Current Concepts in ACL Injury in the Skeletally Immature Athlete

Riverside Orthopedic Institute
Riverside Community Hospital

Steven A. Brown, DO
• No conflicts of interest
Introduction

- Intrasubstance ACL Injuries in skeletally immature patients were once thought to be very rare occurrence

- Increased frequency in reporting Intrasubstance ACL injuries
  - Dodwell ER, AJSM 2014
    - 1990- 17.6/100,000
    - 2009- 50.9/100,000

- Multifactorial
  - We are at an all time high for organized sports participation
    - 30 million children (1)
  - Push for specialization of their specific sport
  - Sports being started at an alarming early age
  - Increase in year-round athletics
Anterior Cruciate Ligament

• Tibial eminence fracture were thought to be ACL tear equivalent in the skeletally immature patients
  • Rang M, ed. Children's Fractures. 2nd ed 1983:290
  • “Complete ligamentous disruption only occurs after growth plate closure”
    – Just Not True

• ACL injuries in the skeletally immature patient population was largely non-operative
  – Bracing/Activity modifications
  – Unintended negative social/emotional consequences
  – Recent studies have shown that non-operative management results in poor outcomes
    • Meniscal & articular cartilage damage
• Pendulum has swung towards surgical treatment
• What Surgical Treatment?
<table>
<thead>
<tr>
<th>Study</th>
<th>Patients and Treatment</th>
<th>Outcomes</th>
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<tbody>
<tr>
<td>Graf BK et al. Arthroscopy, 1992</td>
<td>12 SIM pts with ACL tears treated conservatively</td>
<td>60% experienced further meniscal injury, 12/12 recurrent instability</td>
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<tr>
<td>Mizuta et al. JBJS Br 1995</td>
<td>18 SIM pt with ACL tears treated conservatively</td>
<td>16/18 fair/poor function, 11/18 degenerative changes</td>
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<td>Millett et al. Arthroscopy 2002</td>
<td>39 pts: Early vs delayed reconstruction (6 wks) 17-Early vs 22-Delayed</td>
<td>Higher rate of medial meniscus tears in delayed: 36% (8) vs 11% (2)</td>
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<td>Aichroth et al. JBJS Br 2002</td>
<td>60 pts SIM with ACL tears 37 pts elected to have sx 23 pts (12.5 y/o) treated non-op</td>
<td>7 additional meniscal tears 10/23 OA changes</td>
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<td>Henry et al. KSSTA 2009</td>
<td>56 pts: Early vs Delayed reconstruction (12 weeks)</td>
<td>Early Group: lower rate of medial meniscus tear (16% vs 41%)</td>
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<td>Lawrence et al. AJSM 2011</td>
<td>70 pts &lt;14y/o ACL tears 41 acute surgical treatment 29 delayed surgical treatment 12 week delay in tx</td>
<td>Increased MMT (24% vs 7%) Increase Lateral Compartment Chondral Injury – 45% vs 10%</td>
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</table>
Indications for Non-operative treatment

• Large indication for conservative treatment
  – Important to recognize which young patient are potential candidates for non-operative treatment

• Kocher MS. AJSM 2002
  – Patients with partial tears of the ACL, <50% of the diameter of the ligament who are 14 years of skeletal age or less
Preferred Non-operative Treatment

• After initial Injury to ACL, rehabilitation is divided into three subsequent phases

• Initial phase
  – Directed at resolving swelling to regain full range-of-motion
    • NWB, Crutches, Knee immobilizer
    • Ice, Anti-inflammatory medication

• Second phase
  – Restore muscle strength & restore neuromuscular control
    • Physical therapy

• Third phase
  – Preventive medicine
Operative Treatment

- Growing body of literature to support early ACL reconstruction thus creating a paradigm shift towards surgery

- Indications for ACL reconstruction in the SIM patient
  - Tears involving more than 50% diameter of the ACL
  - Patients with persistent knee instability
  - Patients not willing to lower their activity level
Fear of ACL Reconstruction in the Skeletally Immature Patients

• Physeal Arrest Resulting in Abnormal Physeal Growth
  – Distal Femur Valgus
  – Limb Length Discrepancy
  – Tibial Recurvatum
  – Genu Valgum
Risk of Growth Disturbance

Kocher, JPO 2002
15 Cases of postoperative deformity
Herodicus Society and the ACL study group

- Distal Femoral Valgus Deformity (8 cases)
- Tibial Recurvatum (3 cases)
- Genu Valgum (2 cases)
- LLD (2 cases)

- Risk Factors
  - Hardware placed lateral distal femoral physis or tibial tubercle apophysis
  - Bone Plug placed across DFP
  - Large Tunnels (12mm)
Physeal Anatomy

- Distal Femoral Physis
  - The distal femoral growth plate closes completely at an average age of 19 in males, and 17 in females
    - Contributes little to length after age 14F/16M
  - Contributes ~70% of total length of the femur and ~37% of total length of the leg
    - 10mm/yr
  - Distal femoral physis closes after tibial physis
• Proximal Tibial Physis
  – The proximal tibia growth plate closes completely at an average age of 18 in males, and 16 in females
    • Contributes little to length after age 13F/15M
  – Contributes ~55% of total length of the tibia and 25% of total length of the leg
    • 6mm/yr
  – Proximal tibia physis closes approximately 1 year before distal femur physis
Surgical Options

