Coupled Biomechanical-Epidemiological studies for the Assessment of ACL Injury Risk

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Clinical Dilemma

There is a 4 to 6-fold higher incidence of serious knee ligament injuries in females participating in jumping and cutting sports than males

Literature: Injury Incidence Female vs. Male

Females suffer a 4 - 6 x increased incidence of knee injury over males participating in the same sports.

– Arendt	AJSM, 1995
– Chandy & Grana	Physician & Sportsmed, 1985
– Ferretti et al.	AJSM, 1992
– Gerberich et al.	Physician & Sportsmed, 1987
– Gray et al.	Intl J Sports Med, 1985
– Hutchinson et al.	Sports Medicine, 1995
– Lindenfeld et al.	AJSM, 1994
– Malone et al.	J Southern Orthop Assoc, 1993
– Whiteside	Physician & Sportsmed, 1980
– Zelisko et al.	AJSM, 1982

		Increased Rate
Chandy & Grana	High school sports	4.6 x
Ferreti, et al	Pro volleyball	4 x
Gray, et al	Basketball (ACL)	5 x
Lindenfeld, et al	Soccer	6 x
Malone, et al	Various sports (ACL)	6.2 x
Whiteside, et al	Sport specific	1 - 10 x
Zelisko, et al	Pro basketball	2.2 x

NCAA
- Greater than 100,000 female participants
- 1/10 of female participants suffered a knee injury

High school injury rate: 1/50 participants
- 2.9 million participants
- 50,000 + high school female knee injuries/year

Theories to Explain Increased Incidence

Structural
- wider pelvis
- increased Q-angle
- increased joint laxity
- narrow intercondylar notch

Neuromuscular Differences
- strength
- technique
- coaching

Hormonal – Estrogen
- decreased collagen strength
- increased joint laxity

New Concept: Dynamic Neuromuscular Imbalances in Female Athletes

Ligament Dominance

Quadriceps Dominance

Dominant-Extremity Imbalance

Knee Anatomy
- The knee provides the movements necessary for locomotion and allows for the support of large loads.
- The knee is the largest and one of the most complex joints in the body.
- tibiofemoral and patellofemoral
- Knee Ligament Function
- Ligaments have 2 mechanical functions:
- Limit (gross) motion between bones
- tibia and femur
- Limit (micro) motion between articular cartilage surfaces
- tibia plateaus and femoral condyles

Knee Ligament Function

3 properties allow ligaments mechanical functions to limit motion:
- Attachment Location
- tibia and femur
- Just-taut length
- Controls motion before ligament provides resisting force
- Stiffness
- Controls movement after ligament taut

Motion of the Knee Joint:

6 Degrees of Freedom

3 Rotations:
- Flexion/Extension
- Abduction/Adduction
- Internal Rotation/ External Rotation

Motion of the Knee Joint:
6 Degrees of Freedom
3 Translations:

- Anterior/Posterior
- Medial/Lateral
- Compression/ Distraction

Stability of the Knee

- The geometry of the knee joint provides little stability.
- Therefore, the stability of the knee depends on static and dynamic restraints.
- static restraints

Structure of the Knee: Static Restraints

- Collateral ligaments-major ligaments that cross the medial and lateral aspects of the knee
- Cruciate ligaments-major ligaments that cross each other in connecting the anterior and posterior aspects of the knee

Structure of the Knee:
Static Restraints

- Anterior cruciate ligament (ACL)
- connects the anterior aspect of the tibia to the posterior aspect of the femur
- The ACL is the primary restraint to anterior translation and internal rotation of the tibia (Irrgang, Safran, & Fu, 1996).

*The ACL is the primary stabilizer of the knee.

Biomechanics - Knee Kinematics

- Knee Motion and Axes
- Gait Analysis
- Gait Analysis
- Joint Coordinates: Grood and Suntay

Gait Cadence Parameters

- Normalized Stride Length
- Foot Progression Angle
- Gait Cadence
- Gait Velocity
- Step Width

Injury Epidemiology

- ACL injuries are a common source of disability in the U.S. (Goris & Graf, 1996).
- 100,000/year (Frank and Jackson, JBJS)
- ACL injuries result in nearly 1 billion dollars in medial costs per year in the US.

