Disclosures

• No financial disclosures
Objectives

• Review bone anatomy and physiology
• Discuss mechanism and risk factors for stress injury
• Discuss common stress injuries
Bone anatomy

- **Cortical bone**
  - Surrounds the periphery of the bone
  - Dominates diaphysis of long bones
  - Dense, <5% porosity
  - Less metabolically active, less turnover
  - Withstands compressive, but not bending forces
Cortical Bone

Cortical Bone

the periosteum covers the outer surface of bone, and is the site of new bone formation in physiologic remodeling.

the endosteum invests the inner surface of bone and is the site of bone resorption in physiologic remodeling.

Bone anatomy

• Cortical bone
  ◦ Surrounds the periphery of the bone
  ◦ Dominates diaphysis of long bones
  ◦ Dense, <5% porosity
  ◦ Less metabolically active, less turnover
  ◦ Withstands compressive, but not bending forces

• Trabecular bone
  ◦ Central bone
  ◦ Network of struts and plates, oriented to withstand stress
  ◦ 50-90% porosity
  ◦ 20% of bone mass
  ◦ Greater surface area = more turnover
  ◦ Intolerant to compressive forces
Osteoclast/osteoblast

- Osteoclasts
  - Resorb bone

- Osteoblasts
  - Produce new bone
Calcium Homeostasis

C-Cells = Calcitonin

Parathyroid = PTH
Calcium Homeostasis

High Serum Calcium

↑ Calcitonin

↓ Serum Calcium

↓ PTH

+ Calcium Homeostasis

- Calcium Homeostasis
Calcium Homeostasis

Low Serum Calcium

- Calcitonin

↑ Serum Calcium

↑ PTH
Parathyroid Hormone

- ↑ Serum Calcium
- ↑ Intestinal Ca++ Absorption
- ↑ 1,25 OH Vitamin D
- ↑ Bone Ca++ Resorption
- ↑ Ca++ Resorption

↑ Osteoclasts
↓ Parathyroid Hormone
Parathyroid Hormone

- ↓ Intestinal Ca++ Absorption
- ↓ 1,25 OH Vitamin D
- ↓ Serum Calcium
- ↓ Ca++ Resorption
- ↓ Bone Ca++ Resorption

1,25 OH Vitamin D ➔ ↓ Serum Calcium ➔ ↓ Intestinal Ca++ Absorption ➔ ↓ 1,25 OH Vitamin D

Osteoclasts ➔ -

Bone Ca++ Resorption ➔ -

↓ Serum Calcium ➔ ↓ Bone Ca++ Resorption ➔ ↓ Osteoclasts ➔ ↓ 1,25 OH Vitamin D ➔ ↓ Intestinal Ca++ Absorption ➔ ↓ 1,25 OH Vitamin D
Vitamin D

7-Dehydrocholesterol → Cholecalciferol

Dietary Vitamin D

25-OH Vit D → 1,25 OH Vit D

Stimulates Gut Absorption of Ca^{++}

Ergocalciferol
Poor Vitamin D Intake

7-Dehydrocholesterol → Cholecalciferol → Ergocalciferol → 25-OH Vit D → 1,25 OH Vit D → LESS DIETARY CALCIUM ABSORPTION

↓ Dietary Vitamin D
Mechanism of stress fracture

• Stress Fractures are associated with
  ◦ Strenuous activity
  ◦ Repeated activity
  ◦ New or increased activity
Wolff’s Law

• Bone responds to stress by continually remodeling with a resulting INCREASE in the strength of bone.

• Stress reaction/fractures happen when remodeling is unable to keep up with repetitive stress/force.

Risk Factors for Stress Fracture

- **Extrinsic: Individuals anatomic and metabolic characteristics**
  - Hormones
  - Bone quality
  - Anatomic alignment

- **Intrinsic: Factors external to the individual**
  - Training regimen
  - Dietary intake
  - Equipment
  - Training surface
Risk Factors for Stress Fracture

• **Extrinsic:**
  - Menstrual dysfunction/prefmature menopause
  - BMI < 21 [women]
  - Individuals anatomic and metabolic characteristics
  - Anatomic factors vary based on site
  - Overall fitness

• **Intrinsic:**
  - Accelerating training regimen
  - Low vitamin D and calcium intake
  - Hard training surfaces
  - Poor footwear
A Quick Word About Female Athlete Triad
Spectrum of Female Athletic Triad

