ACL Injuries: Diagnosis, Treatment, and Prevention

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Objectives

- Epidemiology of anterior cruciate ligament (ACL) injury
- Injury mechanisms
- Risk factors
- Diagnosis
- Treatment
- ACL injury prevention
ACL: Anterior Cruciate Ligament

- Primary stabilizer of the knee
- Prevents tibia from sliding forward on femur
- Protects the menisci from shearing forces
Epidemiology of ACL Injury

- ACL injuries in young athletes have increased over the past two decades, probably due to:
  - Growing number of children and adolescents participating in organized sports
  - Increased participation in high-demand sports and intensive training regimens at an earlier age
  - Greater rate of diagnosis due to awareness that ACL injuries can happen in younger children and more frequent use of advanced imaging
Epidemiology of ACL Injury: Who is Most Vulnerable?

- **Athletes**
  - ACL injury rate in general population = 1:3000
  - Over 70% of ACL injuries are sports-related
  - Riskiest sports involve jumping/landing or quick change of direction (pivoting)
    - Soccer
    - Football
    - Basketball
    - Gymnastics
Epidemiology of ACL Injury: Who is most vulnerable?

- Adolescents and young adults

- High school athletes: 5.5 per 100,000 athletic exposures
- Collegiate athletes: 15 per 100,000 athletic exposures

Epidemiology of ACL Injury: Who is Most Vulnerable?

- **What about children?**
  - No well-designed studies in children <14 years of age
  - There have been reports of sports-related ACL injuries in children as young as 5 years of age
  - ACL tears appear to be rare before age 12
    - Of 1,722 ACL injuries seen over a 6-year period at a sports medicine center, only 57 (3%) were in children <14 years of age
Epidemiology of ACL Injury: The Gender Gap

- Females
  - 4-6 times more likely to tear the ACL than males in similar sports
  - More likely to have surgery for an ACL injury
  - Less likely to return to sports after ACL injury
High School ACL injury rates per 100,000 athlete exposures (AEs) by sport

Impact of an ACL Injury

- **Physical**
  - Surgery and/or 6-9 months of rehabilitation

- **Social/academic**
  - Athletes miss whole seasons of play
  - Often limits future sports participation
  - Negative impact on academic performance

- **Financial**
  - Treatment is $17,000 - $25,000 per injury

- **Long-term health**
  - Despite treatment, 10-fold greater rate of early-onset knee osteoarthritis (15-20 years post injury)
ACL Injury Mechanisms

- 70-80% are “non-contact”
  - Landing from a jump
  - Quick change of direction
  - Stopping suddenly

View a video of a non-contact ACL injury in a girls’ volleyball practice at [http://www.youtube.com/watch?v=l9-LDYZI3Kc](http://www.youtube.com/watch?v=l9-LDYZI3Kc)
ACL Injury Mechanisms

- Most common body position during non-contact ACL injury:
  - Hip internally rotated, adducted
  - Knee near full extension
  - Tibia externally rotated
  - Foot everted and planted
  - Body decelerating
  - Combo of above leads to apparent valgus collapse of knee
    • “Dynamic knee valgus”
Learning Objectives

- Describe history pearls that suggest an ACL tear in an adolescent athlete
- Describe the differential diagnosis of an acute traumatic knee hemarthrosis
- Explain physical exam methods that help to make the diagnosis of an ACL tear
- Explain surgical techniques that can be used in patients with open growth plates and an ACL tear
Outline

- Anatomy/function
- Diagnosis
- Treatment
- Safe techniques of surgery with open growth plates
- Rehab tips
- Outcomes
ACL Anatomy

- **Length**
  - 22-41mm (mean 32mm)
- **Width** 7-12mm
- **Cross-sectional diameter** 36-49mm²
- **2 bundles**
  - Anteromedial and posterolateral
  - Named for tibial attachment sites
Function

- Resists anterior tibial translation and internal tibial rotation
- Secondary restraint to varus/valgus stress
Important History Pearls

- How did the injury occur? Contact? No contact twist?
- Could the athlete continue to play?
- Significant swelling?
- Previous injuries?
- A ‘pop’?
- Menarche in females?
Pearl: Mechanism of Injury

- 70% of ACL injuries are noncontact with knee in “dynamic valgus” position
  - Tibia internally rotated
  - Knee close to full extension
  - Foot planted
  - Body decelerating
Important Exam Pearls

- Swelling
- Lachman test
- Bone tenderness
- Medial lateral instability
- Drawer sign
- Range of knee motion
- Can the patient bear weight?
Lachman Test
KT 1000 Test
Differential Diagnosis of an Acute Knee Hemarthrosis