The ACL as a Sensor of
Force and Torque

- Rich Innervations/Specific Mechanoreceptors
- Kennedy, 1982
- Schultz, 1984
- Johansson, 1991

The ACL is:

- Sensitive
- Vulnerable

Non-contact Injury Mechanism

Why is the Female ACL MORE Vulnerable?

•Examine the Injury Mechanism:

•Valgus

•Low flexion

•Single leg

3 Potential Neuromuscular Imbalances
Ligament Dominance
↑ Medial Knee Motion is associated with ↑Valgus Torques
Valgus Stress > 29 N-m puts the collateral ligaments in the high-slope segment of the stress curve

- Markolf et al. JBJS, 1978
- Increased risk of femoral condylar lift-off from tibial plateau

Valgus moment > 35 N-m elicits pain in female athletes

- Pope et al. JBJS, 1979

Valgus Torques Related to Peak Impact Force

Injury Mechanism
Measure movement similar to knee injury mechanism

- Landing from jump
- Deceleration when cutting
- Box drop vertical jump and a lateral cutting maneuver

Mechanisms of Injury

- Almost 80% of ACL injuries are noncontact in nature.
- Injuries often occur landing from a jump, cutting, or decelerating.
- A combination of knee flexion and internal tibiofemoral rotation is the most common mechanism of injury

The Motion analysis and Biomechanical Studies

Examine Differences in Female athletes and male athletes in:

Test the effect of a combined jump and strength training program on females':

landing kinematics and kinetics

dynamic strength and balance of lower extremity

Compare the results of untrained and trained females with untrained athletic males

Hypotheses

Females would show different landing mechanics than males.

An effective jump training program would:

- decrease peak landing forces
- decrease magnitude of moments (torques) at the knee
- increase lower extremity strength
- increase vertical jump height

Materials & Methods:

Testing: Pre and post-training

- Valgus Displacement at knee
- Flexibility and Knee exam
- Vertical jump height
- Dynamometer
- Biomechanical

Biomechanical Testing

- Peak landing forces
- Knee-hip-ankle
  - kinematics: flexion angles
  - kinetics: moments (2 planes - flexion/extension, adduction/abduction)

