Mass General Brigham
Spaulding Rehabilitation

Not all bone stress injuries are the same: updates in diagnosis, management and prevention

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Conflicts of interest

None to disclose related to this talk

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Objectives

- **To discuss how risk factors may differ by anatomy**
- **To outline strategies to evaluate and treat injuries**
- **To present current evidence on injury prevention**

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Bone Stress Injury - Failure of skeleton to withstand *submaximal* forces acting over *time*

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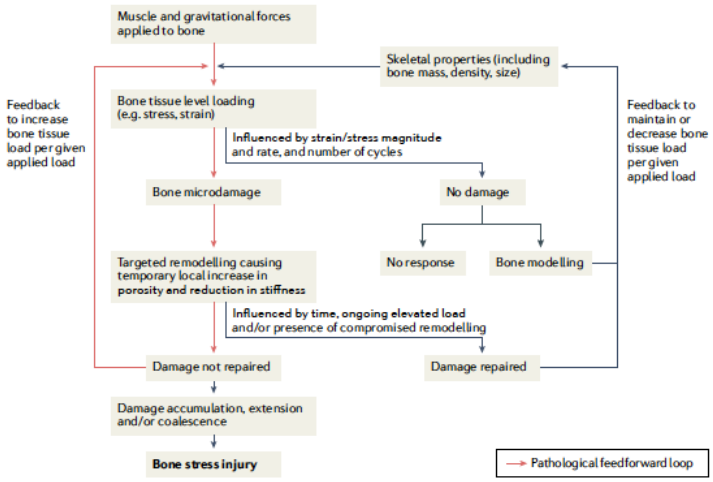
Pathogenesis of Bone Stress Injury



Hoenig, et al. Nature Reviews Disease Primers, 2022

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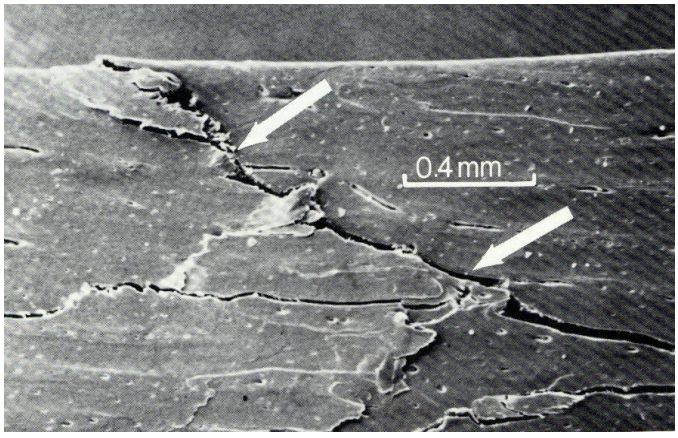

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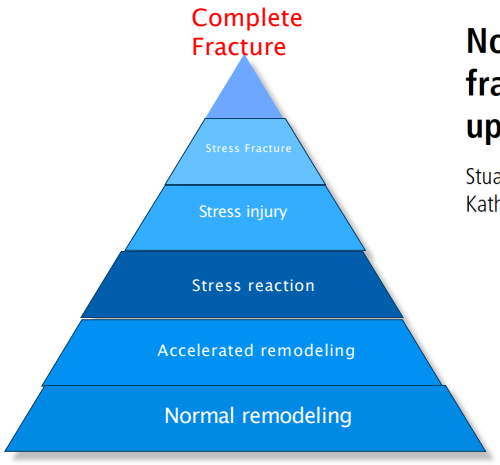
A continuum of injury



Not all bone overuse injuries are stress fractures: it is time for updated terminology

Stuart J Warden [1,2] Tim Hoenig [3] Austin M Sventeckis,[1] Kathryn E Ackerman [4] Adam S Tenforde[5]

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Current challenges

- **Terminology "stress fracture" historically used for any injury**
- **Anatomical location influences prognosis**
- **Risk factors may differ by injury and population**
- **Standard protocols do not exist for treatment and prevention**

Hoenig, et al. Not all bone stress injuries are stress fractures. BJSM 2023.

