HSS educational activities are carried out in a manner that serves the educational component of our Mission.

As faculty we are committed to providing transparency in any/all external relationships prior to giving an academic presentation.

Frank A. Cordasco, MD, MS
Hospital for Special Surgery

Disclosure: I DO have a financial relationship with a commercial interest.
Types of financial relationships and the companies with whom I have relationships are as follows:

- ConMed/Linvatec: Royalties from intellectual property
- Arthrex: Consultant

Pediatric ACL Debate
All Epiphyseal

Frank A. Cordasco, MD, MS
Associate Professor of Orthopaedic Surgery
The Sports Medicine and Shoulder Service
Hospital for Special Surgery
Weill Cornell Medical College
New York, NY

Outline

• Skeletally Immature Athletes: Increasing Incidence of Injury (ACL, Shoulder Dislocation, “Tommy John”, Hip Labrum, etc.)
• Early Diagnosis Important
• Non-operative Treatment Often Unsuccessful
• Surgical Treatment: Higher Failure Rates than Adults
• Return to Sport Assessment Critical
ACL Injury in the Child and Young Adolescent with Significant Growth Remaining

Increasing Incidence of ACL Injury

- Increase in Sports Participation and Level of Competition (Title IX doubled denominator)
- Societal and Parental Pressures
- D1 Scholarships and D3 “College Hook”
- Improved Examination, Imaging and Diagnostic Methods: Increased Awareness and Index of Suspicion

Gender Specific Differences

- Females 4-6 X higher risk knee injury
- Females 2-8 X higher risk of ACL tear
Public Health Costs > $2 Billion Annually

- High Cost surgical treatment and rehabilitation per Athlete
- Loss of season
- Academic performance  Trentacosta et al AJSM '09
- Scholarship funding
- Mental health

Physeal Anatomy

- Distal Femoral Physis
  - Contributes ~70% of total length of the femur and 37% of total length of the leg
  - 0.375 inches (1.0 cm) of growth/yr
  - The distance from ACL (femoral origin) to femoral physis remains unchanged from gestational age

Physeal Anatomy

- Proximal Tibial Physis
  - Contributes ~55% of total length of the tibia and 25% of total length of the leg
  - 0.25 inches (0.64 cm) of growth/yr
  - The medial border of the ACL insertion closely defines the medial extent of the tibial apophysis
Skeletally Immature: Imaging

The Dilemma Historically

Nonoperative

Operative

Delayed Reconstruction

Risks:
- Ongoing instability
- Meniscus injury
- Cartilage injury
- Restricted activity until skeletal maturity: compliance

Early Reconstruction Risks:
- Growth disturbance
- Angular deformity

Non-Adult Type Reconstruction:
- Less "Anatomic"
- Possible revision in future, bridge to adult type reconstruction

Risk of Growth Disturbance

- Herodicus Society and the ACL study group, 15 cases of postoperative deformity were reported (Kocher, JPO 2002)
- Distal femoral varus deformity (8 cases)
- Tibial recurvatum (3 cases)
- Genu valgum (2 cases)
- Leg length discrepancy (2 cases)

Associated risk factors:
- Hardware placed across the lateral distal femoral physis
- Bone plug (BPTB) placed across distal femoral physis
- Large (12mm) tunnels
- Hardware across tibial tubercle apophysis
- Lateral extra-articular tenodesis
- Over-the-top femoral position
Nonoperative Treatment Outcomes

