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REVIEW

Paediatric anterior cruciate ligament injury

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Abstract

The number of paediatric anterior cruciate ligament injuries is rising at a greater rate than in the adult population, as a result of the increased participation of children and adolescents in sports. This review explores the key presentations, diagnostic and management plans, and prevention methods associated with paediatric anterior cruciate ligament injuries. This injury presents as an acute pop and effusion, with limitations in gait, and can be extremely debilitating. Clinical examination and magnetic resonance imaging are used to diagnose the injury. The pivot shift and Lachman test remain the most valid exams when suspecting an anterior cruciate ligament tear. Management of the injury can be surgical or non-surgical depending on the severity of the tear and associated injuries. The surgical approach chosen is determined by the patient's Tanner classification, considering potential damage to the physes of the bone. Management plans should include rehabilitation consisting of strength, proprioception and neuromuscular training, to maximise the patient's recovery. Injury prevention programmes, consisting of strength training and neuromuscular training, should be followed by young athletes to reduce anterior cruciate ligament injuries. Compliance and earlier implementation coupled with an understanding of the biomechanics of anterior cruciate ligament injuries and verbal feedback maximise the benefit of neuromuscular training.

Key words: Anterior cruciate ligament; Neuromuscular training; Paediatric; Prevention; Rehabilitation

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Introduction

The anterior cruciate ligament is a key structure in providing stability of the knee in the sagittal and rotational planes. Injuries to the anterior cruciate ligament are not uncommon in children and the incidence is increasing at a rate greater than that of the adult population (Werner et al, 2016) with an estimated rate of 121 per 100 000 (Beck et al, 2017). This is likely to be a result of the increasing participation of children in competitive sporting events and recreational physical activities. The typical mechanism of injury is pivoting, with the knee partially flexed (Trivedi et al, 2017).

Anterior cruciate ligament injuries can be extremely debilitating to young patients. They can be associated with meniscal tears and chondral injuries, with a significant morbidity of time away from physical activity. If left untreated, the child may not be able to return to their pre-injury level of activity.

Therefore, it is important to emphasise both methods of preventing and the management of paediatric anterior cruciate ligament injuries. Despite becoming increasingly prevalent and their disabling nature, there is continued discussion as to the optimal approach and surgical techniques to these injuries.

Presentation

A child suspected of having an anterior cruciate ligament injury typically presents with a history of a non-contact injury (Trivedi et al, 2017), often with a 'pop', acute knee pain and effusion (Ardern et al, 2018). The patient complains of symptoms of instability (the sensation of the knee giving way) and potentially associated mechanical symptoms of the knee locking (which might indicate an associated meniscal tear). There is an inability to engage in certain physical activities, such as rapid changes of direction and dynamic movements.

On physical examination, the child may walk with an abnormal gait, avoiding full extension of the knee. In an acute presentation, an effusion may be visible and palpable, whereas in a more chronic presentation, there may be reduced muscle bulk of the affected quadriceps.

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Figure 1. Lachman knee examination.

Figure 2. Pivot shift knee examination.

On specific anterior cruciate ligament testing, there is likely to be a positive anterior draw on the Lachman test (Figure 1) with increased excursion compared to the unaffected side and a weaker 'endpoint'. The pivot test (Figure 2) is a passive test to assess for anterolateral rotational instability of the knee (Ayeni et al, 2017). The sensitivity and specificity of these tests are 87% and 93% respectively for the Lachman exam, and 61% and 97% for the pivot shift test (Table 1) (Coffey and Bordoni, 2020).

Diagnosis

The diagnosis of an anterior cruciate ligament tear can be based principally on the history and clinical examination. Magnetic resonance imaging is the imaging modality of choice,