Physeal Sparing (extraphyseal)
- Modified McIntosh
- Anderson Technique
- All Epiphyseal

• Hybrid

• Transphyseal
Brief Overview of ACL Surgical Options: Algorithm Based on Skeletal Age

• Step 1: Determine skeletal age
  – HSS Short Hand, Greulich and Pyle Atlas

• Step 2: Determine Growth Remaining
  – Arithmetic method

• Step 3: Select the indicated surgical reconstruction based on years of skeletal age growth remaining
  – >6 - McIntosh
  – 3-6 – All Epiphyseal
  – 1-3 – Hybrid
  – <1 – Transphyseal
Assessing Skeletal Age

Heyworth DE et al, Hospital for Special Surgery, New York, NY, AAOS 2011
Reconstruction of the Anterior Cruciate Ligament in the Skeletally Immature Athlete: A Review of Current Concepts

AAOS Exhibit Selection

Peter D. Fabricant, MD, Kristofer J. Jones, MD, Demetris Delos, MD, Frank A. Cordasco, MD, MS, Robert G. Marx, MD, MSc, Andrew D. Pearle, MD, Russell F. Warren, MD, and Daniel W. Green, MD, MS

Investigation performed at the Hospital for Special Surgery, New York, NY
Modified McIntosh

- >6 years growth remaining
- IT Band
- Kocher et al. JBJS Am 2005
  - 44 Pts, Tanner I/II
  - 2 revision at 5,8 yrs
  - 98% nl lachman, 100% nl pivot
  - No growth disturbances
  - Most closely restores native ACL kinematics (Kennedy et al AJSM 2011)
Anderson Technique

- 3-6 years growth remaining

- Tunnels are drilled in the epiphysis

- Anderson AF, JBJS Am. 2004
  - Transepiphyseal tunnels
  - Mean age 12.9
  - Mean follow up 4.1 yrs
  - Short LLD in 1 pt (3mm)
  - Good clinical results
All Inside, All Epiphyseal

- 3-6 years of growth remaining
- McCarthy et al. Arthroscopy 2012
- Sockets NOT Tunnels, created inside out
- Advantage is no hardware distal to Tibial Physis
  - Avoids potential growth disturbances
  - Graft should not be effected by growth
Hybrid Technique

- 1-3 years of growth remaining
- All Epiphyseal techniques used on femur
- Transphyseal technique on tibia
  - Smaller bone tunnels
    - 8-9mm
  - More vertical tunnels
    - Decrease cross sectional area
Transphyseal Technique

- <1 year of growth remaining

- Goals
  - Decrease amount of physeal damage
    - Vertical Tunnel
    - Decrease aperture
  - Graft 8 – 9mm
  - Soft Tissue graft
  - More centralized tunnel

- Tibial Tunnel more central, slightly medial to lateral
- Femoral Tunnel more vertical using the transtibial over the top guide
Graft Selection: Bone Plug vs Soft Tissue

• BTB considered gold standard but....

• Concerns over placing bone plug across physis
  – Physeal bar

• Additionally, harvest of a BTB graft in the skeletally immature would result in violation the tibial tubercle apophysis with risk of premature closure

• Thus, hamstring grafts have become gold standard SIP
Autograft versus Allograft

- Literature documents clear differences in revision rates for primary ACL btw auto vs allograft
  - 7.7x increase in failure rate with hamstring allo versus auto
    - Pallis M et al. AJSM 2012
  - 15x increase in failure rate with BTB allo versus auto
    - Ellis HB et al. Arthroscopy 2012
- Gold standard is to use Autograft tissue
### Graft Size

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<tr>
<th>Magnussen et al. Arthroscopy, 2012</th>
<th>18 pts required revision</th>
<th>16/18 required revision were younger than 20y/o &amp; graft size was &lt;8mm</th>
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<td>MOON Group</td>
<td>14 revision</td>
<td>Only pts with grafts &lt;8mm required revisions 13/14 that required revision were under the age of 18</td>
</tr>
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</table>

**Age of patient and graft size matter**

**Grafts should at least be 8mm**
Transphyseal Data

- The prevalence of physeal arrest increases when physeal damage is >7 % of total physeal volume

  - Increasing the graft diameter from 6 to 11 mm will increase the volume percentage from 2.3% - 7.8%

  - Increasing the tunnel drill angle from 45* to 70* will decrease the volume percentage of physeal damage from 4.1% to 3.1%
  - 0.2% decrease for every 5* increase in tunnel angle

- 9mm drill produces a tunnel to growth plate damage of < 7%

- Guzzanti et al. JBJS Br 1994
- Shea KG et al. JBJS Am 2011
Reconstruction Failure in Adolescent Athletes

• Why do ACL reconstruction is SIM patients fail
  – Age, age, age

• Shelbourne et al AJSM 2009
  – Risk of re-tear 8.7% if < 18 y/o
  – Risk of re-tear 1.7% if >18 y/o

• Kaeding et al (MOON Cohort) Sports Health 2011
  – Highest re-tear rates in 10-19y/o

• Must counsel parents/patients higher failure rate
In Conclusion

- ACL tears in the skeletally immature patients are significantly increasing
- There is a paradigm shift towards operative management
- Non-operative management leads to increase in meniscal tears and articular cartilage damage
- Wrong operative management can lead to physeal growth abnormalities
- Skeletal age will determine which ACL reconstruction is the best indicated for your patients
Thank You