Low Energy Availability

- Does NOT require an eating disorder

- Inadequate caloric intake:
  - Pathologic caloric restriction
  - Expending more calories than are taken in
Female Athlete Triad

Higher Incidence of Bone Stress Injuries With Increasing Female Athlete Triad-Related Risk Factors

A Prospective Multisite Study of Exercising Girls and Women

Michelle T. Barrack,*† PhD, RD, Jenna C. Gibbs,§ PhD,
Mary Jane De Souza,‖ PhD, Nancy I. Williams,‖ PhD, Jeanne F. Nichols,‖ PhD,
Mitchell J. Rauh,‖ PhD, PT, MPH, and Aurelia Nattiv,‖ MD
Investigation performed at the University of California, Los Angeles, Los Angeles, California, USA; San Diego State University, San Diego, California, USA; Pennsylvania State University, University Park, Pennsylvania, USA; and University of Toronto, Toronto, Ontario, Canada

N = 259 female athletes (age 18 ± 0.3)
Average BMI: 21.5 ± 0.2
65% exercise ≥ 12hrs/wk

Stress injury in 28 participants (10.6%)

BMI < 21 – 15.3%
Oligo/amenorrhea – 10.9%
Exercise ≥ 12hr/wk – 14.7%

BMI < 21
Oligo/amenorrhea
Exercise ≥ 12hr/wk

29.2%
Treatment should focus on ‘restoration or normalization of body weight as the best strategy for successful resumption of menses and improved bone health.’

-- ACSM 2014 Consensus Statement
Improving Bone Health in Female Athlete Triad

- Weight gain and subsequent resumption of menses are key to prevent further loss of bone mass.
  - Amenorrheic women will lose ~2-3% of bone mass per year if untreated

- Pharmacologic Management:
  - Combined oral/non-oral contraceptives

  **OCPs DO NOT RESTORE SPONTANEOUS MENSES and provide a false sense of security**

- OCP therapy is NOT associated with consistent improvement in BMD and may further compromise bone health
- Transdermal estrogen may avoid this further compromise
OCP Inhibition of Bone Health

Growth Hormone

+ 

IGF-I

Increased bone density
OCP inhibition of Bone Health

Growth Hormone

\[ \text{Synthetic function inhibited} \]

Estrogen

First pass metabolism

IGF-I

IGF-I is already decreased in amenorrheic athletes
Common Stress Fractures
Femoral Neck Stress Fracture

• Slow onset groin or lateral hip pain
• Worse with weight bearing
• Recent change in activity intensity/volume
• Insufficiency [elderly] vs Stress [young athletes]
Femoral Neck Stress Fracture

Tension-side

Compression-side

Femoral Neck Stress Fracture

A

Tension-side

B

Compression-side

HIGH RISK
Femoral neck stress fracture

- Always start with an X-ray


<table>
<thead>
<tr>
<th>Radiologic Procedure</th>
<th>Rating</th>
<th>Comments</th>
<th>RRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI hip without IV contrast</td>
<td>9</td>
<td>Timing of the study after injury and age of the patient are important considerations.</td>
<td>O</td>
</tr>
<tr>
<td>Tc-99m bone scan whole body with SPECT hip</td>
<td>6</td>
<td>Because of the high risk of complications, it is not advisable to wait 10-14 days in most cases.</td>
<td>⭐⭐⭐⭐</td>
</tr>
<tr>
<td>X-ray hip repeat in 10-14 days</td>
<td>5</td>
<td>This procedure may be useful if MRI cannot be performed.</td>
<td>⭐⭐⭐⭐</td>
</tr>
<tr>
<td>CT hip without IV contrast</td>
<td>5</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td>MRI hip without and with IV contrast</td>
<td>1</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td>CT hip with IV contrast</td>
<td>1</td>
<td></td>
<td>⭐⭐⭐⭐</td>
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<td>1</td>
<td></td>
<td>⭐⭐⭐⭐</td>
</tr>
<tr>
<td>US hip</td>
<td>1</td>
<td></td>
<td>O</td>
</tr>
</tbody>
</table>

Note: Rating scale: 1, 2, 3 = usually not appropriate; 4, 5, 6 = may be appropriate; 7, 8, 9 = usually appropriate. IV = intravenous; RRL = relative radiation level; SPECT = single-photon emission computed tomography; US = ultrasound.
Treatment

• Compression side:
  • Reduced weight bearing to allow healing
  • Gradual return to activity once pain free

• Tension side:
  • High risk of nonunion
  • Non-weightbearing status
  • Refer to orthopedics
Common Sites of Stress Fracture in the Foot & Ankle

Lower Extremity Stress Fracture Imaging

- Always start with an X-ray

**Variant 9.** Suspected stress (insufficiency) fracture of lower extremity, excluding pelvis and hip. Negative radiographs. Next imaging study.

