



# Risk Factors for Bone Stress Injuries

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## Disclosures

I have no product endorsements or other financial relationships to disclose



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# Outline

## Part one: Risk factors and REDs

Risk factors for bone stress injury

Role of REDs

## Part two: Can we prevent BSIs

Registered dietician counseling

Bone loading programs

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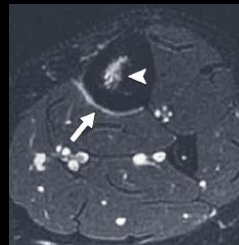
# What is a bone stress injury?

Failure of skeletal remodeling to keep pace with the *progression or volume* of repetitive loading activities

*Continuum* of injury

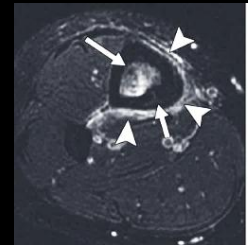
Grading of BSIs: *Prognostic* value

Grade 1-3:  
Stress Reaction



Kijowski R et al. 2012

Grade 4:  
Stress Fracture

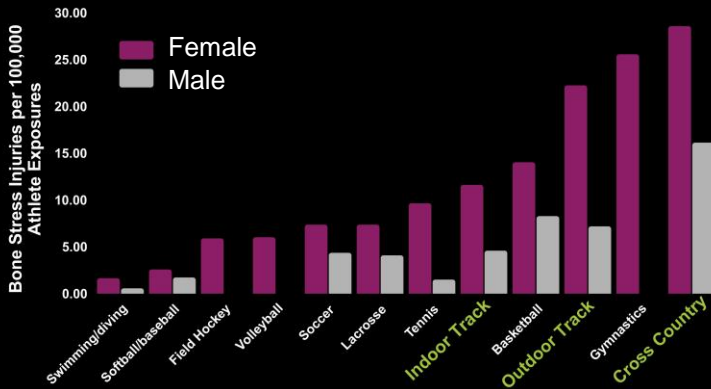


Kijowski R et al. 2012

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# BSIs are prevalent among runners

## BSI Epidemiology: NCAA Athletes, 2004-2014



### Metatarsal and tibial BSIs

- Males: 77.2%
- Females: 56.0%

### Trabecular-rich BSIs

More common in females

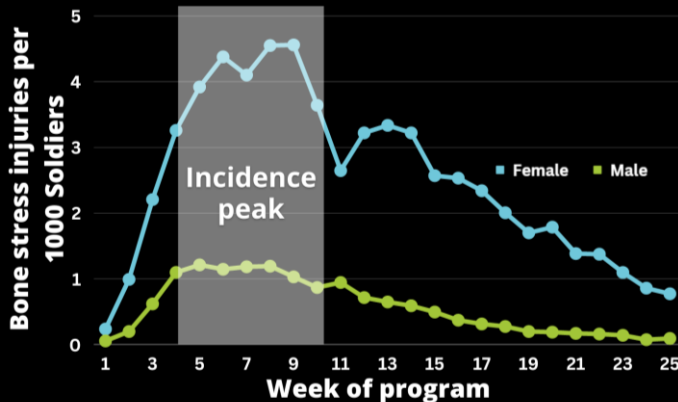
Rizzone, KH., et al. The epidemiology of stress fractures in collegiate student-athletes, 2004-2005 through 2013-2014 academic years. *J. Athl. Train.* 52, (2017).



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# Bone stress injuries lag 4-10 weeks behind spikes in workload

