ACL Injuries in the Skeletally Immature Athlete

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Faculty Financial/Conflict of Interest Disclosure

- Arthrex- Consultant
- Ikioo- Advisor/Consultant

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Outline

- Introduction
- Injury Prevention
- Non-operative management
- Operative management
- Algorithm and Summary

Introduction

- There has been a sharp increase in attention paid to ACL tears in the skeletally immature patient
  - Incidence of the injury is increasing
  - Greater evidence and research efforts
  - More training of subspecialists

Epidemiology

- CDC estimated 2 million high school and >4 million athletes under age 14 treated for sports injuries annually
  - ACL injuries affect 1 to 3% of the athletic population annually. (Moses et al. Res Sports Med 2012)
- ACL injury and ACL reconstruction in children or adolescents is rising at a rate significantly higher than adults.

- Compared incidence of ACL tears as compared to tibial eminence fractures from 1999-2011
  - 400% increase in incidence of ACL injuries
- Single sports specialization, year-round competition, less free play

Injury Prevention

- Who is at risk?

Risk factors

- Females
  - 4 to 6 fold greater rate of injury than males
    - (Hewett et al. AJSM 2005)
    - (Myer et al. BJSM 2015)
  - At higher risk during puberty, while males are higher risk at ages 5 to 12
    - (Straccolini et al. Sports Health 2015)

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Risk factors

- Females
- History of prior ACL injury
  - 30 to 40 times more likely to have secondary ACL rupture, ipsilateral and contralateral [1]
    - Poorer hip to ankle coordination[2]
    - Quadriceps strength asymmetry[3,4]

[1] Wiggins et al. AJSM 2016
[2] Paterno et al. Clin Biomech 2015
[3] Ithurburn et al. AJSM 2015
[4] Schmitt et al. Med Sci Sports Exerc 2015

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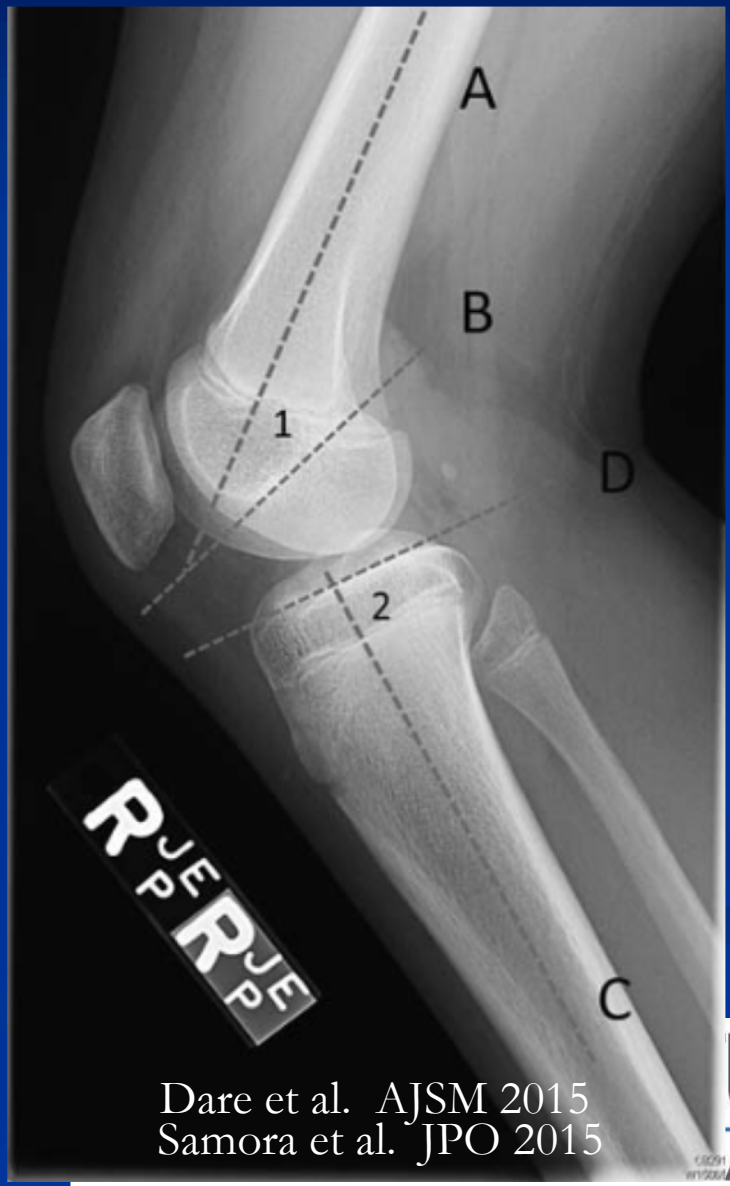
Risk factors

