Injury Prevention for the Female Athlete – Special Considerations for Research and Care

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HARVARD MEDICAL SCHOOL TEACHING HOSPITAL

Wu Tsai Human Performance Alliance

Female Athlete Program

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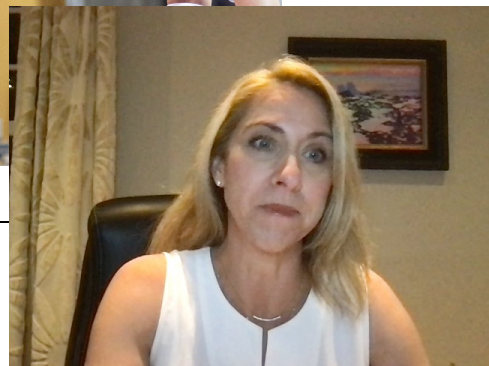
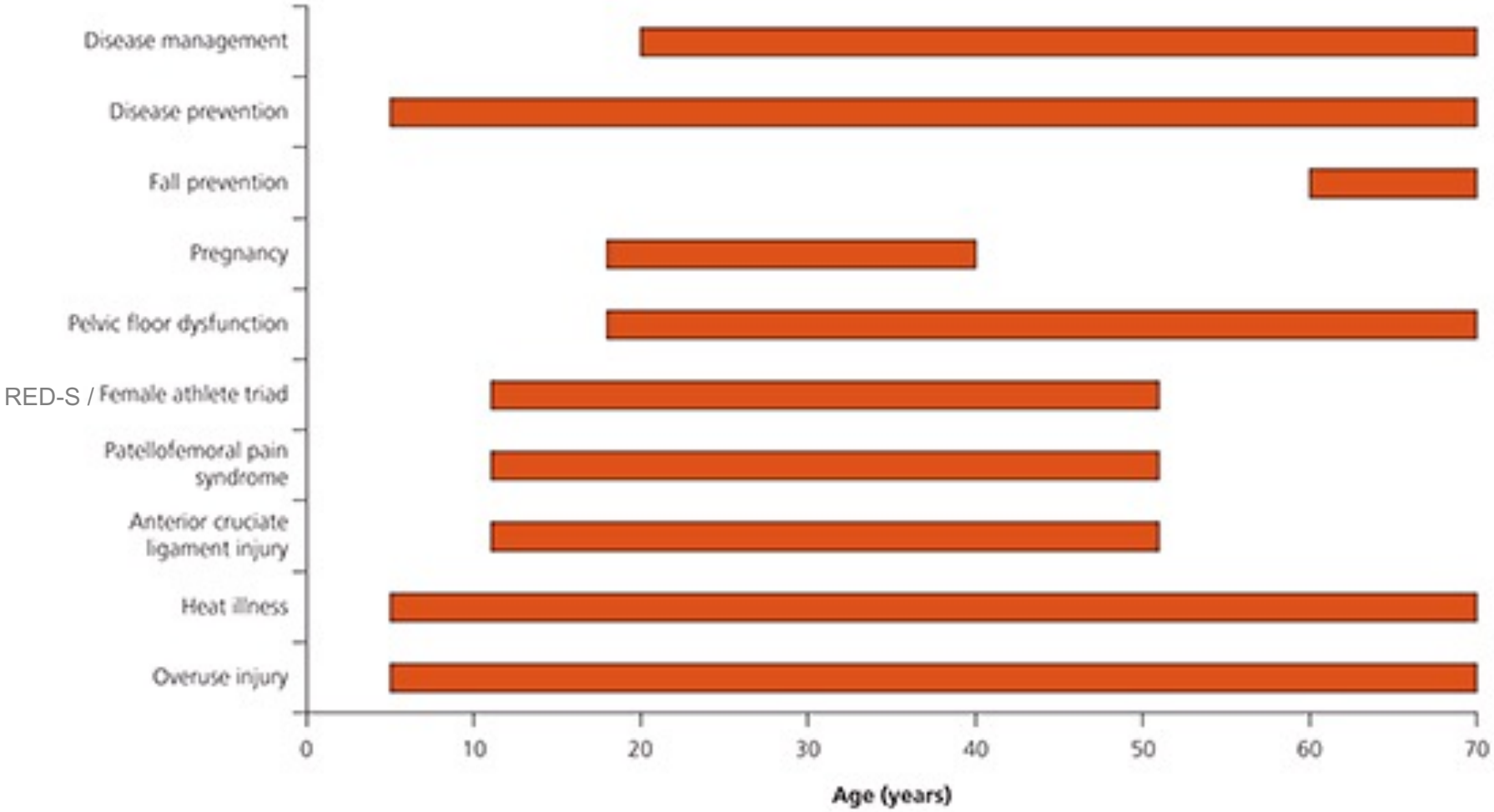
  - Hologic
  - USRowing, USA Swimming, USOPC

Teenage girls make up the fastest growing segment of children and adolescents participating in organized athletics!



Common Concerns for Female Athletes by Age



Injury Patterns in Female vs. Male Athletes

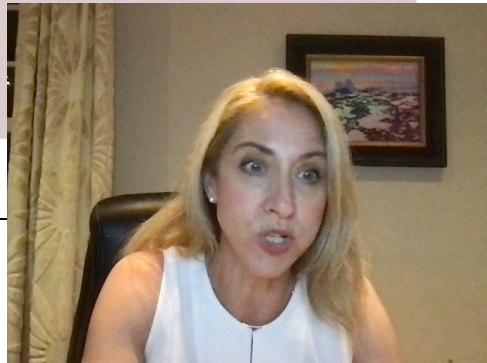
- Higher rates of ACL injuries
  - Adolescent girls participating in pivoting and jumping sports have 2-8X rate of ACL injuries compared to boys in the same sports
- More patellofemoral syndrome
- Greater concussion rates, more symptoms, and more time lost to concussion
  - Greater reporting?
- Greater prevalence of eating disorders
- More bone stress injuries

Lincoln AE, et al. Am J Sports Med, 2011.
Covassin T, et al. J Athletic Training, 2016.
Rizzone K & Ackerman KE. Clin Sports Med, 2021.

Physiological Differences in Women compared to Men

Morphological/Physiological Variable	Result
~30% lower max cardiac output	Less capacity to move blood, ↓ work capacity
~25%-50% Lower VO_2 max	Less work capacity
Lower blood volume	Less O_2 carrying capacity
~45% Less lean body mass	Women 40-60% weaker upper body strength, 25% weaker lower body strength
~11% lower hemoglobin	↓ O_2 carrying capacity of blood
~30% greater body fat %	More metabolically "dead mass" to carry while working
~Greater HDL	In untrained women, leaves less capacity for training

Lewis DA, et al. Sports Medicine, 1986. Hilton EN and Lundberg TR. Sports Med, 2021.