## Bone mass lowest



Day 0: Microdamage starts accumulating

Day 10-31: Osteoclasts remove microdamage

Day 31-36: Bone mass is lowest

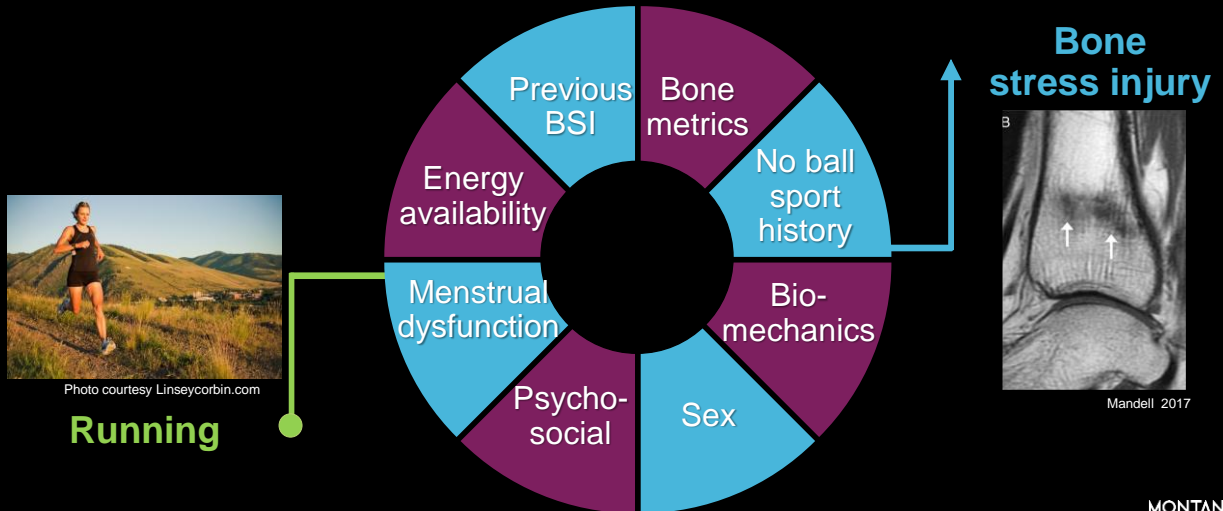
Day 37-90: Osteoblasts: New bone

Kardouni, JR., et al. "Timing of Stress Fractures in Soldiers During the First 6 Career Months: A Retrospective Cohort Study." *J. Athl Tr* 56.12 (2021): 1278-1284; Rauh, M. J. (2014). *JOSPT*, 44(10), 793-804; Rauh, MJ. (2014). Summer training factors and risk of musculoskeletal injury among high school cross-country runners. *JOSPT*, 44(10), 793-804; Warden, SJ, Edwards, WB, & Willy, RW. (2021). *Current Osteopor Reports*, 19(3), 298-307



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# Risk factors for bone stress injuries



Tenforde, A. (2013) et al. *Medicine & Science in Sports & Exercise* 45.10 (2013): 1843-1851; Hoengig T et al. Bone stress injuries. *Nat Rev Dis Primers*. (2022); Ackerman, KE. Et al, (2015). *Medicine and Science in Sports and Exercise*, 47(8), 1577.

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# High exercise volume associated with poorer bone health

+5% greater BSI risk for every additional hour over 4 hours/week of exercise (OR:1.05; 95% CI: 1.02–1.09)

≥12 hrs/wk exercise: 4.9x greater risk of BSI (OR: 4.9; CI 1.4 –16.9)

16.7-30.1% Ultrarunners: BMD Z scores < -1.0



lrunfar.com

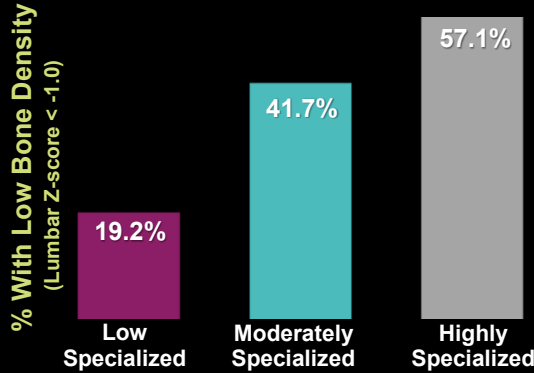
Loud, KJ., et al. "Correlates of stress fractures among preadolescent and adolescent girls." *Pediatrics* 115.4 (2005); Barrack, MT., et al. (2014). Higher incidence of bone stress injuries with increasing female athlete triad-related risk factors: a prospective multisite study of exercising girls and women. *AJSM*, 42(4), 949-958; Haeg, TB., et al.. (2022). Prevalence of Female and Male Athlete Triad Risk Factors in Ultramarathon Runners. *Clinical Journal of Sport Medicine*, 32(4), 375-381.