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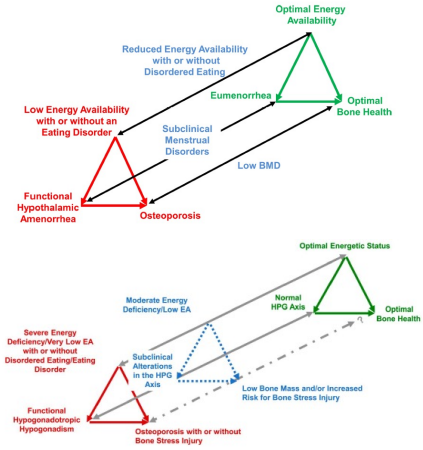
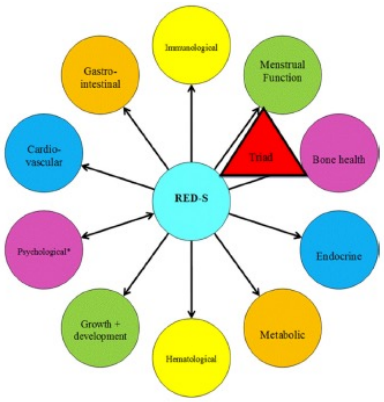
Female and Male Athlete Triad



Relative Energy Deficiency in Sport (REDs)



De Souza, et al. Female Athlete Triad BJSM, 2014
Mountjoy, et al. RED-S, BJSM 2023.
Nattiv, et al. Male Athlete Triad CJSM 2021

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Low energy availability

(−)

BRAIN / HYPOTHALAMUS

↓ **Sex Hormones**
- Menstrual dysfunction
- Reduced testosterone (men)
- Reduced bone mass

↓ **Growth Hormone Sensitivity**
- Loss of muscle
- Reduced bone mass

↓ **Thyroid Hormones**
- Suppressed metabolism

↑ **Stress Hormone Levels**
- Loss of muscle
- Reduced bone mass
- Menstrual dysfunction

Chan JL, Mantzoros CS. Lancet 2005;366:74-85.

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Anatomical location of BSI different by Triad risk category

Anatomic Distribution of BSI by Risk Category[a]

Location	Low Risk (n = 9 Athletes)	Moderate Risk (n = 11 Athletes)	High Risk (n = 5 Athletes)
Foot	Metatarsal (n = 4)	Metatarsal (n = 2)	
	Tarsal navicular (n = 2)		
	Cuboid (n = 1)	Calcaneus (n = 1)	
	Talus (n = 1)	Talus (n = 1)	
Nonfoot	Ulna (n = 1)	Tibia (n = 2)	Tibia (n = 1)
		Femoral shaft (n = 1)	Femoral shaft (n = 2)
Pelvis/hip	Femoral neck (n = 1)	Sacrum (n = 5)	Sacrum (n = 1)
			Ilium (n = 1)

Cortical Rich Bone ----------→ Trabecular Rich Bone

Tenforde, et al. Association of the Female Athlete Triad Risk Assessment Stratification to the Development of Bone Stress Injuries in Collegiate Athletes, AJSM 2017

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Anatomical site of injury and association low BMD

- **4.6-fold increased risk low BMD (Z-score < -1.0) for BSI at site of high trabecular content (pelvis, femoral neck and calcaneus)**
- **Male runners with BSI 6.1-fold increased risk low BMD**
- **Similar findings to prior report in female athletes**

Tenforde, Popp, Ackerman et al. Low Bone Density in Male Athletes Associated with Bone Stress Injuries at Anatomical Sites of Greater Trabecular Content, AJSM 2018
Marx, et al. Stress fracture sites related to underlying bone health athletic females. Clin J SM, 2001.
Tenforde, et al. Factors Associated With High-Risk and Low-Risk Bone Stress Injury in Female Runners: Implications for Risk Factor Stratification and Management. OJSM, 2024.

