• I have no disclosures
Outline

• Introduction
• Epidemiology
• Mechanism and Injury Characteristics
• Risk Factors Specific to Females
• Treatment Implications/Outcomes
• Prevention Strategies
• Future Goals
ACL Structure and Function

- Primary restraint to anterior tibial translation
- 2 bundles—anteromedial and posterolateral to control translation and rotation.
ACL Structure and Function

- A proprioceptive structure as 1% of its volume is occupied by nerve tissue
- Surrounded by synovium so it is an intraarticular and extrasynovial structure
ACL Tears in Female Athletes

• 2.3% increase per year for children between ages 6-18 in USA\(^1\)

• \(\sim 200,000\) annual incidence\(^2\)
  – Increasing steadily over 20 year period

• **Females > Males**

• Discrepancy begins after puberty\(^3\)
  – Female rates increase more
ACL Tears in Females: Character and Mechanism of Injury

- **Non-contact ACL** injury most common\(^{10-12}\)
  - Approximately 70% of ACL injuries non-contact

- **Mechanism\(^{13}\)**
  - Foot strike with LE at or close to **full extension**
  - +/- forceful valgus moment at knee
  - +/- tibial internal rotation moment

- Deceleration + cutting most common

- **Sports that require pivoting, landing, and sudden deceleration** (soccer, gymnastics, basketball, handball, field hockey, lacrosse)
ACL Tears in Females: Character and Mechanism of Injury

- Boden et al, 2009\(^\text{13}\)
  - Video analysis of non-contact ACL injuries
  - “Safe” vs “Provocative” landing positions
  - Injured athletes
    - Significantly higher hip flexion angles at contact
      - Torso posterior, knee must extend
  - Hamsting not protective in full extension (upright body posture)
  - Lateral trunk displacement
  - Quadriceps dominant when an anterior translation force is placed on the tibia
ACL Tears in Females: Risk Factors for Injury

- Extrinsic Factors?
- Intrinsic Factors?
  - Q-angle
  - BMI
  - Hyperlaxity
  - ACL size
  - Notch width
  - Posterior tibial slope
  - Landing mechanics
  - Neuromuscular factors
  - Genetics
  - Hormonal factors
Extrinsic Risk Factors

• Has not been proven in literature

• 15 year surveillance in NCAA, no change in rates of ACL injury for men or females$^{29}$

• Single study has found higher rates in females, not males, on artificial surfaces$^{30}$

• Non-sex-specific: shoe/floor interface, weather, bracing $^{9,30}$
  – More cleats, larger cleats, turf, dry climate, etc
Intrinsic Risk Factors: Q-Angle

- Angle formed by a line drawn from the ASIS to central patella, and line drawn from central patella to tibial tubercle

- Larger in females
  - Supine: 2.7 to 5.8 degrees larger
  - Standing: 3.4 to 4.9 degrees larger

- Hypothesized to increase lateral force vector via quad and predispose ACL

- Static Q-angles not predictive of knee valgus or ACL risk
Intrinsic Risk Factors: Hyperlaxity

- Females have increased generalized hyperlaxity compared to male counterparts\(^\text{14}\)
  - Both sagittal (hyperextension) and coronal (V/V)

- After puberty, flexibility decreases in boys, not girls\(^\text{33}\)
  - Sit and Reach tests increase in girls, decrease in boys\(^\text{34}\)
  - Knee abduction (valgus) increases during female puberty

- Knee flexibility\(^\text{35}\)
  - 47 human cadavers, robotic system to test flexibility
  - Female knees with increased
    - Internal rotation laxity
    - Valgus laxity
    - Anterior laxity - 1.3mm average, only at 50 degrees of flexion
  - Male knees with increased IR and valgus stiffness

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**Figure 1.** Brighton’s modification of the Carter and Wilkinson scoring system. Give yourself 1 point for each of the maneuvers you can do, up to a maximum of 9 points.
Intrinsic Risk Factors: Hyperlaxity

- ACL injured females with more knee recurvatum and increased ability to touch palms to floor\(^{14}\)

- Women with generalized joint laxity\(^{32}\)
  - 2.7 x greater risk of ACL injury

- Laxity not just in the knee
  - Increased foot laxity\(^{36,37}\)
    - navicular drop
    - tibial translation
Intrinsic Risk Factors: ACL Size

- Standardized for BW, females have smaller ACL\(^9\)

- Female ACLs demonstrated to have:
  - Less collagen fibrils per unit area\(^38\)
  - Smaller tensile elastic modulus\(^39\)
  - BUT – neither linked to increased ACL tears

- Dienst et al, 2007\(^40\)
  - Females with thinner ACL midsubstance
  - Correlated with notch width size

