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ACL injury prevention: What we know, what we don't, what we can put into practice now.

Carol Mack, PT, DPT, SCS, CSCS, PN-1

Learning Outcomes

After this course, participants will be able to:

- Identify at least two current gaps found in the literature regarding ACL injury prevention.
- Describe the role of motor learning in rehabilitation or prevention of ACL injury.
- Describe the implementation of at least two strategies in ACL injury rehabilitation and prevention programs.
- List at least three ACL injury risk reduction strategies in athletes.

Carol Mack

- Owner of CLE Sports PT & Performance
- DPT, Duquesne University, 2006
  - Four years varsity soccer
- Board Certified Specialist in Sports Physical Therapy
  - Specialties:
    - End-stage rehabilitation of soccer athletes
    - Female athletes
    - Runners.
- Certified Strength & Conditioning Specialist
- Precision Nutrition Level 1 Certified Coach.

Carol Mack

- Member, US Olympic Committee Volunteer Medical Staff.
- PT, Performance Coach, Beaumont School Athletics
- Distance Coach, Fleet Feet Sports Cleveland
- Former Chair, Female Athlete Special Interest Group (American Physical Therapy Association)
- Former chair, Cleveland Clinic's "Match Fit" soccer performance enhancement and injury risk reduction program

ACL INJURY:

WHAT WE KNOW

Statistics

- 1 in 3000 in US (Miyasaka 1991)
- Women's soccer:
  - Professional soccer: .09 per 1000 hours
  - Amateur, collegiate: .1-.31
  - Adolescent: **1.0**

(Agel 2005
Arendt 1999
Giza 2005
Le Gall 2008)

ACL INJURY

- High school athletes
  - Significant risk: soccer, football, basketball, lacrosse
  - Girls: 1.6-fold increase in injury rate

Gornitzky et al. Sport-Specific Yearly Risk and Incidence of Anterior Cruciate Ligament Tears in High School Athletes: A Systematic Review and Meta-analysis. Am J Sports Med, 2016

Why?

- Neuromuscular, biomechanical = "**neuromechanical**"

The factor we can modify?

- Anatomic
- Genetic
- Hormonal
  - What contributes to a structurally weaker ligament???

- ACL Research Retreat VII

continuED

Why?

- Structurally weaker ligament???
  - External loading factors likely impact injury risk
- Does this interplay explain why screening methods inconsistent?

\- ACL Research Retreat VII

continuED

Why?

- "Need a **<u>comprehensive</u>** assessment of **modifiable** <u>and</u> **non-**modifiable factors on injury risk (so anatomy, genetics, hormones, neuromechanics)"
  - What combination could reliably predict injury risk?

\- ACL Research Retreat VII

Neuromuscular risk factors

- Sudden deceleration with change of direction
- Single leg landing
  - Rapid knee abduction + internal rotation
  - Some lateral trunk motion
  - Posterior center of mass

Neuromuscular Risk Factors Associated With ACL Injury

Ligament dominance
Quadriceps dominance
Leg dominance
Poor trunk control

Ligament Dominance aka “Knee valgus”

“Knee valgus”

Poor Knee Control

Quadriceps Dominance

Muscle imbalance:

- Quads vs hamstrings/glutes
- “Stiff landing”

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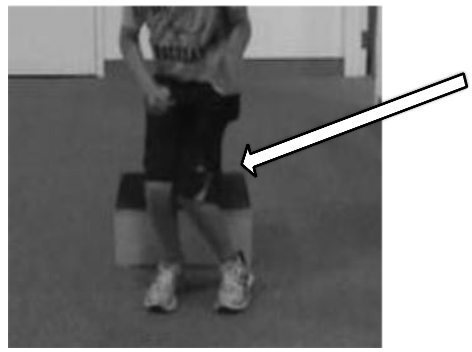
Leg Dominance

Brophy, et al (MOON Group 2012)

- Dominant leg injured in 57% of soccer athletes
- No difference in RTP based on injury of dominant or non-dominant leg
- Soccer players with ACL-R on non-dominant limb with higher future rate of contra-lateral ACL-R



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Poor Trunk Control

Greater trunk displacement = positive predictor ACL injuries college females (not males)

Increased trunk flexion at landing:
- Increased hip flexion, hip extensor moment
- Decreased ground reaction force
- Increased quad activation

Zazulak (2006, 2007), Ford (2007)

Neurocognitive insufficiency?

