ACL injury in the female athlete: Train it or sprain it

Anterior Cruciate Ligament

• Keeps tibia from moving forward (anteriorly translating) under femur
• Helps restrain against internal and external rotation

MRI of normal and torn ACL
Muscles controlling motion and forces through knee

- Quadriceps
- Hamstrings
- Core stabilizers
  - Hip
  - Trunk

Quadriceps extend knee and pull tibia forward (load ACL)

Hamstrings flex knee and prevent tibial anterior translation (protect ACL)
Back, abdomen, and hip stabilize core

Alpine Ski Lessons

Alpine skiing injury statistics: 1971-1982

• 50% injury reduction from 1971-1982
• Tibia and ankle injury rates decreased 90%
• Knee injuries:
  – from 3 to 20% of total injuries (ACL 10%)
  – significant ligament damage from 17% to 70%
  • Absolute number increased significantly

Ettlinger '95 AJSM
Equipment and surface changes from 1971-1982

- Boots: leather to plastic
- Skis: more durable, faster, quicker turning
- Bindings: releasable & anti-friction devices
- Surface: more grooming and man-made snow allowing higher speeds

Can a training program reduce serious knee injuries?

- Ski patrol subjects shown video of ACL injuries noting technical factors associated with injury
- Subjects once aware of high risk positions, work to avoid getting into these positions

Positions associated with ACL injury

- Phantom foot
  - Skier weight back
  - Uphill arm back
  - Hips below knees
  - Uphill ski unweighted
  - Weight on inside edge of downhill ski
  - Upper body facing downhill ski
Technical changes to avoid risky scenarios

• Before fall:
  – arms forward
  – skis within shoulders' width
  – hands over skis
  – avoid jumping
  – land with knees bent

• While falling:
  – flex knees
  – don't stand until stopped
  – avoid reaching back with uphill hand

Results of training program

• By the third year of the program, the subject group had a 62% reduction in serious knee sprains (p<0.005) compared to a control group of patrollers
• 70% subjects men

What are skiing’s lessons?

• Knee injury rates are modifiable
• Technique changes may be part of puzzle
• A certain level of training may be necessary to positively change technique (subjects all professional skiers)
• Beware of “safer” equipment
  – Injury relocation instead of prevention
  – Higher performance may equal more injuries
Title IX- 1972
Educational programs receiving federal assistance cannot exclude anyone from participation on the basis of sex.

1972 2007
• 300,000 female HS athletes
• 3 million female HS athletes
• 30,000 female college athletes
• 205,000 female college athletes

20 years after Title IX, “Female ACL epidemic” comes into focus
• Indoor soccer: girls 43% of players, 80% of ACL tears (Lindenfeld AJSM '94)
• NCAA soccer: 2.4x higher (Arendt & Dick AJSM '95)
• NCAA basketball: 4.1x higher (A & D AJSM '95)
• Alpine skiing: 3.1x higher (Stevenson et al IOJ '98)
• Overall non-contact injuries in soccer, volleyball, basketball: 2.4-9.5x higher (prevention of non-contact ACL injuries '99)

Fast forward 15 years
• Currently 3-40 ACL tears per hour
• 50% age 15-25
• In women, peak incidence age 15-19
  - Murray 13
• About 50% have associated cartilage injury
  - Granier '99
• OA in > 50%; 12 years post injury regardless of treatment
  - Lohmander '04
Possible explanations for female ACL injury rates

- Hormonal Factors
- Anatomic Factors
- Heredity
- Neuromuscular Factors
- Biomechanical Factors

Hormonal Factors-basic science

- Increasing estrogen levels decrease collagen synthesis in vitro human tissue (Yu ‘99)
- Estrogen treated rabbits with lower ACL tensile strength (Slauterbeck ‘99)

Hormonal Factors-Clinical Research

- More ACL injuries menstrual days 10-14 (Wojtys et al ‘98)
  - Didn’t control for OCPs
- 20 of 21 ACL injuries follicular or luteal (Arendt et al ‘99)
- More ACL injuries around ovulation (mid-cycle) and less luteal phase (between ovulation and menses) (Wojtys et al ‘02)
  - OC use diminished significance
Hormonal Factors-Clinical Research

- OCP users have statistically less laxity on KT-1000 (Martineau CJSM ‘04)
  - Results most significant for OCP users not currently menstruating
  - Authors ¿ Might continuous OCPs protect against injury by decreasing laxity

Agel, Arendt ‘06

- Survey of NCAA soccer and BB programs
  - 3150 athletes
  - Evaluating ankle sprains and ACL tears
  - Recall of menstrual cycle different than prospective assessment
  - OCP use and day of menstrual cycle not a/w injury

