Advances in Optimizing Bone Health in Runners

Adam S. Tenforde, M.D.

Assistant Professor, Spaulding Rehabilitation Hospital, Department of Physical Medicine and Rehabilitation; Director of Running Medicine, Spaulding National Running Center, Cambridge, MA
Conflicts of Interest

Nothing to disclose
About Me

All-American runner and member of 3 National championship teams at Stanford

Competed in Olympic Trials in 10,000 meters

Enjoy running Boston Marathon annually

Wife Kate Tenforde Olympian 10,000 meters at Athens 2004
Introduction

- Bone plays a critical role in health of athletes including runners.

- Consequences of impaired bone density including risk for recurrent bone stress injuries.
Screening for impaired bone health historically was more limited to older females and those recognized with disease states affecting bone.

Bone health has received greater attention in younger populations, especially given recognition of health issues in female athletes.
Objectives

▪ Describe the influence of sports participation and loading activities on bone accrual and lifelong bone health.

▪ Discuss risk factors for impaired bone health in runners, including the Female Athlete Triad.

▪ Apply knowledge to treatment and develop prevention strategies.
Influence of loading on bone development

- Wolff’s Law describes how bone adapts to mechanical loading.

- Muscle-bone unit theory in children highlights the importance of muscle activity on bone development.

Athletes who participate in weight bearing sports have ~10% greater bone mass than non-athletes.

• Early puberty represents the most critical time to participate in sports that emphasize weight-bearing and high-impact exercises.

• 26% of final bone mass is acquired between ages 11.5-13.5 in girls and 13-15 in boys.

The Challenge

- Up to 90% of peak bone mass is reached by ages 18 and 20 in females and males, respectively.

Influence of Sports Participation on Bone Health in the Young Athlete: A Review of the Literature

Adam S. Tenforde, MD, Michael Fredericson, MD

PM R 2011;3:861-867
Types of loading

▪ High impact
  -Gymnastics, karate, volleyball, other jumping sports

▪ Multidirectional impact
  -Soccer, basketball, racquet games, speed skating

▪ Repetitive low-impact
  -Distance running

▪ Non-impact
  -Swimming, cycling
High and Multidirectional impact loading

- High-impact and multidirectional-impact loading activities enhance bone density and bone geometry, particularly in anatomic locations directly loaded by those sports.

Repetitive low-impact loading

- Participation in long-distance running may lead to modest improvements in BMD and geometry over non-impact sports and sedentary individuals; however, the results are not consistent.

Non-impact loading

- Participation in non-impact sports (cycling, swimming) may be associated with lower BMD and impaired bone strength than sedentary controls.

Ball Sports

Running

▪ 1000 loading cycles per mile

▪ Peak impact 2-2.6 times body weight

▪ Most loading is vertical and within the sagittal plane

Soccer

▪ 1000-1500 loading cycles per training session

▪ Peak impact range 2-5 times body weight

▪ Multidirectional loading from stopping, jumping and cutting
Ball Sports

Ball sports participation may reduce future fracture risk!

- Milgrom reported military recruits who participated in 2 or more years of ball sports had 42-84% reduction in stress fractures.
- Fredericson found 50% reduction in track and field athletes who participated in ball sports.
- Tenforde identified 81% reduction in stress fractures in male runners who played basketball.

Both biomechanical and biological factors contribute to overall bone health.

Genetics may explain a majority of total bone mass.

Sex-specific risk factors are important to identify, especially in younger athletes and active individuals at risk for fracture.
Female Athlete Triad