ACL-injured athletes with decreased…
Reaction time
Processing speeds
Visual-spatial awareness

Possible connection: central processing (reaction time, automaticity) and neuromuscular insufficiency

Swanik 2007, 2015
Herman, 2015

Time to stabilization

- DuPrey 2016:
  - Backwards jump/land: increased time to stabilize increased ACL injury risk
    - 1.58 +/- .39 seconds: ACL injured
    - 1.09 +/- .52 seconds: uninjured
  - Odds ACL rupture increased 3-fold for every second increase

Biomechanical risk factors

- Anterior tibial forces
- Tibiofemoral compression

- Knee abduction + knee internal rotation moments
  - Combined with external moment to the knee = biggest strain

(Oh 2012
Shin 2009, 2011
Kiapour 2014)

Biomechanical risk factors

- Sudden deceleration with change of direction
- Single leg landing
  - Rapid knee abduction + internal rotation
  - Some lateral trunk motion
  - Posterior center of mass

Maturation?

- Influence on biomechanical, neuromuscular factors affecting ACL strain
  - BUT… how does it affect biomechanics?

Barber-Westin SD 2005; 2006
Hass, 2005
Hewett 2004, 2010, 2015
Quatman 2006
Ford 2010
Sigward 2012
Holden 2015

Epidemiology

- Boys: more ACL injuries before puberty (Stracciolini et al)
- Girls: steeper increase in incidence by age
  - 5-12 years: higher ACL injury/total injury ratio in boys

Maturational Differences

- Physiology of growth and development
  - Roemmich, Rogol 1995
- Growth Velocity/"Growth Spurt"
  - Girls- velocity increases sharply at ~10 years
  - Boys- ~12 years

Growth and Development

- Peak velocity
  - Girls- 10.5 cm/year around age 12
  - Boys- 12 cm/year around age 14
- 13 cm difference in mean height between males, females at end of puberty

Anaerobic Power Development

- Boys- linear rate of increase during childhood
  - Onset of puberty- steeper linear rate
  - Increases until ~19 years
- Girls- linear rate plateaus ~15 years

Strength Development

- Literature- isometric strength (Roemmich, Rogol 1995)
  - Linear increase for girls and boys during childhood
    - Boys- acceleration during puberty
    - Girls- rate does not change
- Muscular endurance- similar trend

Neuromuscular Spurt- Or Not?

- *"Increased **power**, **strength**, and **coordination** that occurs with increasing chronological age and maturational stage in adolescent **boys**"*
  - Hewett et al 2004; Ford et al 2010; Quatman et al 2006
- **NOT** seen in **females**

Neuromuscular Spurt- Or Not?

- Males:
  - Increased vertical jump height throughout puberty
  - Increased ability to absorb force
- Girls
  - Plateau in peak power ~16 yrs
  - Significant increase in valgus knee position vs males after puberty
  - Decreased knee flexor torque

Implications- Females

- Neuromuscular adaptation does not match increase in height
- Long lever arm without control

"Motor Awkwardness"

- 6 month period in adolescence
- Trunk and leg length increase; muscles not at full strength

Davies, 2000

Quatman-Yates, 2011

Anatomic risk factors

- Knee geometry related to higher-risk biomechanics

(McLean 2010, 2011
Dejour 1994
Giffin 2004
Lipps 2012
Shultz 2012)

Anatomic risk factors

- ACL injured athletes:
  - Smaller ACL's
    - Area, volume
  - Greater lateral posterior-inferior tibial plate slopes
  - Smaller femoral notch widths, notch-width indexes
  - More prominent/thicker bony ridge femoral intercondylar notch

*(Shelbourne, 1998
Ireland 2001
Khan 2011)*

Anatomic risk factors

- Females:
  - Smaller ACLs
  - Less collagen fiber density
  - Decreased mechanical properties
    - Strain, stress at failure
  - Greater tibial slopes
  - Taller femoral notch heights
  - Smaller femoral notch widths

