Knee Injury Prevention

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**27 Years of Observation has led to many research ideas**

- **80 males, 64 females**
  - Knee injuries: Number (% of gender)
    - Males, 11 (13%); Females 34 (53%) \(p<.0001\)
  - 20 (18%) underwent surgery
    - Males 6 (7.5%); Females 20 (31%) – 21 surgeries \(p=.0007\)
  - ACL reconstructions: 2 males, 8 females

- M. L. Ireland, C. Wall, *“Epidemiology and Comparison of Knee Injuries in Elite Male and Female United States Basketball Athletes”*
Sports-Related Injuries Among High School Athletes—United States, 2005-2006 School Year

• Title story in MMWR (CDC)
  • 1971-72: 4 million
  • 2005-06: 7.2 million

• 1.4 million injuries
  • Rate 2.4 injuries per 1000 athletic exposures
  • 425 Schools, 9 sports
  • No statistical significant difference in sex, soccer vs. basketball ($p<0.05$)

High School Overall Injuries, 34 Years
Increased from 4 million to 7.2 million
### Sports-Related Injuries Among High School Athletes—United States, 2005-2006 School Year

**MMWR (CDC)**
Sept. 29, 2006 p. 1038.

**Study by Comstock, RD**

#### TABLE. Sport-specific injury rates* in practice, competition, and overall — High School Sports-Related Injury Surveillance Study, United States, 2005–06 school year

<table>
<thead>
<tr>
<th>Sport</th>
<th>Rate Practice</th>
<th>Rate Competition</th>
<th>Rate Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys’ football</td>
<td>2.54</td>
<td>12.09</td>
<td>4.36</td>
</tr>
<tr>
<td>Boys’ wrestling</td>
<td>2.04</td>
<td>3.93</td>
<td>2.50</td>
</tr>
<tr>
<td>Boys’ soccer</td>
<td>1.58</td>
<td>4.22</td>
<td>2.43</td>
</tr>
<tr>
<td>Girls’ soccer</td>
<td>1.10</td>
<td>5.21</td>
<td>2.36</td>
</tr>
<tr>
<td>Girls’ basketball</td>
<td>1.37</td>
<td>3.60</td>
<td>2.01</td>
</tr>
<tr>
<td>Boys’ basketball</td>
<td>1.46</td>
<td>2.98</td>
<td>1.89</td>
</tr>
<tr>
<td>Girls’ volleyball</td>
<td>1.48</td>
<td>1.92</td>
<td>1.64</td>
</tr>
<tr>
<td>Boys’ baseball</td>
<td>0.87</td>
<td>1.77</td>
<td>1.19</td>
</tr>
<tr>
<td>Girls’ softball</td>
<td>0.79</td>
<td>1.78</td>
<td>1.13</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.69</strong></td>
<td><strong>4.63</strong></td>
<td><strong>2.44</strong></td>
</tr>
</tbody>
</table>

* Per 1,000 athlete exposures (i.e., practices or competitions).

**Competition MUCH greater risk than practice**
Women’s Participation

• High school:
  • Pre-Title IX, 1972: 300,000
  • 2008: 3,000,000
  • 10x increase

• College:
  • Pre-Title IX: 30,000
  • 2008: 205,000
  • 7x increase

Increase in Women’s Participation over 36 Years:
  High School: 10X
  College: 7X
Basketball ACL Injury Rates
NCAA 1989-2003

*Rates Given are per 1000 Athlete-Exposures.

Ratio of Average Rates
Women: Men
3.38

Avg. For Women
Avg. For Men
0.27
0.08
Soccer ACL Injury Rates
NCAA 1989-2003

*Rates Given are per 1000 Athlete-Exposures.
Basketball
VROOM . . .

