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

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Background: The female athlete triad (referred to as the triad) contributes to adverse health outcomes, including bone stress injuries (BSIs), in female athletes. Guidelines were published in 2014 for clinical management of athletes affected by the triad.

Purpose: This study aimed to (1) classify athletes from a collegiate population of 16 sports into low-, moderate-, and high-risk categories using the Female Athlete Triad Cumulative Risk Assessment score and (2) evaluate the predictive value of the risk categories for subsequent BSIs.

Study Design: Cohort study; Level of evidence, 3.

Methods: A total of 323 athletes completed both electronic preparticipation physical examination and dual-energy x-ray absorptiometry scans. Of these, 239 athletes with known oligomenorrhea/amenorrhea status were assigned to a low-, moderate-, or high-risk category. Chart review was used to identify athletes who sustained a subsequent BSI during collegiate sports participation; the injury required a physician diagnosis and imaging confirmation.

Results: Of 239 athletes, 61 (25.5%) were classified into moderate-risk and 9 (3.8%) into high-risk categories. Sports with the highest proportion of athletes assigned to the moderate- and high-risk categories included gymnastics (56.3%), lacrosse (50%), cross-country (48.9%), swimming/diving (42.9%), sailing (33%), and volleyball (33%). Twenty-five athletes (10.5%) assigned to risk categories sustained ≥1 BSI. Cross-country runners contributed the majority of BSIs (16; 64%). After adjusting for age and participation in cross-country, we found that moderate-risk athletes were twice as likely as low-risk athletes to sustain a BSI (risk ratio [RR], 2.6; 95% confidence interval [95% CI], 1.3-5.5) and high-risk athletes were nearly 4 times as likely (RR, 3.8; 95% CI, 1.8-8.0). When examining the 6 individual components of the triad risk assessment score, both the oligomenorrhea/amenorrhea score (P = .0069) and the prior stress fracture/reaction score (P = .0315) were identified as independent predictors for subsequent BSIs (after adjusting for cross-country participation and age).

Conclusion: Using published guidelines, 29% of female collegiate athletes in this study were classified into moderate- or high-risk categories using the Female Athlete Triad Cumulative Risk Assessment Score. Moderate- and high-risk athletes were more likely to subsequently sustain a BSI; most BSIs were sustained by cross-country runners.

Keywords: stress fractures; female athlete; running; gymnastics; lacrosse; swimming

The female athlete triad (referred to as the triad) is a medical condition of female athletes consisting of 3 components: low energy availability (EA) with or without disordered eating, menstrual dysfunction, and low bone mineral density (BMD).[5] Our understanding of the triad has advanced from the initial description of the condition in 1992; it is now recognized that athletes may have ≥1 of the 3 conditions, and athletes may fall on a continuum from health to disease.[19,25]

The advances in our understanding of risk factors and management of the triad are reflected in evidence-based guidelines developed by the Female Athlete Triad Coalition in 2014 to help guide medical decision making for female athletes.[5] The resulting Female Athlete Triad Cumulative Risk Assessment includes the following 6 items scored on a scale from 0 to 2: low EA with or without disordered eating/eating disorder, body mass index (BMI), delayed menarche, oligomenorrhea (6-9 periods in 12

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months) or amenorrhea (<6 periods over 12 months), low BMD, and prior stress reaction/fracture.[5] The resulting risk assessment score is used to classify an athlete into 1 of 3 categories: low risk (0-1 points), moderate risk (2-5 points), or high risk (≥6 points).[5]

Using risk assessment scores to help manage treatment for athletes is important, especially considering the evidence for adverse health consequences resulting from the triad. For example, a higher number of triad risk factors is associated with an increased risk for bone stress injuries (BSIs) and low BMD.[1,7,22] In addition, collegiate athletes with triad risk factors including oligomenorrhea/amenorrhea or elevated risk assessment scores had higher grade BSIs on magnetic resonance imaging (MRI) and longer return to play.[11,18] Triad risk factors can be identified in the required preparticipation physical examinations (PPEs). In the largest study to date in National Collegiate Athletic Association (NCAA) Division I athletes, investigators reported the following in a population of 797 female athletes using an electronic preparticipation physical examination (ePPE): 3% had a prior or current eating disorder, 20% experienced irregular menstrual cycles, 3% had a history of low bone density, and 15% had a history of a stress fracture.[15]

To date, no published study has reported the prevalence of athletes within each risk category based on sport or evaluated the association of risk category to subsequent development of a BSI. Our study aimed to describe the prevalence of athletes classified as having low, moderate, and high risk by sport within a population of NCAA Division I athletes. We hypothesized that athletes in lean sports would be more likely to be classified into moderate- and high-risk categories, given the demands related to their sport and associated risk for low EA. In addition, we expected that athletes in the moderate- and high-risk categories would be at an elevated risk for subsequently sustaining a BSI.

