
# Tibial and metatarsal bone stress injuries

Rich Willy, PT, PhD

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# Outline

## Part 1: Basic rehab

- Protected loading
- Progressive loading

## Part 2: Return to run

- The challenges
- Basic rules

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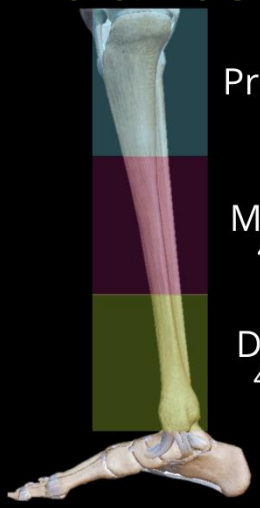
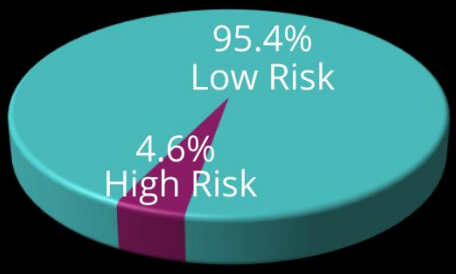
# Tibial bone stress injuries




Site distribution




Risk classification

Orava, S., et al. "Diagnosis and treatment of stress fractures located at the mid-tibial shaft in athletes." *IJSM* 12.04 (1991): 419-422.; Mandell, JC., et al(2017). Stress fractures of the foot and ankle, part 2: site-specific etiology, imaging, and treatment, and differential diagnosis. *Skeletal Radiology*, 46(9), 1165-1186.

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# Low-risk tibial bone stress injuries


Mandell, 2017

## Posteromedial tibial BSI

24-73% of all BSI

Most commonly in runners, military

Low risk

Mandell, 2017

## Anterior cortex tibial BSI

Typically rare: 4.6% of tibial BSI

Jumpers, basketball, dancers, RED-S

Delayed diagnosis: 4.6 months since onset

High risk

Orava, S., et al. "Diagnosis and treatment of stress fractures located at the mid-tibial shaft in athletes." *IJSM* 12.04 (1991): 419-422.; Mandell, JC., et al(2017). Stress fractures of the foot and ankle, part 2: site-specific etiology, imaging, and treatment, and differential diagnosis. *Skeletal Radiology*, 46(9), 1165-1186.

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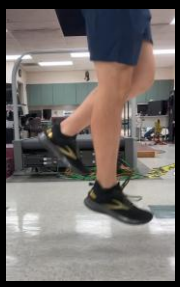
# Single leg hop test

## *Excellent* screen for tibial BSI with *no* false negatives




**Milgrom Positive test: Tibial bone pain of < 10 cm**

**Sensitivity: 1.00**

**Specificity: 0.45**

**+LR: 1.82**

**-LR: 0.00**

**Milgrom et al., J Sci and Med Sp 2021**

Have confidence that <5cm of tenderness is likely BSI, >5cm is MTSS

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Milgrom, C., Zloczower, E., Fleischmann, C., Spitzer, E., Landau, R., Bader, T., & Finestone, A. S. (2021). Medial tibial stress fracture diagnosis and treatment guidelines. *J. of Science and Medicine in Sport*, 24(6), 526-530.

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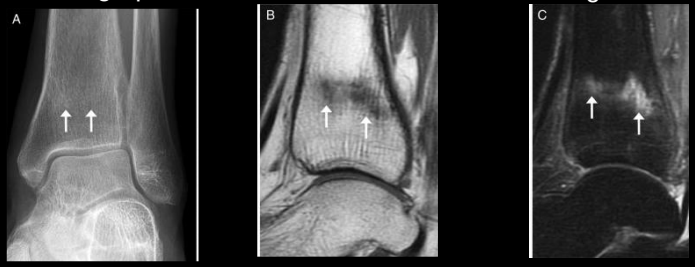
# Tibial Bone Stress Injuries

radiograph | T1-weighted MRI | T2-weighted MRI




Mandell 2017

Radiograph 1st line of diagnosis; MRI most sensitive and specific

**Often used, but not helpful:**

Tuning fork

Therapeutic ultrasound

**As accurate as coin flip**

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Wright, AA., et al. "Diagnostic accuracy of various imaging modalities for suspected lower extremity stress fractures: a systematic review with evidence-based recommendations for clinical practice." *AJSM:* 44.1 (2016): 255-263.