- Valgus
- Rotation
- Out
- Of control
- Movement

It takes 70 milliseconds to tear the ACL
Observation of ACL Injury Patterns

- Allow us to develop hypotheses in the lab for computer modeling
- Bring lab studies back out to the training room
- Joint position and muscle activation is critical to knee stability
- Strength is not as important as timing of activation
  - Best: hamstrings firing on flexed knee-hip
  - Worst: quadriceps dominance in extended hip-knee
What I Have Observed

- **Mechanism of Injury**
  - High risk vs. low risk landing position

Figure 3. Injury to the left knee as observed from the back and left side of the athlete. She has just rebounded and stops to change direction to avoid the defending player. She lands in an upright position with less knee and hip flexion and forward-flexed lumbar spine. After the ACL fails, she falls forward, and knee valgus rotation and flexion increase. She is unable to upright herself and regain pelvis control to avoid ACL injury.
Tire with a sudden blowout is like . . .

. . . a mop-end tear of ACL
Knee: Cone of Stability
NonContact ACL Tear

Anterior Dislocation
Weight Bearing Pivot Shift
Basketball: non-contact, unexpected, not thinking
Position of No Return

- Is it really knee valgus?
  - Seen from frontal plane, YES, but NOT from sagittal plane
- Injury – Landing Pivot Shift
  - Knee: Anterior subluxation of tibia
  - Hip: Internal Rotation and Adduction
- Femoral rotation
  - first internal, then external
  - Anterior tibial translation = “valgus collapse”
Alignment  Proximal control / Core stability

POSITION OF SAFETY

HEAD  Neutral
NECK  Neutral
LUMBAR SPINE  Neutral
PELVIS  Neutral
FEMUR
KNEE

POSITION OF NO RETURN

HEAD  Forward
NECK  Hyperlordotic
LUMBAR SPINE  Anteriorly rotated
PELVIS
FEMUR
KNEE

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“Core Stability”

• Defined as the lumbopelvic-hip complex where a person’s center of gravity is located and all movement begins

• Provides a stable base to allow optimal kinetic chain function

• Weak core does not allow for production of efficient movements leading to possible injury
Core Stability Exercise Principles

- Spine stability system Panjabi: “Clinical instability is loss of spine’s ability to maintain its patterns of displacement under physiologic loads so there is no initial or additional neurologic deficit, no major deformity, no incapacitating pain.”

Core Stability Exercise Principles

- Spine stability system:
  - Neuromuscular control (Neural elements)
  - Passive subsystem (osseous and ligamentous elements)
  - Active subsystem (muscular elements)

- Core stability
  - Improves efficacy and musculoskeletal conditions
  - Reduces low back and lower extremity injuries

Single-Leg Squat is the best assessment of altered core stability and neuromuscular activity

Multiple Factors Resulting in ACL Injuries

- **NOT modifiable:**
  - Anatomic/Structural
  - Hormonal
- **Modifiable:**
  - Neuromuscular/biomechanical
- Expert think tanks agree that modifiable factors are most important
- Emphasize modifiable factors for return-to-play and prevention programs

Simple Single-Leg Squat

• Give clinicians information on neuromuscular control

Plank Test

• Measures lumbar and pelvic control in side or sagittal plane
• Can see excessive lumbar lordosis

Observe in Fatigue and Non-fatigue states

Core Stability Exercise Principles

• Spine stability system Panjabi: “Clinical instability is loss of spine’s ability to maintain its patterns of displacement under physiologic loads so there is no initial or additional neurologic deficit, no major deformity, no incapacitating pain.”