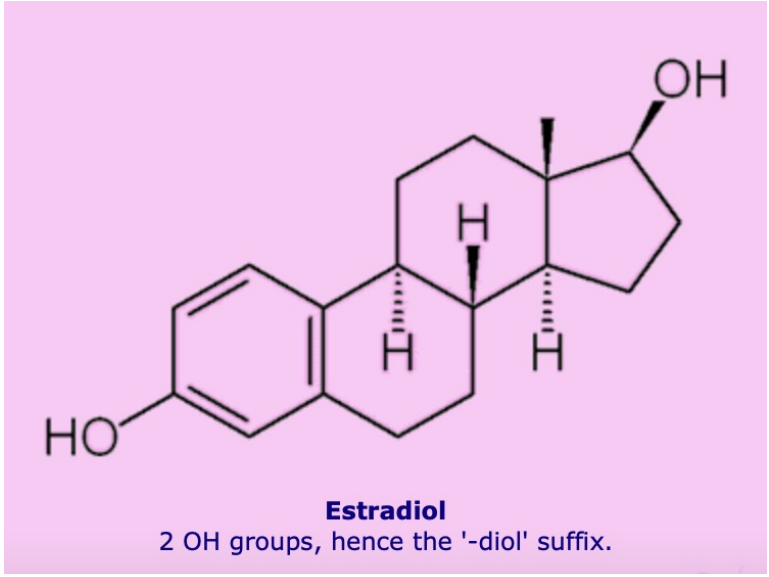
Testosterone and Other Influences

- There are ~ 3000 genes that are differentially expressed in male vs. female skeletal muscle
- Boys are prenatally and perinatally exposed to androgens
- Prior to puberty, boys and girls do not differ much in height, muscle, or bone mass
  - However, 9 yo males are about 9.8% faster over short sprints, 16.6% faster over 1 mile, can jump 9.5% farther, perform 33% more push-ups in 30s, and have 13.8% stronger grip
- Testosterone exposure during puberty in males (resulting in 15-20x more circulating T than children or women) →
  - Greater height in men (12-15cm)
  - Larger bones
  - Greater muscle mass
  - Greater strength

Haizlip KM, et al. Physiology, 2015.
Handelsman DJ, et al. Endocr Rev, 2018.
Catley MJ, et al. Br J Sports Med, 2013.
Hilton EN and Lundberg TB. Sports Med, 2021.

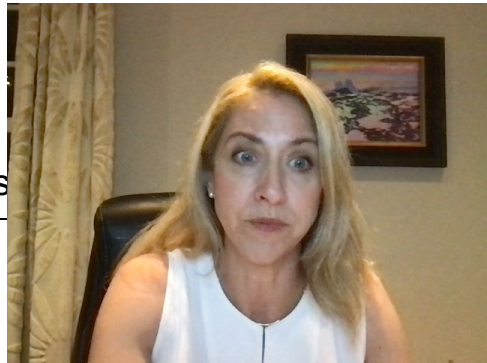
Estrogen

- Anabolic
- Has neuroexcitatory effects
- Aids in membrane stabilization
- Is an anti-inflammatory hormone
- May decrease collagen synthesis and density

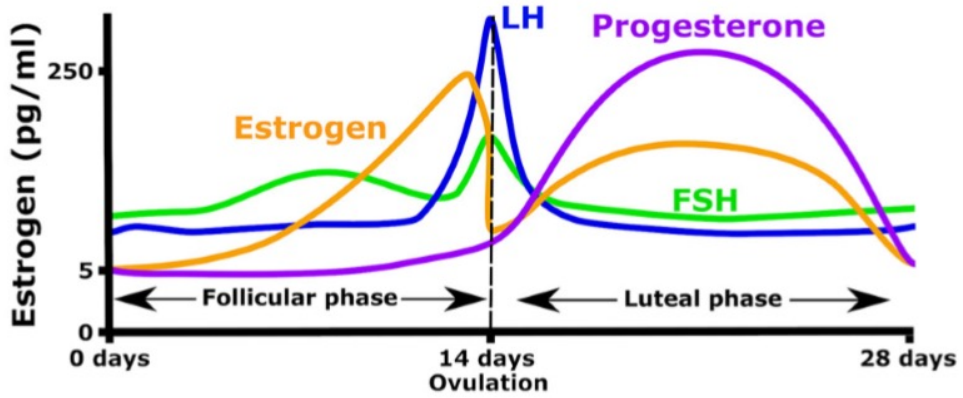


Estradiol
2 OH groups, hence the '-diol' suffix.

Devries MC, et al. Am J Physiol Regul Integr Comp Physiol, 2006.
Wallis GA, et al. Am J Physiol Endocrinol Metab, 2006.
McNulty KL, et al. Sports Med, 2020.
Carmichael MA, et al. Int J Environ Res



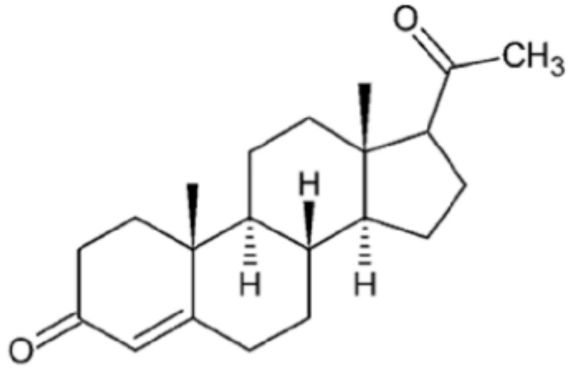
Estrogen



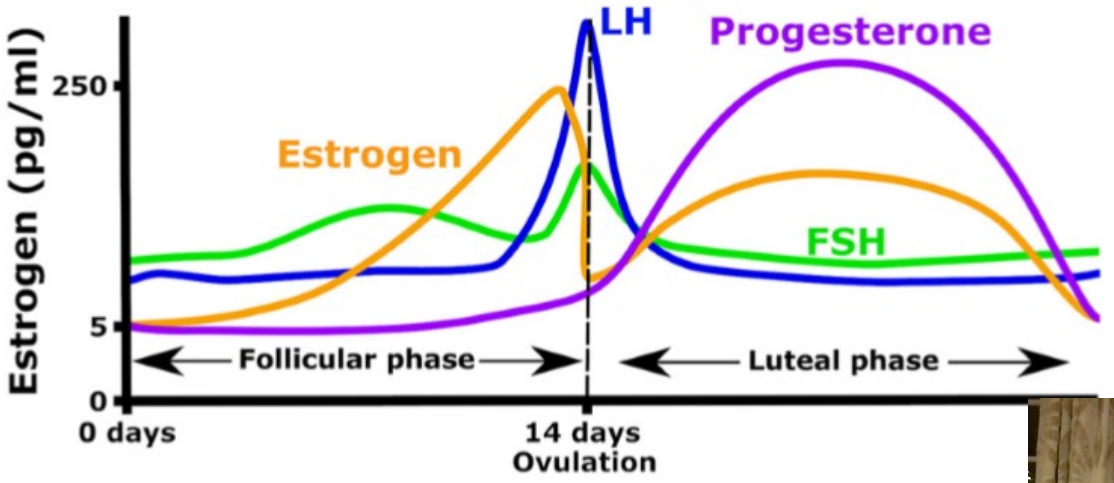
- Anabolic
- Protein-sparing effect
  - During endurance exercise at approximately 65% maximal O_2 consumption, women oxidize more lipids, and therefore decrease carbohydrate and protein oxidation, compared with men
- Estrogen impairs gluconeogenesis
  - Luteal Phase
    - Less reliance on muscle glycogen during submaximal exercise in the fasted state compared to follicular phase and to male athletes
  - Exogenous carbs help overcome impaired gluconeogenesis

Devries MC, et al. Am J Physiol Regul Integr Comp Physiol, 2006.
Wallis GA, et al. Am J Physiol Endocrinol Metab, 2006.
McNulty KL, et al. Sports Med, 2020.
Carmichael MA, et al. Int J Environ Res

Progesterone



- Has anti-estrogenic effects
- Raises core body temperature (may help with short duration and hinder longer duration activities)