METHODS

The Stanford University institutional review board approved this research protocol. This study included female athletes participating in any of 16 sports at Stanford University between 2008 and 2014. All female athletes were invited to participate in a study collecting dual-energy x-ray absorptiometry (DXA) scans to measure bone density and body composition as part of a separate study to develop normative DXA data for athletes. Athletes were eligible to participate and have their DXA obtained throughout the year. At the time of DXA acquisition, weight and height were collected for each athlete. All DXA scans were collected on a GE Lunar iDXA device and were analyzed using enCORE software (version 14.1; GE Medical Systems Lunar). BMD was measured for 3 regions: total body (TB), lumbar spine (LS), and dual femur (F). Areal BMD values (in grams per square centimeter) for TB, LS, and F were standardized to BMD *Z*-scores using available age, sex, and ethnicity normative values within the GE software package. For athletes younger than 20 years, we measured LS and TB and normalized to age, sex, and ethnicity normative values to generate BMD *Z*-scores.

ePPE Questions

- What sports are you currently trying out for?
- Do you currently suffer or have you ever suffered in the past with an eating disorder?
- Have you ever had a menstrual period?
- How old were you when you had your first menstrual period?
- How many periods have you had in the last 12 months?
- Are you presently taking any female hormones (estrogen, progesterone, birth control pills)?
- Have you ever had a stress fracture?

Figure 1. The electronic preparticipation physical examination (ePPE) questions primarily used to characterize sports participation and triad risk categories. Questions are from the PrivIT ePPE (PrivIT patent 8.275.632).

As required by the NCAA and our institution, all athletes completed an ePPE before participating in their sport(s) annually. The ePPE used by our institution was a modified version of the published questionnaire endorsed by 6 major medical sports organizations.[20] The ePPE included questions about the primary sport(s) the athlete intended to play and relevant triad questions including history of an eating disorder, age of menarche, number of periods in the preceding 12 months, use of medications including hormonal therapy and oral contraceptives, prior stress fractures/reactions (including details of physician diagnosis and radiographic confirmation), and other medical complaints. The PrivIT ePPE platform (PrivIT patent 8.275.632) was used to perform PPEs at our institution as reported previously.[15] Questions pertinent to our

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investigation are summarized in Figure 1. The resulting survey responses were downloaded into a summary form that was used by the team physician before clearing an athlete to participate.

For the research study, those athletes who had DXA scans completed for screening were selected for inclusion in this investigation. Subsequently, ePPE summary forms were reviewed by 2 research assistants. Study data were collected and managed using REDCap[9] (Research Electronic Data Capture) electronic data-capture tools hosted at the Stanford Center for Clinical Informatics. REDCap is a secure, web-based application designed to support data capture for research studies, providing (1) an intuitive interface for validated data entry, (2) audit trails for tracking data manipulation and export procedures, (3) automated export procedures for seamless data downloads to common statistical packages, and (4) procedures for importing data from external sources. A subset of 10% of the total survey responses were double-entered for quality control, with >99.9% agreement (fewer than 1 in 1000 errors in data entry identified).

From the ePPE, 4 of 6 scoring criteria were generated: (1) history or current disordered eating/eating disorder, (2) age of menarche, (3) history of oligomenorrhea/amenorrhea in the past 12 months, and (4) history of stress fracture or stress reaction. From the DXA results, the remaining 2 scoring criteria were generated: (5) BMI values based on the height and weight of the athlete obtained at the time of the DXA scan, and (6) BMD *Z*-scores at the LS, WB, and F. The average time (±SD) between DXA scanning and ePPE completion was 109 ± 80 days. A physician with clinical experience in evaluating and managing eating disorders and triad in athletes (J.L.C.) reviewed the ePPE and DXA scan for the 6 criteria in each athlete to generate a cumulative risk assessment score and to assign the participant to a risk category (low, moderate, or high). The risk assessment was based on magnitude of risk for 6 categories, each scored as low (0 points), moderate (1 point), and high (2 points); a total score of 0 to 1 indicates the low-risk category, a score of 2 to 5 points indicates the moderate-risk category, and a score of ≥6 points indicates the high-risk category.[5] We calculated the Female Athlete Triad Cumulative Risk Assessment using the methods described.[5] Because there are limitations from retrospective chart review, we modified the low EA, low BMI, and disordered eating categories as follows:

1. Low EA and loss of body weight: these could not be calculated using the historical PPE data, so a history of disordered eating or eating disorder was assigned a 1 and a current eating disorder was assigned a 2.
2. Low BMI: values of 17.6 to 18.4 kg/m^2 indicated moderate risk and ≤17.5 kg/m^2 indicated high risk. We did not calculate estimated body weight, and we were unable to determine whether an athlete had stable weight.
3. Oligomenorrhea/amenorrhea: the score was assigned based on number of menstrual periods for the previous 12 months according to information from the ePPE form. Of 323 women, 84 were currently using hormonal therapy, were not assigned a triad risk score, and were excluded from the primary analysis.

We used the published criteria for the remaining categories:

4. Delayed menarche: age 15 to <16 years indicated moderate risk and age ≥16 years indicated high risk.
5. Low BMD: for weightbearing sports, a BMD *Z*-score <–1 indicated moderate risk and BMD *Z*-scores ≤–2 indicated high risk.
6. Prior stress fracture/reaction: 1 prior stress fracture/reaction indicated moderate risk, and ≥2 prior stress fractures/reactions and/or 1 high-risk stress fracture/reaction indicated high risk.

In addition, we performed a separate analysis to account for the 84 athletes with an unknown history of oligomenorrhea/amenorrhea who were taking hormonal therapy at the time of ePPE. The oligomenorrhea/amenorrhea status was calculated based on a logistic regression model that included delayed menarche score and LS BMD *Z*-score. The variable chosen were developed after exploratory models were tested in 239 female athletes with reported menstrual status and from an independent data set consisting of 132 women runners.[10]

When we used this model to impute risk categories for the 239 women in our data set with known oligomenorrhea status, it accurately classified 165 of 169 female athletes as having low risk, 47 of 61 as moderate risk, and 9 of 9 as high risk. We found similar performance when we subsequently validated our imputation algorithm on an independent data set of 132 women runners[10]: the algorithm accurately classified 52 of 55 low-risk women, 57 of 72 moderate-risk women, and 5 of 5 high-risk women. The proportion of athletes assigned to each risk category using our iterative model to include 84 athletes taking hormonal therapy can be found in Appendix Table A1 (available online at http://ajsm.sagepub.com/supplemental).

We performed all analyses on the data set with the imputed values (N = 323) as well as the athlete population that excluded women taking hormonal therapy without assigned oligomenorrhea/amenorrhea scores (n = 239). Results were similar for both the athletes without hormonal therapy (n = 239) and including those taking hormonal therapy with estimated oligomenorrhea/amenorrhea status (N = 323). To present findings using the criteria from the Female Athlete Triad Coalition statement,[5] our primary analysis results are for the population of 239 athletes. Our imputed analysis of the full population of 323 athletes is included in Appendix Table A2 (available online). Notably, results are similar using both imputed analysis and limiting the analysis to 239 athletes with known menstrual status.

Bone Stress Injury

BSIs were identified on chart review of each athlete by 2 reviewers. This included search terms through electronic medical records and radiology reports for each athlete, using the following terms and phrases: bone, stress, fracture, injury, “osseous abnormality,” “bone marrow edema,” and “stress reaction.” All potential BSIs identified during initial chart review were subsequently reviewed by a sports medicine physician (A.S.T.). To be included as a BSI for a given athlete, the injury required diagnosis from a physician, imaging confirmation (MRI, computerized tomography, radiograph, or bone scan), and documentation that the injury occurred as a result of sports participation. Injuries that were attributed to trauma or occurred outside of sports participation were excluded. Because the primary goal of this investigation was to characterize risk for BSIs during competitive athletics, only BSIs that occurred while the athlete was still competing in her sport (both in-season and time intervals preparing for her sport) for the institution were included. The date of injury was determined from the date of the clinical assessment when the imaging study was ordered, because most imaging studies were obtained within 1 week of the assessment. To be counted as a prospective BSI, the date of injury occurred after the date of completion for both the DXA scan and the PPE.

Statistical Analysis

The number of athletes belonging to each risk category by sport is descriptive. Each of the 6 components of the risk assessment score is also presented by sport. Sports were divided into lean sports and nonlean sports using criteria by Torstveit and Sundgot-Borgen,[23] modified with all track and field athletes (n = 4) assigned to the lean-sport group. Lean sports included crew, cross-country, field hockey, gymnastics, lacrosse, rowing, swimming/diving, synchronized swimming, track and field, and water polo. Nonlean sports consisted of basketball, fencing, sailing, soccer, softball, tennis, and volleyball.

