Pediatric Anterior Cruciate Ligament Injuries

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Yi-Meng Yen, MD, PhD
Children’s Hospital Boston
Department of Orthopaedics
Division of Sports Medicine
Child and Adult Hip Unit
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Outline

- Epidemiology and presentation
- Review development
- Tibial eminence fractures
- Partial ACL tears
- Full ACL tears
The ACL

- Primary stabilizer of the knee
- Prevents the tibia from sliding forward on the tibia
- Protects the menisci from shear forces
Epidemiology of ACL Injuries

- Sharp rise in ACL injuries in young athletes over the past two decades
  - Increasing number of children and adolescents in organized sports
  - Earlier specialization and year-round training at earlier ages
  - Improved rate of diagnosis due to injury awareness and advanced imaging
Epidemiology of ACL Injuries

- Most vulnerable
  - ACL injury rate in general population is around 1:3000
  - 70% of ACL injuries are sports related
  - Greatest risk occurs in activities that involve pivoting, jumping/landing
    - Basketball
    - Football
    - Soccer
    - Gymnastics
Epidemiology of ACL Injuries

- Adolescents and young adults have highest rate of injury

- High School: 5.5 per 100,000 athletic exposures
- College: 15 per 100,000 athletic exposures

Distribution of patients in the Norwegian National Knee Ligament Registry by age and sex.
Epidemiology of ACL Injuries

Number of ACL reconstruction by Age and Gender

Adolescents with growth remaining are common
Epidemiology of ACL Injuries

Number of ACL reconstruction by Age and Gender

Pre-pubescent ACL repairs are uncommon
Epidemiology of ACL Injuries

• Children
  • No good studies in children < 14
  • Case reports of sports-related ACL injuries in children as young as 5
  • Rare in children under 12 years old
ACL Injuries in Young Patients
ACL Injuries in Young Patients

San Francisco Chronicle

HOMESCHOOLERS SUFFER SETBACK

Growing pains: Children’s sports injuries get worse

Nicole Simon, 15, gets physical therapy from Bruce Valentine at Children’s Hospital. She has injured both her knees in sports.

Most perilous sports

FOR GIRLS
- Soccer
- Basketball
- Gymnastics

FOR BOYS
- Ice hockey
- Football
- Soccer

By Erin Alday
Chronicle Staff Writer

Nicole Simon was 13 when she injured her knee the first time, gliding soccer in a competitive girls league.

She was 15 when she injured the other knee — less than one minute into her first basketball game after recovering from the earlier injury — and ended her athletic career before it had ever really started.

“My whole life revolved around sports, and then it was over,” said the Piedmont girl, who is going through her second round of rehabilitation at the Spine Medicine Center for Young Adults at Oakland Children’s Hospital. “I guess I’ll focus on other things now, like school. I’m trying to make the best of it.”

Pediatricians and sports medicine experts say that cases like Nicole’s have become depressingly common in young athletes. The topic of pediatric sports injuries — from strains and sprains to tendinitis and fractures that need surgery to repair — is a focus of the American Academy of Orthopaedic Surgeons.
Sharp Rise in Serious Sports Injuries in Children

Caleb Seymour, 8, of Holden, Maine, meets New England Patriots quarterback Tom Brady at Gillette Stadium. (ABC News)

By LARA SALahi (@laraalphabc), SRINDA ADHIKARI, and MARK ABDELMALEK, M.D.
Nov. 15, 2011
Epidemiology of ACL Injuries

- Gender Gap
  - Females are 4-6 times more likely to tear their ACL than males in similar sports
  - More likely to have surgery for an ACL injury
  - Less likely to return to sports after surgery
ACL Injury Mechanism

- 70-80% are non-contact injuries
  - Landing from jump
  - Rapid change of direction
  - Sudden stopping
- Body position
  - Hip internally rotated, adducted
  - Knee near full extension
  - Tibia externally rotated
  - Foot everted and planted
  - Valgus collapse of knee
ACL Injury Mechanism

- Chondroepiphyseal separation occurs in response to high energy forces at low load rate
- Ligament injury occurs secondary to lower energy forces at rapid load rate
ACL Injury

- **History**
  - Sports injury
  - Knee twist
  - Heard a ‘pop’
  - Swollen knee

- **Physical Exam**
  - Effusion
  - Block to extension
  - Lachman positive
  - Bone tenderness
  - Alignment
Growth and Development
Assessment of Maturity