Devries MC, et al. Am J Physiol Regul Integr Comp Physiol, 2006.
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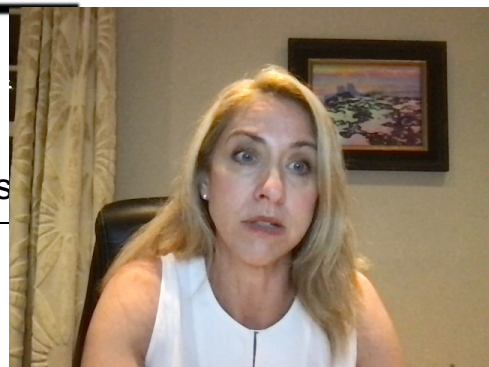
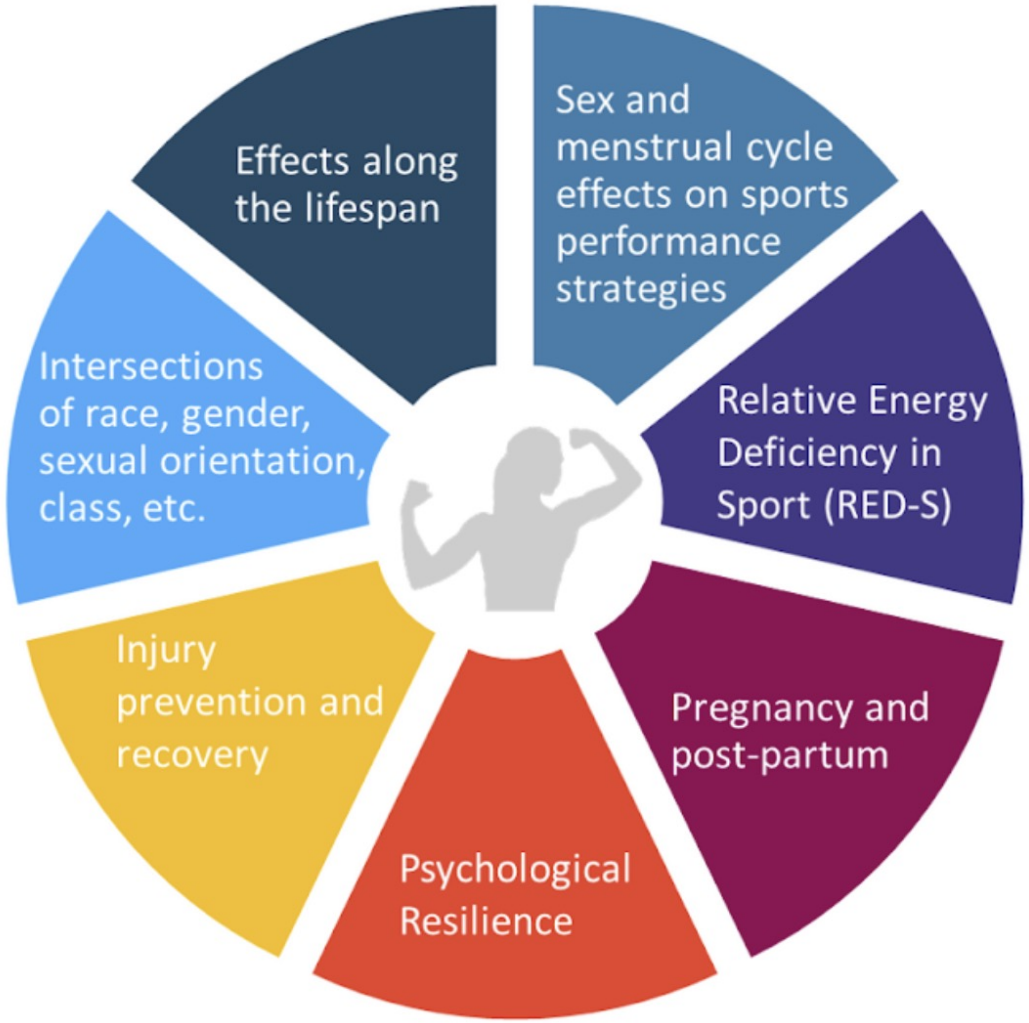
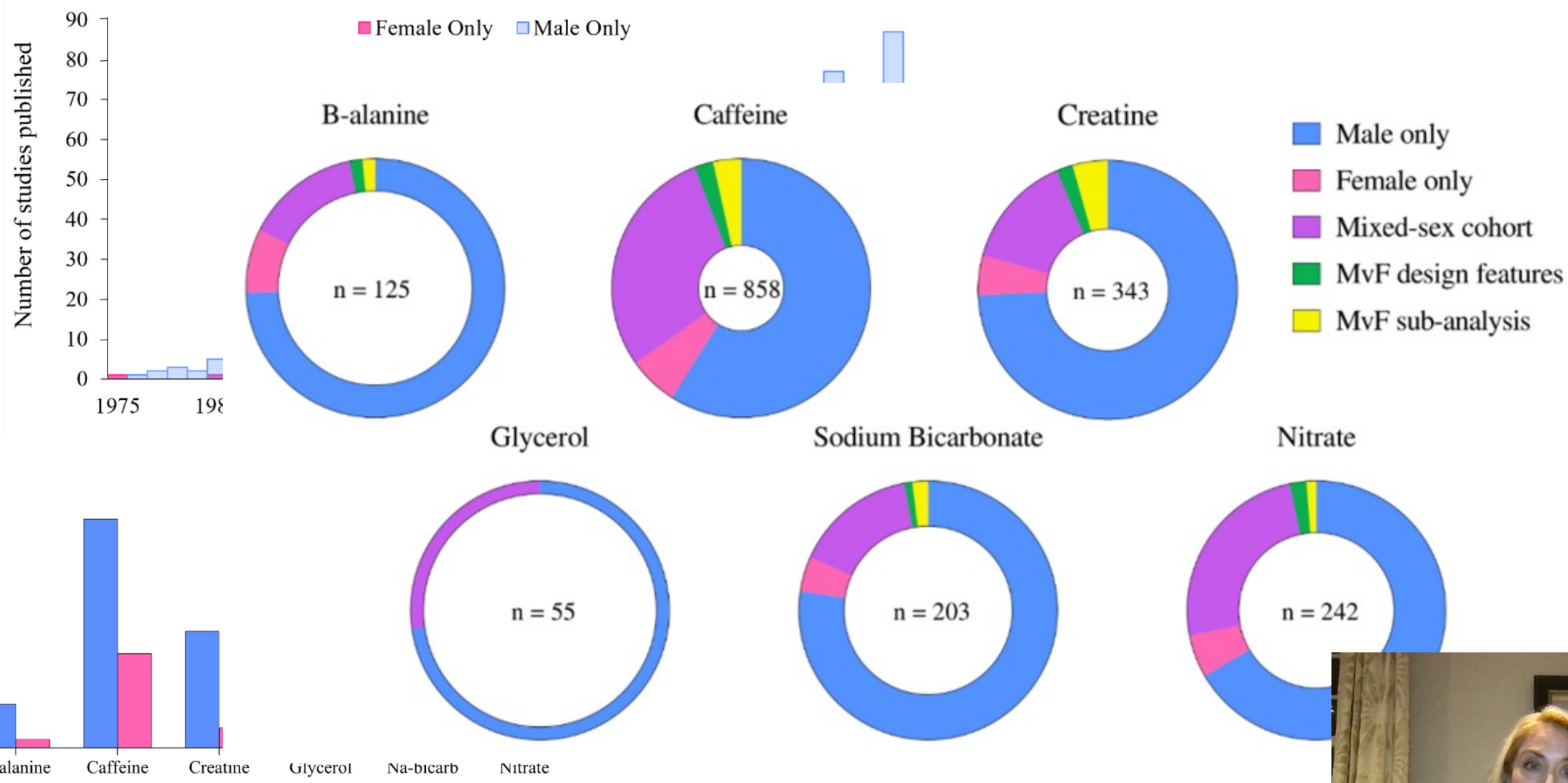
Carmichael MA, et al. Int J Environ Res