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# Nearly 60% of high school runners who specialize have poor bone health

Low bone density, per specialization level



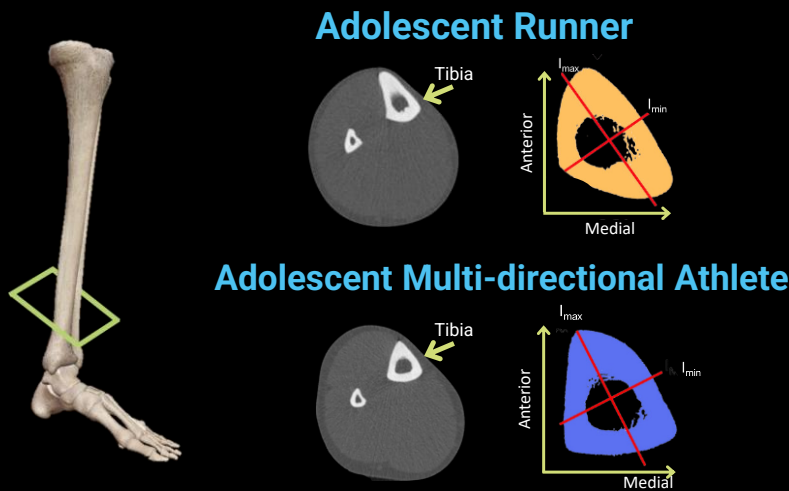
**Highly Specialized**  
"solely running  $\geq 9$  months"

**Moderately Specialized**  
"solely running  $\leq 8$  months"  
-Or-  
"running  $\geq 9$  months plus other sports"

Rauh, M J., et al. "Sport Specialization and Low Bone Mineral Density in Female High School Distance Runners." *Journal of Athletic Training* (2020).



# Tibial and metatarsal shape, size and strength is sport-specific



Data and figures adapted from Sveteckis, AM., et al. *Bone* (2024); Shaw, CN., and Stock JT. *Am J of Physical Anthropology* (2009)



# Low energy availability (LEA)

## Definitions and prevalence

$$\text{Energy availability} = \frac{(\text{Energy intake} - \text{exercise energy expenditure})}{\text{Fat free mass}}$$

### Low energy availability

- Females: ≤30 kcal/FFM/day
- Males: 9-25 kcal/FFM/day

23-79.5% Female endurance athletes

15-70% Male endurance athletes

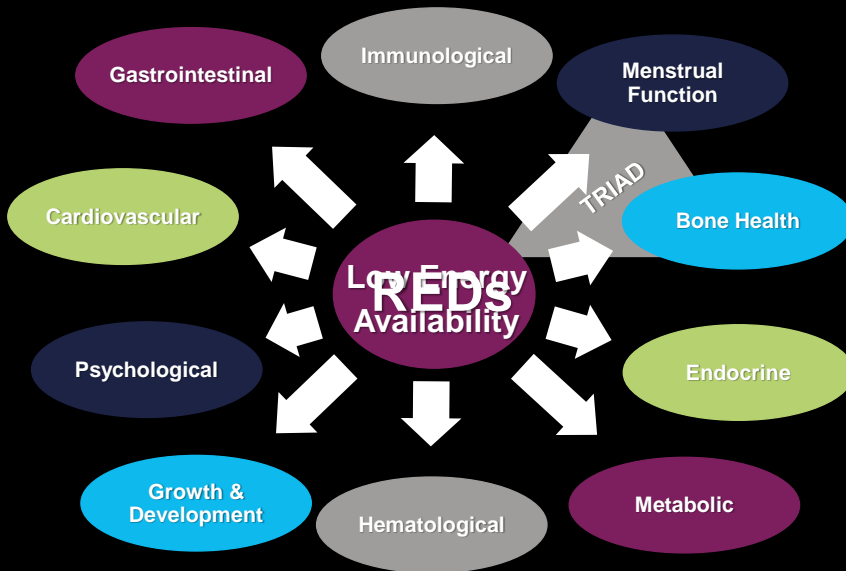


Mountjoy, Margo, et al. "2023 International Olympic Committee's (IOC) consensus statement on relative energy deficiency in sport (REDs)." *BJSM* (2023): 1073-1097.