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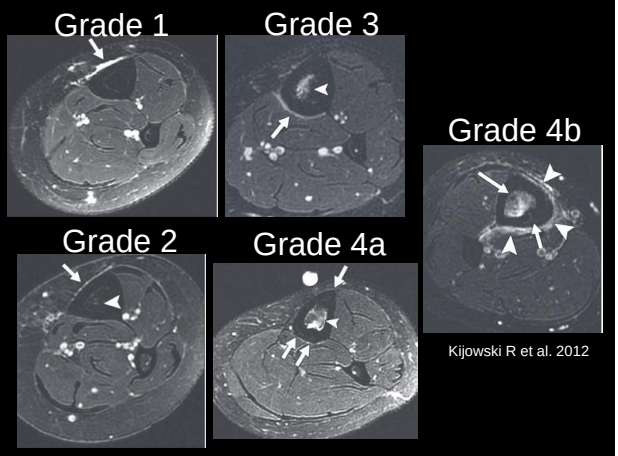
# Fredericson grading system

| Grade | Illustration | Grade | Illustration |
|---|---|---|---|
| **Grade 0:** Normal MR | | **Grade 3:** Moderate bone marrow edema seen on both T2-weighted images and T1-weighted images *return to sport in mean 39-44 days* | |
| **Grade 1:** Periosteal edema only *return to sport in mean 16 days* | | **Grade 4a:** Cortical signal abnormality, not linear in morphology *return to sport in mean 39-44 days* | |
| **Grade 2:** Mild bone marrow edema seen on T2-weighted images only *return to sport in mean 39-44 days* | | **Grade 4b:** Linear cortical signal abnormality *return to sport in mean 71 days* | |

Mandell et al., 2017




Kijowski R et al. 2012

Key point: Grade I: 16 days; Grade 2-4a: 39-44 days; Grade 4b: 71 days

Kijowski R, et al. Validation of MRI classification system for tibial stress injuries. *Am J Roentgenol*. 2012;198(4):878–84; Mandell, JC., et al(2017). Stress fractures of the foot and ankle, part 2: site-specific etiology, imaging, and treatment, and differential diagnosis. *Skeletal Radiology*, 46(9), 1165-1186

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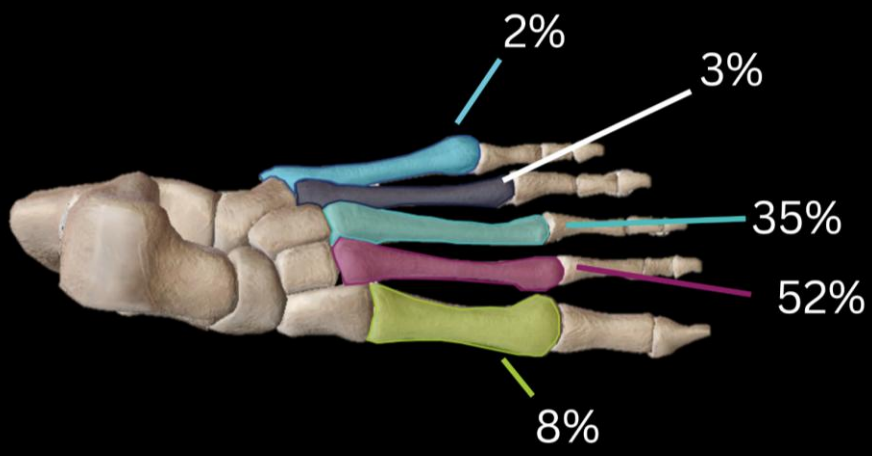
# Metatarsal bone stress injuries

17-35% of all BSI in military, 22% in collegiate runners




Mandell, JC., et al., (2017). Stress fractures of the foot and ankle, part 2: site-specific etiology, imaging, and treatment, and differential diagnosis. *Skeletal Radiology*, 46(9), 1165-1186; Ross JR, et al: The elite football players with a fifth metatarsal fracture. Orthop J Sports Med 2013

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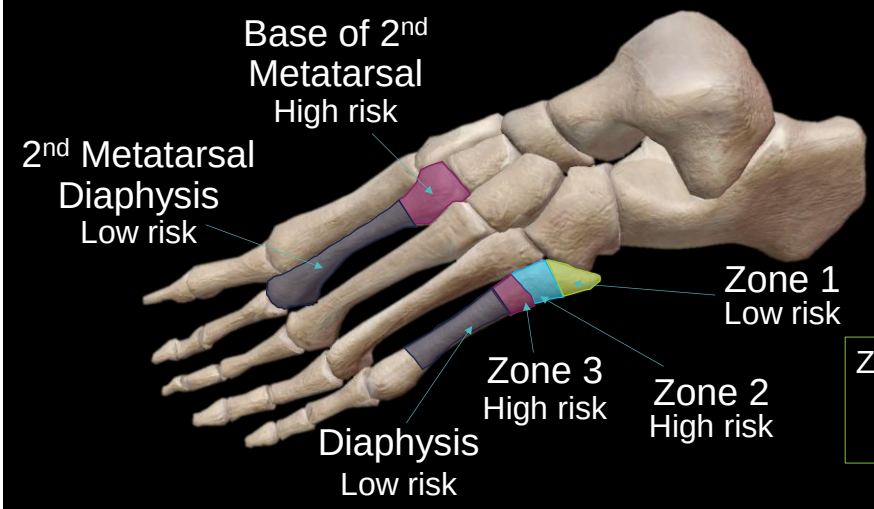
# 2nd & 5th Metatarsal bone stress injuries