- Anderson et al, 2001\(^41\)
  - Female ACL smaller than men, but no link to NW
  - Conclusion that tear rate due to multiple intrinsic factors
Intrinsic Risk Factors: Landing Mechanics

• Female athletes demonstrate:
  – Increased knee valgus angles in landing/cutting
  – Higher knee extensor moments
  – Decreased knee flexion angles in landing
  – Decreased strength in abductors, glute medius
  – Increased lateral trunk angle

• These factors result in increased anterior shear force vectors and compression force vectors which places the ACL at risk.
Intrinsic Risk Factors: Landing Mechanics

- Hewett et al, 2005
  - Cohort analysis of 205 female athletes’ landing mechanics
  - Preseason joint angle and moment analysis
  - 9 ACL injuries
    - Significantly different posture, loading
    - Knee abduction angle 8 degrees > controls
    - 2.5 x greater abduction moment
    - 20% higher GRF
    - Stance time 16% shorter
  - Knee abduction moment predicted ACL injury
    - 72% specificity
    - 78% sensitivity
Intrinsic Risk Factors: Landing Mechanics

- Hewett et al, 2009; landing video analysis\textsuperscript{53}
  - Mean lateral trunk angle higher in females than males in ACL injuries
    - 9.3 degrees in ACL injured, 14 degrees in controls
    - CoM displaced to lateral side of knee
    - Increases lateral compartment axial forces
    - Increased abduction moment, valgus landing

- Myer et al, 2015\textsuperscript{54}
  - Knee abduction moment above 25.3Nm associated with 6.8% ACL injury risk vs. 0.4% risk if below value
  - ACL injured females
    - Increased knee abduction moment
    - Decreased hamstring to quad strength ratio
Intrinsic Risk Factors: Biomechanics

• Compared to males, females land
  – More erect, More knee valgus, More external rotation

• LE is a kinetic chain that starts in the core\textsuperscript{57}
  – Efficient movement, knee stability, energy transfer
  – Weak gluts $\rightarrow$ increased valgus landing
  – Poor hip control $\rightarrow$ increased knee loading

• Zazulak et al, 2007\textsuperscript{58}
  – 277 collegiate athletes
  – Core weakness predicted knee injury
    • 90\% sensitive, 56\% specific for female ACL injury
  – Poor core proprioception predicted female knee injury\textsuperscript{59}
Intrinsic Risk Factors: Genetics

- Patients with ACL tears ~2x as likely as non-injured to have a family member w/ ACL\(^60\)

- Link identified in female twins\(^61\)
  - Familial disposition, mm imbalance, knee stability

- Collagen Genotypes\(^62\)
  - COL5A1 – CC genotype lower in women w/ ACL injury

- Johnson et al, 2015\(^63\)
  - Biopsy samples of torn ACLs, 7 female 7 male
  - ACAN (aggrecan), FMODE (fibromodulin) up in females
  - WISP2 (WNT protein) down regulated in female ACL tear
Intrinsic Risk Factors: Other

• **Hormonal**
  – Menstrual cycle impact on ACL injury risk unclear. No modifications recommended at this time based on menstrual cycle.
  
  – Estrogen receptors are present on ACL fibroblasts, but literature unclear on effect\(^9\)
    • Believed to negatively effect tensile properties
  
  – Dragoo et al, 2011\(^68\)
    • Elite collegiate female athletes
    • Relaxin > 6.0pg/mL \(\rightarrow\) 4 x ACL tear risk

• **Previous Injury**

• **Anatomic factors**
  • Notch width, posterior tibial slope, knee valgus, subtalar joint motion
ACL Tears in Females: Treatment Implications

• Lack of strong data supporting techniques specific to female ACL reconstruction

• Risk Factors summarized as:
  – Playing with “knock knee” position
  – Decreased hamstring strength
  – Reduced hip and knee ROM
  – MULTIFACTORIAL intrinsic risk factors
ACL Tears in Females: Prevention Strategies

- Strengthening, proprioception, motion training, repetition and routine forming
- **Strengthening alone is not enough!**

- Many studies have aimed to investigate the practicality and success of various training programs
- Vertical drop jump test is common
  - Drop from box, immediate max vertical
  - Screening usefulness questioned recently

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[Image of a series of exercises labeled A to E]
ACL Tears in Females: Prevention Strategies

- **Hewett et al, 1999**
  - First study to demonstrate neuromuscular training (NMT) reduces ACL injury risk
  - Prospective cohort study, HS female athletes
  - 6 weeks NMT, 3 x week, 60-90min/session
  - Non-contact ACL risk lower in trained females
    - 72% reduction when compared to untrained
    - None sustained ACL tears

