion fracture, meniscal injuries, patella fracture and distal femur physeal injury. The instability could be related to an acute ACL injury, a tibial spine avulsion fracture, a congenital ACL deficiency, or a generalized ligamentous laxity. Stanitski et al (1993) reported that 70% of acute knee haemarthrosis in children are sport related, and 67% of those injuries were ACL tears.[47] Wessel et al (2001) reported that the incidence of ACL injury has increased in frequency in children between 13-16 years of age and when it occurs in children less than 10 years old, it is usually not associated with

haemarthrosis.[48] Kellenberger and von Laer reported that 80% of patients aged less than 12 years with haemarthrosis had a tibial spine fracture, while 90% of patients aged more than 12 years had an intrasubstance ACL tear.[46]

Clinical and radiological evaluation

At presentation of acute knee injury in skeletally immature patient, a thorough history and physical examination should be conducted. The history should include the activity during the injury, the type of injury, the scenario in which it occurred, the sensation of a "POP", the presence of effusion, the ability to bear weight and the subjective feeling of instability. Other important data includes the height and weight of the patient, age at onset of menses, and the timing of the adolescent growth spurt.[18] Physical examination should include the gait, the presence of effusion, the range of motion, the presence of instability and the type of instability. Evaluation of the uninvolved knee is performed to establish what is normal for the patient. Arthrometric evaluation is considered to confirm injury and to compare with the outcome. Leg-length discrepancy and physiologic age should also be recognized.

Plain radiographs of the affected knee and the normal knee for comparison are part of the initial evaluation. This helps in the identification of bony injuries or intraarticular avulsion fractures of the ligament attachments and joint deformities as well as the state of maturity.[20, 39-41]

Magnetic resonance imaging (MRI) in skeletally immature patient must be considered with caution. It must be carefully correlated with history and clinical examination. The accuracy of MRI in skeletally immature knee injury is not similar to it's accuracy in adults. It has been reported in some series that the false positive MRI findings could be present in up to 75% cases of children with suspected ACL injury.[47,49-52] The cause of this relatively high figure could be due to various reasons, which include, anatomic variations, high incidence of partial injury compared to adults, and less experience of MRI interpretation in skeletally immature patients.[44, 48-52] For these reasons, radiological findings have to be correlated well with the clinical evaluation.

Management of ACL injuries

The natural history of ACL deficient knee in skeletally immature patient is almost similar to those of adults. This includes chronic instability, osteochondral and meniscal pathology, pain, joints effusion, and degenerative changes of the articular surfaces.[24] The increased activity of this age group renders the menisci and the articular structures of the knee more vulnerable to further damage.[43, 46-47]

The outcome of non-operative management of ACL injuries has been shown to produce unsatisfactory results and often leads to further meniscal and osteochondral injuries.[4,12-14,17,24,53] Mc Carroll et al (1994) conducted a comprehensive study of the natural history of ACL tears in skeletally immature patients.[12] They reported 38 athletes who were treated conservatively by modification of activity, bracing and rehabilitation. All 38 patients underwent arthroscopically assisted ACL reconstruction at a later point. Ninety seven percent had episodes of instability prior to ACL reconstruction, 71% had symptomatic meniscal tears at the time of surgery and 50% had attempted to return to their previous level of activity before reconstruction.

Several other studies on the natural history of ACL injury in young patients consistently showed that conservatively treated patients develop knee instability (Table1), which leads to secondary meniscal or chondral injuries especially if activity levels are not modified.[17]

ACL reconstruction in skeletally immature patient

Reconstructing ACL deficient knee in skeletally immature patient is a controversial issue. The

debate still surrounds about the timing of surgery, the graft choice and its size, the technique of graft positioning, and the graft fixation method. The decision of ACL reconstruction is influenced by the patient compliance, skeletal maturity, physiologic age and other psychosocial considerations related to this age group.[1,6-7,9-10,12,15,18-19,26] The treatment is indicated to prevent or modify the functional instability. The aim is to restore a biomechanically stable knee that enables the patient to engage in normal activities or the desired sports.[12,15,28] The difficulties to be addressed when planning ACL reconstruction in skeletally immature patient include:

1. The tunnel placement and orientation in the tibia and the femur and the violation of the growth plate.
2. The choices to achieve stable graft fixation with the least compromise to the growing skeleton.