Table 1. Methods used to perform specific anterior cruciate ligament tests

Test	Method	Results
Lachman test	Flex the knee to approximately 20° Place one hand posterior to the proximal tibia and the other anterior to the distal femur Pull the tibia anteriorly, displacing it from the knee Approximate the distance of displacement and recognise whether there is an endpoint	The test is graded as follows (A=firm endpoint, B=no endpoint) Grade 1: 3–5 mm translation Grade 2 A/B: 5–10 mm translation Grade 3 A/B: >10 mm translation
Pivot shift test	Start with the patient's hip flexed at about 20° with the knee fully extended Maintain an internal rotation of the leg and add a valgus force at the proximal fibula while flexing the knee	In a positive test, the tibia will sublux posteriorly

because of its potential to pick up other associated pathology, such as chondral injuries and meniscal tears (Figure 3). This is particularly important in any child with an acute effusion following injury. Magnetic resonance imaging can identify complete and partial ruptures of the anterior cruciate ligament and can show the type and chronicity of the tear. The sensitivity and specificity of magnetic resonance imaging for diagnosing an anterior cruciate ligament tear is 87% and 90% respectively (Li et al, 2017).

Treatment

The management of anterior cruciate ligament injuries in children depends primarily on the skeletal maturity of the patient, determined by their Tanner staging. This can be determined clinically or confirmed using hand X-rays. Other considerations are the severity of the injury, both clinically and radiologically, and other associated injuries, most commonly meniscal. Comorbidities, physiological demand and significance of symptoms are other patient factors which help determine treatment.

Management of a confirmed anterior cruciate ligament tear in a child can either be conservative or surgical. In both methods, rehabilitation is implemented to maximise and accelerate recovery, and protect from further intra-articular injury such as a meniscal tear (Ardern et al, 2018).

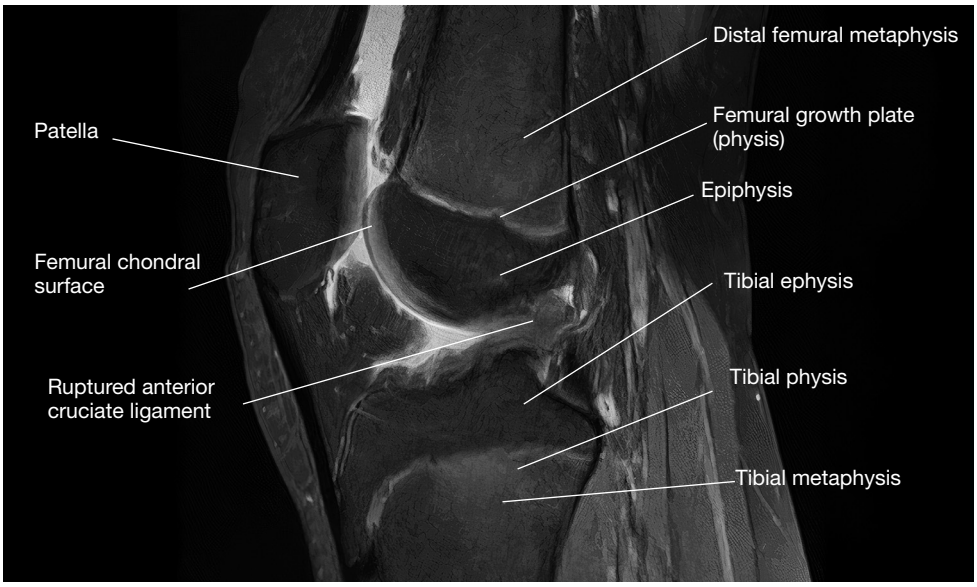

Figure 3. Annotated magnetic resonance image of anterior cruciate ligament tear.

Non-operative

For patients who have a partial anterior cruciate ligament injury or non-displaced tibial spine avulsion injury (fracture of the bone that the anterior cruciate ligament attaches to), there is a role for non-operative treatment. If the patient does not complain of instability and has a negative pivot test, then non-operative treatment can be considered. This involves wearing a protective brace and activity modification. Patients are referred for physiotherapy to prevent atrophy of the muscles, particularly the quadriceps, and improve proprioception and stability (Trivedi et al, 2017). They are slowly integrated back into dynamic sports with the help of ongoing proprioception training and neuromuscular training.

Although effective, correct patient selection for non-operative treatment is key. A meta-analysis (Dunn et al, 2016) comparing early operative to late operative and non-operative approaches concluded that an early operative decision produced better results. Patients who elected to be managed non-operatively were more likely to report knee instability and develop meniscal damage (Dunn et al, 2016). Studies investigating associated osteochondral injuries have also concluded that there is an increased risk of osteochondral fracture in patients treated non-operatively (Smith et al, 2018). As such, the consensus is that early appropriate reconstruction is recommended for a full rupture.