- Females
- History of prior ACL injury
- Morphology
  - Steeper roof inclination angle
  - Increased lateral tibial slope
  - Smaller notch width index
  - Smaller notch width volume



Dare et al. AJSM 2015
Samora et al. JPO 2015

Neuromuscular Training

- NMT shown to decrease the risk of injury by 73%
- Number needed to treat to prevent one ACL injury is 108
- Time needed to successfully perform NMT is not trivial
- NMT works best with at risk athletes.

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Injury Prevention- ABCs

- Age: Start early
- Fewer ACL injuries documented in younger athletes who performed NMT compared to older athletes. (Myer et al. AJSM 2012)
- NMT programs
  - 14-18yo females 81% reduction (Mandelbaum et al. AJSM 2005)
  - Collegiate females 70% reduction (Gilchrist et al. AJSM 2008)

Sugimoto et al. Curr Phys Med Rehab Rep 2015

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Injury Prevention- ABCs

- Age
- Biomechanics: Change the risk movements

- Modifiable risk factors are increased knee abduction moments, limited knee flexion angles, greater GRF, asymmetrical landing pattern and lateral trunk flexion. (Hewett et al. AJSM 2005) (Hewett, Myers Exerc Sport Sci 2011)

Sugimoto et al. Curr Phys Med Rehab Rep 2015

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Injury Prevention- ABCs

- Age
- Biomechanics
- Compliance: If you don't do it, it doesn't work

- Compliance rates from 6 studies calculated (Sugimoto J Athl Train 2012)
  - When greater than 66%
    - 82% ACL injury reduction
  - When less than 66%
    - 44% ACL injury reduction
  - When less than 33%
    - 12% ACL injury reduction

Sugimoto et al. Curr Phys Med Rehab Rep 2015

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Injury Prevention- ABCs

- Age
- Biomechanics
- Compliance
- Dosage: The more you do it, the less ACL injury

- Duration and frequency of NMT sessions found to be directly associated with ACL injury reduction (Sugimoto et al. Sports Med 2014)
- At least 20 minutes per NMT session, several times per week in-season as well as preseason to obtain full prophylactic effectiveness.

Sugimoto et al. Curr Phys Med Rehab Rep 2015

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Injury Prevention- ABCs

- Age
- Biomechanics
- Compliance
- Dosage
- Exercise: Include variety

- NMT with multiple types of exercise is more effective (Sugimoto et al. BJSM 2014)
  - Balance
  - Plyometrics
  - Strengthening
  - Proximal control training

Sugimoto et al. Curr Phys Med Rehab Rep 2015

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Injury Prevention- ABCs

- Age
- Biomechanics
- Compliance
- Dosage
- Exercise
- Feedback: Your voice is powerful

- Majority of NMT studies incorporated a "feedback" system, which appears to be beneficial. (Parsons et al 2012) (Myer et al. AJSM 2013)
  - "knee over the toe"
  - "don't let knees cave inward"

Sugimoto et al. Curr Phys Med Rehab Rep 2015

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Injury Prevention- ABCs

- Age
- Biomechanics
- Compliance
- Dosage
- Exercise
- Feedback
- Grade of the evidence

- SORT grade for current evidence is "A"
  - 7 level 1 studies
  - 7 level 2 studies

Sugimoto et al. Curr Phys Med Rehab Rep 2015

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Concomitant injuries

- Prevalence of other injuries greater with older subjects, **delay to surgery**, return to activity and obesity (Newman et al. AJSM 2015, Anderson et al. AJSM 2015)
- Meniscal tear prevalence 69.3% (Samora et al. JPO 2011)
  - Success of meniscal tear repair with ACLR 85% simple tears, 59% displaced bucket-handle tears and 57% with complex tears (Krych et al. AJSM 2010)