Important Female Athlete Topics

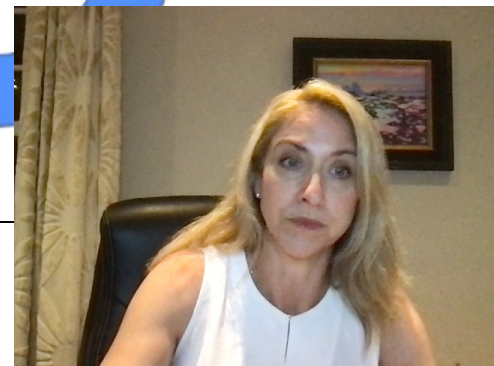


Smith ES, et al. Auditing the Representation of Female Versus Male Athletes in Sports Science and Sports Medicine Research: Evidence-Based Performance Supplements. Nutrients, 2022.

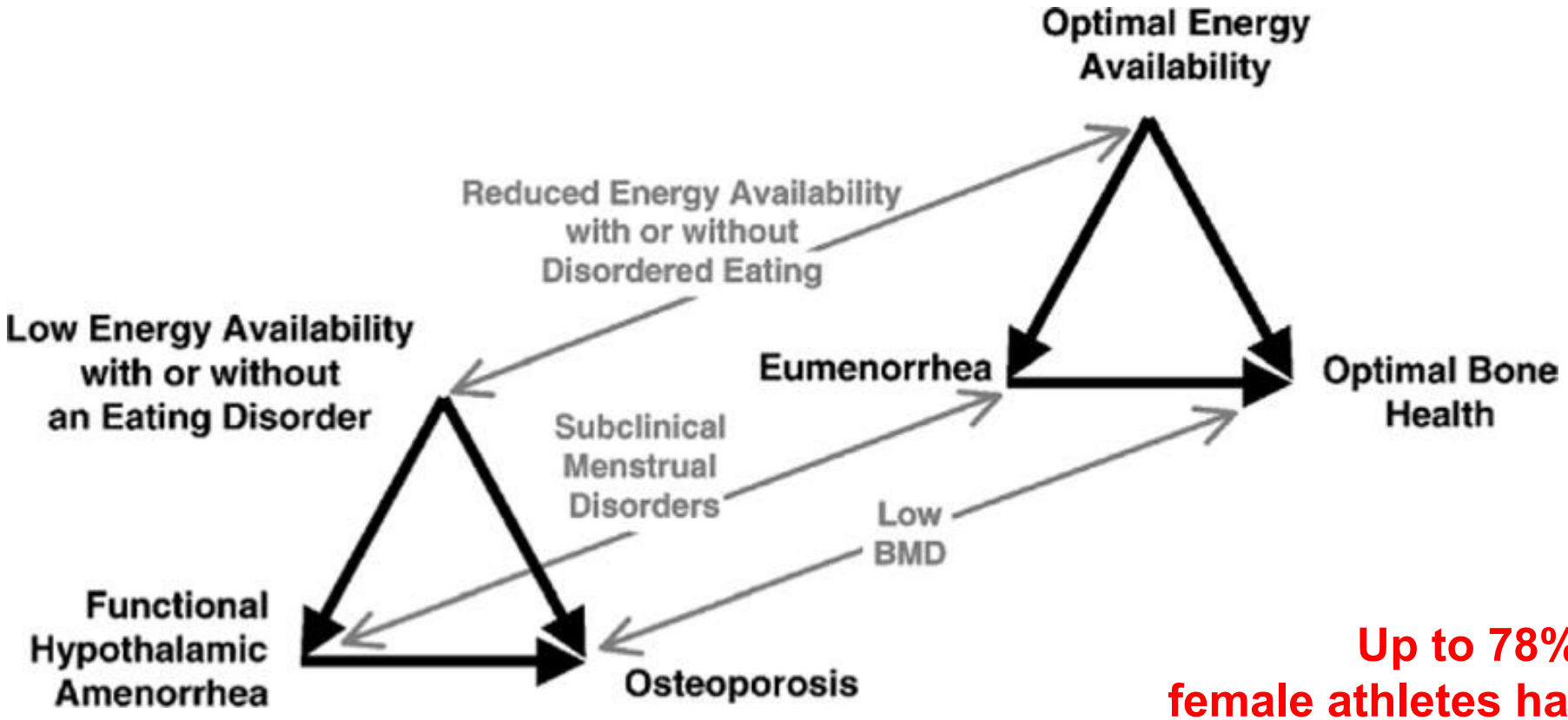


Female Athlete Research

Cowley ES, et al. Women in Sport and Physical Activity Journal, 2021.
Smith ES, et al. Nutrients, 2022.



The Female Athlete Triad

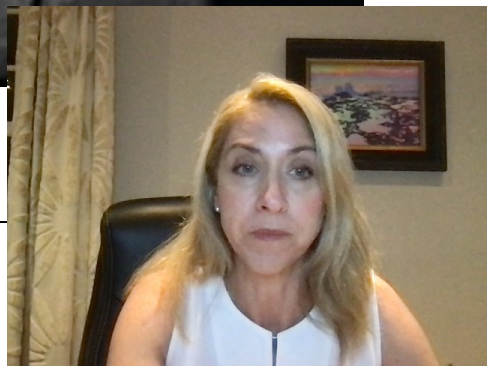


Up to 78% of high school female athletes have ≥ 1 component of the Triad!

Nattiv A, et al. Med Sci Sports Exerc, 2007. De Souza MJ, et al. Br J Sports Med, 2014.