Low Food Intake

- Sex Hormones
  - Menstrual dysfunction
  - Reduced bone mass

- Growth Hormones
  - Loss of muscle
  - Reduced bone mass

- Thyroid Hormones
  - Suppressed metabolism

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

BRAIN / HYPOTHALAMUS

Adequate Food

- Sex Hormones
  - Normal menstruation
  - Optimal bone mass

- Growth Hormones
  - Build and maintain lean muscle
  - Optimal bone mass

- Thyroid Hormones
  - Normal metabolic function

- Normal Stress Hormone Levels

BRAIN / HYPOTHALAMUS

### Risk Stratification

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Low Risk = 0 points each</th>
<th>Moderate Risk = 1 point each</th>
<th>High Risk = 2 points each</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low EA with or without DE/ED</strong></td>
<td>□ No dietary restriction</td>
<td>□ Some dietary restriction†; current/past history of DE;</td>
<td>□ Meets DSM-V criteria for ED*</td>
</tr>
<tr>
<td><strong>Low BMI</strong></td>
<td>□ BMI ≥ 18.5 or ≥ 90% EW** or weight stable</td>
<td>□ BMI 17.5 &lt; 18.5 or &lt; 90% EW or 5 to &lt; 10% weight loss/month</td>
<td>□ BMI ≤ 17.5 or &lt; 85% EW or ≥ 10% weight loss/month</td>
</tr>
<tr>
<td><strong>Delayed Menarche</strong></td>
<td>□ Menarche &lt; 15 years</td>
<td>□ Menarche 15 to &lt; 16 years</td>
<td>□ Menarche ≥ 16 years</td>
</tr>
<tr>
<td><strong>Oligomenorrhea and/or Amenorrhea</strong></td>
<td>□ &gt; 9 menses in 12 months*</td>
<td>□ 6-9 menses in 12 months*</td>
<td>□ &lt; 6 menses in 12 months*</td>
</tr>
<tr>
<td><strong>Low BMD</strong></td>
<td>□ Z-score ≥ -1.0</td>
<td>□ Z-score -1.0*** &lt; - 2.0</td>
<td>□ Z-score ≤ -2.0</td>
</tr>
<tr>
<td><strong>Stress Reaction/Fracture</strong></td>
<td>□ None</td>
<td>□ t</td>
<td>□ ≥ 2; ≥ 1 high risk or of trabecular bone sites†</td>
</tr>
</tbody>
</table>

**Cumulative Risk** (total each column, then add for total score)

- **Low Risk**: ___ points + ___ points + ___ points = ___ Total Score
- **Moderate Risk**: ___ points + ___ points + ___ points = ___ Total Score
- **High Risk**: ___ points + ___ points + ___ points = ___ Total Score

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### Risk Stratification

<table>
<thead>
<tr>
<th>Cumulative Risk Score*</th>
<th>Low Risk</th>
<th>Moderate Risk</th>
<th>High Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Clearance</strong></td>
<td>0 – 1 point</td>
<td>□</td>
<td></td>
</tr>
<tr>
<td><strong>Provisional/Limited Clearance</strong></td>
<td>2 – 5 points</td>
<td>□ Provisional Clearance</td>
<td></td>
</tr>
<tr>
<td><strong>Restricted from Training and Competition</strong></td>
<td>≥ 6 points</td>
<td></td>
<td>□ Restricted from Training/Competition-Provisional</td>
</tr>
</tbody>
</table>

Association of the Female Athlete Triad Risk Assessment Stratification to the Development of Bone Stress Injuries in Collegiate Athletes

Adam S. Tenforde,* MD, Jennifer L. Carlson,† MD, Audrey Chang,‡ BA, Kristin L. Sainani,§ PhD, Rebecca Shultz,‖ PhD, Jae Hyung Kim,¶ MD, Phil Cutti,‖ MS, Neville H. Golden,† MD, and Michael Fredericson¶#
Methodology

- Population of 323 Division 1 Collegiate Athletes
- Female Athlete Triad Risk Assessment Score
- Outcome association of risk category to bone stress injury
## Results