15 female subjects with and without patellofemoral joint pain

Symptomatic females demonstrated weakness in hip abduction and ER compared to age-matched controls
Core Stability Measures

- 80 females, 60 males
- Intercollegiate basketball and track athletes
- Measurements of core stability were made prior to the season
- Injury records were kept

Methods: Isometric strength

- Trunk
- Hip
- Thigh

• (Average force/BW) * lever arm (m)
Straight Leg Lowering Test

- 9° / second
- Angle at which low back raises off the tester’s hand

Side Bridge Test

- Time in seconds athlete able to maintain side bridge with hips & knees off the table
RESULTS & CONCLUSIONS:

- Hip external rotation strength was the only useful predictor of injury status.
- Males produced greater hip ABD, ER, and lumbar spine stability measures.
- Uninjured athletes were significantly stronger in hip ABD and ER.
Methods: TF Valgus (projection)

Single leg stance

Single leg squat (45°)

- Average projection angle (degrees)
Conclusions

- Simple clinical measures allow testing of athletes in training room setting
- Increase in TF valgus moderately explained by core strength
Ongoing ACL Research at the University of Kentucky
## Risk Factors Contributing to ACL Injuries

### Intrinsic

- Alignment
- Hyperextension
- Physiologic Rotatory Laxity
- ACL Size
- Notch Size/Shape
- Hormonal Influences
- Inherited Skills/Coordination
# Risk Factors Contributing to ACL Injuries

<table>
<thead>
<tr>
<th>Extrinsic</th>
<th>Combined (potentially changeable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>Proprioception (Position Sense/Balance)</td>
</tr>
<tr>
<td>Conditioning</td>
<td>Neuromuscular Order of Firing</td>
</tr>
<tr>
<td>Shoes</td>
<td>Acquired Skills</td>
</tr>
<tr>
<td>Motivation</td>
<td></td>
</tr>
</tbody>
</table>
### Risk Factor Categories

(Murphy *et al.*) – ACL Risk

<table>
<thead>
<tr>
<th>Intrinsic</th>
<th>Extrinsic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Age</td>
<td>1. Level of competition</td>
</tr>
<tr>
<td>2. Sex (Male / Female)</td>
<td>Games / Practice</td>
</tr>
<tr>
<td>3. Phase of menstrual cycle</td>
<td>2. Skill level</td>
</tr>
<tr>
<td>4. Previous injury and Inadequate Rehabilitation</td>
<td>3. Shoe type</td>
</tr>
<tr>
<td>5. Aerobic fitness</td>
<td>Edge-Cleats</td>
</tr>
<tr>
<td>6. Body size</td>
<td>Other Cleats</td>
</tr>
<tr>
<td>7. Limb dominance</td>
<td>4. Ankle bracing</td>
</tr>
<tr>
<td>8. Flexibility</td>
<td>5. Playing surface</td>
</tr>
<tr>
<td>9. Muscle strength imbalance</td>
<td></td>
</tr>
<tr>
<td>10. Reaction time</td>
<td></td>
</tr>
<tr>
<td>11. Limb girth (Wide / Narrow notch)</td>
<td></td>
</tr>
<tr>
<td>12. Postural stability</td>
<td></td>
</tr>
<tr>
<td>13. Anatomic alignment</td>
<td></td>
</tr>
<tr>
<td>14. Foot morphology</td>
<td></td>
</tr>
</tbody>
</table>

#### 5 Significant ACL Factors

Risk Factors, Noncontact ACL

- Being female
- Not hormonal levels during cycle
- Previous injury and inadequate rehab
- Narrow notch, therefore smaller ACL size
- Games
- 1st degree relative
- Younger age in females
- Landing patterns valgus extended knee
- Core dysfunction / weakness
Risk Factors for Lower Extremity Injuries

- Fatigue
- Previous injury
- Shoe-surface interface
- Game situation
- Awkward landing
- Combination
Family History Risk Factor

• 742 subjects with a family history of ACL tear

• Including only first-degree relatives, participants with ACL tear were more than twice as likely to have a first degree relative with an ACL tear, compared to participants without an ACL tear.

Does age, level of play increase ACL Risk?

Soccer athletes <16 who move up are more likely to be injured than seniors

ACL Reconstructions
KSM Experience

• Females are younger than males by 5 years


Fig. 1. Theory linking growth, neuromuscular (NM) adaptation, trunk NMC, “dynamic valgus,” and knee joint load to anterior cruciate ligament (ACL) injury risk.