Thomson A (2018)

Zone 2 & 3 Nonunion rates:
11-50% Nonsurgical
0-11% Surgical

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Patel, Karan A., et al. "Stress Fractures of the Fifth Metatarsal in Athletes." *JAAOS-Journal* (2021): 10-5435; Mandell, JC., et al.. (2017). Stress fractures of the foot and ankle, part 2: site-specific etiology, imaging, and treatment, and differential diagnosis. *Skeletal Radiology*, 46(9), 1165-1186

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# Case study

## 22-year old female runner

Female NCAA cross country runner

Pain running, worse with spikes. Night pain

Posteromedial Tibial BSI, Grade IVa

LEAF-Q score: 9; Scores ≥8 “at-risk for LEA”

+LR: 7.8; -LR: 0.24


PC: SCVSignal

Note: Athlete not pictured

**How will we guide the return to run process?**

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

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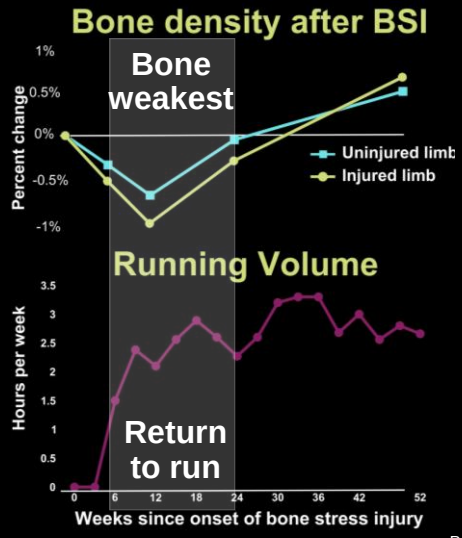
# Return to run after bone stress injury coincides with lowest bone strength




## Clinical take home

The athlete might *feel* like they're ready to go…

But, *1 out of 3* runners experience a BSI recurrence in the first year

Popp, KL., et al. AJSM 49.1 (2021): 226-235.

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# Low risk tibial BSI

## Protected weight bearing

**Weeks 1-3, depending on grade and pain**

### Goals

Pain-free gait and activities of daily living; Promote healing

### Intervention

Crutches: Partial weightbearing

If pain still present: non-weight bearing

Some opt for a walking boot: Consider gait disturbances

Avoid use of NSAIDs: impair bone healing

Strength training and hopping for opposite limb

Crosstraining: Limited period of controlled weight bearing

Warden, S. J., Edwards, W. B., & Willy, R. W. (2021). Optimal Load for Managing Low-Risk Tibial and Metatarsal Bone Stress Injuries in Runners: The Science Behind the Clinical Reasoning. *Journal of Orthopaedic & Sports Physical Therapy*, (0), 1-28.

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# Low risk tibial BSI

## Initiation of rehabilitation

**Start in Week 1-6, depending on grade**

### Interventions:

Continued hopping and loading of uninvolved limb

Progressive resistance exercises

- Moderate rep and load (3X10) => low rep, high load (4x4-6)
- Monitor closely for pain, either during or post-session

Wean to 1 crutch => full weight bearing

Crosstraining: Elliptical (when full weightbearing) or Alter-G treadmill

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Warden, S. J., Edwards, W. B., & Willy, R. W. (2021). Optimal Load for Managing Low-Risk Tibial and Metatarsal Bone Stress Injuries in Runners: The Science Behind the Clinical Reasoning. *Journal of Orthopaedic & Sports Physical Therapy*, (0), 1-28.

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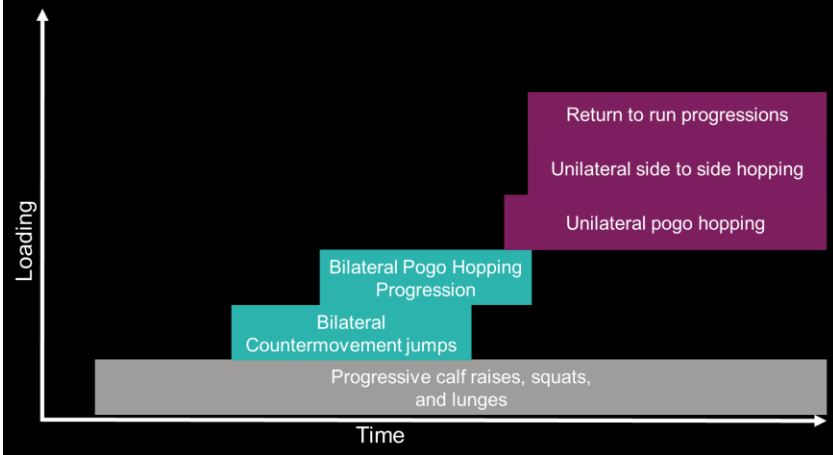
# Tibial BSIs

## Rehabilitation Overview

- Begin body weight calf raises as soon as tolerated, without pain
- If pain occurs, take 2 days off, and go back one stage.
- Uninjured limb: Daily, 3x10 reps single leg vertical and side-to-side hopping




### Interventions

High rep, low load (3X15) => low rep, high load (4x4-6)

Jumps and hopping: 2x10 reps, 2x/day, 3-5x/week

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Adapted from: Warden, Stuart J., W. Brent Edwards, and Richard W. Willy. "Optimal load for managing low-risk tibial and metatarsal bone stress injuries in runners: the science behind the clinical reasoning." *JOSPT* (2021): 322-330.