Operative treatment

Operative intervention is the gold standard treatment for patients who have a radiologically confirmed complete anterior cruciate ligament rupture, or partial tears but with ongoing instability symptoms. Symptomatic partial tears might warrant further diagnostic arthroscopy under anaesthesia to evaluate any meniscal or chondral pathology with the intention of proceeding as required by the pathology.

The critical consideration in paediatric anterior cruciate ligament reconstruction is the patient's skeletal maturity. This is graded by the Tanner classification and reflects the maturity of the physis. The physis, or growth plate, is located between the epiphysis and metaphysis of the femur and tibia. Damage to the physes can interrupt their ability to proliferate and constitute longitudinal growth (DeFrancesco et al, 2018).

Delaying surgery can be advantageous to progress skeletal growth (and the Tanner stage) of the child to minimise the risk of growth disturbance. Below are the surgical options categorised by the Tanner staging of the patient.

Tanner I/II

Physeal-sparing reconstruction: For patients who are most skeletally immature, a physeal-sparing procedure can be performed. An autograft, typically the iliotibial band with its attachment to Gerdy's tubercle, is rerouted through the femoral notch and attached to the anterior proximal tibia (Fabricant and Kocher, 2016). The technique restores the stability of the knee without direct violation of the physis. This is commonly referred to as the 'over the top' technique because of its extra-articular nature.

Epiphyseal anterior cruciate ligament reconstruction: Patients who are Tanner I but more commonly II may consider an epiphyseal anterior cruciate ligament reconstruction. A prepared hamstring autograft is fed through tunnels that are exclusively transphyseal in the horizontal plane parallel to the physis, to reconstruct the anterior cruciate ligament (Cruz et al, 2017).

Tanner III/IV

Partial transphyseal anterior cruciate ligament reconstruction: This technique is a hybrid of the previous two. It involves a transphyseal tibial tunnel with an over-the-top technique as used in the physeal-sparing technique. This ensures there is no damage to the physis of the femur. This technique is considered for Tanner III/IV patients to balance the risk of physeal damage with ligamentous stability.

Transphyseal anterior cruciate ligament reconstruction: A transphyseal anterior cruciate ligament reconstruction may be considered for Tanner III/IV patients. This method creates a tunnel for the intra-articular graft through both the tibia and femur but is done in a more vertical manner than the more anatomical oblique tunnel in an adult type anterior cruciate ligament reconstruction. This is performed under radiological guidance

and lessens the total physeal surface area involved, thus minimising its violation (Fabricant and Kocher, 2016). The central nature of the tunnel also reduces the risk of any angular growth disturbance.

Tanner V

Adult type anterior cruciate ligament reconstruction: In Tanner V patients the reconstruction of the anterior cruciate ligament can be done in the same way it is done in adults. Typically, a hamstring autograft (or equivalent) is fed through a transphyseal tunnel through both the tibia and femur. However, even in those who are approaching skeletal maturity the surgeon might still consider the risks of violating the physis and adopt a more physeal-sparing approach to the procedure.

Anterior cruciate ligament reconstruction can disturb the growth plates; children with limb growth potential of 5 cm or more are at a higher risk of iatrogenic growth disturbance (Davis et al, 2016), including premature growth arrest, angular deformity, limb overgrowth and leg length discrepancy. A retrospective study of patients who had a 5-year minimum postoperative follow up observed that 7.5% required revision anterior cruciate ligament reconstruction (Nogaro et al, 2020).

Tibial spine avulsion injury

Tibial spine fractures are fractures of the bony attachment of the anterior cruciate ligament and can coincide with an anterior cruciate ligament tear because of the similar mechanisms of injury. These fractures are rare, with an incidence of 3 per 100 000 children per year (Tuca et al, 2019). Classification of the tibial spine fracture determines the approach taken for treatment. If the fracture is non-displaced, a non-operative approach is taken, aspirating the haemarthrosis and immobilising the knee for 3–4 weeks before carrying out rehabilitation (Tuca et al, 2019). In the case of a displaced tibial spine avulsion injury, surgery is required for reduction and fixation of the fracture. Following a diagnostic arthroscopy, the operation starts with anatomically reducing the fracture and recessing it to tighten the anterior cruciate ligament, followed by fixation using either a screw or a suture to reduce the bony fragment (Tuca et al, 2019). Screw fixation might require a further operation to remove the screw.