Non-operative treatment

- Activity modification
- Bracing
- Continued Rehabilitation

***effective in highly compliant individuals

Non-op treatment

- French arthroscopic society
  - 53 pts treated non-op
  - 36% reported instability events
  - 17% had meniscal tears
  - 40% underwent ACL reconstruction

Non-op treatment

- Ramski et al. AJSM 2014. Meta-analysis
  - 11 studies included
    - 13.6% vs 75% experienced instability with op vs non-op, respectively (33.7 times more likely)
    - Non-op were 12 times more likely to have MMT
    - No patients treated non-op returned to previous level of play
    - 37% of patients treated non-op eventually underwent surgery
    - IKDC 95 vs 87 with op vs non-op, respectively.
  - Only 1 level 2 study, 10 level 3 studies included

Is it ok to treat non-op or delay surgery until skeletal maturity?

Probably not

ACL Repair

- Cohort study (AJSM 2018 Albright)
  - Ages 7-18
  - Repair with IB (22 pts)versus quad tendon (157 pts)
  - Mean f/u 2.7 y
  - 10.66 times higher rupture HR in repair group
  - 48.8% rates of re-rupture in repair
  - 4.7 % in reconstruction

Skeletal maturity

- Chronological age ≠ Physiologic age
- Tanner Stage
  - Poor interobserver and intraobserver reliability (Slough et al. Med Sci Sports Exerc 2013)

Table 1: Physiologic age as measured by Tanner Staging

Tanner Stage	Males	Females
Stage 1: Prepubescent	• No pubic hair • Bone age younger than 12 years	• No pubic hair • No breast development • Bone age younger than 11 years
Stage II	• Minimal pubic hair • Bone age younger than 12 years	• Minimal pubic hair • Breast buds • Bone age younger than 11 years
Stage III: Pubescent	• Pubic hair over penis • Voice changes • Bone age of 13 to 14 years	• Pubic hair on mons • Enlargement of breasts • Axillary hair • Bone age of 12 to 13 years
Stage IV	• Adult pubic hair • Axillary hair • Bone age of 13 to 14 years	• Adult pubic hair • Areola enlargement • Bone age of 12 to 13 years
Stage V: Postpubescent	• As adult • Bone age of 14 to 16 years	• As adult • Bone age of 13 to 14 years

Skeletal maturity

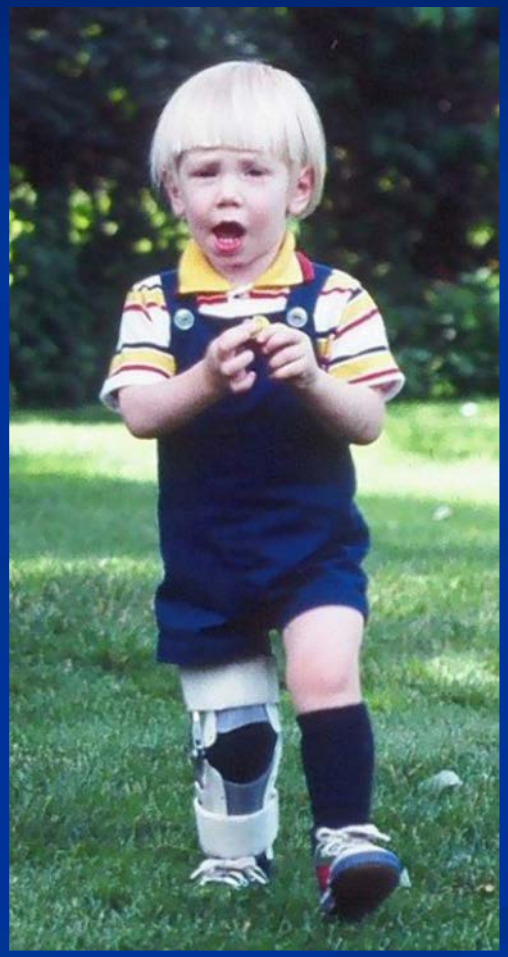
- Hand and wrist bone age
  - PA of left hand and wrist compared with Greulich and Pyle Atlas
  - Relies on predictable pattern of ossification

Age (*yr*)		
Girls	Boys	Hand Radiograph Finding
10	12.5	Appearance of hook of hamate
11	13	Appearance of MP sesamoid of thumb
NA	13.5	Proximal radial aspect of radial epiphysis has met maximum width of distal radial metaphysis; no capping
12	14	Capping of distal radial epiphysis
13	15	Closure of thumb distal phalanx physis
13.5	15.5	Closure of index finger distal phalanx physis
14	16	Closure of index finger proximal phalanx physis

*MP = metacarpophalangeal, NA = not available, and closure = bridging by >50% bone across physis.