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# Metatarsal BSI (low risk): Initial treatment
## mean: 11.7 weeks to return to full participation

### Goals
Pain-free gait and activities of daily living

Promote healing

### Intervention
Crutches or walking boot, stiff soled-shoe: 4-6 wks

Strength and hop training of opposite limb

Mobilize 1st MTP daily

Crosstraining: Stationary cycling, pedaling through heel

Miller, T. L., et al. (2018). Sports Health, 10(4), 340-344.Troy, KL., et al. (2020). A Narrative Review of Metatarsal Bone Stress Injury in Athletic Populations: Etiology, Biomechanics, and Management. *PM&R*; Warden, S. J., Edwards, W. B., & Willy, R. W. (2021). Optimal Load for Managing Low-Risk Tibial and Metatarsal Bone Stress Injuries in Runners: The Science Behind the Clinical Reasoning. *Journal of Orthopaedic & Sports Physical Therapy*, (0), 1-28;

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# Metatarsal BSI: Initiation of rehabilitation
## Initiate as soon as pain allows

Tourillon, R., et al. (2019).

### Interventions
Intrinsic foot strengthening (may begin week 3)

Wean off boot/crutches, Consider a graphite shoe insert

### Heel raise progression
High rep, low load (3 sets of 15 reps) => low rep, high load (4 sets of 6-8 reps)

Monitor closely for pain, either during or post-session

Warden, S. J., Edwards, W. B., & Willy, R. W. (2021). Optimal Load for Managing Low-Risk Tibial and Metatarsal Bone Stress Injuries in Runners: The Science Behind the Clinical Reasoning. *Journal of Orthopaedic & Sports Physical Therapy*, (0), 1-28; Tourillon, R., et al. (2019). How to evaluate and improve foot strength in athletes: an update. *Frontiers in Sports and Active Living*, 1, 46.

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# Heel raise progression for metatarsal BSIs

## Shoes on

## Shoes off

Windlass raises

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# What if the athlete experiences pain, either during or after session?

| | | | |
|---|---|---|---|
| **Tendon rehab** | 0-3/10 Safe | 4-5/10 Acceptable | 6-10/10 Excessive |
| **BSI rehab** | 0/10 Safe | 1-10/10 Excessive | |

Pain during recovery is not ok!

*Don't* panic

3 days of cross training (stationary bike, pool, etc). No strengthening.

Resume program, but go back 1-step in program

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Warden, SJ., Edwards, WB., & Willy, RW. (2021). Optimal Load for Managing Low-Risk Tibial and Metatarsal Bone Stress Injuries in Runners: The Science Behind the Clinical Reasoning. *JOSPT*, (0), 1-28.

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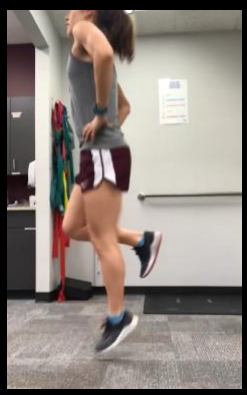
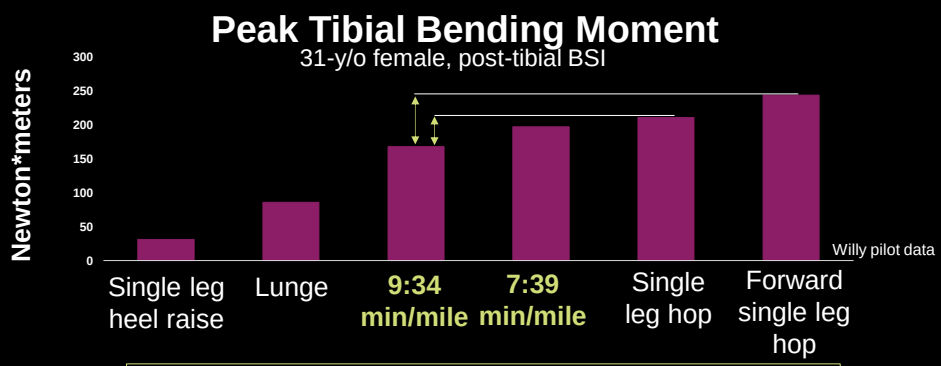
# When do we know a runner is ready for a return to run?