Rehabilitation

During rehabilitation, numerous techniques are used to treat patients, in addition to close monitoring. Aggressive cryotherapy decreases pain, although there is limited evidence that it decreases swelling postoperatively (Bednarski and Kiwerski, 2019).

Immediate weight bearing

Patients should be encouraged to begin weight bearing progression immediately. This decreases patellofemoral pain as well as encouraging acclimatisation of the knee back to supporting the patient's weight (Cavanaugh and Powers, 2017). Weight bearing should be done progressively using crutches or while suspended in water to prevent further injury.

Range of motion

Emphasis should be placed on accomplishing complete knee extension range of motion. Cavanaugh and Powers (2017) explain that range of motion flexion goals of 120° should be achieved at 4 weeks following surgery and full symmetrical flexion achieved by 12 weeks. This is enforced through exercises involving active knee extension such as squat variants and single leg stands.

Neuromuscular training and strength training

Neuromuscular control is the primary aim in prepubescent children rather than muscular strength and hypertrophy because of their lack of androgenic hormones (Ardern et al, 2018). Neuromuscular training should be commenced in older adolescents, as well as progressive strength training in the form of physiotherapy, once they are able to bear at least 50% of

their weight (Cavanaugh and Powers, 2017). This often involves the use of resistance bands to induce progressive use of muscles. Appropriate exercise includes isometric quadricep and hamstring contractions with active knee motion as well as eccentric training.

Return to sports

Over 90% of children and adolescents return to sport after an anterior cruciate ligament reconstruction (Kay et al, 2018). The clinical decision about when a child can return to sport is an important aspect of patient care and can be influenced by the results of numerous qualitative and quantitative assessments. The re-rupture rate in children and adolescents is approximately 10%, but the risk for patients who return to pivoting sports is approximately 25% (Ardern et al, 2018). Patients are at the highest risk of reinjury within the first 12 months postoperatively, so are advised against returning to pivoting sports before then.

A systematic review (Davies et al, 2017) on algorithms used to determine suitability of returning to sport observed only a small percentage of the appropriate literature describes objective criteria. The authors concluded that, in most cases, return to sport is based only on postoperative time and the subjective view of both the patient and the physician. There is not yet an accepted objective measure of function, strength and psychometrics that would be acceptable before return to dynamic sports.

Prevention

The increasing incidence of anterior cruciate ligament injury in children and adolescents has led to research into the mechanism of injury as well as the modifiable risk factors. This is key since the skeletal immaturity of the paediatric and adolescent population means the management of anterior cruciate ligament injuries can be more complex with increased risks compared to the adult population. Although certain risk factors are non-modifiable, such as female gender, there are modifiable risks that can be addressed and optimised to minimise anterior cruciate ligament injuries.

To address this increased risk, Sugimoto et al (2015) analysed 14 large-scale clinical trials testing the efficacy of neuromuscular training focussing on female athletes. Female athletes have a two to four-fold higher risk of anterior cruciate ligament injuries than male athletes (Sugimoto et al, 2015), although there is no clear evidence of sex being a risk factor in younger children (5–12 years) (Hutchinson et al, 2016).

Despite these results being drawn from female participants, neuromuscular training has shown similar positive results for men when compared to control groups who did not perform neuromuscular training exercises (Nessler et al, 2017). The literature describes strategies to minimise the risks of anterior cruciate ligament injuries using neuromuscular training in addition to addressing other modifiable risk factors (Table 2) (Nessler et al, 2017).

Conclusions

The incidence of paediatric anterior cruciate ligament injuries is rising as a result of the increased participation of young children and adolescent in sports. As a result, there is increased awareness of the risk factors and methods of prevention in the form of anterior cruciate ligament injury prevention programmes which incorporate a mix of neuromuscular training, plyometrics and strength training.