*(Chandrashekar 2005, 2006
Hashemi 2008
Hudek 2011)*

Anatomic risk factors

- Knee joint laxity
  - ACL-injured patients with…
    - Anterior knee laxity
    - Genu recurvatum
    - General joint laxity
    - Internal rotation knee laxity
- HOWEVER…much variation individual joint laxity
  - Genetic
  - Hormonal
  - Anatomic

*(Scerpella 2005
Woodford-Rogers 1994
Kramer 2007
Loudon 1996
Myer 2008
Ramesh 2005
Branch 2010)*

Anatomic risk factors- laxity

- Females with…
  - Greater anterior knee laxity
  - Genu recurvatum
  - Varus/valgus, IR/ER
  - General joint laxity
- Acute increase during exercise and across menstrual cycle

*(Deie 2002
Eiling 2007
Heitz 1999
Shultz 2004, 2010, 2011)*

Anatomic risk factors

- Lower extremity alignment
  - No clear consensus to a single factor
  - Complications:
    - Maturation
    - Rate of development
    - Males, females

Genetic risk factors

- Growing research
- DNA sequence variants associated with injury risk
  - Collagens, proteoglycans
- Subset associated with ACL ruptures in females
  - Not males

Genetic risk factors

- Most research on…
  - White populations
  - Small sample sizes

(Ficek 2013
Khoschnau 2008
O'Connell 2015
Posthumus. 2009, 2010
Stepien-Slodkowska 2013)

Hormonal risk factors

- Relaxin
  - NCAA I female athletes
    - Elevated concentrations in ACL

(Dragoo 2003, 2011)

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INJURY PREVENTION:
WHAT WORKS????

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INJURY PREVENTION

- Arundale, et al 2018 JOSPT: Clinical Practice Guidelines, ACL Injury Prevention
- **Grade A (strong evidence):** knee injury prevention programs
- Strongest evidence for female soccer players
  - 12-25 yrs
  - Other sports with high risk injury

INJURY PREVENTION

- Grade A:
  - Multiple components of training
  - Multiple sessions/wk (over 30 min total)
  - At least 20 min/session
  - Start pre-season
  - NEED COMPLIANCE!

ACL INJURY:

WHAT WE DON'T KNOW

continued

Neuromuscular control vs absolute strength

"To various degrees, the amount of maximal strength is related to movement mechanics, but how this is related to injury risk is unclear."

- ACL Research Retreat VII

Husted et al, 2018: no relationship

continued

Myklebust, 2013: "ACL injury incidence in female handball 10 years after the Norwegian ACL prevention study: important lessons learned"

- Unknown **what factor** of ACL injury prevention is most successful
- Recommend the following description instead of "injury prevention"

"Reduce injury rate by at least 50%"

Screening

- Unknown which elements of screening tools predict risk
  - LESS, tuck jump
- May be population specific
  - LESS ID-ed elite youth soccer athletes at higher risk (sensitivity 86%, specificity 64%)
  - Could not predict future injury in adults

Screening

- Sport-specific screening?
  - Cutting sport vs jumping sport
- What are the most critical risk factors?
  - Gender?
  - Asymmetry and tear patterns?
  - Population differences?

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Screening- knee valgus?

- Valgus is documented risk factor
  - *Hewett, 2005, Koga 2010, Olsen, 2004, Krosshaug 2007, McLean, 2004*
- But…ACL + MCL injuries only 4%-17%
  - ACL significantly greater injury risk **at 25°**
    - Previous studies: MCL disruption at higher load than ACL

Quatman et al. Preferential loading of the ACL compared with the MCL during landing: a novel in sim approach yields the multiplanar mechanism of dynamic valgus during ACL injuries. Am J Sports Med. 2014

continuED

Screening- knee valgus?