Single leg hop test




**Single leg hop test**
Predictive of functional recovery post-BSI

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Warden, SJ., 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)

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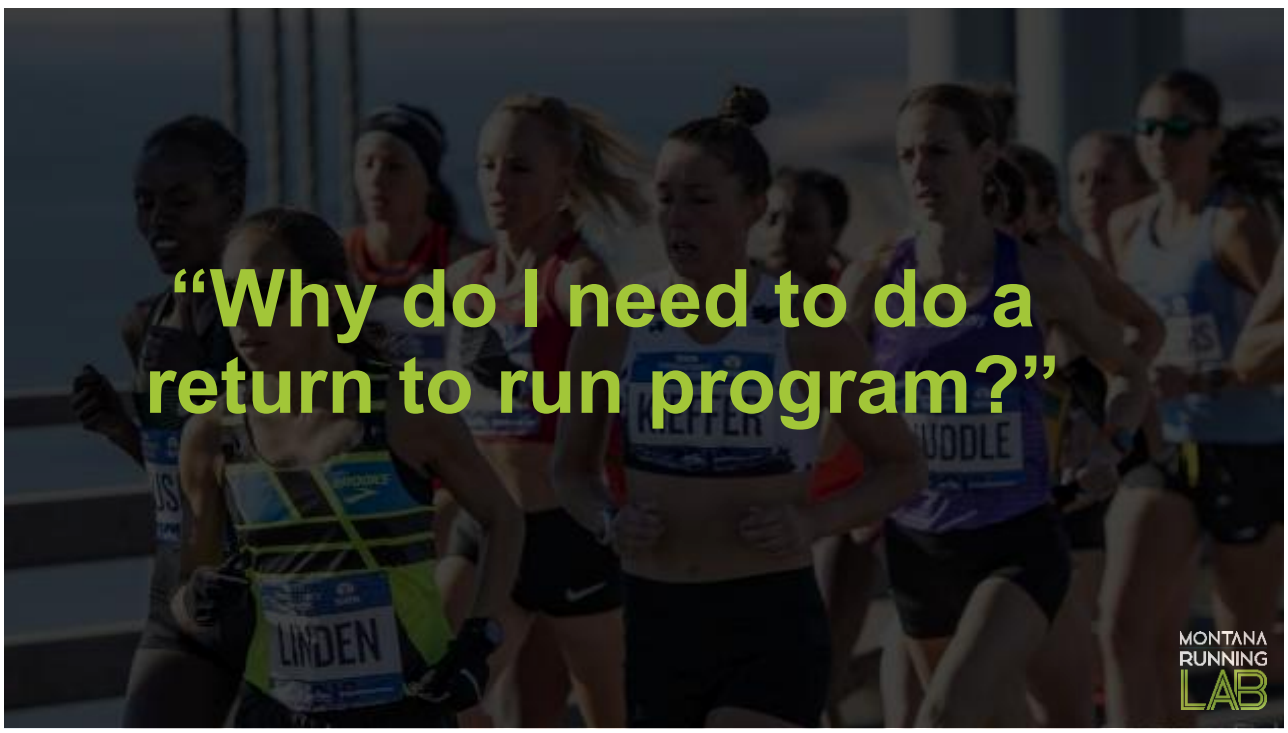


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# Prolonged running results in increasing bone stress

Post-BSI: Lack run-specific fitness

2nd Metatarsal pressures and stresses increase as a run progresses

Increased risk of other injuries after lay-off

Critical to follow schedule


Interval app: IOS app store

**Example program: See Warden et al., *JOSPT* 2014**

Rice H, et al. *MSSE*.2019;51(11)Donahue SW, Sharkey NA. . *J Bone Joint Surg*. 1999; 81a(9): 1236- 1244.
Troy, KL., et al "*PM&R* 13.11 (2021): 1281-1290.

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# Psychosocial challenges in the return to run process

**Drive for perfection and leanness**

**Exercise compulsion & dependence**

**Fear of letting down team & coach**

**Loss of sense of self**

Ackerman K et al.. Low energy availability surrogates correlate with health and performance consequences of Relative Energy Deficiency in Sport. *BJSM.* 2019;53(10); Kong, P & Harris, L.M. The Sporting Body: Body Image and Eating Disorder Symptomatology Among Female Athletes…. *J. Psychol*. 2014, 149