Techniques

- Extraphyseal
  - Micheli-Kocher
- All-epiphyseal
  - Anderson
  - Ganley-Lawrence
  - Cardosco and Green
- Transphyseal
  - Partial transphyseal
  - Complete transphyseal



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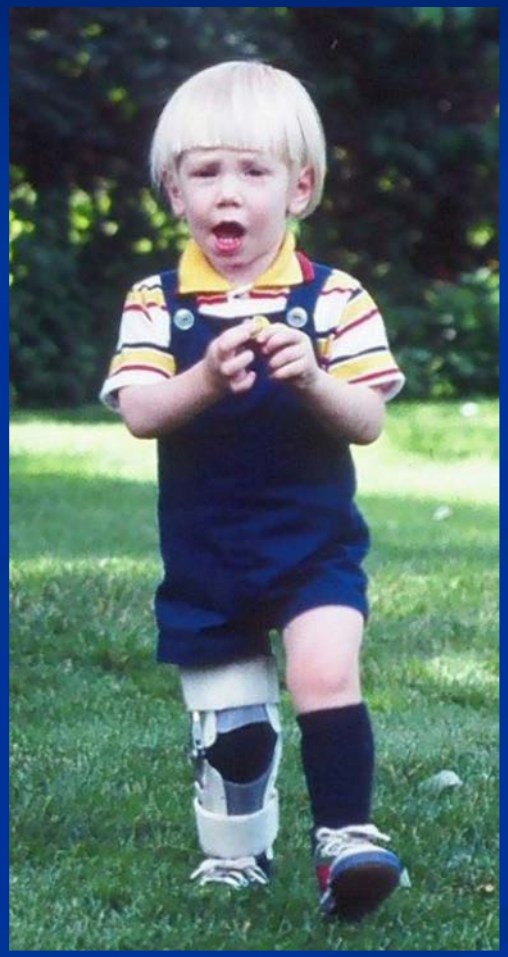
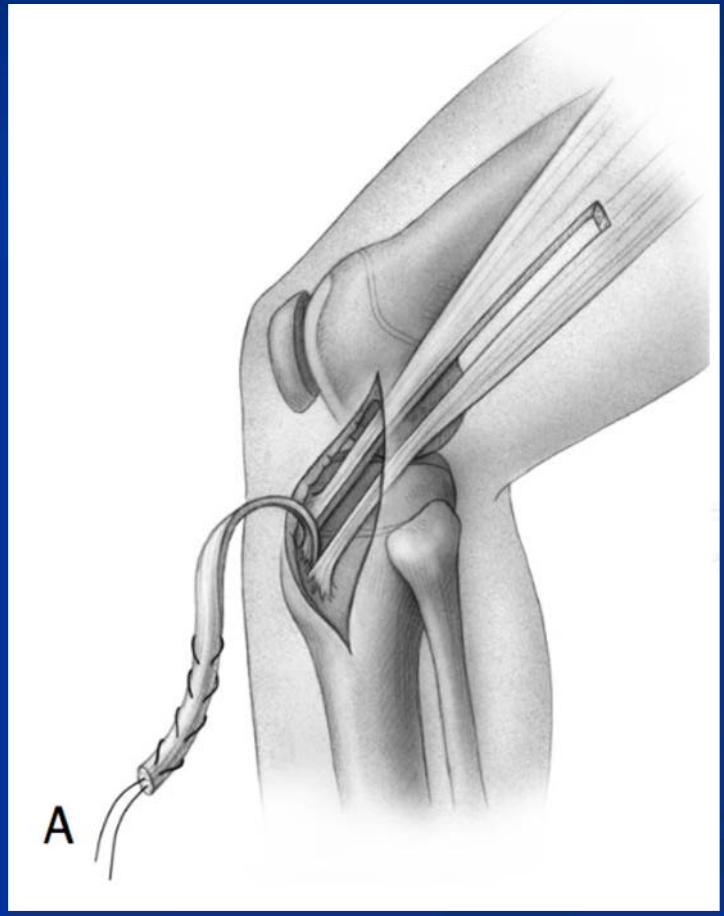