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# REDs (Relative Energy Deficiency in Sport)



Mountjoy, Margo, et al. "The IOC consensus statement: beyond the female athlete triad—relative energy deficiency in sport (RED-S)." *BJSM*, 48.7 (2014): 491-97



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# Screening for REDs

LEAF-Q & LEAM-Q

## Look for:

- >12 hours of weekly exercise
- *Not finishing workouts or poor performance*
- Menstrual dysfunction and/or low sex drive
- Recent diet change or dietary restriction
- Stress fracture history  $\geq 2$  low-risk fracture,  $\geq 1$  trabecular bone or high-risk fracture
- Anemia
- *GI Distress*

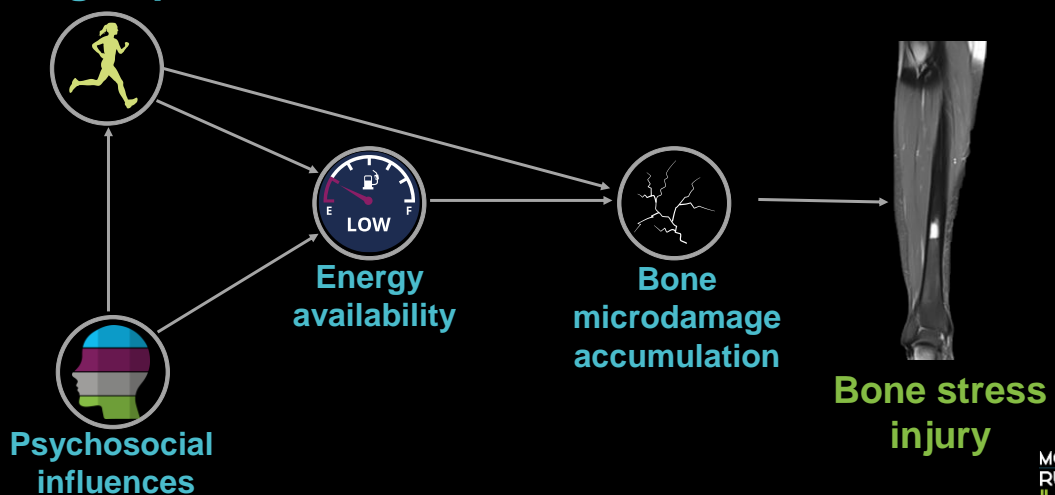
Davelaar, CM, et al., (2020). Validation of an Age-Appropriate Screening Tool for Female Athlete Triad and Relative Energy Deficiency in Sport in Young Athletes. *Cureus*, 12(6); Sim, A, & Burns, SF. "Questionnaires as measures for low energy availability (LEA) and relative energy deficiency in sport (RED-S) in athletes." *Journal of Eating Disorders* 9.1 (2021): 1-13.

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# The pathway to a BSI is complicated

Running exposure



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# Can we reduce the risk of bone stress injuries?

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## Clinical scenario



Note: Athlete not pictured

Pc: Wade Denniston

16-year old, female high school track athlete

Grade IVa tibial BSI last season

DEXA Z-Scores:

- L1-L4: -1.1
- Femoral neck: 0.2

LEAF-Q score: 9; Scores  $\geq 8$  "at-risk for LEA"

+LR: 7.8; -LR: 0.24

**"Can we reduce the risk of another BSI in this runner?"**

Melin A, et al. The LEAF questionnaire: a screening tool for the identification of female athletes at risk for the female athlete triad. *BJSM*. 2014

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# Three principles for bone loading programs

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## Multi-directional, high strain rate loading

### Pre-Adolescent basketball

Half the risk of bone stress injury  
later in life

### 30 years after playing soccer

+0.3-0.5 higher Z-scores  
40-60% lower risk of fracture



PC: Gary Higgins

Tveit, M., et al. (2015). Exercise in youth: High bone mass, large bone size, and low fracture risk in old age. *SJMS*, 25(4), 453-61; Tenforde, AS., & Fredericson, M. (2011). Influence of sports participation on bone health in the young athlete: a review of the literature. *PM&R*, 3(9), 861-7.