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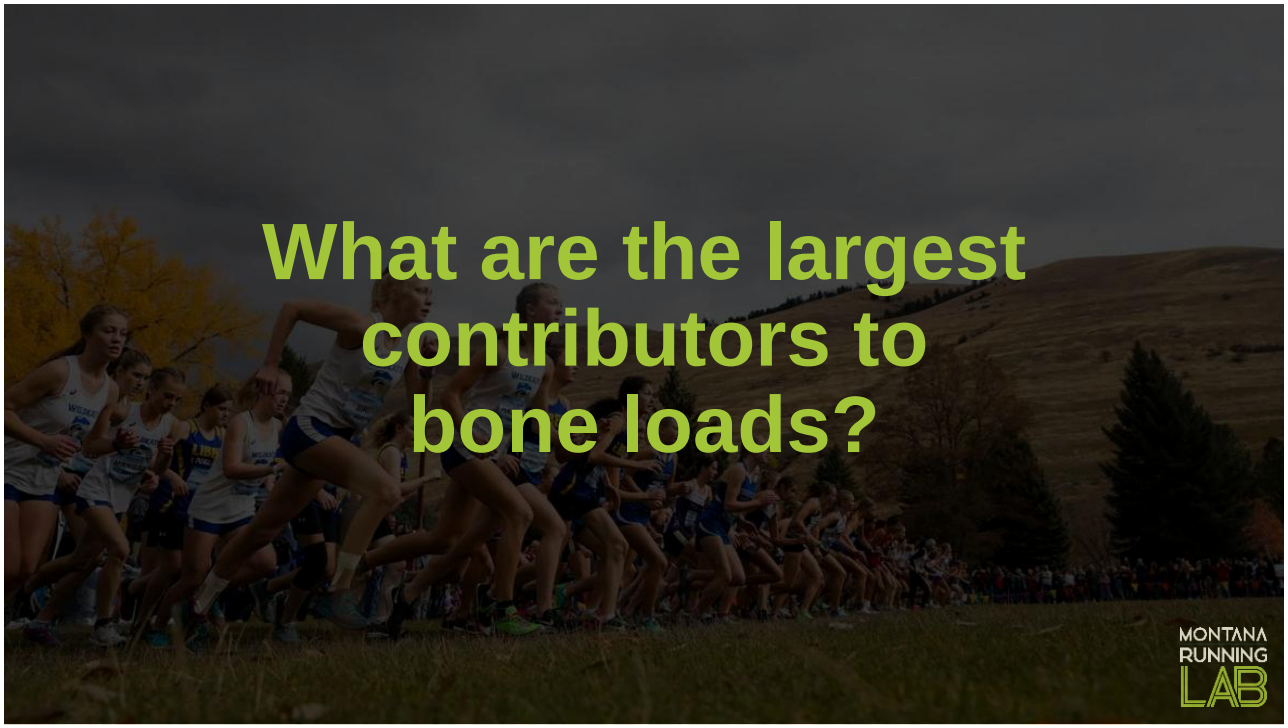


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# Are higher impact forces a *prospective* risk factor for bone stress injuries?


Journal of Biomechanics

A hierarchical clustering approach for examining potential risk factors for bone stress injury in runners


Vertical Loading Rate Is Not Associated with Running Injury, Regardless of Calculation Method


A 2-Year Prospective Cohort Study of Overuse Running Injuries

The Runners and Injury Longitudinal Study (TRAILS)

Higher impact forces i.e., loading rates, were *not* associated with increased risk of bone stress injury

Impact forces were not associated with *any* running-related injury

Schmida, et al. (2022). Vertical Loading Rate Is not Associated with Running Injury, Regardless of Calculation Method. *MSSE; Martin JA, et al.* A hierarchical clustering approach for examining potential risk factors for bone stress injury in runners. *J Biomech. 2022*; Messier, SP., et al. "A 2-year prospective cohort study of overuse running injuries: the runners and injury longitudinal study (TRAILS)." AJSM: (2018)

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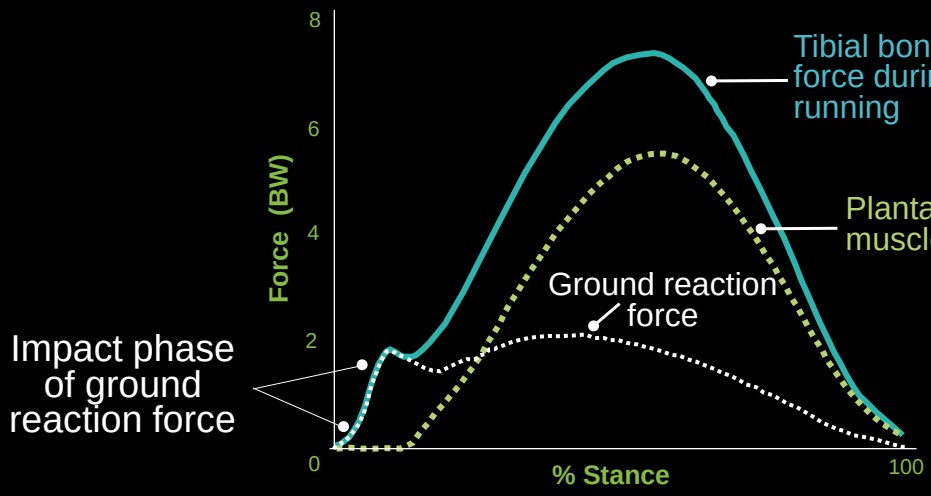
# Muscles, not impacts, are the primary contributor to tibial bone forces




Adapted from Matijevich, S., et al. "Ground reaction force metrics are not strongly correlated with tibial bone load when running across speeds and slopes: Implications for science, sport and wearable tech." *PloS one* 14.1 (2019)

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# Where does this leave us in the management of bone loading in runners?