Extraphyseal

- Micheli and Kocher
  - Modification of the McIntosh procedure described in 1976
  - Uses ITB to perform and intra- and extra-articular reconstruction



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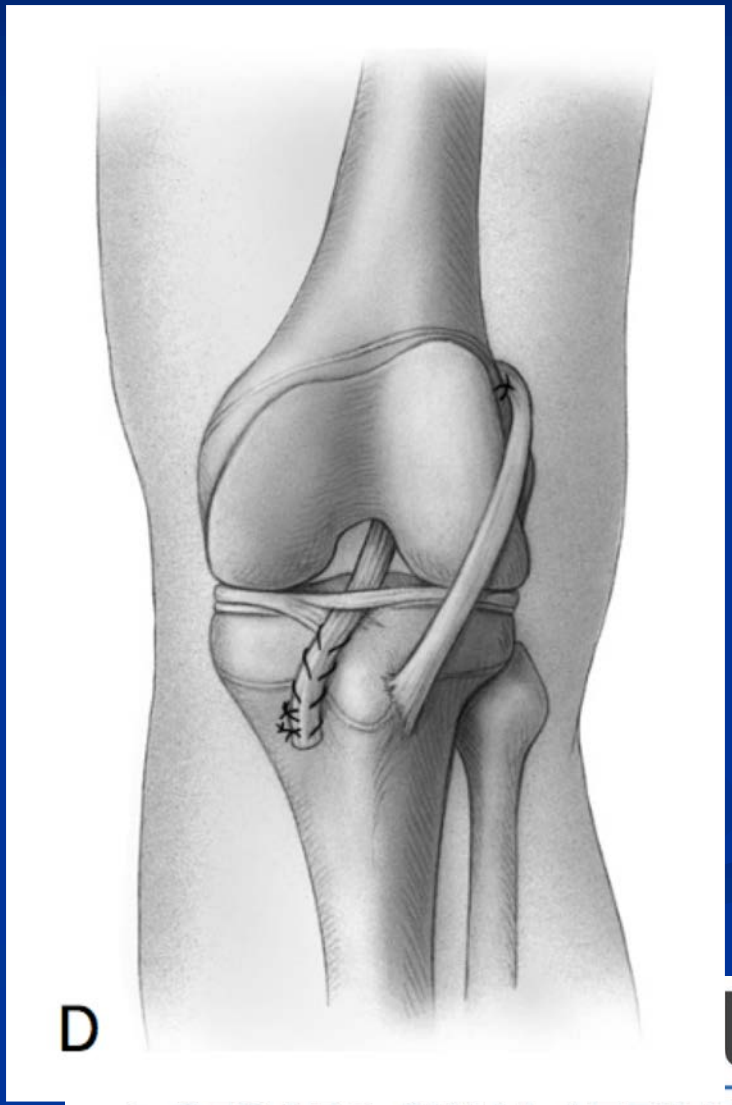

Extraphyseal

- Outcomes
  - Kocher et al. JBJS 2018
    - 96.8% grade A Lachman, 98.8% grade A pivot shift
    - 6.6% re-rupture
    - 48% lateral thigh asymmetry
      - (1.6% pain)

Extraphyseal

- Outcomes
  - Willimon et al. AJSM 2015
  - 22 patients, mean age 11.8 years
  - Mean follow-up 3 years
  - 6 (27%) knees underwent reoperation
    - 3 (14%) underwent revision ACL surgery
    - 3 underwent subsequent meniscal surgery
    - Mean IKDC score was 95.0
    - All who did not require additional ACL surgery had normal Lachman/Pivot shift