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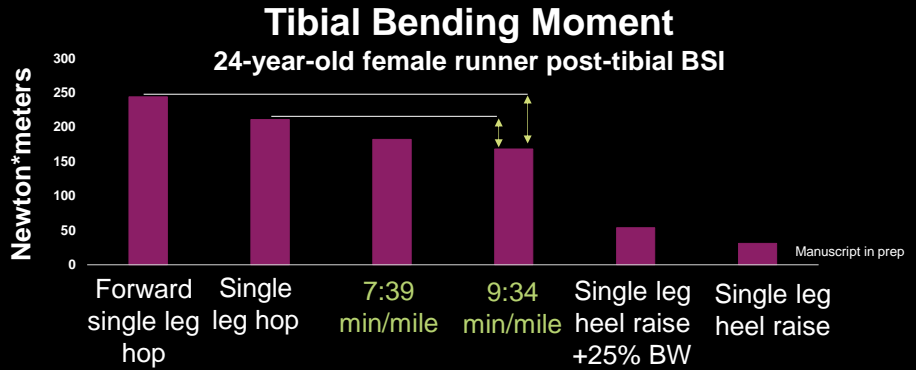
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Principle 1

# Exercises must exceed routine running loads to be osteogenic



Single leg hopping



Only *plyometrics* load tibia adequately

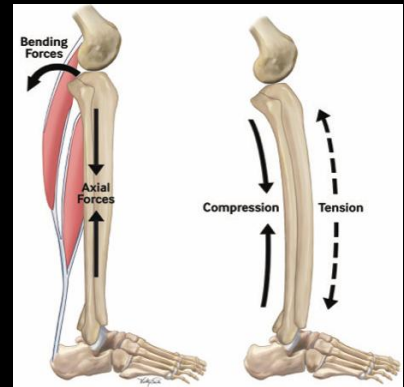
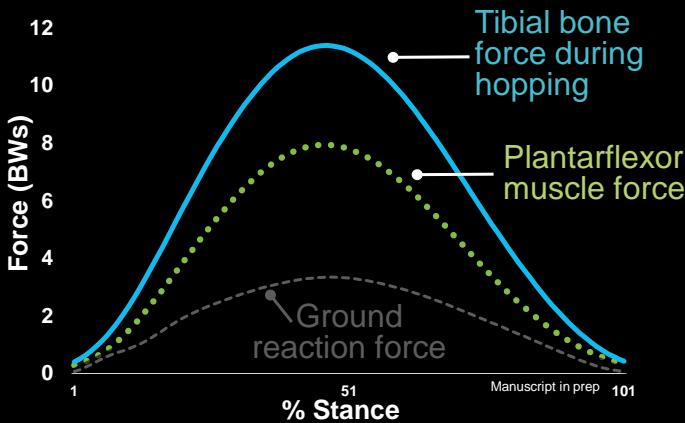
Warden, S.J., et al. (2021). Optimal load for managing low-risk tibial and metatarsal bone stress injuries in runners. *JOSPT*, 51(7); Swenson Jr EJ, et al. The effect of a pneumatic leg brace on return to play in athletes with tibial stress fractures. *AJSM*. 1997;25(3)