Hormonal Factors-Conclusions

- Uneven distribution of injury through menstrual cycle suggests some hormone involvement but role unclear
- Oral contraceptives’ role in injury unclear but they may decrease ligamentous laxity
Anatomic factors

Anatomic factors that increase ACL risk
• Increased ligamentous laxity
• Smaller femoral notch
• Increased posterior tibial slope

Anatomic Factors-Ligamentous laxity
• Females > ligamentous laxity and associated proprioceptive deficits (Rozzi '99)
• Beighton score >4: > 5x injury risk (Ostenberg and Roos '00)
• Additional studies correlate laxity by KT-1000, Beighton, or knee hyperextension with increased injury risk
Anatomic Factors-Notch width

- Narrow notch has smaller ligament with suggestion of increase injury risk regardless of gender
  - Shelbourne ’98

Posterior tibial slope

- 21.7% increased risk of noncontact ACL injury with each degree increase of the lateral tibial plateau slope among females only.
  - Beynnon ’14

Inherited predisposition- familial

- Case control 171 surgical ACL tears vs matched controls:
  - subjects with ACL tear over 2x as likely to have 1st degree relative with ACL tear
  - Flynn et al ’05
Inherited predisposition—racial

- Cohort study WNBA
- ACL tear rate per 1000 athletic exposures
  - white/European 0.45/1000
  - A.A./Hispanic/Asian 0.07/1000
- White/European 6x ACL injury rate

Trojan AJSM 06

Anatomic factors—summary

- Women are more lax and laxity is associated with injury
- Smaller ligament more likely to be torn in both genders
- Post tibial slope risk factor for women
- Predisposition to tear ACL inherited

Unfortunately, anatomy is hard to change
Neuromuscular gender differences

- Men through voluntarily muscle contraction, increase knee stiffness more efficiently than women  
  Bryant, Cooke '88
- Time from nerve firing to peak muscle contraction (electromechanical delay) is twice as fast in men  
  Komi, Karlsson '78

Neuromuscular gender differences

- Men have greater muscle cross section
- Female athletes are more quad dominant and hamstring inhibited  
  Huston '96
  - Hamstrings activate later and weaker than quads
  - Unopposed quad contraction is sufficient to tear the ACL

Role of gender in biomechanics

- Gender differences occur after maturation  
  - Prepubertal boys and girls have no difference in ACL injury rates
  - Rate climbs for girls after age 13
  - Knee flexion angle with jump stop decreases for girls after 13 (Yu et al AJSM '05)
Quad/ham ratios through puberty

- Through puberty % increase in strength
  - Boys: Quads-148%, hams-179%
  - Girls: Quads-44%, hams-27%
- Quad/ham ratio (p<0.05)
  - Immature boys (1.58)  Mature boys (1.48)
  - Immature girls (1.74)  Mature girls (2.06)

Ahmad et al, AJSM ’06

Is PFP predictor for ACL tear?

- Girls age 13:
  - > 15 Nm knee abduction load landing increases risk patellofemoral pain
- Girls age 16:
  - >25 Nm increases risk PFP and ACL tear
  - Those with ACL tear lower ham/quad ratio than PFP group
    - Myer ’14

Neuromuscular summary

- Females quad dominant
- Unopposed quad contraction sufficient to tear ACL at lower flexion angles
- Quad/ham ratio increases and knee flexion at landing decreases for girls at puberty (around age 13) coincident with rise in ACL injury rates
Biomechanical Factors-video

- ACL tears occur with combined loads (rotation + varus/valgus) with rapid deceleration, cutting, pivoting, or landing
- Women cut and land more upright with increased trunk, hip, and knee extension
- This position facilitates quad activation and inhibits hamstrings

Biomechanical Factors-video

- During injury
  - Knee flexed < 30 degrees
  - Valgus position of knee
  - Foot externally rotated
  - Center of gravity behind knee

Hewett et al AJSM ’05

- Cohort 205 females soccer, VB, BB
- Pretest drop jump with force plate and 3-D cameras
- Over 3 seasons, 9 ACL tears
- Injured
  - Less flexion
  - 2.5 x greater external knee valgus moment
  - 20% higher vertical ground reaction force
Neuromuscular and Biomechanical summary

- Video and biomechanics portray a high risk scenario for ACL injury
- High risk scenario
  - Quad dominance relative to hamstring and posterior/lateral hip
  - Low knee flexion angles at landing
  - Increased dynamic valgus

What are potential prevention strategies?