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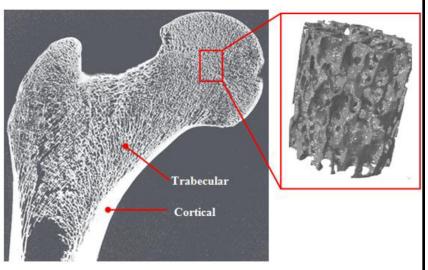
Sex hormones may influence components of bone differently

- Two primary components of bone
  - Cortical bone – dense and compact
  - Trabecular bone – honeycomb with greater surface area
- Differences in trabeculae (spacing, number) are influenced by amenorrhea in female athletes



from (http://www.theodora.com/anatomy/the_femur.html)

- Theory: Bone in the lumbar spine, pelvis, and calcaneus may have greater trabecular bone content and preferential risk for injury with hormonal disruptions

Ackerman, et al. Fractures in relation to menstrual status and bone parameters in young athletes. MSSE, 2015.
Pathria, Chung and Resnick. Acute and stress-related injuries of bone and cartilage: pertinent anatomy, basic biomechanics, and imaging perspective. Radiology. 2016

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Physical Exam

- **Features on exam:**
  - Tenderness with direct palpation
  - Pain with hop test
  - Tenderness with direct percussion
  - Tenderness with indirect percussion
- **Greater number of positives associated with higher grade injuries**

Fredericson, et al. Tibial stress reaction in runners. Correlation of clinical symptoms and scintigraphy with a new magnetic resonance imaging grading system. AJSM, 1995.

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Imaging

- Imaging modalities may include x-rays, MRI, bone scan, and CT
- Consideration of imaging type and frequency includes the clinical relevance, location and risk

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Imaging

- MRI more frequently used as diagnostic test of choice
- High rate of false negative findings with x-ray
- Note: false positives are possible!

Bergman, Fredericson, et al. Asymptomatic tibial stress reactions: MRI detection and clinical follow-up in distance runners. Am J Roentgenol, 2004
Tenforde, et al. Metatarsal Bone Marrow Edema and Correlation to Bone Stress Injury in Male Collegiate Basketball players. OJSM, 2022.

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Grading Severity of Injury with MRI

TABLE 1
MRI Grading Scales for Bone Stress Injuries[a]

MRI Grade	Fredericson et al[18]	Arendt et al[2]	Nattiv et al 2013 (Current Study)
1	Mild to moderate periosteal edema on T2; normal marrow on T2 and T1	Positive signal change on STIR	Mild marrow or periosteal edema on T2[b]; T1 normal[c]
2	Moderate to severe periosteal edema on T2; marrow edema on T2 but not T1	Positive STIR plus positive T2	Moderate marrow or periosteal edema plus positive T2; T1 normal
3	Moderate to severe periosteal edema on T2; marrow edema on T2 and T1	Positive STIR plus positive T2 and T1	Severe marrow or periosteal edema on T2 and T1
4	Moderate to severe periosteal edema on T2; marrow edema on T2 and T1; fracture line present	Positive fracture line on T2 or T1	Severe marrow or periosteal edema on T2 and T1 plus fracture line on T2 or T1

Nattiv et al. Correlation of MRI Grading of Bone Stress Injuries With Clinical Risk Factors and Return to Play. Am J Sports Med, 2013

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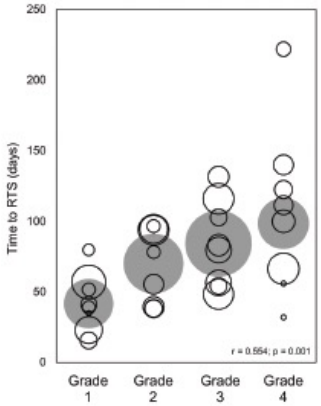
MRI Grade Can Predict Return to Play