<table>
<thead>
<tr>
<th>Study</th>
<th>Patients</th>
<th>Treatment</th>
<th>Return to Activity</th>
<th>Further Meniscal Injury</th>
<th>Recurrent Instability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graf et al. (1992)</td>
<td>12</td>
<td>brace</td>
<td>60%</td>
<td>12/12</td>
<td>60%</td>
</tr>
<tr>
<td>Mizuta et al. (1995)</td>
<td>18</td>
<td>nonoperatively</td>
<td>60/16</td>
<td>11/13</td>
<td>60%</td>
</tr>
<tr>
<td>Millett et al. (2002)</td>
<td>19</td>
<td>early vs delayed</td>
<td>36/30</td>
<td>13/13</td>
<td>60%</td>
</tr>
<tr>
<td>Aichroth et al. (2002)</td>
<td>23</td>
<td>nonoperatively</td>
<td>11/18</td>
<td>11/18</td>
<td>60%</td>
</tr>
<tr>
<td>Henry et al. (2009)</td>
<td>16</td>
<td>Early vs Delayed reconstruction</td>
<td>16/18</td>
<td>16/18</td>
<td>60%</td>
</tr>
</tbody>
</table>

Nonoperative Treatment Outcomes

- 70 pts < 14 yo: Delay in Treatment > 12 weeks
- Results in Increased Risk of Irreparable Medial Meniscus Tears and Lateral Compartment Chondral Injury

Lawrence et al. AJSM '11

Surgery is the Conservative Treatment

Determination of Skeletal Age
Skeletal Age Does Not = Chronologic Age
Physiological Maturity & Projected Remaining Growth

- Parental & Sibling heights
- Shoe size stability
- Onset of menarche/axillary hair: preceded by growth phase of peak height velocity (M-13.5/F-11.5)

Skeletal Growth

- Determination of skeletal maturity
  - Tanner scale
  - Bone age (Based on PA Left Hand xray)
    - Greulich-Pyle Atlas
      - Most Common
        - Preferential Pattern of Ossification: Estimate Skeletal Age
  - HSS Shorthand Bone Age Measurement Scale
    - Prediction of Bone Age Without Use of Atlas
      - Focus on Recognition/Memorization of X-ray findings
      - Equivalent Accuracy to GP atlas (Heyworth et al. AAOS, 2011)
      - “Simple approach”: Pubescent vs Prepubescent
Physiological Maturity & Projected Remaining Growth

Green-Anderson Growth Chart
Guide to estimate remaining growth. Skeletal age is determined using GP Atlas or Short-Hand method.

ACL Reconstruction Techniques in the Skeletally Immature

• Physesal-Sparing Techniques
  - Combined Intra-articular/Extra-articular: Modified McIntosh Kocher JBJS 05
  - All-Epiphyseal (AE): Guzzanti/Stanitski AJSM 03, Anderson JBJS 05, Ganley CORR 10, Cordasco/Green Arthroscopy Tech 12

• Partial Transphyseal Techniques
  - Over-the-Top Femur and Transphyseal Tibia
  - AE Femur and Transphyseal Tibial

• Complete Transphyseal Techniques
  Paladit Gun Sports Med 11

HSS PREFERRED SURGICAL TREATMENT ALGORITHM

Activity Modification: Bracing/Physical therapy
Symptomatic Determination of Skeletal Age

1yr of remaining skeletal growth
  Transphyseal (Hamstring or ITB)

2-3yrs of remaining skeletal growth
  All-inside Partial Transphyseal (Hamstring)

3-6 yrs of remaining skeletal growth
  All-inside All-Epiphyseal (Hamstring)

>6 yrs of remaining skeletal growth
  All-Epiphyseal vs. Physical sparing ITB reconstruction
Physeal-Sparing: Modified McIntosh

Kocher, Micheli JBJS Am 2005

- ITB harvested proximally → over the top position → under meniscal coronary ligament (Intra/Extra)
- 44 patients, Tanner I/II
- 2 revisions at 5, 8 years
- 98% normal/near normal Lachman
- 100% normal/near normal Pivot
- Mean IKDC 96.7, mean Lysholm 95.7
- No growth disturbances
- Kinematic Study: Over-Constrained (Kennedy et al AJSM 2011)

Skeletally Immature: Imaging

- X-rays: AP, lateral, notch, merchant views
- Standing AP alignment (bilateral hip to ankle)
  - LLD
  - LE alignment
- If Suspicious for LLD, CT Scanogram to measure Magnitude and Source (Tibia vs. Femur)