- ACL tear
- *Tibial spine fracture*
- Patellar dislocation
- Meniscal tear
- *Osteochondral fracture*
- *Epiphyseal fracture of the femur or tibia*
Case #1: Knee Injury

- 13-year-old female soccer midfielder hyperextends her left knee and rotates her body weight on her left leg while taking a shot on goal. She feels a ‘pop’ in her knee and cannot continue to play. She limps off the field. The knee swells up over the next hour while on the bench.
Exam

- Lachman +
- Drawer +
- Pivot unable to do
- Collaterals stable
- Meniscal signs –
- Pulse 2+
- Sensation and foot motion normal
Methods to Determine Maturity

- Chronological age
- Skeletal age
- Tanner stage—physiologic age
- Height of parents and sibling
- Height of patient

Dilemma

- Pediatric ACL injuries are a balancing act of non-operative treatment which may risk future meniscal and cartilage damage versus the operative risk of iatrogenic growth disturbance to the growth plate.
In Our Case:

- After a discussion with the family and athlete about the injury, and treatment options and outcomes, the family decides to try bracing, modified activity, and rehab strengthening.
Non-operative Treatment

Classic Approach

- Physical therapy, activity limitations, no cutting sports, and bracing until skeletal maturity

- If the patient has continued instability, or does not tolerate decreased activity level
  -> operative management
Non-operative Treatment Advocates

**Woods GW, et al. AJSM. 2004***
- 13 adolescents—no increase in meniscal or articular damage by waiting until physeal closure
- Strict activity restriction key

**Moksnes H, et al. AJSM. 2013**
- 20 patients <12 years of age with complete ACL tears
  - 65% able to return to pre-injury function
  - 50% defined as “copers”
    - Resumed pre-injury function

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“Conservative care resulted in additional injury, meniscal tears, osteochondral fractures, MCL tears—therefore—recommend surgery”

Surgical Approach Advocates

- Early ACL reconstruction

Most literature involving pediatric ACL tears treated non-operatively had poor outcomes—repeat meniscal and chondral injury

Six weeks later the patient returns after another instability episode, despite a brace, wishing to continue to play soccer. The parents and athlete request surgical treatment.
Indications for Surgery

- Complete ACL tear with functional instability in day-to-day activities
- Failed non-operative treatment
- ACL tear plus a meniscal and/or chondral injury
- Surgery is usually delayed for 4 weeks post injury to regain normal range of motion and reduce hemarthrosis
- Also, patients need to be ‘mature’ enough to participate in post-op rehab process
Pediatric ACL Growth Concerns When Using ‘Adult Techniques’

- **Growth**
  - Distal femur ~ 10mm/year
  - Proximal tibia ~ 7mm/year

- **Growth completion**
  - Boys ~ 16 years old
  - Girls ~ 14 years old

**Reports of Growth Changes**


**Shortening or Angular Deformity**
Techniques that avoid injury to the growth plates:

Iliotibial band technique

All epiphyseal technique
Physeal Sparing Combined Intra/Extra-articular Reconstruction with Iliotibial Band

Outcomes Iliotibial Band Technique

- Physeal sparing combined intra/extra-articular reconstruction with iliotibial band
  - 44 patients
  - Mean 5-year follow up
  - 43/44 normal or near normal lachman
  - 44/44 normal or near normal pivot shift
  - No growth disturbance noted
  - 2 required revisions (1 at 5 years, 1 at 8 years)

- This surgery provides excellent functional outcomes with a low revision rate and low chance of growth disturbance

Trans-epiphyseal anterior cruciate ligament reconstruction in pediatric patients: surgical technique

All-epiphyseal anterior cruciate ligament reconstruction in skeletally immature patients

Outcomes All-epiphyseal Technique

**Anderson AF, et al. JBJS. 2004***
- All-epiphyseal—hamstring graft
  - 12 patients—ave age 13
  - Mean 4-year follow up
  - Limb lengths equal—mean growth 16 cm
  - IKDC score ave 96/100
  - Normal for 7 patients; near normal for 5 patients

**Lawrence JT, et al. CORR. 2009**
- All-epiphyseal
- 3 patients—ave age 11
- All returned to sports
- No growth problems

- All epiphyseal surgery is safe and efficacious in skeletally immature athletes
- Need long term follow up and larger numbers

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Rehab and Follow Up Tips

Prior to surgery
- Ice
- Range of motion
- Full weight bearing

Post op 0-2 weeks
- Knee extension brace
- Ice
- Advance to full weight bearing

2 weeks
- Brace stopped
- Range of motion, quad, ham, hip and core rehab

3 months
- Light jogging, biking

6 months
- Cutting sports
- ACL brace for high risk sports for 1 year
- X-rays at 6 months
- Annual clinical follow up—LLI, angular growth, re-injury until age 18