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Study or Subgroup	MRI low grade Mean	SD	Total	MRI high grade Mean	SD	Total	Weight
cortical-rich							
Albisetti et al. 2010	37.8	3.6	10	54.5	9.8	9	17.9%
Beck et al. 2012	50	26.1	18	55.2	30.9	19	12.8%
Kijowski et al. 2012	29.9	11.5	20	57.8	26.3	50	17.1%
Maquirriain & Ghisi 2007	56.6	31.4	11	84	20.8	8	10.6%
Nattiv et al. 2013	88.9	11.2	22	131.6	14.7	14	17.0%
Subtotal (95% CI)			**81**			**100**	**75.3%**
Heterogeneity: Tau² = 154.79; Chi² = 25.45, df = 4 (P < 0.0001); I² = 84%							
Test for overall effect: Z = 3.90 (P < 0.0001)							
trabecular-rich							
Harris et al. 2020	74.7	14.6	7	94.3	54.6	3	2.8%
Nattiv et al. 2013	119.7	63.7	3	266.7	44.8	4	1.7%
Ramey et al. 2016	74.2	41.5	10	113.2	45.3	17	7.2%
Rohena-Quinquilla et al. 2018	73.8	43.9	55	114.7	41.6	35	12.9%
Subtotal (95% CI)			**75**			**59**	**24.7%**
Heterogeneity: Tau² = 454.52; Chi² = 6.47, df = 3 (P = 0.09); I² = 54%							
Test for overall effect: Z = 3.13 (P = 0.002)							
Total (95% CI)			**156**			**159**	**100.0%**
Heterogeneity: Tau² = 179.23; Chi² = 36.55, df = 8 (P < 0.0001); I² = 78%							
Test for overall effect: Z = 5.09 (P < 0.00001)							
Test for subgroup differences: Chi² = 1.92, df = 1 (P = 0.17), I² = 47.9%							

Hoenig, et al. Correlation of MRI Grading of Bone Stress Injuries With Clinical Risk Factors and Return to Play. Am J Sports Med, 2021

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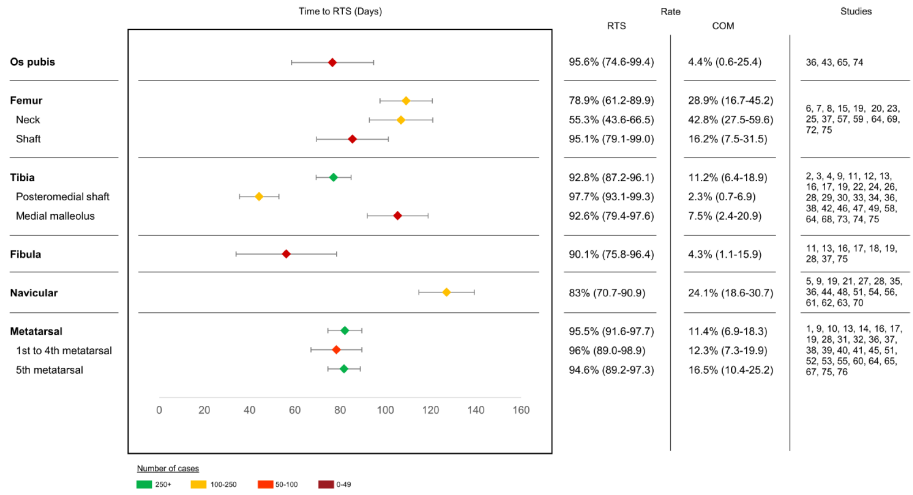
Anatomical Location influences recovery



Hoenig, et al. Return to sport following high-risk and low-risk bone stress injuries. BJSM 2023

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High-Risk bone stress injuries

- **Femoral neck (particularly tension-sided!)**
- **Anterior tibial cortex**
- **Fifth metatarsal metaphyseal-diaphyseal junction**
- **Tarsal navicular**

Hoenig, et al. Delphi on Bone Stress Injuries: BJSM 2025

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Management

Location and severity of injury guides treatment

- All injuries: optimize energy intake, calcium 1200-1300 mg daily, vitamin D 1000 IU daily
- Analgesics rarely needed, avoid NSAIDs
- Activity modification, including boot/crutches in certain high-risk injuries
- Sleep normalization and quality
- Consideration for workup bone density: DXA, medical workup, diet assessment
- Physical therapy and progression to gait retraining
- Refractory cases: consider shockwave or medications