Various studies have been performed on the physes of animals to identify the effect of trauma, pressure and drilling and ligament reconstruction on the bone growth and limb development. Furthermore, these studies stressed on the drill hole size,[54-58] the placement of soft tissue graft,[59-61] the hardware placement[54,62,63] and the graft tension.[64] It has been shown that ACL reconstruction in the skeletally immature patient can cause partial or complete physeal arrest.[19,45,56-57] This could be due to the formation of bony bridge across the growth plate or tension creation across the growth plate.[61,64]

Methods of ACL reconstruction in skeletally immature patient

1. Physeal sparing technique (both tibia and femur)

Various physeal-sparing techniques have been described for primary repair of ACL. They were designed to avoid placing drill holes across both the tibial and the femoral growth physes because primary repair of ACL injury is associated with high rate of instability and failure.[65-66] However, Brief (1991), and recently Kocher et al (2006) have described a technique that avoids placing the tunnels across both the femoral and the tibial physes. This technique utilizes the distally attached semitendinosus and gracilis tendons or the iliotibial band graft by passing them under the anterior horn of the medial meniscus, through the intercondylar notch, passing over the top and attaching with staples above the physes of the lateral distal femoral condyle.[67-68] There were no reports of growth disturbances in these patients at 36 months follow up. Eight of the nine patients in the study denied instability and were satisfied with the result. Micheli et al (1999) also described the use of iliotibial band as a femoral and tibial physeal sparing technique in 17 prepubescent children.[69] However, the validity of these techniques was limited by the small size of the number of patients and a relatively short term follow up.

Physeal sparing technique (Femoral side only)

Lipscomb and Anderson (1986) reported transphyseal tibial and femoral sparing ACL reconstruction in 11 patients with open physes and 13 patients with partially closed physes. The semitendinosus and gracilis tendons were left attached distally and passed proximally by 6.4 mm trans-tibial drill hole to the tibial anatomic point. The femoral 8 mm drill hole was placed superior and posterior to the femoral anatomic point and directed 70-90 degrees to the long axis of the femur avoiding drilling across the femoral physes.[8] The patients were followed up for an average of 35 months. Sixty two percent of the patients returned to their previous level of activity during this period. One case had leg length discrepancy due to misplaced staples. Mc Carroll et al (1988) also reported satisfactory results of an almost similar technique.[13] There were no growth deformities at skeletal maturity. Andrew et al (1994) reported the outcome of eight skeletally immature athletes ACL reconstruction. They used the facia lata or Achilles tendon allografts passed through tibial (6-7 mm) vertically oriented drill hole and to the femoral over the top position. They also didn't report any

unsatisfactory results.[3] Lo et al (1997) reported five patients who were treated for ACL tears with similar technique utilizing the semitendinosus /gracilis grafts or quadriceps- patellar tendon grafts, and after an average of 7.4 years follow up none of the patients had limb length discrepancy or deformity and four patients had returned to their previous level of activity. [27] Almost similar results were reported by Bisson et al (1998).[6]

2. Non Physeal sparing techniques

This involves the transphyseal tibial and femoral passage of the graft. Athletes who were close to skeletal maturity were treated with standard technique as in adults.

Mc Carroll et al (1994) reported the results of 60 athletes who were treated by transphyseal ACL reconstruction.[12] They used bone-patellar tendon-bone autografts in all patients. The average age was 14.2 years (range 13-17), and the average follow-up period was for 4.2 years. During the follow-up period, the average increase in height was 2.3 cm, and there were no growth disturbances or deformities. Matava and Siegel (1997) reported successful intra-articular ACL reconstruction in eight patients.[9] The hamstring tendon autografts were used; 7-9 mm tunnels were placed and the grafts were secured with buttons or staples. The average age of the patients was 14.8 years and the average follow-up period was 32 months. All the eight athletes were able to return to their previous level of activity. However, there was 7 mm shortening of the operated limb of one of the patients, 5 mm of the femur and 2 mm of the tibia, with no angular deformities. Aronowitz et al (2000) used the Achilles tendon in 19 adolescents with skeletal age of more than 14 years and at 25 months of follow-up, 16 out of the 19 patients returned to their previous level of activity.[5]

These studies showed encouraging results; however, they were conducted in a limited number of cases and most of the study population was approaching skeletal maturity. The data did not address the issue of those patients who still have significant remaining period of growth.