Dynamic Neuromuscular Analysis (DNA) Training Program

I. Plyometric training

II. Core Stability Training

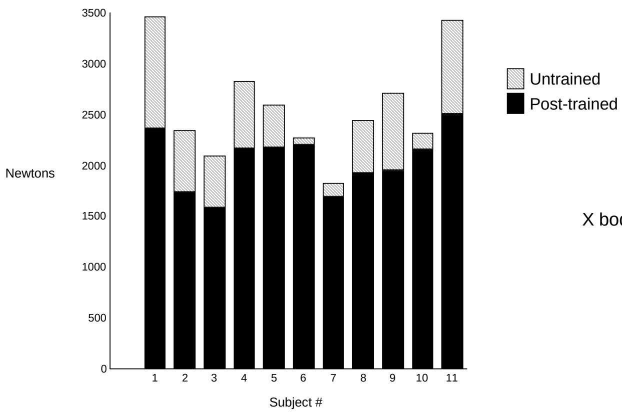
III. Weight training

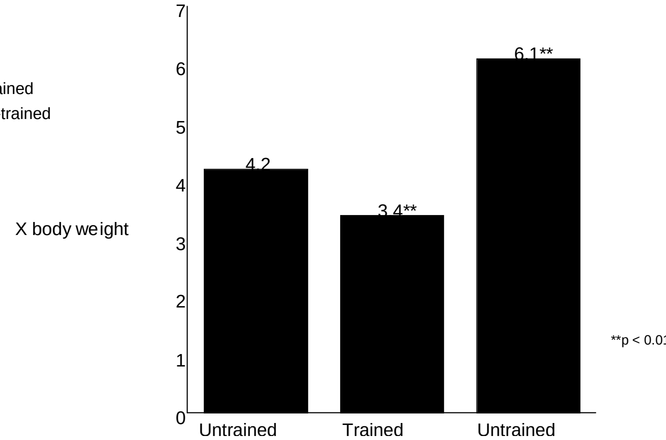
Neuromuscular Training Techniques

- Correct posture
  - spinal column erect, shoulders back
- Body alignment
  - chest over knees over balls of feet
- Overall Core Stability-Balance is absolutely crucial!
- Soft (silent) landings
  - toe to mid-foot rocker
- Instant recoil for next jump: focus on energy absorption and reapplication.

Results

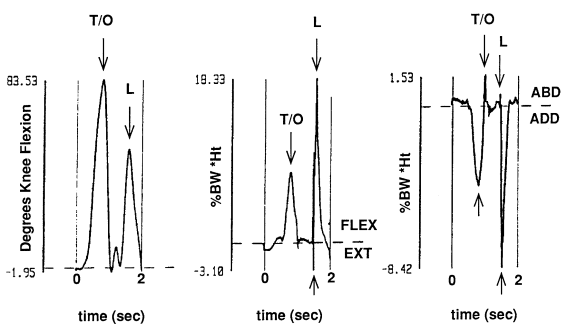
Peak Landing Forces in Individual Female Subjects: 10/11 showed decreases with

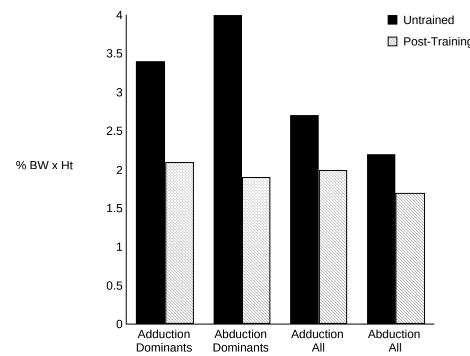




training.

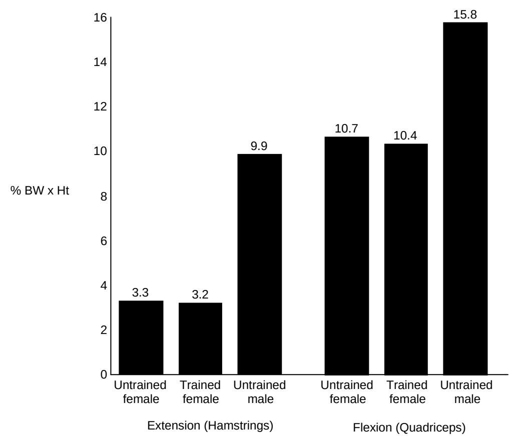
External Knee Motion (degrees) and Moments (% BW x Ht)





Female Subjects: Valgus/varus Moments

Females vs. Males: External Extension & Flexion Moments



Multiple Regression Analysis

Knee, hip, and ankle

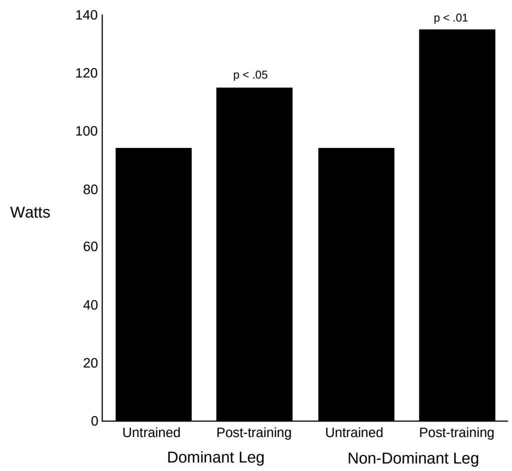
- flexion angles
- flexion & extension moments
- adduction & abduction moments