Fig. 2. Mechanical model linking 1) lateral trunk motion to change in direction of the ground reaction force vector ($\Delta$GRFv), 2) hip adductor torque, and 3) knee load during cutting and landing anterior cruciate ligament (ACL) injuries.

Fig. 3. Conceptual model of lateral trunk motion leading to increased ground reaction force vector (ΔGRFv) and hip adductor torque and knee load.
Development of probability of high knee abduction moment (pKAM)


SUMMARY: 4 articles: development of probability of high knee abduction moment (pKAM)

• Clinical-based algorithm developed to predict probability of a high pKAM based on 2-dimensional video data as a measurement tool to mass screen for injury risk

• 15/16-year-old female soccer/basketball athletes

• pKAM values ranged between 0 and 1, with 84% sensitivity, 64% specificity, and C statistic .85
Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes.

- Pre-screened female athletes will demonstrate neuromuscular control and increased valgus joint loading predicting ACL injury risk
- 205 female athletes: soccer/basketball/volleyball
- 3D joint angles and joint loads during jumping/loading task:
  - 9 athletes: ACL tear – 2.5X greater knee abduction moment, 20% higher ground reaction force

Knee Abduction Moment predicted ACL Injury Status
73% specificity, 78% sensitivity

High knee abduction moment (pKAM)

• Based on analysis of 2D video data with standard video cameras to provide measurement tool that has capacity for larger populations for mass screening of injury risk

Hypothesis

• Clinic-based algorithm would predict athletes at increased risk for ACL injury
  • 1885 Female athletes
    • Recruited 2008-2011
    • Soccer / Field hockey / Basketball / Gymnastics / Lacrosse / Rugby / Ultimate Frisbee / Volleyball
  • 20 ACL tears, 45 controls

Results

• No relationship between risk of suffering ACL injury and pKAM as determined by clinic-based algorithm
  • Conditional logistic regression analyses did not reveal statistically-significant relationships

Conclusions

• The pKAM was not associated with non-contact ACL injury in our group of injured athletes and matched controls

Conclusion

• Additional research is needed to develop alternative clinic-based algorithms for prediction of ACL injury risk that can be applied in an efficient manner to large groups of participants involved in activities that are associated with an increased risk of suffering ACL injury.

In other words... 

• If we don’t know the factors causing increased risk of injuries, we can’t predict why prevention programs are working.

Prevention Programs

Injury Prevention-ACL Tear

Simple as: ABC’s

• Agility
• Balance
• Core
• Strength
What the programs have in common

- Emphasize safe landing positions
- Neuromuscular recruitment
- Should be sport-specific
- Program must be done properly and participation documented
- Look at all lower extremity injury rates, not just ACL tears
Prevention Programs

- Published results: do reduce risk of injury
  - Adolescent Females (Tim Hewett, Ohio)
    www.cincinnatichildrens.org/svc/alpha/s/sports-med/acl.htm
  - Soccer (Bert Mandelbaum, Santa Monica, CA)
    www.aclprevent.com
  - Team Handball (Grete Myklebust, Norway)
    www.ostrc.no/en/
Prevention Program Websites

- Cincinnati Children’s Hospital
  www.cincinnatichildrens.org/svc/alpha/s/sports-med/acl.htm
- PEP Program
  - ACL Prevent
    www.aclprevent.com
  - Soccer program
  - Santa Monica, California
Leveling the playing field

By Annie Hayashi

How Neuromuscular Training Gets Girls Back in the Game

Sophia was a very talented volleyball and basketball player. By the time she was age 16, college scouts were already recruiting her. Then she played the volleyball game that ended all games. She went up for a spike, hit the ball just right, and landed hard on her left leg. She heard the “pop” as her left anterior cruciate ligament (ACL) ruptured. Her scholarship prospects were gone as quickly as her ACL was torn.