- "Rethinking dynamic knee valgus"
  - *Dischiavi et al, 2019 JOSPT*
- Triplanar movement
  - Requires **control** (vs prevention)
- Look at how trunk, pelvis rotate over a fixed femur

Sport-Specific Training

- Basketball players: greater ground reaction force, decreased stance time in drop vertical jump
- Soccer players: with greater GRF, decreased stance time in cutting
- May warrant sport-specific neuromuscular training and screening
    - Basketball: jumping/landing
    - Soccer: unanticipated cutting

(Cowley 2006)

Compliance

- HOW could it affect injury rates or injury risk??
    - 53% coaches implemented injury prevention program after workshop (Frank et al 2015)
        - Two-thirds invited coaches declined to participate
            - Main reason: **lack of time and/or interest**
- Athletes: higher compliance vs coaches (Sugimoto, et al 2017)
    - Middle school: less compliant vs high school

Compliance

- NCAA men's soccer:
  - High compliance = significant reduction injury, time loss

Silvers-Granelli HJ, 2018

Compliance- Barriers to Implementation

- ID beliefs/behaviors that are barriers to implementing programs
- Should we also "sell" the performance enhancement benefit?
  - Need further research

Compliance-
Performance Enhancement Benefits

- May help "sell" to community
- Performance enhancement and injury risk reduction
- May need to include sports performance tests as metrics
  - For athletes
  - For future studies

Compliance

- Swart, 2014
  - "Universal neuromuscular training" would **save $100 per player per season**
  - Would reduce incidence **from 3% to 1.1%** per season

MOTOR LEARNING

Role of Central Nervous System (CNS)?

- Altered central nervous system- possible role
- Brain functional MRI after <u>unilateral</u> ACL injury (Grooms 2015):
  - Increased activation motor planning, sensory processing, visual motor control areas <u>bilaterally</u>

Role of CNS?

- Is there a disconnect?
  - How do we take conscious awareness in training/rehab to automatic movement pattern?

Motor learning, defined

- "Relatively permanent acquisition of motor skills" (Schmidt 2004)
- Learning process similar for many different types of motor skills

Motor learning stages

- Fitts & Posner:
  - Cognitive
  - Associative
  - Autonomous

Motor learning stages

- Cognitive Phase
  - Conscious attempt to determine what has to be done
  - “Step by step”
  - Focus of attention on entire pattern

Motor learning stages

- Associative Phase:
  - Begins when basic movement pattern acquired
  - Movements more consistent, automatic, and economical
  - Some attention shifts to other aspects of performance

Motor learning stages

- Autonomous Phase
  - Motion is fluent; seemingly effortless
  - Movements accurate, consistent, efficient
  - Little to no attention required- skill considered "automatic"

Practice makes perfect?

- "Old school belief:" Athletes need attention to every detail and step initially
  - Must practice over and over
- NOT supported in the literature
  - Repetition not optimal
  - Pattern variations may stimulate brain to problem solve
    - Find the optimal solution during unanticipated events
      - "True" sports simulation?

Types of motor learning

- Explicit learning: Acquisition of motor skills with an internal focus
  - Internal focus: directed to body movements
    - "Keep your knees over your toes"
    - "Land with your feet shoulder width apart"

continuED

Types of motor learning

- Implicit learning: Acquisition of motor skills with an external focus
  - External focus: directed towards outcome or effects of movement
  - "Imagine sitting down in a chair when landing"

continuED

Internal focus

- Constant focus on repetition- reduces athlete's motivation
- Conscious control of own movement
  - Skills may not transfer to automatic performance
  - Less ability to "problem solve"
- Increased psychological stress- detrimental effect on performance? (Masters 2008, Poolton 2007)

External focus

- Effectively establishes sport-specific movements (Schöllhorn 2006, Wulf 2001)
  - Basketball free throw, tennis serve, golf swing
- Facilitates movement automation; accelerates learning (Wulf 2009, Zachry 2005)

External focus

- Better retention newly learned skills
  - Better balance (Laufer 2007)
  - Reduced peak vertical GRF with jumping (Onate 2001)
- Resilient under fatigue and stress

External focus and fatigue

- Fatigue had no effect on motor performance with external focus
- Motor performance under internal focus deteriorated (Poolton 2007, Masters 2007)

Premotor cortex

- Role in conscious attention to memorized movements (Simon 2002)
  - Active if no movement generated
  - Attention to memorized movements may reduce brain resources for motor control
- Skill learned with external focus: resources available for other factors
  - Opponent, teammates, field conditions