Graft Options

- **Hamstring Autograft** in most cases
- **BTB Autograft** reserved for Adult-Type Reconstructions in Older Adolescents with closing physes
- **Allografts**: High Failure Rates in the Adolescent population (Moon Consortium ‘10, Kappa Delta Award ‘12)
GraftLink Hamstring Autograft

- ST +/or Gracilis
- Short Thick Graft
- 65-70mm Long
- 9-12mm Diameter
- Biomechanically Stiffer

Effect of Drill Tunnel Size

- Incidence of Physeal Arrest increases: Tunnel Drilling >7% of Total Physal Volume (Guzzanti, JBJS Br 1994)
- Graft radius may be the most important variable affecting the volume of physeal injury
  - Variation of graft diameter from 6mm to 11mm will increase volume % removed from 2.3% to 7.8%
- Increasing tunnel Drill Angle from 45° to 70° will decrease volume % removed from 4.1% to 3.1% (mean 0.2% decrease in physeal damage for each 5° increase in drill angle)
- Volume % of physis removed decreases linearly with age
- Double-bundle techniques substantially increase the volumetric injury to the physis (Shea, JBJS Am 2011)

Effect of Soft Tissue Tensioning

- Excessive soft-tissue graft tension across an open physis may induce premature physeal closure
- In a canine model, fascia lata autograft tensioned to 80N across femoral and tibial tunnels led to significant valgus deformity in the distal femur and significant varus deformity in the proximal tibia (Edwards, JBJS Am 2001)
Animal Models: Summary

- Tunnels filled with soft tissue grafts may not result in transphyseal bone bridges
- Grafts placed under tension may cause physeal injury
- The cross-sectional area of the drill hole should be minimized in transphyseal approaches
- More Central and Vertical Tunnels (Non-Adult Approach)
- Issue: In animal models remaining growth duration quite brief compared to adolescent boys in particular

Transepiphyseal ACLR

Anderson JBJS Am 2004

- Quad Hamstring
- Femoral and Tibial Tunnels
- Outside-In Technique
- Intraoperative Fluoroscopy
- Endobutton-Washer Femoral Fixation
- Screw and Post Tibial Fixation Distal to Tibial Physis

All-Inside Techniques in Adults
Routine and Easy
All-Inside All Epiphyseal ACL

McCarthy et al

- Sockets Not Tunnels Created Inside-Out
- Quad Hamstring Autograft using a GraftLink Technique with Tensioning Buttons
- No Hardware Distal to Tibial Physis

Femur: Flip Cutter - 2.75 cm Socket 70 Degree Lens

Tibia: Flipcutter – 2cm Socket

Cannulas

Useful for Suture and Instrument Management Graft Passage
All-Epiphysyal Advantages

• Graft placed within Native ACL Footprints as performed in Adult ACLR
• Avoids Potential Growth Disturbance Related to Transphyseal Drilling
• Graft should not be effected by Growth as it is All-Epiphysyal
• Avoids Lateral Arthrotomy necessary for OT and Modified McIntosh

All-Inside Sockets versus Outside-In Tunnels

• Avoids Graft Fixation distal to the Tibial Physis or Proximal to the Femoral Physis and Potential for Tethering/Growth Disturbance and the need for associated HWR
• Shorter Graft 60-70mm
• Thicker Graft 9-12mm
• Biomechanically Stiffer
• Theoretically: “Blind Sockets” may provide improved Biologic Milieu for Healing of Tendon-Bone Interface

All-Inside AE ACLR EFFECTIVE Biomechanical Contact Stress & Kinematic Analysis Study

• Kinematics: Restored Anterior and Rotational Stability
• Contact Stress: Decrease Posterior Joint Contact Stresses Compared to the ACL Deficient Knee.