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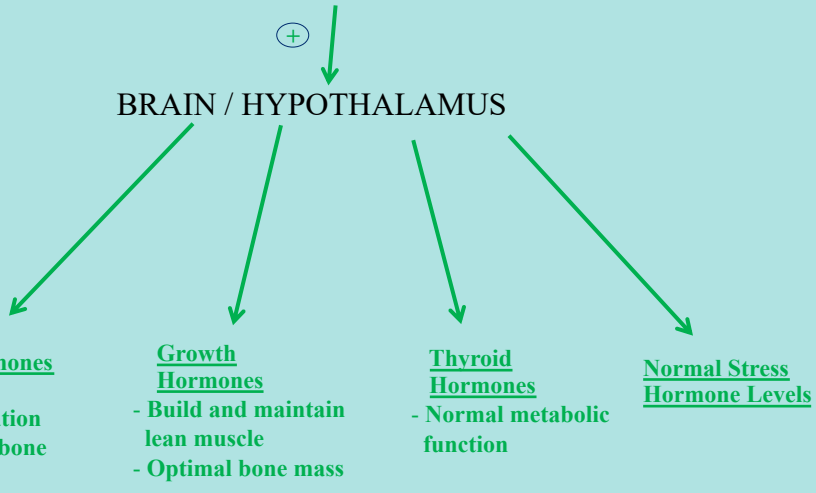
Ensure Adequate energy availability



Chan JL, Mantzoros CS. Lancet 2005;366:74-85.

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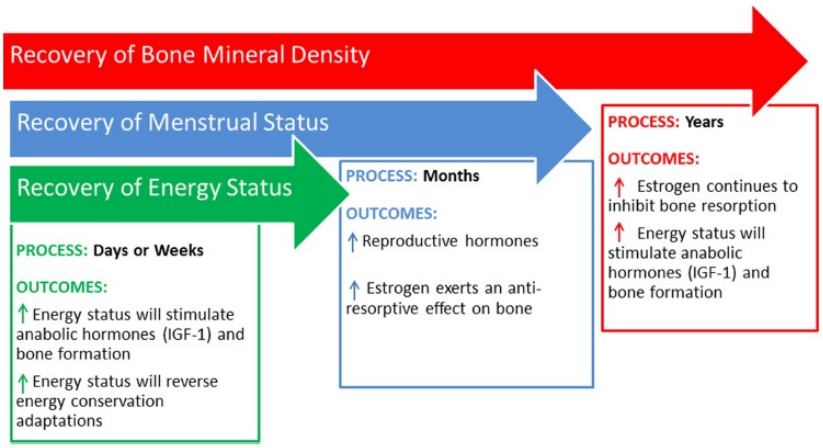
Physiological Response to Adequate Energy Availability



De Souza et al, Female Athlete Triad Coalition Consensus Statement BJSM, 2014.

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Consider DXA to Evaluate Bone Density

- One 'high risk' Triad Risk Factor
  - DSM-5 diagnosis of eating disorder
  - BMI ≤ 17.5 kg/m2, <85% estimated weight, OR recent weight loss ≥ 10% in one month
  - Menarche > 16 years of age
  - Current OR history of < 6 menses over 12 month period
  - 2 prior stress reactions/fracture, 1 high risk stress reaction/fracture, or low energy non-traumatic fracture
- Two or more 'moderate risk' Triad Risk Factors
  - Current or history of disordered eating 6 month
  - BMI between 17.5-18.5, <90% estimated weight, or 5-10% weight loss over 1 month
  - Menarche age 15-16
  - Current OR history 6-8 menses in 12 month period
  - Prior Z-score between -1 and -2
- 1+ non-peripheral, 2+ peripheral traumatic fractures with 1 or more moderate/high risk factor or ≥ 6 months on medications that influence bone should also be considered

De Souza et al. 2014 Female Athlete Triad Coalition Statement, Br J Sports Med, 2014.