Is less flexion in the female knee to blame? The orthopedic literature indicates that female athletes tear their ACLs more often than their male counterparts. Some research has shown that a reduction in hamstring-to-quadriceps ratio may increase the risk of ACL injury.

Neuromuscular training, including biofeedback and motion analysis techniques, may help reduce the incidence of ACL injuries among female athletes.
Sports Injury (ACL) Prevention

- Timothy E. Hewett, Ph.D.
- www.cincinnatichildrens.org/sportsmed
Prevent injury and Enhance Performance

- Soccer athletes, 14–18 years of age
- Study design cohort Level of Evidence 2
  - 1041 Female subjects, 52 teams
  - 2 to 3 times per week
    - Not on game days
- 20 minute program
- Performed throughout the season, not just 6 weeks

Mandelbaum BR, et. al., “Effectiveness of a Neuromuscular and Proprioceptive Training Program in Preventing Anterior Cruciate Ligament Injuries in Female Athletes: 2 Year Follow-up,” AJSM 33(7) 1003-10.

http://aclprevent.com
PEP emphasizes correct form:
**ACL tear reduction 88% in 2000 and 74% in 2001**

Rate per player (trained-untrained)/rate x 100

<table>
<thead>
<tr>
<th>2000 and 2001 Combined</th>
<th>No. Subjects</th>
<th>No. ACL Tears</th>
<th>Resultant Rate per Player</th>
<th>Relative Risk</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trained</td>
<td>1885</td>
<td>6</td>
<td>3.18</td>
<td>0.1814</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Untrained</td>
<td>3818</td>
<td>67</td>
<td>17.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>5703</td>
<td>73</td>
<td></td>
<td></td>
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</table>

Mandelbaum BR, et. al., “Effectiveness of a Neuromuscular and Proprioceptive Training Program in Preventing Anterior Cruciate Ligament Injuries in Female Athletes: 2 Year Follow-up,” AJSM 33(7) 1003-10.
Lower Extremity Injury Prevention Program

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University of Kentucky
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Lexington, Kentucky USA
Tel.  (859) 218-3131
www.ukhealthcare.uky.edu/sportsmedicine

SPECIAL THANK YOU

• James E. Ireland Foundation
• Post-Time Productions
• Athletic Trainers, Certified: Aaron MacDonald,
  Amy Waugh, Michelle Meeks, Jantzen Merrimen
Lower Extremity Injury Prehab Program
Message: Performance enhancement, not injury prevention

1. High Knees
2. High Knee Shuffle
3. High Knee Hold
4. High Knee Fig-4
5. Butt Kick
6. Power Skip
7. Toy Soldiers
8. Carloca
9. Side Lunge
10. Lunge
11. Hopscotch
12. Vertical Jump
13. Side-to-Side Cutting
14. Forward-Back Cutting
ACL Injury Prevention

- Mental preparation
- Physical training
- Coaches cries
  - Land
    - Softly
    - Light as a feather
    - Like a spring
  - Get Down
    - More bent hip/bent knee position
Return to Play after ACL Reconstruction?

• Months or Years?

Question is: how to test by objective measures

• Jumping / landing
• Treadmill
• Functional Assessment in PT
• Fatigue
• Confidence in Landing
Functional Assessment

© 2004, KY Sports Medicine
Remember the Core!
Landing is EVERYTHING!
Not all injuries are preventable. Things happen!
Determine and rank order of importance of risk factors.