McCarthy, Tucker, Green, Imhauser, Cordasco
AOSSM 12 (Nominated: Herodicus Award)
AJSM 13
All-Inside AE ACLR: SAFE
Physeal-Sensitive SPGR MRI
3 Joint Standing X-Ray

• First 25 pts: AE & PTP ACLR @ 12 months Post-op
• Tibial Physeal Compromise: AE 1.7%
PFP = 7.3%
• Femoral Physeal Compromise 1.5% (1 in each group)
• Neither technique resulted in Growth Disturbance
• Both All-Inside ACLRs: Safe and Effective @ Early Follow-up in Skeletally Immature Patients.

Nawabi, Potter, Green, Condello AOSSM'13
Versatility: All-Inside
Partial Transphyseal

Versatility: All-Inside
Complete Transphyseal

Hospital for Special Surgery Rehabilitation Protocol

- Post-Operative Phase 1 (Weeks 0-4)
  - Full knee extension
  - Maximum 90° passive flexion
  - Painless mobility
  - Improve quadriceps contraction
  - Home exercise program (HEP)

- Post-Operative Phase 2 (Weeks 4-8)
  - ROM 0-125°
  - Normalize WBAT gait
  - Single-leg stance without pain and with neuromuscular control

- Post-Operative Phase 3 (Weeks 8-16)
  - Full ROM
  - Improve quadriceps and core strength
  - Eccentric quadriceps control

- Post-Operative Phase 4 (Weeks 16-20)
  - Maximize strength and flexibility
  - Demonstrate athletic-ready position stance
  - HSS ACL Prevention Assessment at Week 16

- Post-Operative Phase 5 (Weeks 20-28)
  - Symptom-free running and flexibility
  - Proper dynamic control with jumping and cutting
  - Independent gym program

- Post-Operative Phase 6 (Weeks 28-Return to Sport)
  - Hop Test
  - 85% limb symmetry
  - Lack of apprehension with sport specific movements
  - Dynamic control with sport-specific movements
  - Flexibility appropriate for sport
  - Patient/caregiver compliance with sport-specific bracing
ACL Reconstruction Failure in Adolescent Athletes

- Shelbourne et al AJSM 2009
  - Risk of Retear 8.7% if <18
  - Risk of Retear 1.7% if >18
- Kaeding et al (MOON Cohort) Sports Health 2011
  - Highest re-tear rates in 10-19 yo
  - Risk of re-tear decreases by factor of 2 with each decade
  - Must Counsel Parents Regarding Higher Potential for Failure

Re-Injury

- These Young Athletes have Unacceptable Failure Rates with Non-Operative Treatment
- Ipsilateral Failure Rates are Relatively High with Surgical Treatment (5-12%)
- Contralateral ACL Injury Rates are Higher (7-15%)
- What Can we do to Diminish these Numbers both on the Prevention Side and Post-Operatively?

Return to Sport (RTS)

- Less than 50% of Athletes RTS within the First Year
- Post ACLR: 20-25% of Young Athletes will sustain a second Knee Injury
  - Hewett AJSM 12 ePub
- 63% HS and 69% C FB RTS and only 43% RTS at previous level
  - McCullough (Moon) AJSM 12
Revision ACL Reconstruction in Adolescents

- 36 patients, Age 12-17, 22 Female, 14 Male
- Interval between Primary and Revision: Average 18 months
- Physeal Status @ Primary: Open 10, Partially Open 3, Closed 21
- Primary Graft: BTB 15, HS 13, Allograft 8
- Reason for Failure: Non-Contact 23, Contact 7, Persistent Instability 5, Infection 1
- Revision: Complete Transphyseal in all
- F/U 2 years: Lachman Negative or 1A in 91%, Pivot Negative 96%
- Mean IKDC subjective score: 89.1
- Only 57% returned to the same or higher level of activity sport
- 8% required additional revision

Reinhardt et al ISAKOS 2011, CORR 2011

HSS Program

- Postoperative Guideline
  Moksnes J Orthop Sports PT 12, McCarthy et al
  Arthroscopy Techniques 2012

- ACL Prevention Program
  Sadoghi JBJS 12, Mandelbaum AJSM 05,
  Logerstedt AJSM 12

- Back to Sport: Independent of Time
  Myer, Hewett AJSM 12

References

Thank You