Principle 2

# Muscle forces are the primary contributor to bone loads

## Unilateral pogo hopping

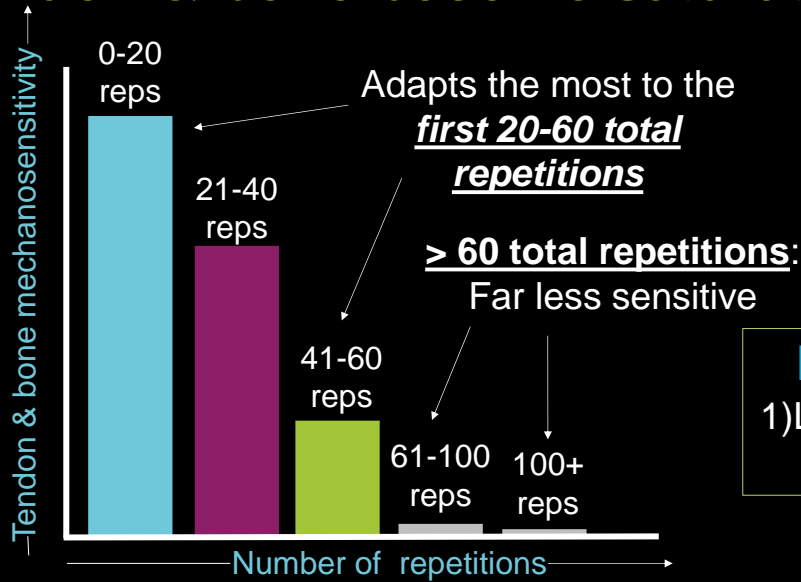


Adapted from O'Leary et al., 2021

Scott and Winter. "Internal forces of chronic running injury sites." *Med. Sci. Sports Exerc.* 22:357±369, 1990



## Principle 3

**Tendon & bone become saturated quickly****Key points**

- 1) Low volume, and
- 2) when fresh

Umemura et al. *J. Bone Miner. Res.* 1997; Magnusson et al., *Nat Rev Rheumatol.* 2010; Warden SJ et al., *Curr. Osteoporosis Res* 2021

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**Heavy squatting in young female athletes****4 sets of Fast & Heavy squats**

3-5 reps at 85-90% 1 rep max  
3x/week for 12 weeks

**Results**

Bone Mineral Density (BMD):

- ↑ Lumbar spine BMD by +2.2%
- ↑ Femoral neck BMD by +1.0%

**Key point**

Only a few *fast & heavy* reps  
needed for bone health

Mosti, MP. "Maximal strength training improves bone mineral density and neuromuscular performance in young adult women." *Journal of Strength & Cond Res* 28, no. 10 (2014): 2935-2945.

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# Sample program: Main elements

## Bone health

### Femoral neck, lower leg and foot

### Lumbosacral region

Lateral skaters

Drop jump

Deadlift

Squat



Resistance training: 2-3x/week  
 Plyometrics performed 3-6x/week

Prior to runs, or  
 at least 4-hours apart



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# Bone loading programs with and without adequate energy availability

## Adequate energy availability

~8% *increase* bone formation biomarker (P1NP) with plyometrics

## Low energy availability

Bone formation (P1NP) *not affected* by added plyometrics

**You can't *out-jump* underfueling**

Hutson, MJ., et al. "High-impact jumping mitigates the short-term effects of low energy availability on bone resorption but not formation in regularly menstruating females: A randomized control trial." SJMSS 33.9 (2023)



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# Take home points

- 1 Address the **pathway** to a BSI
- 2 Screen for **REDs**. Refer out when appropriate
- 3 **Combined lifting-plyo** program probably best
- 4 Loading is not a substitute for **energy availability**

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Lab: Sydney Lane, Riley Jones, Savannah Cheff, Jaren Lue



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# Females experience greater tibial bone stress across speeds

## Female vs. male runners

Smaller bone diameter and cross sectional area

Thinner bone cortices

Lower polar moment of inertia

## Temporospatial differences

+20.3 steps to run 1-km



**Females: Greater tibial stress per kilometer**

Meardon, S. A., Derrick, T. R., Willson, J. D., Baggaley, M., Steinbaker, C. R., Marshall, M., & Willy, R. W. (2021). Peak and per-step tibial bone stress during walking and running in female and male recreational runners. *AJSM*, 49(8), 2227-2237; Willy internal lab data