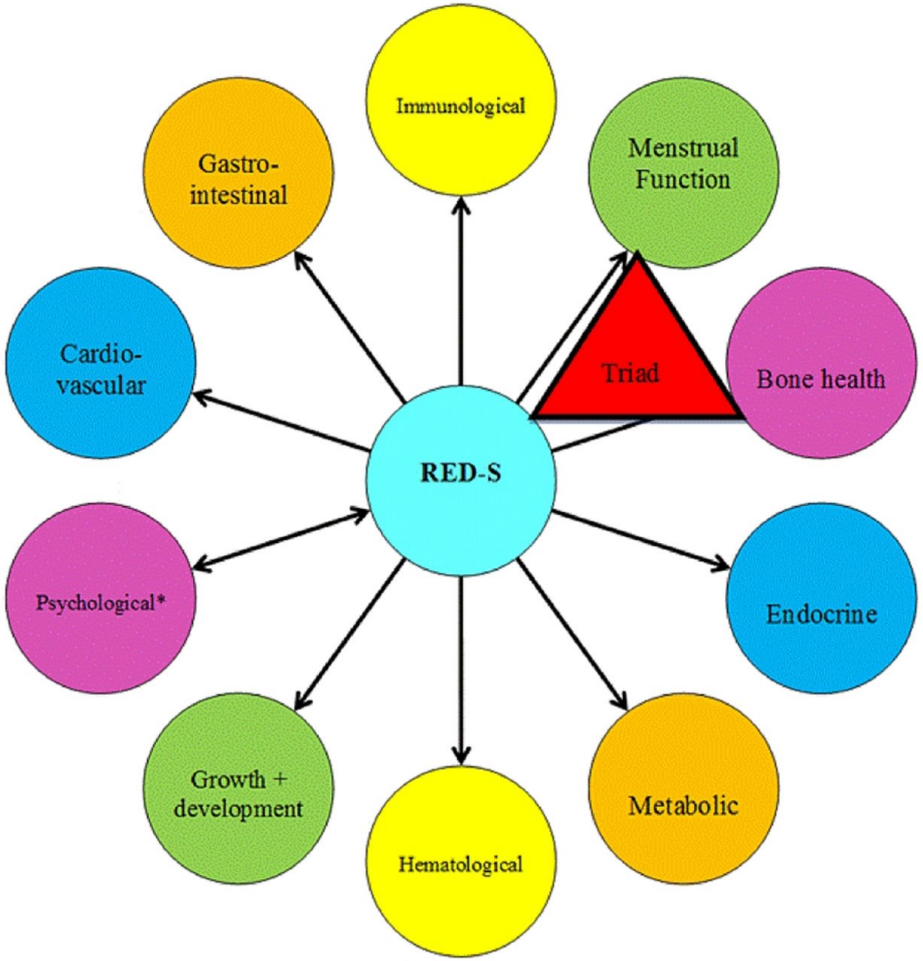
Stress Fractures (Bone Stress Injuries)

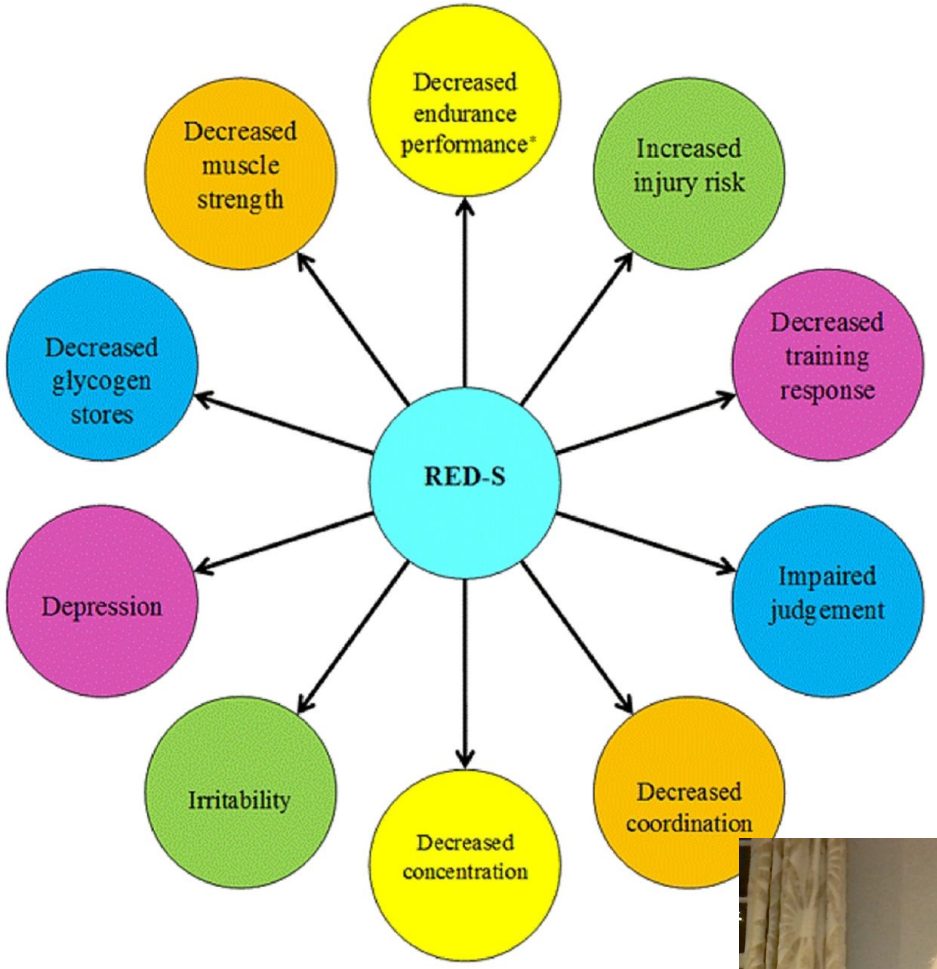
- Microfractures in cortical bone as a result of abnormal bone remodeling in the setting of repetitive stress impact
  - 1.5-3.5x more common in females than males
  - Location depends on activity, biomechanics, and other factors



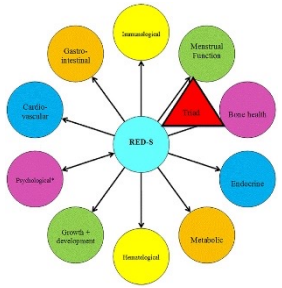
Ohta-Fukushima M, et al. J Sports Med Phys Fitness, 2002.

Relative Energy Deficiency in Sport (RED-S)



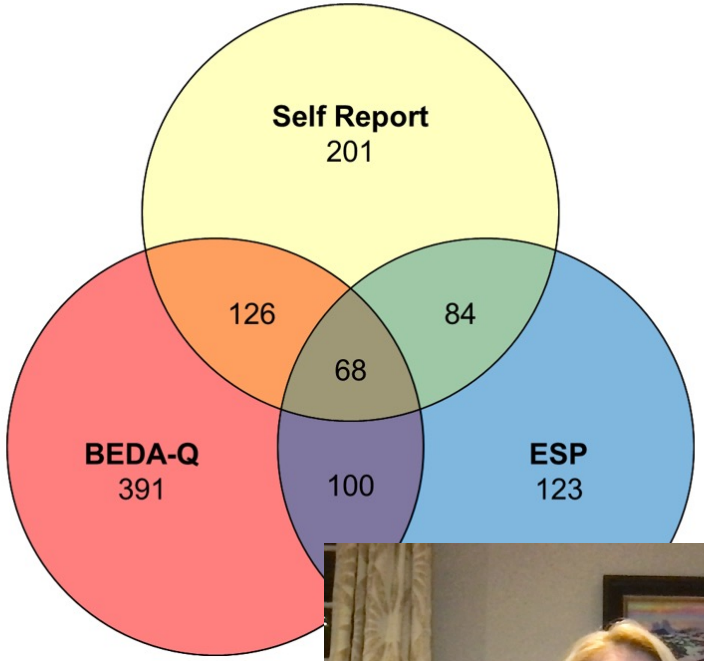


Mountjoy M, et al. Br J Sports Med, 2014, 2018.

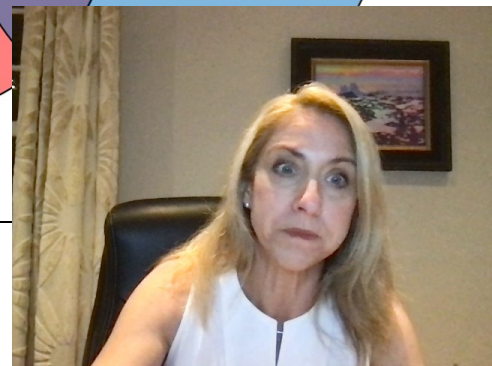


Female Athletes at Risk for RED-S

- Survey of 1000 female sport medicine clinic patients (age 15-30 years, ≥4 hrs/wk of exercise)
  - Surrogate markers of Low EA:
    Self-report or DE/ED, BEDA-Q, ESP
  - 84.5% response rate
  - Low EA 47.3%



Ackerman KE, et al. Br J Sports Med, 2018.