- Adolescent Growth Spurt
  - Girls: 10.5yrs
  - Boys: 12.5yrs

- Peak Height Velocity
  - Girls: 11.5yrs (preceded by onset of menses)
  - Boys: 13.5yrs

- Methods
  - Chronological age
  - Skeletal age
  - Tanner stage
  - Height of parents/patient
Differential diagnosis of acute traumatic knee hemarthrosis

- ACL tear
  - Stanitski et al (1993): 65 pts - 47%
- Tibial spine fracture
- Patellar dislocation
- Meniscal tear
- Osteochondral fracture
- Epiphyseal fracture
Tibial Spine Fracture

• The original “Pediatric ACL injury”
• Anatomy
  • ACL attaches to intercondylar eminence
• High energy force at low load rates – bicycle fall
CT Scan
Tibial Spine Fracture

• When to fix?
  • Meyers & McKeever Classification *(JBJS 1959)*
    - Type I minimal displacement
    - Type II hinged
    - Type III completely displaced
  • Algorithm
    - Type I – Casting
    - Type II – Attempt at closed reduction and casting vs. Fixation
    - Type III – ORIF vs ARIF
Tibial Spine Fractures

- Fixation Methods
  - Suture
  - Screw
  - Bioabsorbable implants

- Mah, JPO 1996
Meniscal Entrapment

- Kocher et. al. (AJSM 2003)
- Retrospective Case Series
  - 80 skeletally immature pts
    - 1993-2001 (n=136)
    - nonreducible tibial spine fx (n=80)
    - 23 Type II, 57 Type III
    - operative treatment
- Findings
  - meniscal entrapment
    - Type II fx: 26% (6/23)
    - Type III fx: 65% (37/57)
  - Entrapment
    - anterior horn medial meniscus (36)
    - intermeniscal ligament (6)
    - anterior horn lateral meniscus (1)
Suture Fixation
Technique Pearls

• Fixation
  • Pull sutures out tibial tunnels
  • Tie over bone bridge
  • Pitfall: Adequate incision / tibial exposure to ensure knot tied down to bone
Rehabilitation

- Protocols vary, no consensus
  - Hinged knee brace
    - Initial ROM 0-30 x 4 weeks
    - Then full
  - Partial WB with brace locked in extension x 4 weeks, then WBAT with brace locked in extension
  - Transition to ACL brace and start PT at week 6
  - Sports in ACL brace at 3-4 months
Prognosis

• **Studies**
    - recommended ORIF for displaced fractures
    - more laxity in closed treatment vs fixation
  - Baxter & Wiley (JBJS 1988)
    - mild-moderate knee laxity in 45% pts
    - functionally not significant
  - Janarv et al (JPO 1995)
    - laxity 3-9 mm in 38% (functionally not significant)
  - Willis et al (JPO 1993)
    - anterior laxity in 64% (50 pts) @ 4 yrs
    - no complaints of instability
    - Laxity: 6.1 mm KT-1000 MMD
    - Function: 99.5 Lysholm Score
Complications

• Complication
  • Loss of Flexion or Extension
  • Prevalence: 0.5 – 40%

• Avoiding Complication
  • Early Mobilization

• Treatment
  • Early
    • Aggressive PT
    • Dynamic Splint
  • Late
    • Arthroscopic LOA
    • Gentle Manipulation!
Manipulation

- Gentle Manipulation!
  - Stiffness after open reduction and casting for type II tibial spine fx.
Manipulation

- Manipulated under anesthesia to get flexion
Tibial Spine Summary

- **Type I Fractures:**
  - long-leg cast: extension

- **Type II & III Fractures:**
  - Aspiration & Reduction
  - Nonreducible: ARIF or ORIF

- **Fixation Options**
  - Cannulated Epiphyseal Screws
  - Suture Fixation
  - Bioabsorbable Implants
Controversies: Pediatric ACL Injuries

- Partial vs. Complete tears
- Initial Management
  - Nonoperative vs Operative?
- Operative Management
  - Technique
    - Extra-physeal
    - Partial Trans-physeal
    - Complete Transphyseal
  - Graft Choice / Fixation
  - Age / Skeletal Maturity
- Complications
  - Growth Disturbance
ACL Injuries: Partial Tear

• Question
  • What is the prognosis of partial ACL injury in skeletally immature patients?