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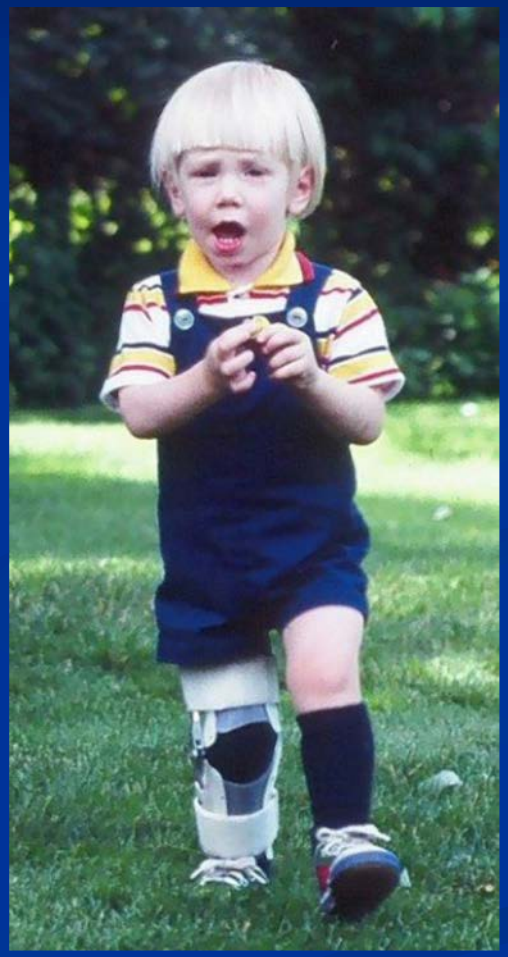

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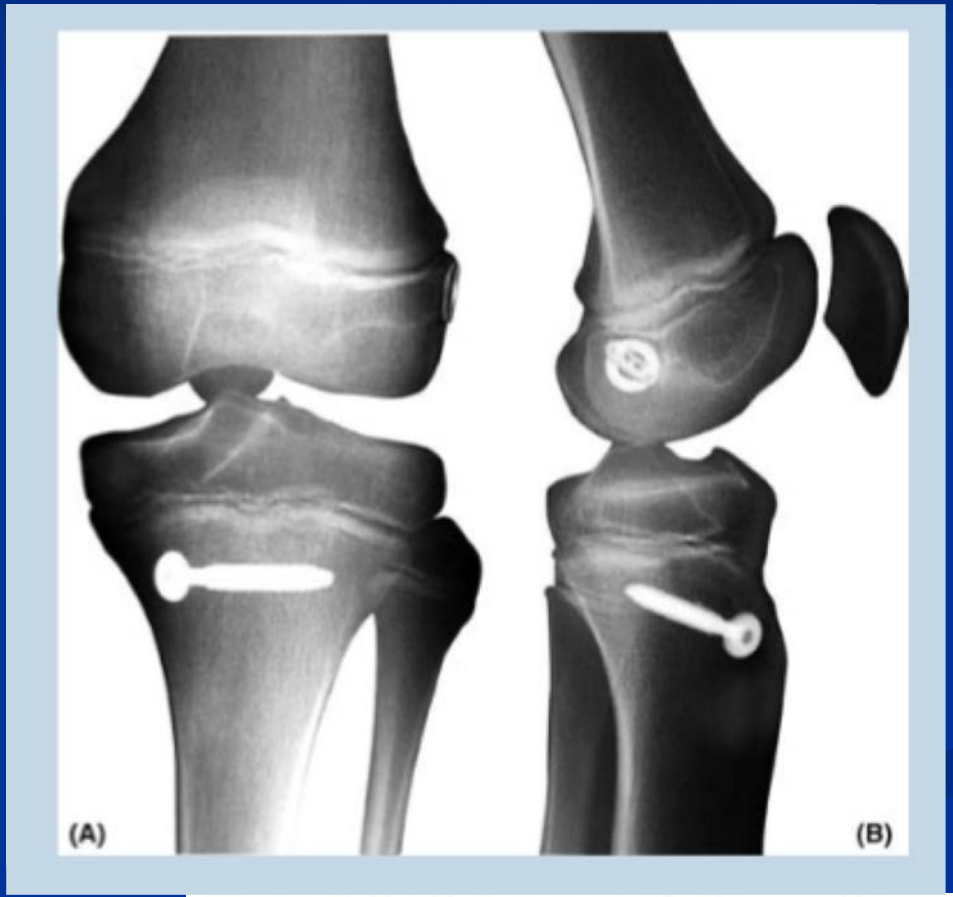
All-epiphyseal

- Anderson technique first described in 1980s
  - Fluoroscopic guidance and confirmed arthroscopically



Anderson and Anderson. Sports Health 2009.