Benefits of external focus

- Sports performance
  - Higher jump-and-reach height, increased force production (Makaruk 2012, Wulf 2009)
    - Vertex jump trainer as external object
    - "Reach fingers as high as possible"

Benefits of external focus

- ACL Injury Prevention/Rehab
  - Improved knee flexion (Makaruk 2012, Onate 2005)
  - Improved neuromuscular coordination (Wulf 2007)
  - Lower peak vertical ground reaction force (McNair 2000, Onate 2001, Wu 2012)
  - Improved landing technique; increased jump performance (Benjaminse 2015)

External focus

- Gokeler et al: Internal focus (IF) vs external (EF)
  - EF group significantly larger:
    - Knee flexion angle at initial contact
    - Peak knee flexion
    - Total ROM
    - Time to peak flexion

TRAINING METHODS: IMPLICIT LEARNING (EXTERNAL FOCUS)

Dyad training

- Athlete watches a teammate or peer
- Observation & practice more effective in combination (Shea 2000, 1999)

Dyad training

- Alternating between practice forms more effective than individual, isolated practice:
    - Physical
    - Observational
    - Dialog with partner
- Benefits of dyad training transfer to situations where participants have to perform the movement individually

Shea, J Mot Behavior 1999

Dyad training

- Benefits:
  - Motivation: athletes may set higher level goals after seeing peers
  - Increased ownership: shared learning strategies may increase athlete's responsibility

Video feedback

- Utilizes mirror neurons:
  - Link observation (visual input) to performance (motor output) (Buccino 2004, Iacoboni 2005, Molenberghs 2009)
    - "Core Circuitry" that communicates with other neural systems (Iacobini)

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Video feedback

- Can observe skilled or unskilled athlete
  - Both effective - squat form
  - Athlete can ID movement deficits and develop corrective strategies

Benjaminse 2015, McCullagh 1989

continuED

Video feedback

Real-time feedback

- Positive effect on task performance
- Influences motor memory
  - Gait modifications in real-time influenced kinematic/kinetic factors related to knee pain (Barrios 2010, Noehren 2011)

Intertial sensor-based feedback

- Vibratory buzzer: responds to appropriate knee flexion angle
- Auditory feedback: beeps when athlete completes exercise properly
- Visual feedback
  - Graphs of progress
  - Laser pointer- athlete can "point" knee to proper position

Feedback frequency

- High frequency that promotes <u>external</u> focus (implicit learning) superior to low frequency (Wulf 2010)
- High frequency that promotes <u>internal</u> focus- detrimental

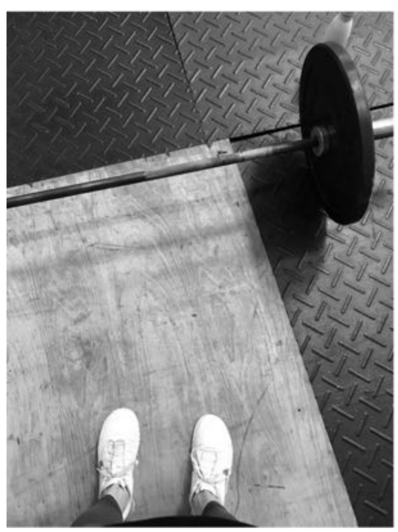
Feedback frequency

- Self-controlled learning
  - Athlete decides when to receive feedback; has control over practice
  - Allows athlete to assume more active role in skill development
    - Increased compliance?

Feedback type

- Combination of expert and self-feedback improved peak knee flexion angles vs self-feedback alone (Etnoyer 2015)

CASES/CLINICAL EXAMPLES



Static unilateral stability

Dynamic control

Dynamic unilateral control

Dynamic unilateral control

Walking lunge (Benjaminse 2015):
"Reach towards cone with your knee"

Dynamic unilateral control

Single leg squat (Benjaminse 2015)

- EXPLICIT/IF: "Keep your knee over your foot"
- Implicit/EF: "Reach towards cone with your knee"

Single leg jump

- Instruction in single leg jump
  - EXPLICIT/IF: "Jump as far as you can. Think about extending your knees as rapidly as possible"
  - IMPLICIT/EF: "Jump as far as you can. Think about pushing off the floor as hard as possible"