• Study (Kocher, AJSM, 2002)
  • Prospective Cohort
    • 45 pts, 13.9 yrs old, 6.1 yr F/U
    • Skeletally Immature
    • Arthroscopically Documented
  • Treatment
  • Outcome
    • 31% (14/45) Subsequent Reconstruction
    • Prognosis poorer for >50% tears, older pts, posterolateral bundle injuries
ACL Injuries: Partial Tear

• Conclusions
  • Favor non-operative treatment in:
    • Younger patients
    • < 50% tears
    • Anteromedial bundles tears
Conservative Treatment

• Approach
  • Physical therapy, activity limitation, no cutting or pivoting sports, bracing until skeletal maturity
  • If unable to tolerate or continues to have instability, consider operative management
Conservative Treatment

- Advocates to Non-operative treatment
  - Woods (AJSM 2004)
    - 13 adolescents – no increase in meniscal or articular damage by waiting until skeletal maturity
    - Key is strict activity modification
  - Moksnes (AJSM 2013)
    - 20 patients with complete ACL tears followed with longitudinal MRIs
    - 65% able to return to pre-injury level of activity
    - No increase in meniscal tears or cartilage injury at 2 years
  - Funahashi (AJSM 2014)
    - 24 patients (38% of cohort) – no symptoms at 2 years
    - Those that delayed ACL reconstruction did not have increase incidence in meniscal tears
Surgical Treatment

- Early ACL reconstruction
  - Angel & Hall *(Arthroscopy 1989)*
    - 5/7 failure (ACL reconstruction)
  - Graf et al *(Arthroscopy 1992)*
    - 7/8 failure (ACL reconstruction, meniscal tears)
    - 16/23 failure (ACL reconstruction)
  - Mizuta et al *(JBJS-B 1985)*
    - 1/18 return to preinjury sport level, 6/18 meniscal tears
  - McCarroll et al *(AJSM 1988)*
    - 3/16 return to preinjury sport, 4/16 meniscal tears
  - Millett et al *(Arthroscopy 2002)*
    - ↑ medial meniscus tears with delay in treatment
  - Lawrence et al *(AJSM 2011)*
    - 70 children: time (OR 4.1), instability (OR 11.4)

- Conservative treatment results in additional injury
Pediatric ACL

Our protocol at BCH:

Complete ACL Tear, Skeletally Immature Patient

- Pre-Pubescent
  - Tanner 1 or 2
  - Boys age < 12
  - Girls age < 11
  - Rehabilitation
  - Activity Modification
  - Functional Brace

- Adolescent with growth remaining
  - Tanner 3 or 4
  - Boys age 13-16
  - Girls age 12-14
  - Trans-physeal reconstruction
    - Hamstring graft + Metaphyseal fixation
  - Physeal-sparing reconstruction
    - IT Band technique

- Older adolescents, closing physis
  - Tanner 5
  - Boys age > 16
  - Girls age > 14
  - Adult ACL reconstruction
    - Hamstring or Patellar Tendon
    - Interference fixation
ACL Injuries: Growth Disturbance

- **Animal Models**
  - Guzzanti (JBJS 1994)
  - Rabbit, 2mm tunnels, 3/21 Disturbance
  - Edwards (JBJS 2001)
  - Canine, 80N, Femoral Valgus

- **Clinical Series**
  - 2 Cases
  - Lipscomb (JBJS 1986)
  - Koman (JBJS 1999)

- **Question**
  - Are there cases of growth disturbance from ACL reconstruction in skeletally immature patients?
Growth Disturbance

Survey of The Herodicus Society and The ACL Study Group Kocher et al (JPO, 2002)

- 8 Cases: Distal Femoral Valgus with Bony Bar
  - 3: Implants (Interference Screws) across Physis
  - 3: Patellar Tendon graft bone block across Physis
  - 1: Large (12 mm) Tunnel
- 2 Cases: Genu Valgum without Bony Bar
  - Lateral Extra-Articular Tenodesis
- 2 Cases: Leg-Length Discrepancy
  - 2.5cm shortening (PT bone block across physis)
  - 3.0cm overgrowth (6mm hamstrings graft)
- 3 Cases: Recurvatum with Apophyseal Bar
  - Hardware across Tibial Tubercle Apophysis
Growth Disturbance

- Physeal injuries do occur, although rarely
- Most commonly seen with
  - Implants across physis
  - Bone across physis (patellar tendon graft)
  - Large tunnels (>12mm)
  - Extra-articular tenodesis affect
Reconstruction Techniques

Extra-Articular

- Dahlstedt 1988
- McCarroll 1988
- Lazzarone 1990
- Graf 1992
- Nakhostine 1995

Physeal Sparing

- DeLee 1983
- Brief 1991
- Janarv 1996
- Micheli 1999
- Anderson 2004
- Guzzanti 2004

