Prevention of Stress Fractures in Young Runners

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Objectives

- Provide background on risk factors for stress fracture injuries and low bone density in runners
- Discuss injury prevention strategies in young runners

Stress Fractures

Failure of skeleton to withstand *submaximal* forces acting over *time*

Introduction

- Stress fractures account for up to 20% of all sports injuries.

Fredericson et al. Stress Fractures in Athletes. Top Mag Reson Imag, 2007

Incidence

- In track-and-field athletes, stress fractures account for 34% injuries in women and 24% in men.

Fredericson et al. Stress Fractures in Athletes. Top Mag Reson Imag, 2007

Growing Up Today Study

Field et al. Prospective study of physical activity and risk of developing a stress fracture among preadolescent and adolescent girls? Arch Pediatr Adolesc Med, 2011

Epidemiology of Stress Fractures in High School Runners

- Study evaluating stress fractures across high school sports found that girls were more likely to fracture than boys
- Girls' and boys' cross country were two of the top three highest rates of stress fracture

Changstrom, et al. Epidemiology of Stress Fracture Injuries Among US High School Athletes 2005-2006 Through 2012-2013. Am J Sports Med, 2015

Risk Factors

Female Athlete Triad

- Energy imbalance
- Menstrual dysfunction
- Low bone mineral density

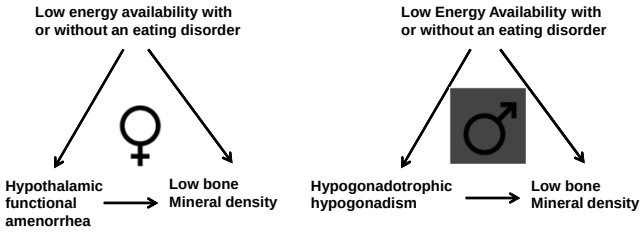
ACSM Position Statement, 2007

Male Athlete Triad?

- 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

Burge, et al. Idiopathic hypogonadotropic hypogonadism in a male runner is reversed by clomiphene citrate. Fertility and sterility, 1997.
Thienpont, et al. Stress fracture of the inferior and superior pubic ramus in a man with anorexia nervosa and hypogonadism. Acat orthopaedic Belgica, 2000.

Parallels of Female Athlete Triad in Male Athletes



Tenforde, et al. Parallels of Female Athlete Triad in Male Athletes: under review.

Sports Influence Bone Health

- Athletes who participate in weight bearing sports have ~10% greater bone mass than non-athletes.
- The Triad can predispose to low bone mass.

Fehling, et al. A comparison of bone mineral densities among female athletes in impact loading and active loading sports. Bone, 1995.
Risser, et al. Bone density in eumenorrheic female college athletes. Med Sci Sports Exerc, 1990.
Nattiv et al. American College of Sports Medicine Position Stand: The Female Athlete Triad. Med Sci Sports Exer, 2007.

Influence of Bone Loading

- Wolff's Law describes how bone adapts to mechanical loading
- Muscle-bone unit theory in children

Frost and Schoenau. The "muscle-bone unit" in children and adolescents: a 2000 overview. J Pediatr Endocrinol Metab 2000

The Challenge

– 90% of peak bone density should be attained by age 18 in females and age 20 in males.

Baxter-Jones, et al. Bone mineral accrual from 8 to 30 years of age. JBMR, 2011

Bone Mineral Density

Early Exposure

- 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.

MacKelvie et al. Is there a critical period for bone response to weight-bearing exercise in children and adolsecents? Br J Sports Med, 2002

Can We Modify Bone Development in Young Athletes?

Tenforde & Fredericson. Influence of sports participation on bone health in the young athlete. PMR Journal, 2011

Types of Loading Activities

- High-impact
  - Gymnastics, karate, volleyball and other jumping sports
- Multidirectional-impact
  - Soccer, basketball, raquet games, speed skating
- Repetitive low-impact
  - Distance running
- Non-impact
  - Swimming, cycling

High Impact 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.