Gokeler, et al

Single leg jump

Single leg jump

Single leg hop (Benjaminse 2015)

- EXPLICIT/IF: "Extend your knees as rapidly as possible"
- IMPLICIT/EF: "Jump as close to the cone as possible"

Single leg jump

Cutting maneuvers

- "Core Position and Control movement strategy" (CORE-Pac) (Celebrini 2012, 2013)
  - Single focus of attention/whole body orientation
  - Styrofoam ball at center of mass (COM)
    - Attempt to get COM over plant foot
  - "Move from the center" & "Lead with the belly button"
    - vs "Bend your knees"

continuED

Other examples

continuED

BOTTOM LINE:

FOCUS ON THE

GOAL

VS THE PROCESS

WHAT WE CAN PUT INTO PRACTICE NOW

INJURY PREVENTION

- Arundale, et al 2018 JOSPT: Clinical Practice Guidelines, ACL Injury Prevention
- **Grade A (strong evidence):** knee injury prevention programs
- Strongest evidence for <u>female</u> soccer players
  - 12-25 yrs
  - Other sports with high risk injury

INJURY PREVENTION

- Grade A:
  - Multiple components of training
  - Multiple sessions/wk (over 30 min total)
  - At least 20 min/session
  - Start pre-season
  - NEED COMPLIANCE!

Implications

- Short timeframe may limit amount of NMT activities,
  - Reduced training effect?
- Long timeframe may not be practical
  - 2 studies with long NMT were pre-season programs
  - Long NMT could decrease practice time
- Success of intervention vs compliance?

Pre-Season vs In-Season

- Gilchrist et al
  - First half of soccer season: similar ACL injury rates control vs intervention
  - Second half
    - 0 ACL injuries intervention group
    - 5 ACL injuries control group
- LaBella et al
  - No ACL injuries with NMT in second half of basketball season

Time to NMT Effect

- Gains/change in movement patterns may take time
- Initiation of NMT pre-season may be more effective

PEP

- Santa Monica Sports Medicine Prevent Injury and Enhance Performance Program
  - Warm up, stretching, strength, plyometrics, agility
  - On field before practice, no equipment required
  - ~20 minutes; 3x/week

PEP

- Research supporting (Mandelbaum, Am J Sports Med, 2005)
  - 14-18 year old females
  - >1000 athletes intervention group (>1900 control)
  - Year 1: **88%** decrease ACL injury rate intervention grp
  - Year 2: **74%** reduction

PEP

- Research supporting (Gilchrist, Am J Sports Med, 2008):
  - NCAA D1 females (61 teams, 1435 athletes)
    - 583 intervention
  - Intervention ACL injury rate 1.7x less (41% decrease)
  - Intervention athletes with history ACL injury less likely to have second injury vs controls

FIFA 11+

- Warm-up program to improve strength, awareness, neuromuscular control
- Research (Soligard, BMJ, 2008)
  - 125 soccer clubs (Norway) over 8 months
    - 1892 females age 13-17
  - Intervention group significant lower risk overall injury

FIFA 11+

- "FIFA 11+ Kids"
  - 7-13 years
- Rössler 2015:
  - 38% fewer injuries vs control
  - 50% fewer serious injuries (out >28d)

Harmoknee program

- Awareness of injury risk with structured warm-up
- Warm-up, muscle activation, balance, strength, core stab
  - At soccer practice
- 94% of teams had >75% compliance
- Research (Kiani, Arch Intern Med, 2012)
  - 77% reduction knee injury incidence, 90% reduction noncontact knee injury incidence

Sportsmetrics

- Proprioception training, plyometrics, core stabilization
- Certification program

Summary programs

- PEP: 82% reduction; reduction risk recurrent injury
- HarmoKnee: 78%
- 11+: 52% reduction

- PEP most effective
- 11+ and HarmoKnee significant reduction knee injury risk
- Sportsmetrics- positive influence (Noyes, 2012)

Herman, BMC Medicine, 2012

continuED

Core strength

- Caution with cues!
  - Ab bracing INCREASED peak ground reaction force
  - Decreased knee and hip flexion (Campbell 2016)

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