- Components of effective interventions
  - Plyometrics
  - Technique training
  - Training > 1 x week
  - Duration of training > 6 weeks
ACL Tears in Females: Prevention Strategies

- **Mykleburst et al, 2003**
  - Prospective cohort study over 3 seasons
  - Norwegian female handball players, >850
  - Intervention occurred in seasons 2 and 3
  - 29 ACL injuries in first season (control)
  - 23 ACL injuries in 2\(^{nd}\) season, 17 injuries in 3\(^{rd}\) season
  - **Significant reduction in NC-ACL tears**
  - Elite division athletes with training
    - Significant reduction in overall ACL injuries
    - When normalized for exposure, **36% lower risk**
  - Compliance an issue
    - High drop out rates

- **Lim et al, 2009**
  - Improved strength and flexibility in female basketball players s/p NMT intervention
ACL Tears in Females: Prevention Strategies

- **Mandelbaum et al., 2005**
  - Cohort study, female soccer, 2 seasons
  - Over 1000 players vs matched controls
  - Significant decrease in ACL tear incidence per 1000 player-exposers in trained group
  - Overall, 6 tears in trained, 67 in untrained

- **Petersen et al., 2005**
  - Female German handball athletes
  - 10 teams vs 10 controls
  - Balance board, jumps, bounce mat
  - ACL injury risk 80% lower in trained (trend)
ACL Tears in Females: Prevention Strategies

- **Hewett et al, 2017**
  - Targeted NMT (TNMT)
    - No running, 5 performance levels
    - Supervised by athletic trainer; generalizable
  - TNMT significantly improved
    - Hip control
    - Peak trunk flexion
  - High risk athletes improved more

- **Pollard et al, 2017**
  - 30 female soccer players; baseline info
  - 12 week participation in NMT intervention
  - Improved knee landing mechanics, trunk flexion, energy absorption at both knee and hip
**ACL Tears in Females: Prevention Strategies**

**AAOS Appropriate Use Criteria**

“Moderate” strength evidence to support use according to AAOS Evidence Based Clinical Guideline Management of Anterior Cruciate Ligament Injuries

<table>
<thead>
<tr>
<th>Indication Profile</th>
<th>Procedure Recommendations</th>
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<tbody>
<tr>
<td>Sex</td>
<td>Supervised ACL Prevention Program</td>
</tr>
<tr>
<td>Pubertal Status/Maturity</td>
<td></td>
</tr>
<tr>
<td>Level of Activity</td>
<td></td>
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<tr>
<td>Sports Participation</td>
<td></td>
</tr>
<tr>
<td>Athlete Risk, Per Screening Evaluation</td>
<td></td>
</tr>
</tbody>
</table>

- Sex: Male, Female
- Pubertal Status/Maturity: Pre-Pubertal, Pubertal, Post-Pubertal/Mature
- Level of Activity: Competitive athlete, Recreational athlete
- Athlete Risk, Per Screening Evaluation: High Risk, Low Risk

Submit
ACL Tears in Females: Prevention Strategies

- Length of program matters!\(^{92}\)
  - Padua et al, 2012
  - One group performed program for 3 mo
  - One group performed program for 9 mo
  - Both improved performance, but only extended duration group retained improvements 3 months s/p stopping program

- Training fades with discontinuation

- Maintenance program important to make part of training!
ACL Tears in Females: Prevention Strategies

• Most effective in\textsuperscript{93,94}
  – Younger patients
  – Higher risk athletes
  – Elite performance athletes

• Components of a valuable program
  – Dynamic strengthening of LE kinetic chain
  – Plyometrics, proprioceptive training
  – Technique training
  – Multiple times a week
    • 10 minutes / 3 x week minimum recommendation
  – Preseason implementation
  – Continued throughout season
  – Longer duration of intervention
  – Identify at risk players
FIFA 11: Apply to Other Sports

• ACL injury prevention program initially for soccer players
• 10-15 min warm-up
• Core stabilization, eccentric training of thigh muscles, proprioceptive training, dynamic stabilization and plyometrics.
• Studying Applicability to other sports
ACL Tears in Females: The Future

• Wearable Technology?\textsuperscript{95}
  – Decker et al, 2016
  – Device measures posture and GRF
  – Improvements; NNT = 92

• Better, longer-term population based studies on the relationship between genetics, hormonal environment and ACL injuries in females

• Medium and long term outcomes with prevention strategies
ACL Injuries in Female Athletes: Summary

- Female athletes are at greater risk for ACL injury
- Risk factors are multifactorial
- Prevention strategies can identify high risk athletes and help to reduce ACL injury risk
- Future studies will help guide better prevention and treatment programs
Thank you

- Questions?
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