Aichroth et al (2002) reported results of a prospective study of 45 adolescent patients treated for ACL injuries, whose average chronological age was 12.5 years. They used the four-strand hamstring technique. The drill holes originated from the anatomical footprint of the ACL and were oriented to cross the physes as perpendicular as possible. The mean follow-up period was 49 months. There were neither any leg length discrepancies, nor any physeal arrest during the follow-up of these patients.[24] This study documented that placement of transphyseal tunnels may not cause clinically significant growth plate arrest when anatomy and choice of fixation devices are carefully planned and considered. The young average age of the patients studied (12.5 years) indicates that these patients had remaining growth potential which was not affected by ACL reconstruction.

Conclusion

ACL injuries in pediatric and adolescent population are becoming more common with the recent trend of more involvement of this age group in competitive sports. The natural history of this injury is similar to that of the adults. Midsubstance ACL injuries are seen more frequently and are being increasingly recognized. Poor result is expected if functionally unstable knee is treated non-operatively. A guarded approach to ACL reconstruction is recommended in skeletally immature patients. ACL reconstruction in younger patients with significant growth remaining carries a risk of growth plate injury. Modification of activity of ACL injured child, proper rehabilitation and planning adolescent age ACL reconstruction, carry the least risks of growth plate violation. For those patients who are approaching skeletal maturity and with little growth remaining, it is recommended to perform the standard procedure used in adults for ACL reconstruction. Future prospective, randomized, studies are required to compare the results based on the graft type, size, placement, and fixation for different age groups.

Figure 1: Sagital MRI view of the immature knee showing the normal ACL origin and insertion at the chondroepiphyseal junctions of the proximal tibia and distal femur.

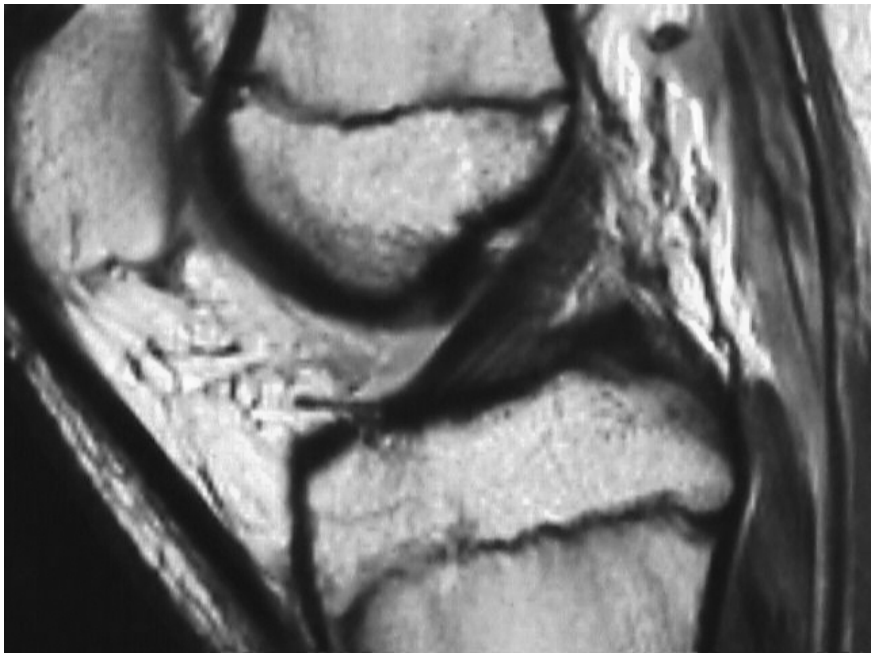

Table 1: Summary of the natural history of anterior cruciate ligament injury before or without reconstructive surgery

STUDY	YEAR	No. of patients	Follow up (months)	Instability (%)	Meniscal injury(%)
Mc Carroll et al[13]	1988	16	27	100	NA
Angel and Hall [4]	1989	27	51	55	NA
Graf et al [53]	1992	8	24	100	87
Mc Carroll et al [12]	1994	38	29	97	71
Mizuta et al[14]	1995	18	51	94	NA
Aichroth et al [24]	2002	23	72	100	NA
Gebhard et al [1].	2006	68	32	100	41
Mc Intosh et al [7].	2006	16	41	100	69

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