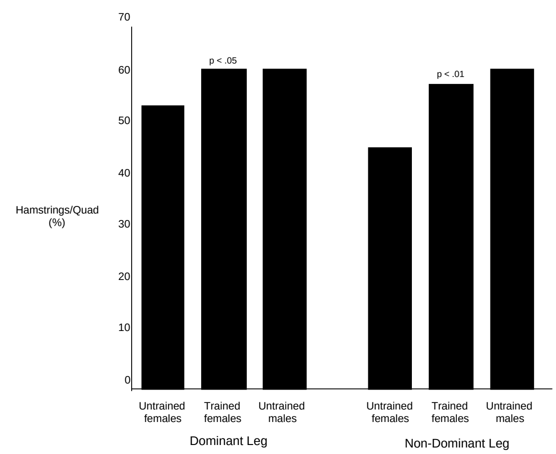
Valgus and varus moments at the knee:

the sole significant predictors of peak landing forces.

Note: These data support the concept of ligament dominance at the knee in female athletes.

Females: Isokinetic Hamstrings Power (average power in Watts)





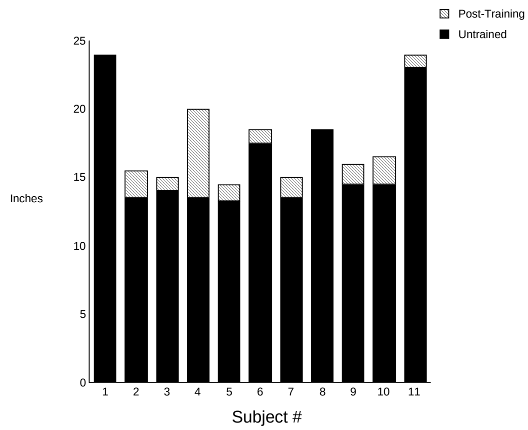
Females and Males: Isokinetic Peak Torque Ratio

Isokinetic Hamstrings Strength

Dominant leg: increased 13%
Non-dominant leg: increased 26%
Imbalance corrected

Note: These data support the concept of quadriceps dominance and dominant-extremity imbalance at the knee in female athletes.

Individual Female Subjects: Vertical Jump Height



Summary of Results: Females

Peak landing forces decreased 22% (80% of mean body weight) with training.
Peak valgus and varus moments at the knee decreased 40-50%.
These moments served as significant predictors of peak landing forces.
Hamstrings strength increased significantly, reducing strength imbalances between the hamstring and quadriceps and the hamstrings of non-dominant and dominant legs
Peak jump height was increased approximately 10% with 6 weeks of training.

Summary of Biomechanical Results: Males

Untrained males showed peak landing forces 45% higher than untrained females, 80% higher than trained females
Males demonstrated adduction and abduction moments which were significantly greater than trained, but not untrained, females
The external extension (hamstrings) moment was 3-fold higher in males than untrained or trained females
Hamstrings to quadriceps peak torque ratio was higher in males than untrained females, but similar to females post-training

Conclusions

1. Proper neuromuscular training can decrease peak landing forces
2. Decreases in the magnitude of the adduction/abduction moment at the knee are predictors of decreases in peak landing forces
3. Training significantly enhanced hamstrings strength and power, and reduced hamstrings to quadriceps and side-to-side strength imbalances
4. Males may compensate for high peak landing forces with high hamstrings activity
5. Adduction and abduction moments were decreased from approximately 40 NM to 20 NM with training
6. The decreases in these moments may decrease the risk of lateral joint lift-off and associated ligamentous injury (Markolf, et al; Noyes, et al)

The Epidemiology Study

A Prospective Study of the Effects of Neuromuscular Training on the Incidence of Knee Injuries in Female Athletes

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Hewett et al., 1996 (AJSM)

- Marked imbalance between hamstrings and quadriceps prior to training
- Males activate knee flexors upon
- landing 3 x level of females
- Training
  - corrects deficits
  - decreases landing forces
  - increases power, strength, and jump height

-Biomechanical Results: Decreases with Training

1) Peak Landing Forces and 2) Ab/Adduction Moments

Purpose

- prospectively evaluate the effect of neuromuscular training on serious knee injury rates in female athletes