Interrelationship of Components of the Triad/RED-S

- Low energy availability
  - ↓ BMI, fat mass, & lean mass
  - ↓ in FSH, LH, estradiol, androgens
  - ↓ insulin, glucose, IGF-1, T3, and leptin
  - ↑ in fasting PYY, ghrelin, cortisol, and GH resistance

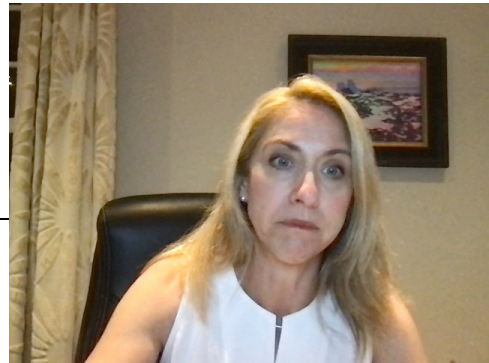
Gordon C, et al. J Clin Endo Metab, 2017.
Ackerman K and Misra M. "Neuroendocrine Abnormalities in Female Athletes" in The Female Athlete Triad- A Clinical Guid

Ligamentous Injuries

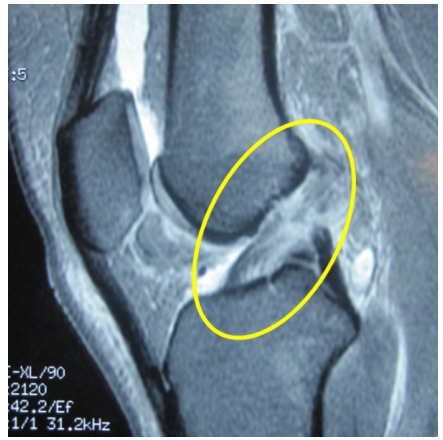
- Most common sports injuries of youth
- Children similar until puberty
  - Girls and boys have an equal number of ligament sprains prior to adolescence

- Puberty
  - Girls and boys have a higher rate of sprains immediately following their growth spurt (PHV) and into maturity
  - Girls: peak incidence between 10-14 yrs (5.4/1000 py)
  - Boys peak incidence between 15-19 yrs (8.9/1000 py)

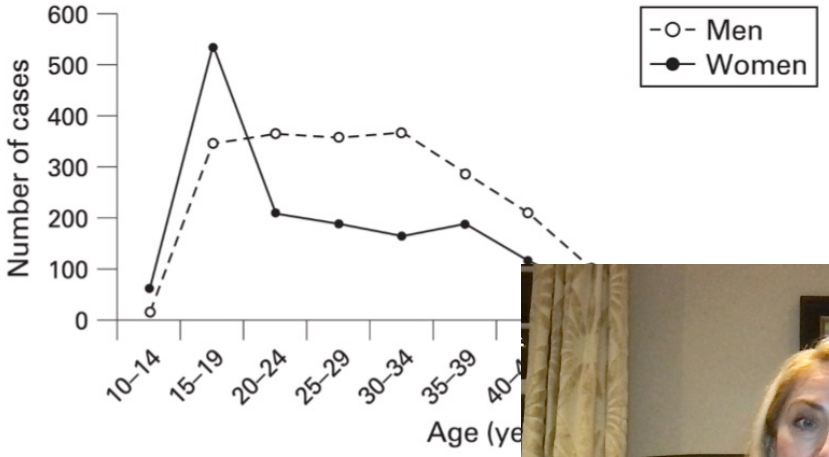
Waterman BR, et al. J Bone Joint Surg Am, 2010.

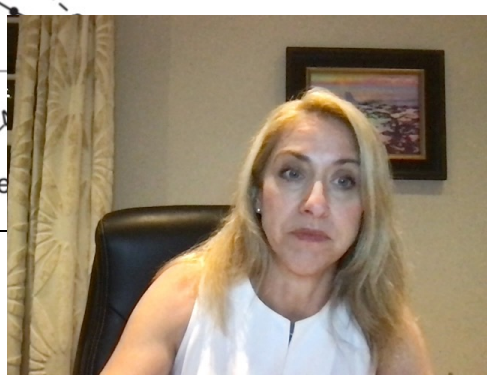


ACL



- No published differences in ACL injury rates between the sexes prior to puberty
- Adolescent girls participating in pivoting and jumping sports have 2-8X rate of ACL injuries than boys in the same sports
- Female athletes are also at greater risk for developing ACL injuries in high school and college, but their injury rate is similar in professional sports
  - Increased lateral tibial slope
  - Smaller ACL size
  - Suboptimal landing mechanics





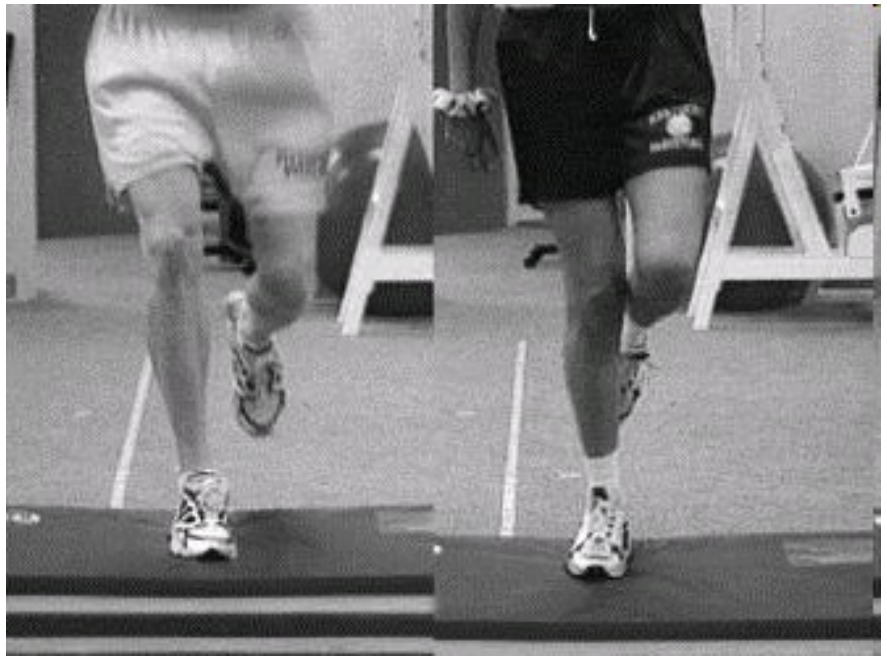
Granan LP, et al. Acta Orthop, 2009.

Lin CY, et al. PM R, 2018.