Ferry et al. Bone geometry between elite female soccer players and swimmers. J Bone Miner Metab, 2011
Nikander et al. Femoral neck structure in athletes subjected to different loading modalities. J Bone Miner Res, 2005
Nikander et al. Cross-sectional geometry of tibia in athletes subjected to different exercise. Osteoporosis Int, 2010
Hind et al. Bone cross-sectional geometry in male runners, gymnasts, and swimmers. Eur J Appl Physiol, 2012

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.

Duncan et al. BMD in adolescent female athletes. Med Sci Sports Exerc, 2002
Barrack et al. Suppressed bone mineral accrual in female adolescent runners. J Bone Miner Res, 2010

Non-Impact Loading

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

Smathers et al. Bone density in competitive cyclists and untrained controls. Med Sci Sports Exer, 2009

Running

- 6000 loading cycles on each leg per typical training session
- Peak impact forces on one leg reach 2.2-2.6 times BW
- Acceleration and deceleration occurs primarily in the vertical direction near the saggital plane

Soccer

- 1000-1500 loading cycles per training session
- Peak impact forces on one leg range from 2.0-5.0 times BW
- Stopping, cutting, and jumping produce forces from all directions

Running vs. Soccer

Fredericson et al. Regional Bone Mineral Density. Br J Sports Med, 2007

Role of Bone Loading

- Bone exhibits *cellular desensitization* to a continuous mechanical load, exhibiting a threshold above which additional strain exposures do not benefit bone.

Burr et al. Effects of biomechanical stress on bones. Bone, 2002

Prevention of Stress Fractures?

Israeli Military Study

Recruits with a history of playing ball sports for 2 years had 46-84% reduction in stress fractures.

vs

Runners had the same incidence as sedentary controls.

Milgrom et al. Using bone's adaptation ability to lower the incidence of stress fractures. AJSM, 2000

Background

Higher impact forces and higher rates of force development create stiffer, stronger, more fracture resistant bones.

Milgrom et al. In-vivo strain measurements to evaluate the strengthening potential of exercises on the tibial bone JBJS, 2000

Calbet et al. High femoral bone mineral content and density in male football (soccer) players. MSSE, 2001

Ball Sports Study

- Retrospective study of 156 elite female and 118 elite male distance runners, ages 18-44
- Detailed evaluation of previous participation in soccer or basketball

Fredericson et al. Effects of ball sports on future risk of stress fracture in runners. CJSM, 2005

Ball Sports Study

- Previous participation in ball sports was associated with a 50% reduction in developing a stress fracture in both sexes.
- Dose-dependent with a reduction of 13% per year played.
- Females with menstrual irregularities *did not* confer benefits from ball sports.

Current Research

Identifying Modifiable Risk Factors For Stress Fractures in Young Runners

Tenforde, Fredericson et al. Identifying Sex Specific Risk Factors for Stress Fractures in Adolescent Runners. MSSE, 2013.

Tenforde, et al. MSSE 2013

Identifying Sex-Specific Risk Factors for Stress Fractures in Adolescent Runners

ADAM S. TENFORDE[1], LAUREN C. SAYRES[2], MARY LIZ MCCURDY[2], KRISTIN L. SAINANI[3], and MICHAEL FREDERICSON[1]

Methodology

- Study design: prospective observational cohort in 748 high school athletes
- Method: baseline questionnaire and monitoring for prospective stress fracture injuries (SFI)
- Outcome: relationship of baseline characteristics to development of SFI

Prospective Stress Fractures

- 5.4% of females (N=23)
- 4.0% males (N=11)

Results: Female Stress Fractures

Variable	Univariate	Multivariate model
Fracture History	6.54 (2.63, 16.25)	5.83 (2.32, 14.67)
Previous participation in dance or gymnastics	4.21 (1.66, 10.69)	3.13 (1.20, 8.15)
Lean (BMI<19 kg/m^2)	2.76 (1.18, 6.46)	2.67 (1.11, 6.41)
Late menarche (15 years or older)	3.90 (1.64, 9.31)	2.49 (1.01, 6.17)
Current amenorrhea	1.96 (0.84, 4.54)	--
Number of periods in the previous year, per additional period	0.89 (0.80, 0.98)	--
Prior diagnosis of anorexia or bulimia	5.34 (1.24, 22.96)	--
Previous participation in tennis[a]	3.04 (1.26, 7.33)	--