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# Principle 1
# Control muscle forces, not impacts, to control bone loading

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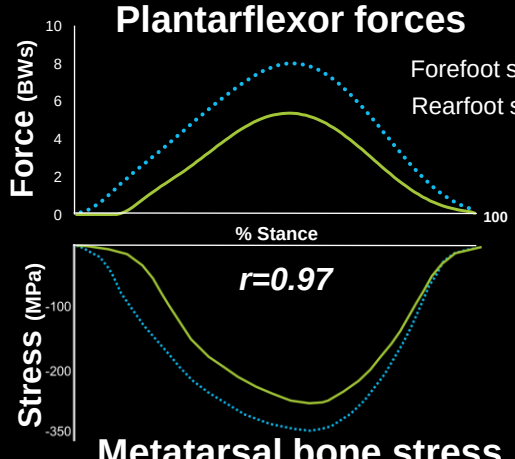
# Example: Metatarsal bone strains vs. plantarflexor forces




**Clinical take home**

Control metatarsal and tibial bone stress by controlling *plantarflexor* forces

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Adapted from Ellison, MA, et al. *J of Biomech* (2020); Willy internal lab data; Edwards WB, et al.. Proceedings 2007 ASB 2007.

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## Principle 1 in practice

# Control dorsiflexion to control tibial and metatarsal bone loads

High drop shoe

Brooks Launch

27 mm heel
17 mm forefoot

10 mm drop

9-12 mm Heel lift

Reduce tibial bone force by *0.8-1.0 body weights* during running

Reduce likelihood of *metatarsal BSI by ~17%*

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Firminger, CR., et al. (2017). *Clinical Biomechanics;* Warden, SJ., Edwards, WB., & Willy, RW. (2021). *JOSPT*; Lee, Kawin KW, Samuel KK Ling, and Patrick SH Yung. *BMC musculoskeletal disorders* 20.1 (2019): 1-12.

29

## Principle 1 in practice

# Spikes and flats are added last

**Greater metatarsal bone strains**

*Rocker shoe*

*High drop shoe*

*Track spike*

*+17% Greater likelihood* of metatarsal bone stress injury in a minimalist shoe or track spike

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Firminger, CR., et al. (2017). *Clinical Biomechanics;* Warden, SJ., Edwards, WB., & Willy, RW. (2021). *JOSPT*

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# Principle 2

## *Small changes* in load per step have an *exponential* effect on bone microdamage

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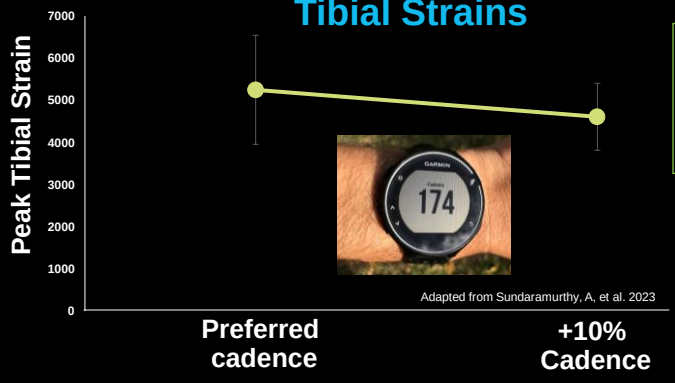
### Principle 2 in practice

## Higher cadence decreases BSI risk

**Effect of Cadence on Tibial Strains**




Adapted from Sundaramurthy, A, et al. 2023

**+10% Higher Cadence**

+12.2% Lower tibial strain

-64.8% Lower tibial BSI risk

Sundaramurthy, A, et al. *BMC Musculo Dis* 24.1 (2023); Willy, RW., et al. *SJMSS.* 26.2 (2016): 197-205; Van Hooren, B, et al. *SJMSS*. 34.2 (2024): e14570.

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## Principle 2 in practice
# Intensity vs volume

- 7:15 min/mile vs. a 10:15 min/mile *increases bone microdamage by 50%*
- Restore run volume (i.e., *consistency*) *first*
- When intensity is added, *temporarily reduce run volume*

Firminger, CR., et al. (2017). *Clinical Biomechanics;* Warden, SJ., Edwards, WB., & Willy, RW. (2021). Optimal load for managing low-risk tibial and metatarsal bone stress injuries in runners: The science behind the clinical reasoning. *JOSPT*;

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# Principle 3
# Adjust training volume periodically to allow bone to catch up