Partial Transphyseal

- Lipscomb 1986
- Andrews 1994
- Lo 1997
- Bisson 1998

Complete Transphyseal

- Lipscomb 1986
- McCarroll 1994
- Matavan 1997
- Aronowitz 2000
ACL Reconstruction

- **Extra-Articular Reconstruction**
  - McCarroll et al (*AJSM* 1988)
    - 10 pts (skeletal immature); IT band tenodesis; 26 mo F/U: 10/10 laxity, 5/10 instability

- **Repair**
    - 8 pts (skeletally immature); repair to femur; 3-8 yrs F/U: 8/8 laxity, 5/8 instability
ACL Reconstruction

• Physeal-Sparing ACLr
  • Brief (*Arthroscopy* 1991)
    • 6 pts (skeletally immature); hamstrings; 3-6yr F/U: 6/6 laxity, 1/6 instability
  • Guzzanti et al (*AJSM* 2003)
    • 8 pts (prepubescent); hamstrings, tibial tunnel; 2-7yr F/U: 1.8mm laxity, 0/8 instability
  • Anderson et al (*JBJS* 2003)
    • 12 pts (skeletally immature); hamstrings & tunnels; 2-8yr F/U: 1.5 laxity, 0/12 instability
  • Kocher et al (*JBJS* 2005)
    • 44 pts (prepubescent); ITB extra & intra-articular; 2-15 yr F/U: 4.5% revision, 96 & 97
ACL Reconstruction

- Partial Transphyseal ACLr
  - Andrews et al (AJSM 1994)
    - 8 pts (open physes); soft tissue allografts; tibial physis->over the top
    - 58 month F/U: 3/8 >3mm laxity, 1/8 poor result, no LLD
  - Lo et al (Arthroscopy 1997)
    - 5 pts (wide open physes); soft tissue autografts; tibial physis->over the top
    - 7.4 yr F/U: 0/5 >3mm laxity, 1/5 poor result, no LLD
ACL Reconstruction

- **Transphyseal ACLr**
  - Lipscomb & Anderson (*JBJS*-A 1986)
    - 24 pts (12-15 yrs old, 11 wide open physes); hamstrings autografts
    - 35 month F/U: 15/24 return to sport, 1.6 mm laxity, 1.3 cm LLD, 2.0 cm LLD
  - Matava & Siegel (*Am J Knee Surg* 1997)
    - 8 pts (skel immature, 14.9 yrs old); hamstrings autografts
    - 32 month F/U: 8/8 return to sport, 3/8 >3mm laxity, no LLD
  - McCarroll et al (*AJSM* 1994)
    - 47 pts (skeletally immature: 20 initial, 20/27 non-op); B-PT-B autografts
    - 4.2 yr F/U: 90% return to sport, no LLD
  - Aronwitz et al (*AJSM* 2000)
    - 19 pts (skeletally immature ≥14 bone age, Achilles allo
    - 2.1 yr F/U; 84% RTS; 97 Lysholm; 1.7mm KT1000
Recommendations

• Avoid Hardware across Lateral Distal Femoral Physis
• Avoid Hardware across Tibial Tubercle Apophysis
• Avoid Bone Plugs across Physes
  • Hamstrings Graft
• Avoid Large Tunnels
• Avoid Extra-Articular Tenodesis
• Minimal Over-the-Top Dissection & Notchplasty
• Consider Physeal Sparing Reconstruction in Prepubescent Patients
ACL tears in Children

Complete ACL Tear, Skeletally Immature Patient

- Pre-Pubescent
  - Tanner 1 or 2
  - Boys age < 12
  - Girls age < 11
  - Rehabilitation
  - Activity Modification
  - Functional Brace

- Adolescent with growth remaining
  - Tanner 3 or 4
  - Boys age 13-16
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  - Tanner 5
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IT Band technique

Rehabilitation
Activity Modification
Functional Brace
Transphyseal Reconstruction

- Transphyseal ACL reconstruction with autogenous hamstrings and metaphyseal fixation (*Kocher et al: JBJS 2007*).
  - 61 knees/ 59 pts (14.7 yrs old (11.6-16.9))
  - 3.6 yr follow-up (2.0-10.2)
  - 3.3% revision rate
  - IKDC: 89.5 ± 10.2/ Lysholm: 91.2 ± 10.7
  - 8.2 cm growth (1.2 - 25.4 cm)
  - No growth disturbance
- This technique appears provides for excellent functional outcome with a low revision rate and minimal risk of growth disturbance.
Complete ACL tears in Children