These programmes have been analysed thoroughly and there is evidence for their efficacy as well as certain factors that they incorporate to minimise the risk of anterior cruciate ligament injury. Prevention programmes should be used with young people through schools and sports academies, focussing on plyometrics, neuromuscular training and strength training. Programmes should also seek to implement the strategies proven to maximise their efficacy.

The Lachman test and pivot test have the highest specificity during a physical examination and magnetic resonance imaging will confirm the diagnosis. Management of an anterior cruciate ligament injury primarily depends on the severity of the injury and the patient's skeletal maturity.

Table 2. Recommended strategies to maximise the reduction in anterior cruciate ligament injuries using neuromuscular training in addition to addressing other modifiable risk factors

Age	When compared to their older colleagues who also completed neuromuscular training, younger athletes were at a significantly lesser risk of developing anterior cruciate ligament injuries. This is hypothesised to be a result of the increased ability of their sensorimotor function to adapt (Sugimoto et al, 2015). Myer et al (2013) found a greater effect of neuromuscular training in 14–18 year olds vs older athletes. The International Olympic Committee 2018 consensus statement (Maughan et al, 2018) concluded that, to be effective, injury prevention programmes should be implemented early in the athlete's developmental process
Biomechanics and hamstring strength	Excessive knee abduction or valgus movement puts patients at a greater risk of anterior cruciate ligament injury (Sugimoto et al, 2015). Steffen et al (2013) concluded that using an injury prevention plan focussing on core stability, balance, dynamic stabilisation and eccentric hamstring strength reduced the rate of anterior cruciate ligament injury in collegiate male football players
Compliance	Greater compliance with neuromuscular training showed greater results, although this was not significant. Coaches who were more experienced in the field, with a healthcare practitioner present, gained greater student compliance (Sugimoto et al, 2015). Emery et al (2015) also emphasised the importance of implementation in influencing athletes' knowledge and behavioural changes in addition to long-term sustainability and compliance
Dosage	Participants who complete neuromuscular training sessions more frequently are less prone to injury. This is also true for participants who do longer sessions over a longer period (Sugimoto et al, 2015). The International Olympic Committee consensus statement confirmed that programmes needed to be performed regularly with consistent implementation and adherence across all levels of competitive play
Exercise	Programmes with a greater variety of exercises, such as strength, plyometrics and balance training, have improved results than those which only included one form of exercise (Nessler et al, 2017). Exercises that involved strengthening stability of segments proximal to the knee had optimal effects (Sugimoto et al, 2015), likely because of their contribution to trunk stability
Feedback	Verbal cues and feedback prove beneficial during neuromuscular training sessions to reduce the risk of anterior cruciate ligament injury compared to controls. Emery et al (2015) found that acknowledging the improvement in performance that relates to injury prevention may facilitate the uptake of preventative programmes by players and coach

Multiple surgical techniques have been developed and the decision of which one to use depends on the skeletal maturity of the patient. In those most skeletally immature, various physeal-sparing techniques are considered, with more acceptability of potential physeal damage as the patient is more skeletally mature.

Postoperative rehabilitation is key to ensure full recovery, and return to sports and functional activity. Re-rupture rates are greater in children than the adult population and those partaking in sports with pivoting movements are particularly at risk. The decision to return to these activities is currently based on time following surgery and subjective assessments, but more work is suggested for a more objective approach to return to these high-risk activities.

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Conflicts of interest

The authors declare that there are no conflict of interests.

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Key points

- Paediatric anterior cruciate ligament injuries are becoming more frequent as a result of increased participation in competitive sports and physical activities.
- On physical examination, acute effusion indicates the need for immediate diagnostic magnetic resonance imaging.
- Various surgical techniques are considered for anterior cruciate ligament reconstruction, depending on the remaining potential growth of the physis of the child.
- Rehabilitation, with emphasis on weight bearing, range-of-motion and neuromuscular and strength training, maximises and quickens recovery.
- Neuromuscular training can be used in addition to education regarding the biomechanics of anterior cruciate ligament injuries to prevent an anterior cruciate ligament tear during physical activity.

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