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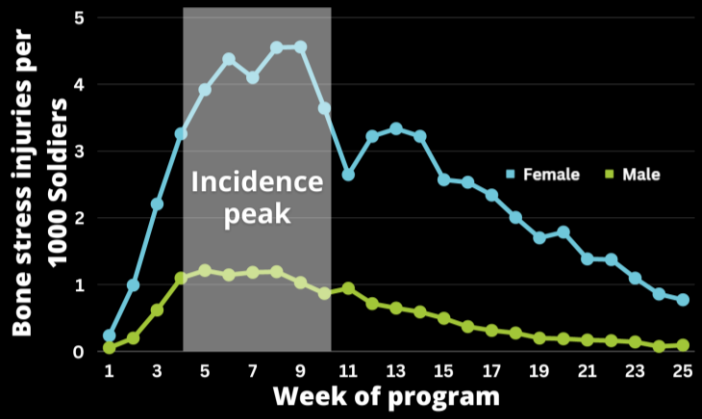
# Bone stress injuries lag 4-10 weeks behind spike in workloads




Program a “de-load” week every 3rd to 4th week

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, MJ. (2014). *JOSPT*, 44(10).

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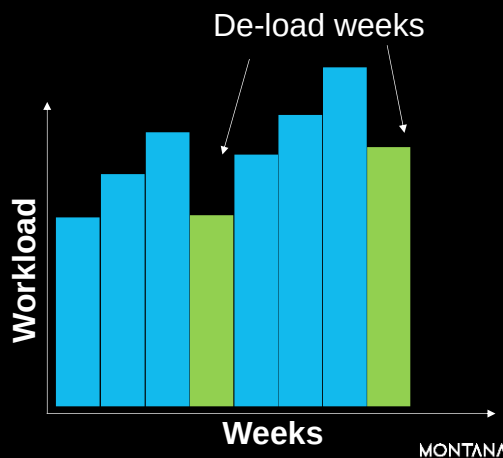
## Principle 3 in practice

# Program regular de-loading weeks

Reduce volume of loading by 25-50%

De-load periodically throughout the season

Rehab: Program de-loading weeks




Warden, SJ, Edwards, WB, & Willy, RW. (2021). Current Osteopor Reports, 19(3), 298-307

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# Structuring a week

## Low REDs risk, competitive High school or NCAA Runner

| Week 1: Low REDs risk | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Session** | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** | **Saturday** | **Sunday** |
| **8am** | Jumps/hops | Jumps/hops | Jumps/hops | Jumps/hops | Jumps/hops | Jumps/hops | |
| **Noon** | 5min warmup, cooldown 7x(2min walk, 1min run). Finish with non-weight bearing aerobic training | Resistance and aerobic cross training | 5min warmup, cooldown 7x(2min walk, 2 min run), Finish with non-weight bearing aerobic training | Resistance and aerobic cross training | 5min warmup, cooldown 7x(2min walk, 3 min run), Finish with non-weight bearing aerobic training | Resistance and aerobic cross training | off |
| **5pm** | | Jumps/hops | | Jumps/hops | | Jumps/hops | |

Three resistance sessions, nine hopping sessions: Low volume, high magnitude

Three progressive run sessions

Three cross-training sessions: Emphasize de-loading

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# Structuring a week

## High REDs risk, High school or NCAA runner

| Week 1: High REDs risk | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Session** | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** | **Saturday** | **Sunday** |
| **Morning** | Jumps/hops | Resistance training | Jumps/hops | | Jumps/hops | Resistance training | |
| **Noon** | 5min warmup, cooldown 7x(2min walk, 1min run), Option: Finish with non-weight bearing aerobic training | Aerobic cross training or walk | 5min warmup, cooldown 7x(2min walk, 1.5 min run), Option: Finish with non-weight bearing aerobic training | Aerobic cross training or walk | 5min warmup, cooldown 7x(2min walk, 2 min run), Option: Finish with non-weight bearing aerobic training | Aerobic cross training or walk | Off |
| **5pm** | | | | | | | |

Two resistance sessions, four hopping sessions: Low volume, high magnitude

Three progressive run sessions

Three dedicated cross-training sessions, three optional cross-training sessions

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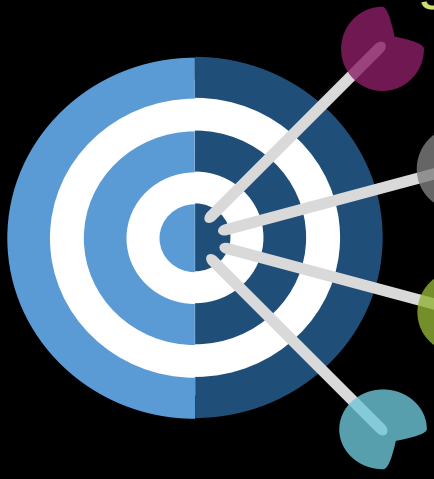
# Tibial and metatarsal BSI recommendations



**Stick with the schedule**
No pain rule. Pause program, if needed

**Muscle forces matter, not impacts**
Leverage biomechanics to reduce bone loads

**Limit exposure to high loads**
Always reduce run volume when adding speed

**Allow bone a chance to catch up**
Recovery week every 3rd or 4th week

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# Acknowledgements

Samaritan Orthopedic and Sports Medicine Conference

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