Return to sport outcomes
- 78-91% return to sport
- Only 44-62% at previous performance level
Back to Our Case: Patient Outcome

- After family discussion they wish to proceed with a physeal sparing combined intra/extra articular reconstruction with iliotibial band
- Did well with surgery
- Now 12 months out and has returned to soccer and now cheer with no signs of instability
- And... both teams are now doing ACL plyometric training 3 times per week
Summary

- Describe history pearls that suggest an ACL tear in an adolescent athlete
- Describe the differential diagnosis of an acute traumatic knee hemarthrosis
- Explain physical exam methods that help to make the diagnosis of an ACL tear
- Explain surgical techniques that can be used in patients with open growth plates and an ACL tear
ACL I
Risk Factors
ACL Injuries: Diagnosis, Treatment and Prevention

- ACL injury risk in young athletes is likely multifactorial.
- Injury data from many fields demonstrate that numerous physical and psychological parameters affect ACL injury rates.
Genetics

- Genetic factors likely play a role.
- The genetic underpinnings of increased ACL injury have only recently begun to be examined.
Hormones

- Hormonal factors also likely play a role.
- Results of studies investigating hormonal factors are both equivocal and controversial.
- The female knee appears to get slightly more lax on the order 0.5 mm, at mid-menstrual cycle.
- Injuries tend to cluster near the start of menses at the polar opposite time in the cycle.
Prior Injury

- One of the single best predictors of future ACL injury is prior ACL injury.

- One study found the incidence rate of ACL injury in athletes who had ACL reconstruction was 15 times greater than that of control subjects.

- Female athletes were 4 times more likely to suffer a second ACL injury in either knee and 6 times more likely to suffer a new ACL injury in the contralateral knee than male athletes.
Prior Injury

- Subsequent injuries to the contralateral ACL are twice as common as re-injury of the reconstructed ACL (11.8% vs 5.8%).
- Genetic, anatomic and neuromuscular factors likely play a role.
Age and Sex

- Although ACL injury rates increase with age in both sexes, girls have higher rates immediately following the growth spurt.

- It is likely that the increases in body weight, height, and bone length during pubertal development underlie the mechanism of increased risk of ACL injury with increasing age.

- During puberty, the tibia and femur grow at a rapid rate.
Age and Sex

- This growth of the 2 longest levers in the human body translates into greater torques on the knee.
- Increasing height leads to a higher center of mass, making muscular control of this center of mass more challenging.
- Increasing body weight is associated with greater joint force that is more difficult to balance and dampen during high velocity athletic movements.
Age and Sex

- In pubertal boys, testosterone mediates significant increases in muscular power, strength, and coordination, which affords them with greater neuromuscular control of these large body dimensions.

- Pubertal girls do not experience this same growth spurt in muscular power, strength, and coordination, which likely explains their higher rates of ACL injuries compared with pubertal boys.

- The fact that preadolescent athletes show no sex differences in ACL injury rates further supports this theory.
Anatomic/Anthropometric Fact

- Greater weight and body mass index (BMI) have been associated with increased risk of ACL injury.
- A study of military recruits found that body weight or BMI greater than 1 standard deviation above the mean was associated with 3.2 and 3.5 times greater risk of ACL injury.
- In a study of female soccer players older than 8 years, BMI was a significant risk factor for knee injury.
Anatomic/Anthropometric Factors

- An increased quadriceps angle (Q angle) has been postulated as a risk factor, but there have been no prospective clinical studies to investigate the relationship between quadriceps angle and ACL injury.

- A narrow intercondylar notch, where the ACL is housed, is proposed to increase ACL injury risk because a narrow notch tends to be associated with a smaller, weaker ACL and could cause increased elongation of the ACL under high tension.

- Some studies have shown that a narrow notch increases risk; however, other studies have shown no association.
Anatomic/Anthropometric Factors

- Subtalar joint overpronation has been associated with noncontact ACL injuries, likely because overpronation increases anterior translation of the tibia with respect to the femur, thereby increasing the strain on the ACL.

- Generalized joint laxity and knee hyperextension were found to significantly increase the risk for ACL injury in female soccer players.

- ACL injured patients have significantly more knee recurvatum at 10 and 90 degrees of hip flexion and an increased ability to touch palms to floor.
Anatomic/Anthropometric Factors

- Athletes with generalized joint laxity had a 2.7 times greater risk of ACL injury than did those without generalized laxity, and those with increased anterior-posterior laxity, as measured by a knee arthrometer, had an approximately 3 times greater risk of ACL injury than did those without increased anterior-posterior laxity.