Results: Male Stress Fractures

Variable	Univariate	Multivariate model
Fracture History	7.29 (1.93, 27.5)	5.73 (1.52, 21.67)
Previous participation in basketball	0.19 (0.05, 0.70)	0.18 (0.05, 0.69)
Seasons of competition during follow-up	2.37 (1.10, 5.11)	2.35 (1.12, 5.00)
Plyometrics	2.93 (0.89, 9.63)	--
Mileage, per additional 10 km of running per week	1.16 (0.97, 1.39)	--
Mile time, per 10 seconds faster	1.13 (0.95, 1.33)	--
Height, per additional inch	1.14 (0.95, 1.37)	--

Conclusions

- Both young females and males are susceptible to stress fracture injuries.
- In females, risk factors associated include prior fracture, low BMI, late menarche and sports emphasizing leanness.
- Males who previously fracture are at increased risk for stress fractures, whereas prior basketball may be protective.

Identifying Sex-Specific Risk Factors For Low Bone Mineral Density in Adolescent Runners

Tenforde, et al American Journal of Sports Medicine: in press, 2015.

Methodology

- Study design: cross-sectional evaluation of risk factors to low bone mineral density (BMD) Subjects: 136 athletes (N=94 females, N=42 males)
- Method: online questionnaire and food frequency questionnaire to characterize risk factors for low BMD and collection of bone density using DXA.
- Outcome: association of baseline characteristics to lower BMD values. Identify clinical risk factors for low BMD (defined BMD *z*-score ≤ -1)

Results

- 13 of 91 girls and 9 of 42 boys met criteria for low BMD for age (BMD *z*-score ≤ -1)
- Body composition (higher lean mass, BMI, and increased android to gynoid fat mass ratio (A:G)) were all associated with higher BMD values
- Participation in basketball, soccer, and plyometrics were each associated with higher BMD, although each did not reach statistical significance (P > 0.05)

Results: Female risk factors for lower BMD

Risk Factor	LS BMD *z*-score ($n = 91$)	TBLH BMD *z*-score ($n = 89$)
Android:Gynoid Fat Ratio	0.49	0.17
Fat mass (per SD)	-0.30*	---
Height (per SD)	0.33**	---
Lean mass (per SD)	---	0.33***
Current MI (yes/no)	-0.03	
History of fracture (yes/no)	0.43	
Interaction of MI with history of fracture[a] (yes/no)	-1.18*	---
Later age of menarche (yes/no)	---	-0.26***
Cups of Milk per day (per SD)	---	0.19**

*$P < 0.05$
**$P < 0.01$
***$P < 0.001$

Results: Male risk factors for lower BMD

Risk Factor	LS BMD *z*-score ($n = 42$)	TBLH BMD *z*-score ($n = 42$)
BMI *z*-score[a]	0.57**	0.60***
Belief that "thinner is faster"[a,b]	-0.90**	-0.46*
Android:Gynoid Fat Ratio	---	0.25**

*$P < 0.05$
**$P < 0.01$
***$P < 0.001$

Results: Risk factors for low bone mass for age

Sex-specific risk factors for BMD z-scores ≤ -1	
Girls	BMI ≤ 17.5 kg/m2, menstrual irregularity and history of fracture
Boys	BMI ≤ 17.5 kg/m2, belief that "thinner is faster"[b]

Conclusions

- Both female and male adolescent runners are at risk for impaired bone health
- In girls, risk factors for lower BMD include lower A:G ratio, current menstrual irregularity and history of fracture, delayed menarche and drinking less milk
- Boys who believe "thinner is faster" and have lower BMI have lower BMD

Conclusions

- Clinical predictors of low BMD (defined BMD *z*-score ≤ -1):
  - Girls: menstrual irregularities with history of fracture OR BMI ≤ 17.5 kg/m^2
  - Boys: belief "thinner is faster" OR BMI ≤ 17.5 kg/m^2
- We can use these findings to identify and target treatment for young runners at risk for low BMD

Influence of calcium and vitamin D on stress fracture prevention

Tenforde, Fredericson, et al. PMR Journal, 2010

Relationship of Calcium and Vitamin D in the Prevention of Stress Fracture Injuries in the Young Athlete

- 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, Fredericson, et al. PMR Journal, 2010

Calcium and vitamin D supplementation reduce incidence of stress fractures

- 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.