Materials and Methods

- 43 sports teams
  12 Cincinnati area high schools
- Sports
  soccer, basketball, volleyball
- 1,263 athletes monitored over one season
  Group 1: 366 females - 15 teams - Trained Females
  Group 2: 463 females - 15 teams - Untrained Females
  Group 3: 434 males - 13 teams - Controls
- Pre-season questionnaires
  - prior injuries

- years of participation

– ATC's: weekly injury reporting forms
  - injuries
  - exposures

Definitions:

– Injury risk exposure:
  - one athlete participating in one practice/match

– Serious knee injury:
  - knee ligament sprain or rupture which caused an individual to seek medical care by an athletic trainer which lead to at least five consecutive days of lost time from practice and match competition

– All serious knee injuries - referred to physician

– All ACL injuries - confirmed by arthroscopy

– All MCL injuries - confirmed by pain along MCL and increased valgus rotation

– Only primary injuries reported

All Serious Knee Injuries

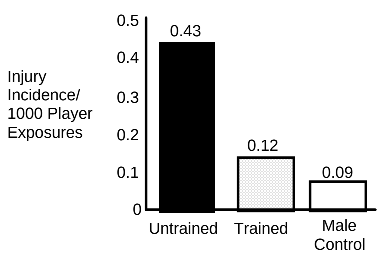

Figure: Serious knee injuries per 1000 athlete-exposures in each of the study groups.

Non-Contact ACL Injuries

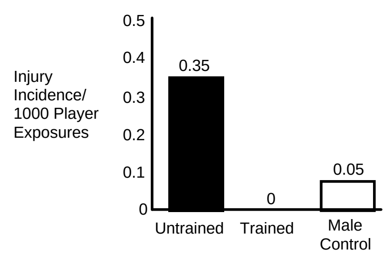

Figure: Noncontact ACL injuries per 1000 athlete-exposures in each of the study groups.

Conclusions

Injury Incidence

– Untrained > Trained 2.4X 3.7X

– Untrained > Males 4.6X 5.5X

– Trained > Males 1.2X 2.3X

Recommendations

Females in jumping, cutting sports should be tested prior to participation
- visually, for landing technique
- isokinetic strength

Train with an effective program those:

- with an excessive varus or valgus knee landing position
- with less than a 55% hamstring/quadricep peak torque ratio on either side
- with side to side differences in strength or coordination

Dynamic Neuromuscular Analysis Training: Concepts

- Dynamic
  - Fast-Paced
  - Sports-specific
    - Henning Basketball Video
- Neuromuscular
  - Optimal neuromuscular patterns learned and drilled
  - Balance
    - Caraffa et al., 1996 Men's Soccer Study
- Analysis
  - Good coaching and feedback
  - Technique perfection
    - Ettinger et al., 1995: Vermont Ski Instructor Study

DNA Components

- Plyometrics
  - Neuromuscular Adaptation to Stretch
    - Series elastic component: Rubber band theory
    - Muscle spindle: Thermostat theory
    - Actin-Myosin cross-bridges: Gear theory
  - Speed of Movement
- Core Stability
  - Balance and Kinetic Chain Control
  - Perturbation
- Strength
  - Functional Speed and Multi-Directional Power
- Biomechanics
  - Safe and Effective Technique Training
  - Biofeedback

What DNA Training Should Not Be

- High Impact
- Jumps from dangerous heights
- Hurdle Jumping
- Aerobic Conditioning
- Goal of maximum number of jumps
- Easy

Important DNA Training Techniques

- Strong Athletic Positioning
  - Erect, athletic position
  - Knees over balls of feet, chest over knees

- Good Body Control
  - No side-to-side or forward-backward motion
  - Ready to react in all planes of motion

More DNA Training Techniques

- Use feet to dissipate impact force
  - Toe-to-mid-foot rocker
    - Soft, Quiet impacts
    - Hit like a feather
    - Roll your feet
- Flex your body and get deep with gluteus
  - Instant recoil for next jump
    - Drop like a shock absorber
    - Take off like a spring