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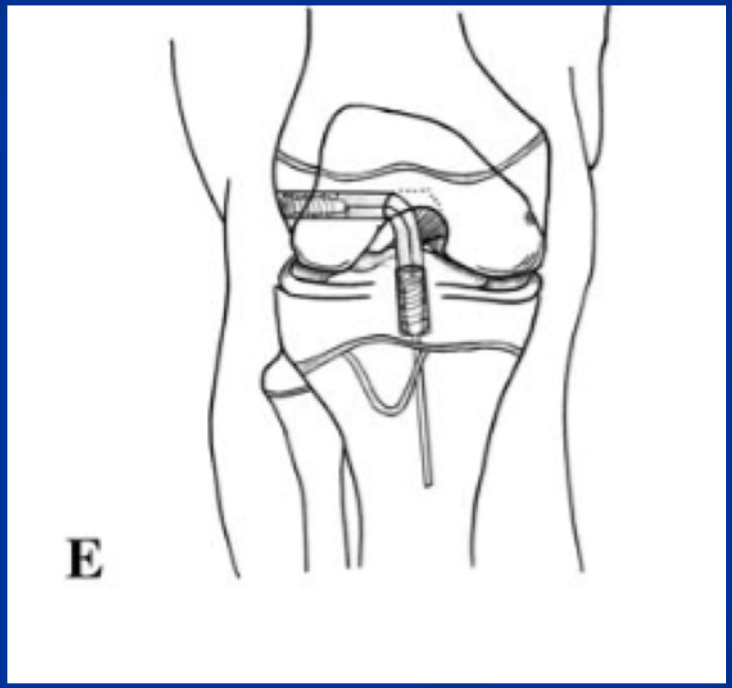
All-epiphyseal

- Lawrence and Ganley
  - Outside-in femoral guide Guide wire placement confirmed using fluoroscopy and intra-operative CT
  - Femoral side fixation with interference screw and tibia with Retroscrew.



Lawrence et al. CORR 2010.

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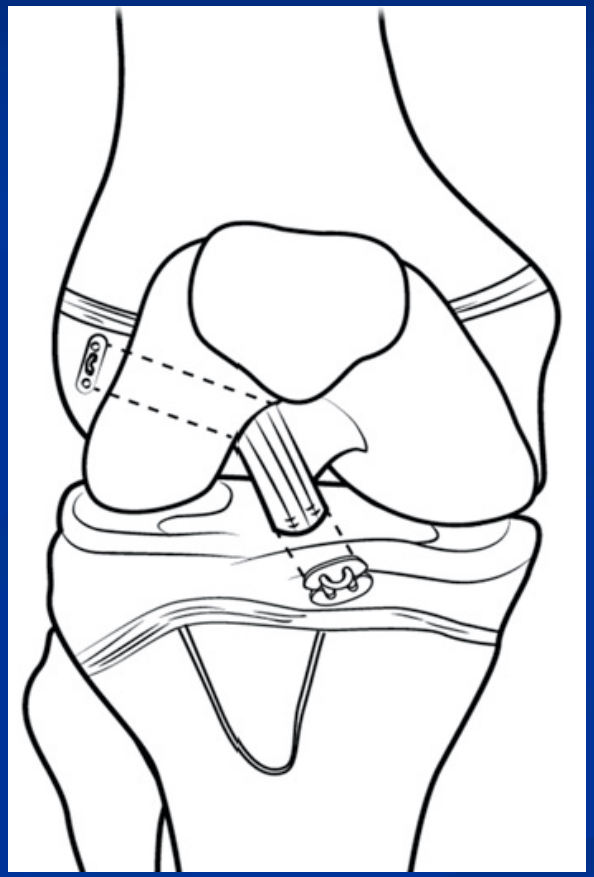
All-epiphyseal

- Cordasco and Green
  - All-inside technique
  - Femur drilled retrograde
  - Tibia drilled retrograde
  - Fixation with suspensory buttons on both femur and tibia



McCarthy et al. Arthroscopy Tech 2012

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All-epiphyseal- Outcomes

- Ganley AE reconstruction (Cruz et al. JPO 2015)
  - 103 pts, avg age 12.1 years old with 21m f/u
  - Overall complication rate 16.5% (17/103)
    - 11 re-ruptures (10.7%)
    - 1 LLD of less than 10mm
    - 2 arthrofibrosis requiring manipulation
    - 2 contralateral ACL ruptures
    - 3 ipsilateral meniscus tears