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<td>MRI lower extremity area of interest (not pelvis or hip) without IV contrast</td>
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<td></td>
<td>○</td>
</tr>
<tr>
<td>X-ray lower extremity area of interest (not pelvis or hip) repeat in 10-14 days</td>
<td>7</td>
<td>This procedure is less sensitive than MRI but is a reasonable alternative.</td>
<td>☢</td>
</tr>
<tr>
<td>CT lower extremity area of interest (not pelvis or hip) without IV contrast</td>
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<td>Varies</td>
<td></td>
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Tibial stress fracture

- Most common stress fracture
- Insidious onset of shin pain worsening with impact activity
  - Provoked with weight bearing, single leg hop
- Posteromedial = low risk (compression)
- **Anterior = high risk**, poor vascular supply and constant posterior muscle forces
  - 5-15%
  - Repetitive jumping, basketball
  - High rate of nonunion
- Risk factors:
  - Intrinsic: pes cavus, small tibial cross-section, foot pronation
  - Extrinsic: hard, hilly running surface; poor shoe quality
Medial Tibial Stress Syndrome

- “Shin Splints”
- Posteromedial tibial pain with tenderness for at least 5cm
- Bone resorption of tibial cortex outpaces bone formation
- Imaging is of limited value
- DDx: Compartment syndrome

Anterior Tibial Stress Fracture

- X-ray has low sensitivity
- “dreaded black line”
- MRI has the best sensitivity

- You don’t always have to image!

Tibial stress fracture

• Posteromedial tibial stress fracture
  ◦ NWB for 6-12 weeks
  ◦ Gradual return to activity when pain free

• Anterior tibial stress fracture
  ◦ NWB for 3-6m
  ◦ Frequent nonunion
  ◦ Surgical fixation is often the preferred first line treatment
Metatarsal stress fracture

- “March fractures”
- Most common stress fracture of the foot
- Typically, mid to distal 2nd and 3rd metatarsals
- X-ray shows subtle periosteal reaction

Case courtesy of A. Prof Frank Gaillard, Radiopaedia.org, rID: 2683
**Metatarsal Stress Fracture**

T2 weighted MR  
T1 weighted MR

Metatarsal Stress Fracture

- **Treatment:**
  - Immobilization with post operative shoe or short-leg walking boot for 4-6 weeks
  - Gradual return to activity once pain free
Navicular stress fracture

• Presents with vague midfoot pain
• Pain with single-leg toe hopping
• Sports that involve explosive sprinting, rapid cutting and jumping
  ◦ Sprinters, tennis players
• Most common in 20ish male athletes
• Risk factors: pes cavus, short first metatarsal, metatarsus adductus
• High risk for non-union
Navicular stress fracture

- X-ray has low sensitivity
  - 66% false negative
- MR is preferred imaging
- CT recommended to characterize fracture
- Treatment with nonweightbearing immobilization for at least 6 weeks
- Refer to foot-ankle orthopedics for management
- May require ORIF

Calcaneal Stress Fracture

- Insidious onset of heel pain with weight bearing
- Pain with calcaneal squeeze test
- DDx: plantar fasciitis, Achilles tendinopathy
Calcaneal Stress Fracture

• Calcaneus = mostly trabecular bone, thin cortex

• Cause: Opposing tension from Achilles tendon and recurrent strike

Calcaneal Stress Fracture

- Often misdiagnosed as plantar fasciitis

Calcaneal Stress Fracture

- Conservative treatment
- Nonweightbearing 4-6 weeks
- Gradual return to activity once pain free
- Rarely require surgical intervention, displacement is rare
Summary

• Stress reactions/fractures often happen after new or increased activity.
• Start evaluation with X-ray and proceed to MRI if needed.
• You don’t always need to image! OK to just treat conservatively like stress fracture is present.
• Treatment: Make pain free (reduced activity, nonweightbearing) and then slowly reintroduce activity
Questions?


• McInnis KC, Ramey LN. High Risk Stress Fractures: Diagnosis and Management. PMR 8 (2016) S113-S124.