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

<table>
<thead>
<tr>
<th>Sport</th>
<th>No. of Athletes</th>
<th>Low Risk</th>
<th>Moderate Risk</th>
<th>High Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basketball</td>
<td>9</td>
<td>9 (100)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Crew/rowing</td>
<td>30</td>
<td>27 (80)</td>
<td>3 (20)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Cross-country</td>
<td>47</td>
<td>24 (51)</td>
<td>16 (34)</td>
<td>7 (14.9)</td>
</tr>
<tr>
<td>Fencing</td>
<td>5</td>
<td>5 (100)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Field hockey</td>
<td>21</td>
<td>16 (76.2)</td>
<td>5 (23.8)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>16</td>
<td>7 (43.8)</td>
<td>9 (56.2)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Lacrosse</td>
<td>16</td>
<td>8 (50)</td>
<td>8 (50)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Sailing</td>
<td>3</td>
<td>2 (66.7)</td>
<td>1 (33.3)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Soccer</td>
<td>5</td>
<td>4 (80)</td>
<td>1 (20)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Softball</td>
<td>19</td>
<td>16 (84.2)</td>
<td>3 (15.8)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Swimming/diving</td>
<td>21</td>
<td>12 (57.1)</td>
<td>8 (38.1)</td>
<td>1 (4.8)</td>
</tr>
<tr>
<td>Synchronized swimming</td>
<td>11</td>
<td>9 (81.8)</td>
<td>1 (9.1)</td>
<td>1 (9.1)</td>
</tr>
<tr>
<td>Track&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4</td>
<td>4 (100)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Tennis</td>
<td>7</td>
<td>5 (71.4)</td>
<td>2 (28.6)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Volleyball</td>
<td>9</td>
<td>6 (66.7)</td>
<td>3 (33.3)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Water polo</td>
<td>16</td>
<td>15 (93.8)</td>
<td>1 (6.3)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>
## Results

### Risk Categories for Subsequent BSI by Sport Participation Status

<table>
<thead>
<tr>
<th>Category</th>
<th>No. of Athletes</th>
<th>BSI, n (%)</th>
<th>Risk Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All athletes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low risk</td>
<td>169</td>
<td>11 (4.7)</td>
<td>Reference population</td>
</tr>
<tr>
<td>Moderate risk</td>
<td>61</td>
<td>18 (16.9)</td>
<td>3.4 (1.5-7.8)</td>
</tr>
<tr>
<td>High risk</td>
<td>9</td>
<td>7 (63.6)</td>
<td>10.4 (4.4-24.7)</td>
</tr>
<tr>
<td><strong>Cross-country runners</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low risk</td>
<td>24</td>
<td>3 (12.5)</td>
<td>Reference population</td>
</tr>
<tr>
<td>Moderate risk</td>
<td>16</td>
<td>8 (50)</td>
<td>4.0 (1.2-12.8)</td>
</tr>
<tr>
<td>High risk</td>
<td>7</td>
<td>5 (71.4)</td>
<td>5.7 (1.5-13.8)</td>
</tr>
<tr>
<td><strong>Athlete risk adjusting for cross-country participation and age</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate risk</td>
<td></td>
<td></td>
<td>2.6 (1.3-5.5)</td>
</tr>
<tr>
<td>High risk</td>
<td></td>
<td></td>
<td>3.8 (1.8-8.0)</td>
</tr>
</tbody>
</table>

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

**Anatomic Distribution of BSI by Risk Category**

<table>
<thead>
<tr>
<th>Location</th>
<th>Low Risk (n = 9 Athletes)</th>
<th>Moderate Risk (n = 11 Athletes)</th>
<th>High Risk (n = 5 Athletes)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foot</strong></td>
<td>Metatarsal (n = 4)</td>
<td>Metatarsal (n = 2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tarsal navicular (n = 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cuboid (n = 1)</td>
<td>Calcaneus (n = 1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Talus (n = 1)</td>
<td>Talus (n = 1)</td>
<td></td>
</tr>
<tr>
<td><strong>Nonfoot</strong></td>
<td>Ulna (n = 1)</td>
<td>Tibia (n = 2)</td>
<td>Tibia (n = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Femoral shaft (n = 1)</td>
<td>Femoral shaft (n = 2)</td>
</tr>
<tr>
<td><strong>Pelvis/hip</strong></td>
<td>Femoral neck (n = 1)</td>
<td>Sacrum (n = 5)</td>
<td>Sacrum (n = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ilium (n = 1)</td>
</tr>
</tbody>
</table>

Cortical Rich Bone → Trabecular Rich Bone

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

- Case reports suggest male athletes may have a combination of disordered eating, hypogonadotrophic hypogonadism, and impaired bone health.

- These parallel characteristics of the Triad in female athletes, although the prevalence of this condition is likely lower in male athletes.


What about Male Athletes?