Injury Prevention Strategies . . .
. . . Harder to sell than performance enhancement to coaches, parents

Key to ACL Injury Prevention
• Understanding and ranking importance of risk factors:
  • Intrinsic
  • Extrinsic
You Never See It Coming . . .
Bottom Line Question with long-term results of ACL reconstruction:

• Can we prevent arthritis?
• Can we restore normal knee function?
• Evidence based results: unknown
• Experience driven: known
36YO Female
Professional basketball athlete
Allograft ACL reconstruction

Injured
PF Osteoarthritis

PF Osteoarthritis
2 Years Post ACL recon

Injured

PF Osteoarthritis
3.5 years postop increasing knee pain
Knee Injury Prevention

Mary Lloyd Ireland, MD
Knee “pack-years” as in smoking: Additive effects of years of participation in basketball.

- Pack-years of smoking on lungs
- Pack-years of activity on knees

? Too many pack years of basketball?
National Cruciate Ligament Registry in Norway

www.haukeland.no/nrl/

- Established June 12, 2004
- Overview: Matt Hasson, “Scandinavian ACL registries could serve as models for large European database,” ORTHOPAEDICS TODAY INTERNATIONAL 2006; 9:25
  www.orthosupersite.com/view.asp?rID=18593
- Study presented at ISAKOS Congress in Florence, May 2007
- Authors: Granan LP, Engebretsen L, Bahr R, Oslo Sports Trauma Research Center, Ullevaal University Hospital, Oslo, Norway
<table>
<thead>
<tr>
<th>Sports Multicenter Outcomes Studies</th>
<th>MOON ACLR, MARS &amp; MeTeOR NIH Funded</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Original</strong> ACLR (Spindler) - 2002-2005</td>
<td></td>
</tr>
<tr>
<td>2. <strong>MOON</strong> SHOULDER (Kuhn) The only prospective longitudinal outcome cohort to identify features that predict success with non-operative treatment of full-thickness rotator cuff tears. Design and sites based on original MOON platform.</td>
<td></td>
</tr>
<tr>
<td>3. <strong>MARS</strong> with AOSSM (Wright) Collaborative multicenter cohort (offered to all AOSSM members) to identify causes and modifiable risk factors for worse outcomes in Revision ACLR. Design based on original platform, but grew to include 83 surgeons (the number needed to accrue enough revision surgeries), with nearly half the sites in private practice.</td>
<td></td>
</tr>
<tr>
<td>4. <strong>MeTeO</strong> R (Katz) Randomized controlled trial to establish efficacy of surgery compared with nonoperative therapy in patients with symptomatic meniscal tear and osteoarthritis. Six of seven study sites were MOON or MARS participants.</td>
<td></td>
</tr>
</tbody>
</table>
www.vanderbiltsportsmedicine.com
“The Uneven Playing Field”

- By Michael Sokolov
  *New York Times, May 11, 2008*

- Janelle Pierson
  - High school soccer player
  - Multiple ACL injuries, both knees
  - Mindset: after surgeries, multiple knee injuries
    - Rehab hard
    - Get back on the field
    - Compete fiercely
    - Hope not to be injured
Establish Risk Factors

- Prioritize Order of Risk
- Document what factors are changed by intervention programs
We must choose the correct risk factors and implement programs at multiple centers to study the impact of those programs.

- If you pick the wrong risk factor(s) or a poor study design, you may be out of a ride to work.

For example . . .
Thank You!

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BIBLIOGRAPHY


KNEE INJURY PREVENTION


Granan LP, Engebretsen L, Bahr R. Study presented at ISAKOS Congress in Florence, May 2007, Oslo Sports Trauma Research Center, Ulleval University Hospital, Oslo, Norway. www.haukeland.no/nrl/


Hewett TE. www.cincinnatichildrens.org/sportsmed


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Ireland ML, Wall, C. Epidemiology and Comparison of Knee Injuries in Elite Male and Female Basketball Athletes. Medicine & Science in Sports & Exercise 1990;22(2) S582.


KNEE INJURY PREVENTION


KNEE INJURY PREVENTION

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Yeow CH et al. Shod landing provides enhanced energy dissipation at the knee joint relative to barefoot landing from different heights. Knee 2011;18(6):407-411.