Landing Dynamics

- Male:
  - more flexion at the knee and hip
  - body weight back
  - knee in less valgus angulation

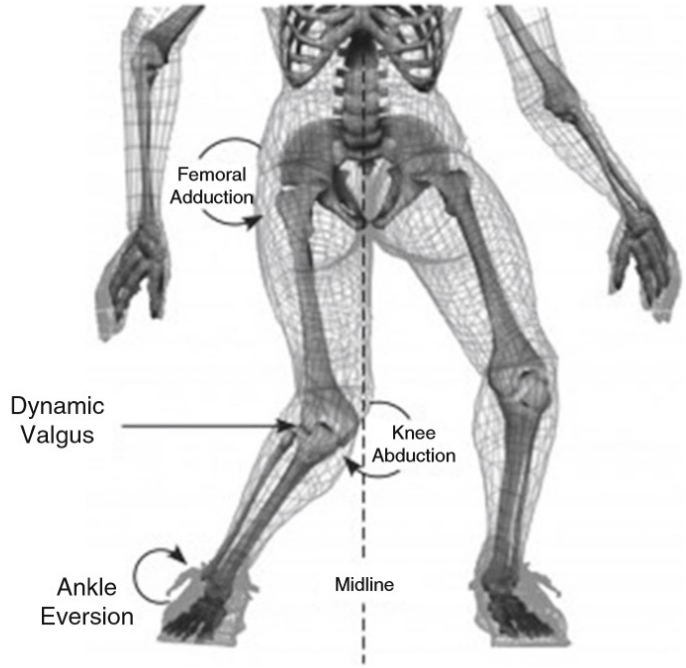
- Female:
  - less knee and hip flexion
  - body weight more forward
  - knee in more valgus angulation



Male Female

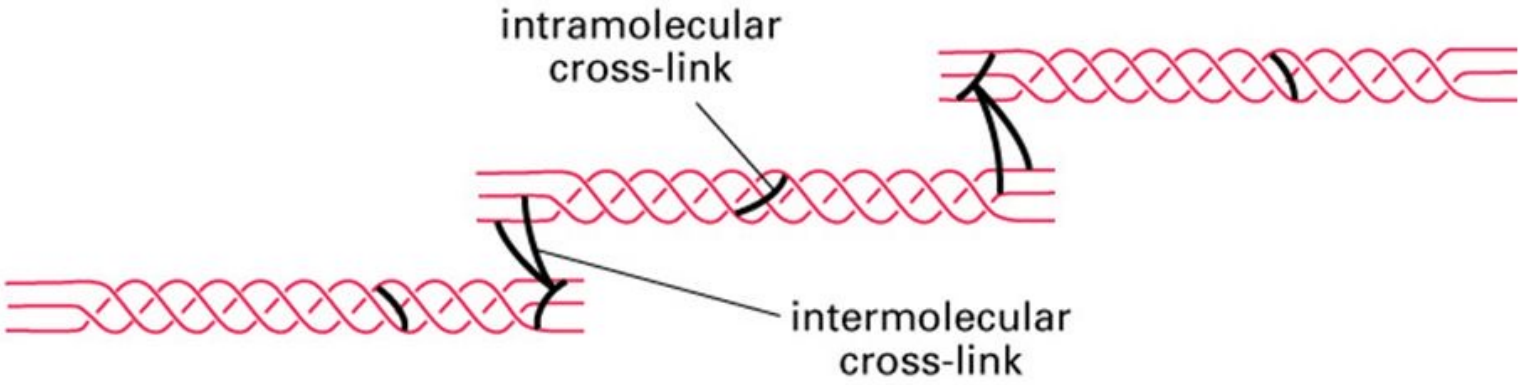
ACL

- Neuromuscular patterns in males and females diverge during maturation
- Females:
  - Anatomical changes in adolescence include widening of the pelvis, increase in the Q angle, and changes in the center of gravity
  - Decreased core stability and strength may cause increased dynamic lower extremity valgus load during sport specific tasks, placing them at increased risk for injury
- Males:
  - Increases in power, strength, and coordination with age that correlate with their maturational stage **(testosterone!)**



Hormonal Effect on Collagen Synthesis?

- Estrogen: increase or decrease in collagen synthesis
- Estrogen + relaxin: decrease collagen synthesis
- Progesterone + testosterone: increase collagen synthesis
- Estrogen + relaxin: decrease collagen cross linking



Hansen M. Proceedings of the Nutrition Society, 2018.
Dehghan F, et al. Scand J Med Sci Sports, 2014.

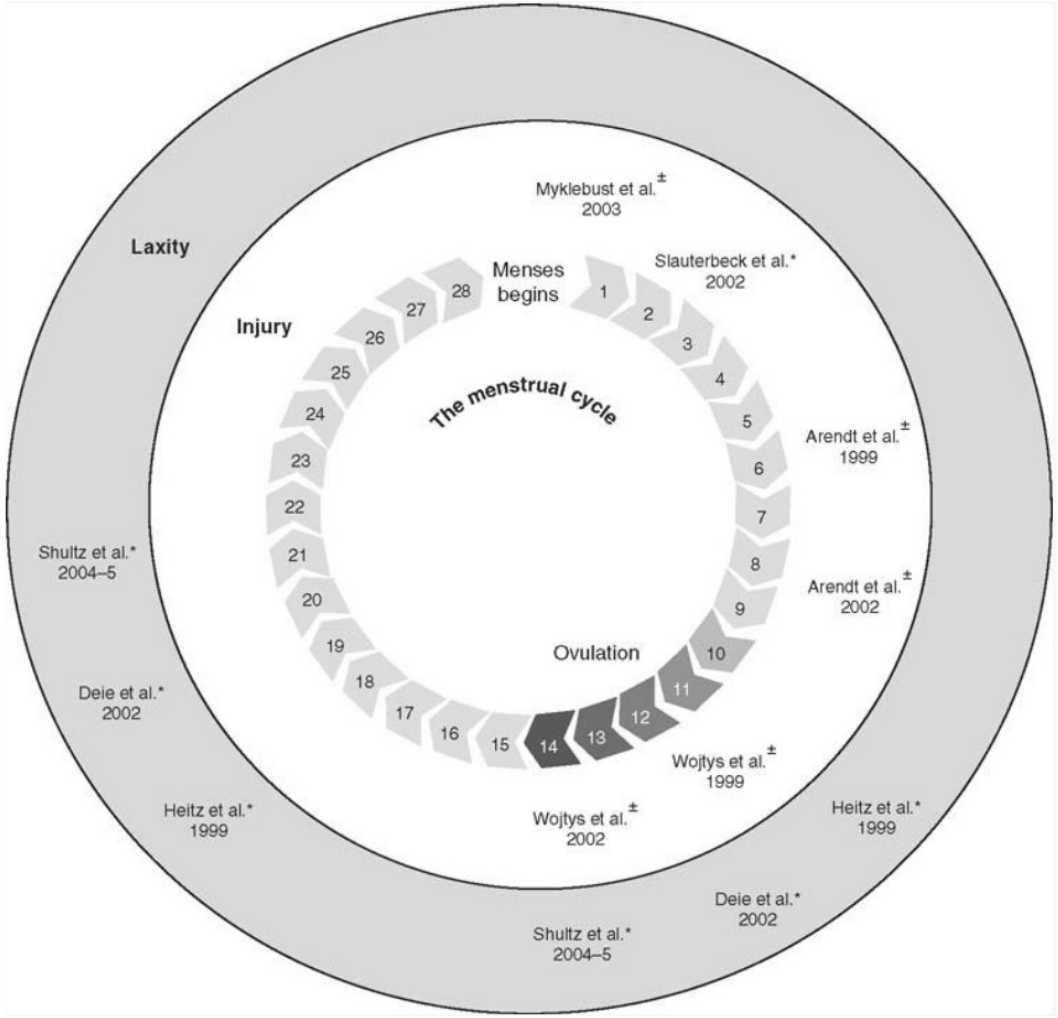
Rahman F and Christian HC. Trends Endocrinol Metal

