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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


Why?

- Neuromuscular, biomechanical = “neuromechanical”
- Anatomic
- Genetic
- Hormonal
  - What contributes to a structurally weaker ligament???

- ACL Research Retreat VII
Why?

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

- ACL Research Retreat VII

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Why?

- “Need a **comprehensive** assessment of **modifiable** and **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”
Leg Dominance


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 contralateral ACL-R

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

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
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

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
Elling 2007
Heitz 1999
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

(Hicek 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)
INJURY PREVENTION:
WHAT WORKS????


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

NEVER NEVER because
LIMITS FEARS
JUST ILLUSIONS
- Michael Jordan
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

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?
Screening- knee valgus?

- Valgus is documented risk factor

- But...ACL + MCL injuries only 4%-17%
  - ACL significantly greater injury risk at 25°
    - Previous studies: MCL disruption at higher load than ACL


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

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 unilateral ACL injury (Grooms 2015):
  - Increased activation motor planning, sensory processing, visual motor control areas bilaterally
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”
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”

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”
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)
- 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"

- 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)
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
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 external focus (implicit learning) superior to low frequency (Wulf 2010)
- High frequency that promotes internal 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 hop  (Benjaminse 2015)

- EXPLICIT/IF: “Extend your knees as rapidly as possible”
- IMPLICIT/EF: “Jump as close to the cone as possible”
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”
Other examples

BOTTOM LINE:

FOCUS ON THE GOAL VS THE PROCESS
WHAT WE CAN PUT INTO PRACTICE NOW

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!

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

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PEP

  - 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

  - 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
Core strength

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

References

References


References