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  - Girls age < 11
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  - Adolescent with growth remaining
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  - Tanner 5
  - Boys age > 16
  - Girls age > 16
  - Adult ACL reconstruction
  - Hamstring or Patellar Tendon
  - Interference fixation

- **Physeal-sparing reconstruction**
  - IT Band technique

- **Rehabilitation**
  - Activity Modification
  - Functional Brace

- **Trans-physeal reconstruction**
  - Hamstring graft + Metaphyseal fixation

- **Physeal-sparing reconstruction**
  - IT Band technique

- **Rehabilitation**
  - Activity Modification
  - Functional Brace
Physeal-Sparing

• All-epiphyseal tunnels
  • Anderson et al (JBJS 2003)
    • 12 pts (skeletally immature); hamstrings & tunnels; 2-8yr F/U: 1.5 laxity, 0/12 instability
  • Concerns:
    • Narrow Margin of Error
    • Physis
    • Apophysis
    • Articular Cartilage
    • Growth Disturbance
    • Tunnels
      • Shallow Tibial Tunnel
      • Acute Turn Femoral Tunnel
    • Biomechanics
Physeal-Sparing

Prepubescents

• BCH Preferred Technique
  • MacIntosh 2 variation (LJ Micheli)
  • Extra/Intra-Articular
• Over-the-Top
• Over-the-Front

• Trade-Off
  • Nonanatomic
    • (but recreates PL bundle)
  • Physeal-Sparing
History of the Technique

• 1976 – Lyle Micheli performed the first “Modified McIntosh” procedure
  • 3 y/o male w/ congenital ACL absence
  • Galway, Beaupre, McIntosh JBJS 1972;54:763-764
    • Proposed leaving distal attachment of ITB, detaching proximally
    • Looped around LCL, reattached distally
    • LJM passed through the ‘over the top’ position, fed into a groove in the proximal tibial epiphysis
• 1980 – Began using for children with symptomatic instability following complete ACL rupture
  • Initially devised as a “temporizing procedure” until skeletal maturity
  • Patients maintained their stability, athletic activities into adulthood
• 1999 – first published report
Micheli IT Band Technique
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Micheli IT Band Technique
Physeal-sparing technique

- Study: IT Band reconstruction
  - Retrospective case series
    - 44 pts (10.3 yrs old (3.6-14.0))
    - 5.3 yr follow-up (2.0-15.1)
    - 4.5% revision rate (4.7 & 8.3 yrs)
    - IKDC: 96.7 ± 6.0
    - Lysholm: 95.7 ± 6.7
    - 21.5 cm growth (9.5 – 118.0)
    - No growth disturbance
  - (Kocher et al, JBJS 2005)
Biomechanical Comparison

• AP Translation: Normal ~ ITB > Transtibial > All-epiphyseal > deficient
• Varus: ITB > Normal ~ Transtibial ~ All-epiphyseal ~ deficient
• Rotation: ITB > Normal ~ Transtibial > All-epiphyseal > deficient
Technique: Rehabilitation

- **Weight Bearing:**
  - 0-6wks: Crutches, TDWB
  - >6wks: WBAT

- **Brace:**
  - 0-2wks: Locked in full extension for WB
    - Upper limit 90° when performing ROM exercises not WBing)
  - 2-6 wks: Unlocked for WBing, 0-90°

- **ROM:**
  - CPM, Immediate ROM 0-90°
  - Alternative: 0-30° x 2wks → 0-60° x 2wks → 0-90° x 2wks

- **Strengthening:**
  - 0-6wks: SLRs, quad sets, patellar mobilization
  - 6-12 wks: closed chain resistance exercises

- **Activities:**
  - 3 months: light jogging → progress to running → agility exercises by 4.5-5 months
  - 6 months: sport-specific exercises → progress to RTP (w/ custom, functional brace x 2yrs)
Prevention
Conclusions

**Recommendations**

- Know Patient’s Growth Remaining
- Shared Decision Making
  - Risks: Nonoperative Treatment
    - Meniscal/ Chondral Injury
  - Risks: Operative Treatment
    - Growth Disturbance
- Understand Pediatric Knee Anatomy
  - Distal Femoral Physis, Proximal Tibial Apophysis
  - Avoid Hardware/ Bone across Physis
- Technique
  - Adolescents:
    - Transphyseal Hamstrings
  - Prepubescents:
    - Physeal-Sparing
References