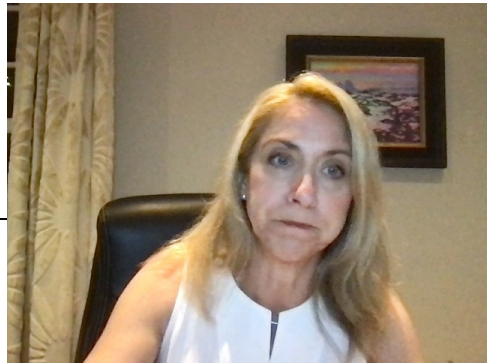
Hormonal Effect on Mechanical Properties

- Premenopausal women have increased ligamentous laxity vs. males
  - No differences between pre-pubertal and postmenopausal males and females
- Some studies found ligamentous laxity increases around ovulation in eumenorrheic women
- Estrogen & relaxin → increased ligament laxity and decreased load to failure (rabbit)
- Testosterone indirectly increases ligament stiffness by decreasing relaxin receptors (rodent)

Quatman CE, et al. J Sci Med Sport, 2008.
Burgess KE, et al. J Orthop Res, 2009.
Slauterbeck J, et al. J Orthop Res,1999.
Deghan F, et al. Int J Mol Sci, 2014.

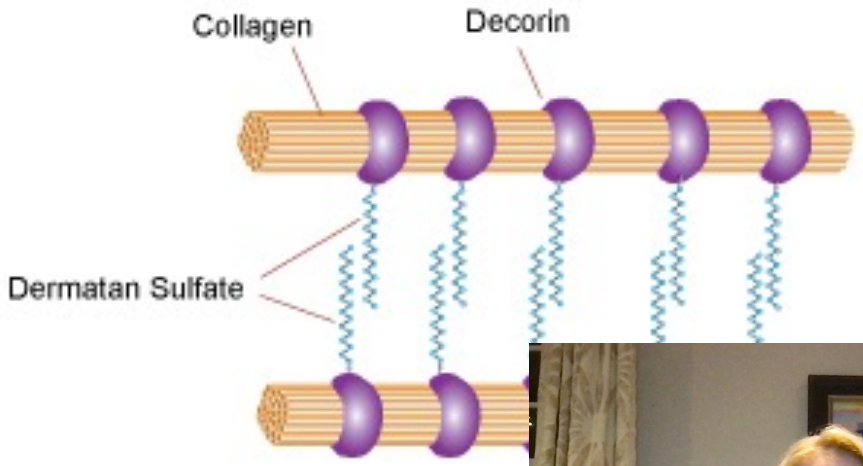
Correlation of Menstrual Cycle Phase and ACL Laxity and Injury

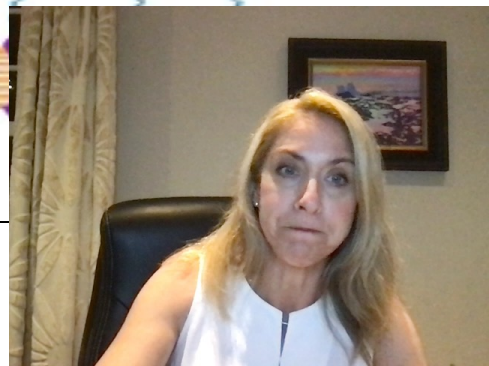




Relaxin & ACL Injury

- Prospective study of collegiate female athletes
- Measured relaxin on days 6-8 of the luteal phase
- Relaxin > 6.0 pg/mL linked to 4x increase in ACL injury
- "Sliding fibril hypothesis"
  - Relaxin alters fiber to fiber bonding
  - Enhanced sliding → creep

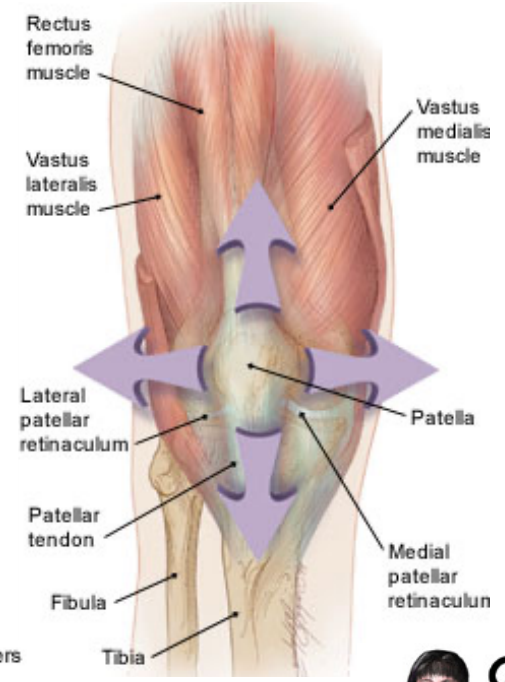


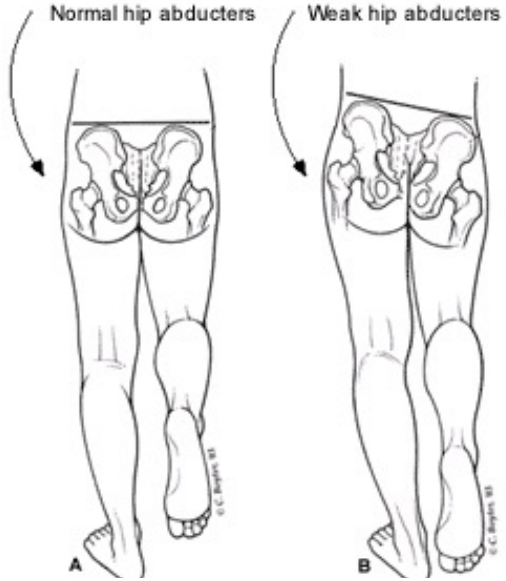


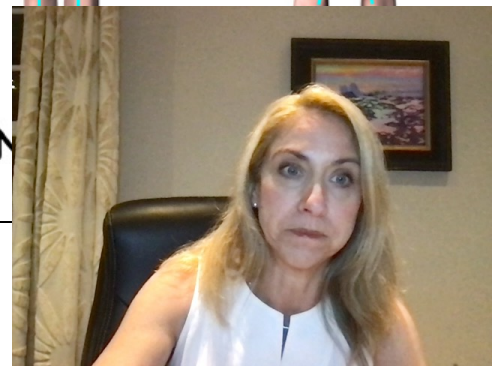
Dragoo JL, et al. Am J Sports Med, 2011.

Patellofemoral Pain

- 20% incidence in women vs 7% in men
- No single biomechanical risk factor
  - Imbalance in the kinetic chain
    - Abduction and core weakness
    - Tight laterally
    - Weak medially
    - Laxity
    - Genu recurvatum
    - Foot pronation
    - Q angle







Boling MC, et al. Am J Sports Med, 2009.

Women can be Hard to Study

- General training status and fitness
- Pre-intervention nutritional status
- Type of exercise studied (time trial vs. exercise to exhaustion)
- Duration and intensity of exercise just prior to intervention
- Phase of menstrual cycle, menstrual dysfunction from low EA, perimenopause, menopause, pregnancy, OCP use, PCOS, etc.
- Time-consuming and expensive!

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Summary

- Be aware of injuries to which female athletes are susceptible
- We need studies considering female athlete hormonal physiology
- We need to redefine treatment algorithms based on research

Thank you!

Questions?

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