Lappe et al. Calcium and vitamin d supplementation decreases incidence of stress fractures in female navy recruits. J Bone Miner Res, 2008

Nutritional factors influence change in bone density and stress fracture risk

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

Nieves, Sainani, et al. Nutritional factors that influence change in bone density and stress fracture risk among young female cross-country runners. PMR Journal, 2010

Continued..

- 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.

Summary

- Sports participation with emphasis on jumping and impact loading confers greatest bone benefits.
- Cross-over effects of ball sports may protect against future stress fractures. Triad must be addressed to confer these benefits.
- Calcium and vitamin D are both important to optimize bone health.

Application to Young Runners

- Recognition of Female Athlete Triad Risk Factors especially changes in menstrual health
- Ensure adequate nutrition including calcium and vitamin D
- Encourage variety of sports participation in young runners in addition to running, including ball sports

Female Athlete Triad

- Most female runners should have her first menstrual period by age 15
- Irregular/cessation of menstrual periods or changes with intense training may suggest inadequate energy availability
- All runners who sustain a stress fracture should be screened for Triad risk factors

Nutrition Considerations

- All runners should be encouraged to consumed calcium-rich foods and ensure target calcium and vitamin D intake recommendations
- Adequate energy availability is important for overall health of both female and male runners

RDA: Calcium

Female and male runners ages 9-18 require 1300 mg of calcium daily

Committee to Review Dietary Reference Intakes for Vitamin D and Calcium, Food and Nutrition Board, Institute of Medicine. 2010

RDA: Vitamin D

Children and adolescent female and male runners require 600 IU of vitamin D daily

Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for calcium and Vitamin D. National Academy Press, 2010

Impact Loading Sports Improve Skeletal Health

- Sports specialization should be avoided in young athletes
- Sports involving jumping and multidirectional loading may be beneficial for optimizing skeletal health and prevention of future stress fractures

Ball Sports

- Ball sports and other jumping, multidirectional loading sports are associated with improved bone health
- Two or more years of ball sports during adolescence have been observed to reduce future stress fracture risk

Prehabilitation to prevent stress fractures and promote bone health

- 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

Tenforde, Fredericson, et al. Participation in Ball Sports May Represent a Prehabilitation Strategy to Prevent Future Stress Fractures and Promote Bone Health in Young Athletes. PM&R Journal: In press

Prehabilitation to prevent stress fractures and promote bone health

- Jumping activities involve high ground reaction forces delivered at a rapid rate.
- Ground reaction forces >3.5x body weight with peak force <0.1 seconds may be most effective stimuli.

Gunter et al. Jump starting skeletal health. Bone, 2008
Gunter et al. Impact exercise increases BMD during growth: an 8-year longitudinal study. JBMR, 2008.
Hind and Burrows. Weight-bearing exercise and bone mineral accrual in children and adolescents: a review of controlled trials. Bone 2007.

Overuse Injuries and Burnout in Youth Sports: A Position Statement from the American Medical Society for Sports Medicine

John P. DiFiori, MD,* Holly J. Benjamin, MD,† Joel Brenner, MD, MPH,‡ Andrew Gregory, MD,§ Neeru Jayanthi, MD,¶ Greg L. Landry, MD,‖ and Anthony Luke, MD, MPH**

(*Clin J Sport Med* 2014;24:3–20)

DeFiori, et al.

- Prevalence of overuse injury varies, highest in runners (68%)
- The strongest risk factor for future overuse injury is prior injury
- Early sports-specialization may not lead to future success in running
- Preparticipation screening and evaluation for risk factors is critical

DeFiori, et al. Overuse Injuries and Burnout in Youth Sports. Clin J Sports Med, 2014.

DeFiori, et al.

- Position statement by AMSSM is available for free online:
- http://pdfs.journals.lww.com/cjsportsmed/2014/01000/Overuse_Injuries_and_Burnout_in_Youth_Sports___A.2.pdf

DeFiori, et al. Overuse Injuries and Burnout in Youth Sports. Clin J Sports Med, 2014.

The Healthy Runner Project: translating running science into clinical practice

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