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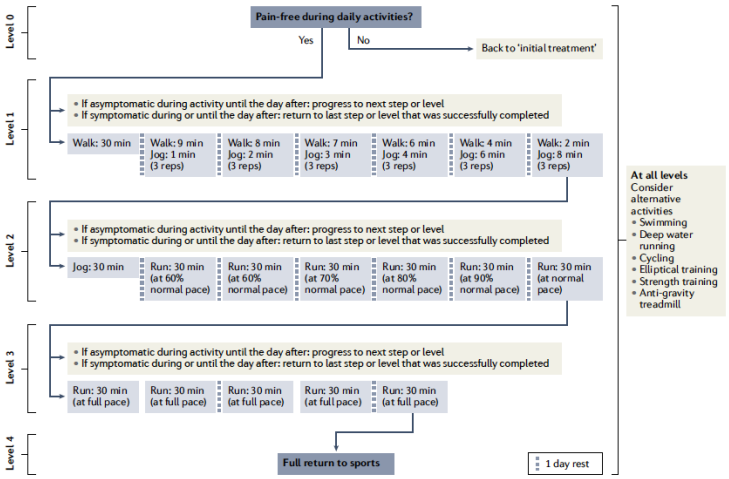
Return to Sport: Pain-Free Progressive Skeletal Loading



Hoenig, Tenforde, Ackerman, Bouxsein, Popp, et al. Nature Reviews Disease Primers, 2022
Warden et al. JOSPT, 2014

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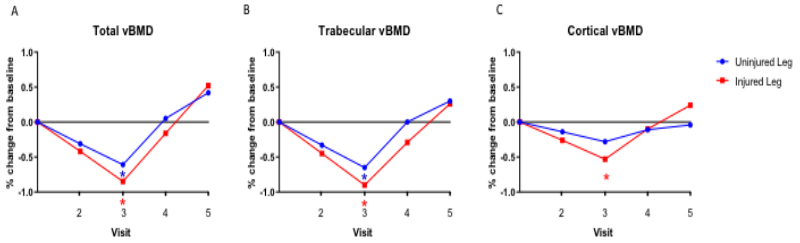
Time to Full Skeletal Remodeling May Take 6 Months



Bone strength in both injured and uninjured limb recovered ~6 months!

Popp, Tenforde, et al. Changes in volumetric bone mineral density over 12 months after tibial bone stress injury diagnosis: Implications for return to sport and military duty. AJSM: 2021.

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Pharmacotherapy

- **Bisphosphonates should be avoided due to concern for teratogens and have a long-have life**
- **Forteo (PTH-rP) is anabolic agent that has not been well-studied in athletes**
- **Consider Transdermal estrogen with micronized progesterone in female athlete with prolonged menstrual dysfunction and bone loss**

Ackerman, et al. Effects of Estrogen Replacement on Bone Geometry and Microarchitecture in Adolescent and Young Adult Oligoamenorrheic Athletes: A Randomized Trial. JBMR, 2020.

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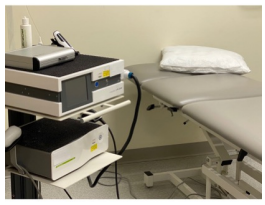
Shockwave Therapy

- **Non-invasive method to stimulate bone healing**
- **Limited evidence in athletes for non-union stress fractures**
- **Athletes: reasonable for predictable healing and to facilitate return to play**



Taki et al. Extracorporeal Shock Wave Therapy for Resistant Stress Fractures. AJSM, 2007.
Moretti, et al. Shock Waves in the Treatment of Stress Fractures. Ultrasound in Med Bio, 2009.
Saxena, et al. Treatment of Medial Tibial Stress Syndrome. JFAS, 2017.

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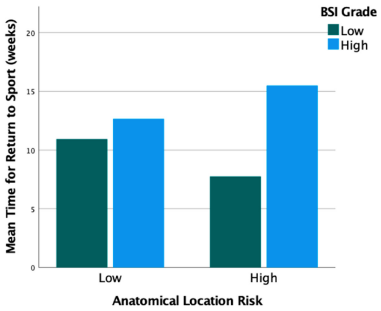
Management of Bone Stress Injuries in Runners

- 41 BSI in 40 runners treated with high energy focused shockwave therapy, including delayed/non-union in 12
- Standard protocol of 3-4 sessions typically once per week, treatment 3000-4000 shocks with goal minimum threshold of 0.30 mJ energy
- Clinical follow-up at 6 weeks to advance rehabilitation program and determine return to sport
- Additional shockwave performed during return to running progression
- 39 of 40 runners had successful return to sport!