- Joint laxity affects not only sagittal knee motion (hyperextension) but also coronal knee motion (valgus), which can strain the ACL and be related to increased risk in athletes.
Neuromuscular Factor

- Muscle strength and coordination have a direct effect on the mechanical loading of the ACL during sport movements.
- Poor neuromuscular control of the hip and knee and postural stability deficits have shown to be risk factors for ACL injury.
- Landing and pivoting sports involve a great deal of rapid deceleration and acceleration movements that push and pull the tibia anteriorly and place the ACL under stress.
- This tibial translation can be modulated by hamstrings and quadriceps activity.
Neuromuscular Factor

- In vivo studies, when subjects were asked to contract their muscles, knee laxity was reduced by 50% to 75%.

- Activation of the quadriceps before the hamstrings, a pattern more frequently seen in females, increases the anterior shear force that directly loads the ACL and also could be related to increased dynamic valgus alignment at initial contact during cutting and landing maneuvers.

- Fatigue is often cited as a potential risk factor for ACL injury; there are relatively few published data to support or refute this.
ACL II
Prevention Programs
Bracing

- It is unlikely that prophylactic bracing can decrease the risk of ACL injury.
- The relative effects of 6 different brace designs on anterior tibial translation and neuromuscular function were studied in chronically unstable ACL-deficient patients.
- Bracing decreased anterior tibial translation in the range of 30% to 40% without the stabilizing contractions of the hamstrings, quadriceps, or gastrocnemius muscles.
Bracing

- With muscle activation and bracing, anterior tibial translation was decreased between 70% and 85%. However, the braces slowed hamstrings muscle reaction time.

- A brace with a 5-degree extension stop decreased extension on landing.

- Knee bracing does not improve functional performance of subjects after ACL reconstruction and may actually reduce running and turning speed.
Bracing

- Functional bracing after ACL reconstruction has been studied using randomized controlled cohorts placed into braced or non-braced groups.

- The braced group was instructed to wear a functional knee brace for all cutting, pivoting, or jumping activities for the first year after ACL reconstruction.

- There were no differences between groups in knee stability, functional testing, subjective knee scores, and range of motion or strength testing. Investigators concluded that post-operative bracing did not change outcomes.

- Data are insufficient at this time to determine whether functional bracing decreases the risk of ACL injury or re-injury.
Neuromuscular Training Programs

- Although ACL injuries occur too quickly for reflexive muscular activation, athletes can adopt or “pre-program” safer movement patterns that reduce injury risk during landing or pivoting or unexpected loads or perturbations during sports movements.

- With sufficient neuromuscular control of knee position to avoid dynamic valgus, knee stability may be improved during competitive sports and the risk of ACL injury can be significantly reduced.
Neuromuscular Training Programs

- A collection of prospective cohort studies and randomized controlled trials have examined the effect of neuromuscular training programs on ACL, knee, and other lower-extremity injuries in soccer, basketball, volleyball, and handball.

- Some studies used only 1 or 2 types of exercises, such as plyometric or balance exercises, and others applied a more comprehensive approach by including plyometrics (repetitive jumping exercises designed to build lower extremity strength and power), strengthening, stretching, and balance training.
Neuromuscular Training Programs

- Systematic examination of the data extracted from these studies leads to a few potentially valuable generalizations.
  - Plyometric training combined with technique training and feedback to athletes regarding proper form were the common components of programs that effectively reduced ACL injury rates.
  - Balance training alone may not be sufficient to reduce ACL injury.
Neuromuscular Training Programs

- Some of the effective programs did not include strength training; those that did were among the most effective at decreasing ACL injury rates.

- ACL injury reduction was greatest for soccer, and combined pre- and in-season training was more effective than pre- or in-season training alone.
Neuromuscular Training Programs

- With respect to age, the greatest reduction in injury risk was demonstrated for female athletes in their mid-teens (14-18 years) compared to those in their late teens (18-20 years) and adults (>20 years), with 72% risk reduction for those <18 years of age and 16% risk reduction for those ≥18 years of age.
  - This suggests the best window of opportunity for ACL injury risk reduction may be during early pubertal maturation, at or just before girls’ neuromuscular risk factors start to become evident and ACL injury rates in girls dramatically increase.
Neuromuscular Training Programs

- It is unknown whether neuromuscular training or other interventions can modulate the increased risk of early-onset degenerative knee arthritis after ACL injury.
- More information about specific evidence-based neuromuscular training programs can be found in the respective articles describing their study results.
- The AAP has compiled a series of instructional videos for pediatricians, athletes, and coaches who would like to learn more about neuromuscular training and preventive exercises.
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