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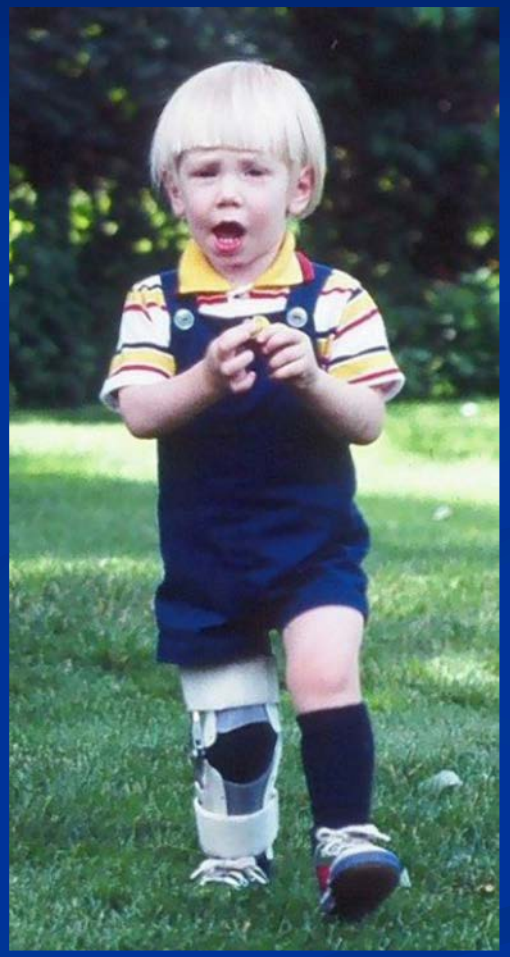

Principles of transphyseal reconstruction

- No hardware across open physis
- No bone block across open physis
- No hardware across open tibial tubercle apophysis
- No large tunnels
- No empty tunnels
- No excessive tension across physis

Transphyeal- Outcomes

- Schmale et al. CORR 2014
  - 29 patients with avg f/u 4 years
  - 4 revision reconstructions and 7 minor operations
    - 38% reoperation rate
  - No LLD or angular deformity
- Kocher et al. JBJS 2007
  - 61 knees in 59 pts, avg age 14.7, mean f/u 3.6y
  - 2 failures (3.3%) revision rate
  - No LLD or angular deformity

Transphyeal- Outcomes

- Frosch et al. Arthroscopy 2010
  - Meta-analysis of 55 articles and 935 pts
  - Mean age 13 and mean follow-up 40 months
  - Rate of LLD or angular deformity was 1.8%
  - Rate of re-rupture was 4.8%
  - Excellent or good IKDC was achieved in 84.2%
  - TP associated with lower risk of LLD or angular deformity than AE. (RR 0.34)

Graft options

- Allograft vs autograft
  - Case-control study of 73 pts, avg age 15.4 (Engelman et al. AJSM 2014)
    - Allograft (n=38) had 11 graft failures (29%)
    - Autograft (n=35) had 4 graft failures (11%)

Complications

- Stiffness
- Growth disturbance
- Re-rupture
  - Wiggins et al. AJSM 2016. Systematic review of 19 articles
    - Overall re-injury rate was 15% (7% ipsi-, 8% contra-)
    - Secondary ACL re-injury rate in pts younger than 25 was 21%
  - Riboh et al. JBJS 2017
    - 91% return to sport
    - 32% ACL injury of any kind
- VTE

Summary

- Pediatric ACL injury is becoming more common
- Injury prevention works (SORT grade A)
- Non-operative treatment or waiting until skeletal maturity puts the knee at risk (SORT grade A)
- Various techniques available that are safe and reliable
  - Type of ACL reconstruction is influenced by the patients skeletal maturity (SORT grade C)

Algorithm

- Identify at-risk athletes
  - Incorporate injury prevention
- Non-operative management used cautiously
  - Mental, physical, emotional, behavioral issues
  - Family preference- shared decision making

Algorithm

- Wide open physes
  - Skeletal age 6-10 years- Micheli- Kocher technique
- Intermediate growth plates
  - Skeletal age 10-12- AE reconstruction
- Nearing skeletal maturity
  - Skeletal age 12-14 - Transphyseal