Parallels with the Female Athlete Triad in Male Athletes

Adam S. Tenforde\textsuperscript{1} · Michelle T. Barrack\textsuperscript{2} · Aurelia Nattiv\textsuperscript{3} · Michael Fredericson\textsuperscript{4}

Parallels of Female Athlete Triad in Male Athletes

- Low energy availability with or without an eating disorder
- Hypothalamic functional amenorrhea
- Low bone Mineral density
- Hypogonadotrophic hypogonadism
- Low bone Mineral density

Four Risk Factors for low BMD

▪ Running > 30 miles per week
▪ History of stress fracture
▪ Less than 85% expected body weight
▪ < 1 serving of daily calcium

37 male athletes with DXA obtained following BSI, site of injury separated by sport

- trabecular-rich sites included sacrum, pelvis, femoral neck and calcaneus
- Runners 2.6-fold increased risk for low BMD (defined as BMD Z-score < -1.0)
- Trabecular-site BSI had associated 2.9-fold higher rate of low BMD

Sports providers can play a critical role in recognizing risk factors for runners to optimize skeletal health and reduce risk for injury. Runners with history of high risk BSI or recurrent injuries require further evaluation of bone health.
Prevention

- Screening including Female Athlete Triad Risk Stratification to address biological risk factors for injury.
- Ensuring adequate calcium and vitamin D is important.
- Biomechanical factors to consider include encouraging softer and well-aligned landings.
- Adequate sleep may reduce injury risk.
- Appropriate loading activities during ‘critical window’ of adolescence may promote optimal bone health.
Most female athletes should have their first menstrual periods by age 15.

Irregular/cessation of menstrual periods or changes with intense training may suggest inadequate energy availability.

All athletes who sustain a stress fracture should be screened for Triad risk factors, in addition to annual PPE. Moderate or high risk scores need to be aggressively managed.
High levels of calcium intake (at least 1500 mg/day) and 800 IU of Vitamin D may be protective against development of stress fractures.

Tenforde et al. PMR Journal, 2010
In an 8-week trial of supplementation with 2000 mg calcium and 800 IU of vitamin D in female military recruits, there was a 20% reduction in fractures.

Calcium

- Fracture risk decreased by 62% per additional cup of skim milk consumed per day.

Women who consumed less than 800 mg of calcium per day had nearly 6 times the rate of stress fracture than women who consumed more than 1500 mg of calcium.

Foot strike patterns

RFS
MFS
FFS

Vertical GRF (N/BW)

% Stance
Foot strike patterns
Inadequate sleep has been found to contribute to increased bone turnover and risk for injury.

18-year old male military recruits were divided into 3 experimental conditions (sleep deprivation 62 hours, 6-hours sleep vertical position, 6-hours sleep horizontally) with measurements of urinary calcium levels and BMD over 7-day period.

40% of sleep deprivation (SD) and vertical sleepers (VS) had 170% and 68% increase in urinary calcium excretion and hydroxyproline.

Both SD and VS populations experienced 5% reduction in BMD compared to non-responders.

Reduction of military basic training marching and 6 hours minimum sleep requirement reduced stress fracture incidence by 62% compared to historical cohort.

Stress fractures sustained were lower grade.

Military recruits who remained injury-free experienced 0.5% increase in bone strength.

Promote ball sports/jumping activities at an early age!

- Applying principles of high impact, ground reaction forces may result in stronger and fracture resistant bones in the setting of optimal nutrition and when performed at a young age.

Physical Education Jumping Intervention

Jumping activities involve high ground reaction forces delivered at a rapid rate.

- A seven-month intervention of box jump in school-aged children had durable benefits 8 years later.
- Ground reaction forces >3.5x body weight with peak force <0.1 seconds may be most effective stimuli.

Summary

- Weight bearing activities are critical during development to promote bone health

- Biological risk factors including the Triad are important to consider, especially in active individuals
Prevention strategies include:

- Screening and treatment of the Triad
- Promoting bone loading activities at an early age
- Ensuring adequate and high quality sleep
- Appropriate nutrition, including adequate energy availability, calcium and vitamin D
Thank you!

@AdamTenfordeMD