Prophylactic bracing

- Deppen '94
- 4 yr HS FB, 8 teams, prospective
- No difference in injury rate and severity
Changes to surface

- Overall, higher friction increases injury risk
  - Shoe/surface interface (Taylor 2012)
- Factors increasing friction
  - Dry surface
  - Warm surface
  - Turf > grass or hard wood

Surface risk factors

- American football higher risk on turf
  - Hershman 2012
- College soccer lower risk on field turf
  - Meyers 2013
- Turf may be safer at lower levels and riskier at highest levels

Injury reduction training programs

- Henning program
- Caraffa program
- Cincinnati Sportsmetrics training program
  - Hewett AJSM '99
- PEP program
  - Mandelbaum AJSM '05
- FIFA 11+
Henning program

- Change plant and cut to accelerated rounded turn
- Land hip and knee flexed, trunk balanced
- Decelerate 3 small steps with knees bent
- Instructional video-practice drills
- 2 Div.1 BB teams: 89% decrease ACL tears comparing 2 years before program to 2 years after. (Renstrom ’08)

Caraffa program

- Balance training program using progressively more difficult balancing boards, 20 mins QD pre-season then 3x wk.
- Non-randomized trial with 300 semi-pro and amateur soccer players suggests seven-fold increased ACL injury rate in those not doing program

Cincinnati Sportsmetrics training program- Hewett et al AJSM ’99

- 3 x wk for 6 wks: stretching, plyometrics, leg closed chain strengthening. Plyos become progressively more difficult and proper jumping technique emphasized
- 1263 H.S. BB, Soccer, VB athletes, 1 season: outcome serious ligament injury
  - Trained girls and boy controls-no difference
  - Untrained girls significantly more injuries
PEP- prevent injury, enhance performance

- Warm-up, stretching, strengthening (core emphasis), plyometrics (emphasize technique, sports specific agility training)
- 15 minutes 3x/week

PEP- U14-U18

- Non-randomized
- First year: 84% reduction ACL tears compared to control
- Second year: 74% reduction

PEP- NCAA D1

- Randomized 2002 season, 35 control and 26 intervention teams
- ACL injury rate significantly lower for practices but not games
- Rate lower in 2cd half of season
  - Program may take 6-8 wks to work
- 6 recurrences in controls and none in intervention group
FIFA-11+
Soligard et al ’08
• http://f-marc.com/11plus/11plus/
• Combination of F-MARC 11 and PEP
• N=1892
• Running, balance, plyometrics, core stability

FIFA 11+
• Recommended twice weekly to start at age 14
• Knee injuries decreased 50%, sig. decrease in all injuries, overuse, and severe
• In MALES, 72% reduction lower ext injury
  • Grooms ’13

Factors that contribute to successful injury reduction program
• Alter loading of tibio-femoral joint
• Proper landing and cutting technique
• Landing softly on forefoot
• Engaging knee and hip flexion
• Land on 2 feet if possible
• Try to avoid excessive valgus
• Focus on “knee over toe” while cutting
  • Renstrom ’08
Factors that contribute to successful injury reduction program

• Multifaceted programs- neuromuscular and educational interventions
• Stretching, proprioception, strength
• Plyometrics, agility, core control
• Feedback on proper technique, body awareness
  • Stojanovic ’12
  • Alentorn-Geli ’08
  • Gagnier ’13

What about compliance?

• 4556 players (Hagglund ’13)
  – High compliance quartile 88% reduction
  – Low quartile: NS injury reduction
  – Significant deterioration compliance though season

What about compliance?

• N=8118 (Wingfield ’13)
  • Overall
    – 64% reduction in ACL tear
    – Other severe knee injury NS
  • Compliant (at least 1 session/wk)
    – 83% reduction in ACL tear
    – 82% reduction severe knee injury
    – 47% reduction in “any acute knee injury”
Do you need to believe?

- Coaches
  - 63% believed inadequate warm-up injury RF
  - None believed it could prevent knee injury
- Players
  - 76% believed inadequate warm-up injury RF
  - 5% believed it could prevent knee injury
- Beliefs did not affect adherence to program
- Years of experience negatively associated with adherence.
  - McKay’14

At what age do you start?

- FIFA 11+ states age 14
- Peak incidence starts at age 15
- Landing knee valgus increases significantly between 5th and 9th grade (Sasaki’13)
- 6 month injury prevention program though puberty significantly decreases valgus alignment (Otsuki’14)

Summary

- Hormonal influence unclear
- Braces don’t work and shoes should be a little slippery
- Anatomic risk factors include laxity, ligament size, and tibial slope
- Neuromuscular and biomechanical factors likely major contributors
  - Valgus, quad dominance, inadequate knee flexion
Summary

- Research suggests injury reduction programs with proper components including technique modification reduce risk around 50%.
- Better compliance improves effectiveness.
- Start at puberty
- Sell program to kid and coach as performance enhancing