Beling, et al. Outcomes Using Focused Shockwave for Treatment of Bone Stress Injury in Runners. Bioengineering, 2023.

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Physical Therapy

- Critical for addressing movement impairments
- Goal to address full kinetic chain
- Gait Retraining with prior bone stress injuries or failure to see improvements with traditional PT program

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Biomechanical risk factors

- **Greater vertical center of mass displacement (Joachim, Gaudette)**
- **Lower step rate (Kliethermes, Gaudette)**
- **Free moment (Milner)**
- **Longer Stride length (Pope)**

Joachim, et al. Preseason Vertical Center of Mass Displacement During Running and Bone Mineral Density Z-Score Are Risk Factors for Bone Stress Injury Risk in Collegiate Cross-country Runners. JOSPT 2023
Milner, et al. Free moment as a predictor of tibial stress fractures. J Biomech, 2006.
Pope, et al. Prevention of pelvic stress fractures in female army recruits. Mil Med, 1999.
Gaudette, et al. Biomechanics associated with bone stress injury in athletes differ by proximal and distal anatomical locations: a cross-sectional analysis. BMJOSEM, 2025.

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Kinematic Variables

- **Peak rearfoot eversion**
- **Peak Hip Adduction**

Milner, et al. Is dynamic hip and knee malalignment associated with stress fractures? Med Sci Sport Exerc, 2005.
Pohl, et al. Biomechanical predictors of retrospective tibial stress fractures in runners, J Biomech 2008.

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Plan should be individualized!

Consensus statement

Youth running consensus statement: minimising risk of injury and illness in youth runners

Brian J Krabak ,[1] William O Roberts ,[2] Adam S Tenforde,[3] Kathryn E Ackerman ,[4] Paolo Emilio Adami ,[5] Aaron L Baggish,[6] Michelle Barrack,[7] John Cianca,[8] Irene Davis,[9] Pierre D'Hemecourt,[4] Michael Fredericson,[10] Joshua T Goldman ,[11] Mark A Harrast,[1] Bryan C Heiderscheit,[12] Karsten Hollander ,[13] Emily Kraus ,[14] Anthony Luke,[15] Emily Miller,[11] Melissa Moyer,[16] Mitchell J Rauh,[17] Brett G Toresdahl,[18] Meagan M Wasfy[6]

Infographic

Infographic. Head to toe considerations for the postpartum endurance athlete

Toqa Afifi ,[1] Michelle T Barrack,[2] Ellen Casey,[3] Molly Huddle,[4] Stephanie A Kliethermes ,[5] Emily Kraus ,[6] Brett G Toresdahl ,[7] Meagan M Wasfy ,[8] Adam S Tenforde [9]

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NARRATIVE REVIEW

PM&R

Bone health and the masters runner

Sara N. Raiser MD[1] | Allison N. Schroeder MD[2] | Richard J. Lawley MD[3] | Adam S. Tenforde MD[4]

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Prevention: Optimize Skeletal Health by Lifestyle

Strategies to optimize skeletal health include:

- **Screening and treatment of the Triad/REDs**
- **Promote bone loading activities at an early age**
- **Ensuring adequate and high-quality sleep**
- **Appropriate nutrition, including adequate energy availability, calcium and vitamin D**

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Future Directions

- Applying current knowledge to enhance skeletal health and injury prevention
- Developing standardized protocols for management
- Build predictive models to modify injury risk
- Deep phenotyping to develop targeted therapies

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Summary

Detailed history, physical exam with imaging can be helpful to confirm diagnosis, location of injury and predict return to activity.

Most injuries will heal with treating risk factors, PT and load management to guide safe return to activity.

Gait retraining, shockwave and other strategies can be considered on individualized case.

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