Statistical analyses were performed using SAS software (version 9.3; SAS Institute). Risk ratios (RRs) with 95% confidence intervals (95% CIs) were generated to calculate each risk category in association to BSI. The RRs for the moderate- to high-risk categories used the low-risk category as reference (the low-risk category was assigned an RR of 1.0). We used Poisson regression with robust standard errors[26] to generate adjusted RRs, adjusted for cross-country participation and age. As a secondary analysis, we examined the independent effects of the individual components of the total risk score using multivariate Poisson regression with robust standard errors. We tested the association between each individual component and prospective BSI in separate models adjusted for age and cross-country participation; those components that met $P < .10$ were then entered into a multivariable model and pruned if $P > .05$.

RESULTS

Risk Categories

A total of 323 athletes from 16 sports had complete DXA and PPE data. Table 1 shows general demographics information. The average age of the athletes was 20.0 years.

TABLE 1
General Demographics of 323 Athletes[a]

Age, y	20.0 ± 1.3
Race/ethnicity	
Caucasian	231 (71.5)
Hispanic	13 (4.0)
Black	19 (5.9)
Asian/Pacific Islander	20 (6.2)
Other	40 (12.4)
BMI, kg/m^2	
Average	22.9 ± 2.7
17.6-18.4 kg/m^2	6 (1.9)
≤17.5 kg/m^2	2 (0.6)
History of eating disorder/disordered eating	7 (2.1)
Delayed menarche	
Age 15-<16 y	38 (11.8)
Age ≥16 y	35 (10.8)
History of oligomenorrhea (6-9 periods)	36 (11.1)
History of amenorrhea (<6 periods)	28 (8.7)
BMD *Z*-score	
<–1	13 (4.0)
≤–2	6 (1.9)
History of stress reaction/fracture	51 (15.8)

[a]Data are reported as averages ± SD or n (%) unless otherwise indicated. BMD, bone mineral density; BMI, body mass index.

Table 2 shows the prevalence of athletes assigned to the low-, moderate-, and high-risk categories by sport for the population of 239 athletes who were not taking hormonal therapy and who had a known history of oligomenorrhea/amenorrhea. Three sports had a large proportion of athletes in the moderate- or high-risk categories, including gymnastics (9 of 16; 56.3%), lacrosse (8 of 16; 50%), and cross-country (23 of 47; 48.9%). By contrast, no basketball (0 of 9), fencing (0 of 6), and track and field (0 of 4) athletes were assigned to the moderate- or high-risk categories. The proportion of athletes assigned specifically to the moderate-risk category was highest in gymnastics (9; 56.2%), lacrosse (8; 50%), swimming/diving (8; 38.1%), cross-country (16; 34%), and sailing (1; 33%).

Of 9 athletes in the high-risk category only, 7 participated in cross-country, 1 in synchronized swimming, and 1 in swimming/diving.

EA With or Without Disordered Eating

Within the athlete population, few athletes reported a history of disordered eating or an eating disorder (Table 3 shows each of the 6 risk factors by sport). Seven athletes scored a value of 1 or 2 using our criteria. Of these, 3 were cross-country runners.

Body Mass Index

Low BMI (defined as <18.5 kg/m^2) was identified in 8 athletes, and 75% (6 of 8) were cross-country runners. Two athletes had a BMI of ≤17.5 kg/m^2; both were cross-country runners.

TABLE 2
Prevalence by Sport for 239 Athletes Assigned to Triad Risk Categories[a]

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

[a]Data are reported as n (%) unless otherwise indicated. Risk categories are based on risk assessment score by De Souza et al.[5]
[b]Excluding athletes who also participated in cross-country (n = 16).

TABLE 3
Number of Low-, Moderate-, and High-Risk Athletes (N = 323) Within Each Sport by Female Athlete Triad Coalition Scoring Category[a]

Category and Risk	Basketball	Crew/ Rowing	Cross-Country	Fencing	Field Hockey	Gymnastics	Lacrosse	Sailing	Soccer	Softball	Swimming/ Diving	Synchronized Swimming	Tennis	Track[b]	Volleyball	Water Polo
Low energy availability[c]																
Low	9	36	55	6	31	18	29	3	9	26	28	14	8	4	15	25
Moderate	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0
High	0	0	2	0	0	0	1	0	0	0	0	1	0	0	0	0
BMI																
Low	9	36	52	6	31	18	30	3	8	26	28	15	9	4	15	25
Moderate	0	0	4	0	0	0	0	0	1	1	0	0	0	0	0	0
High	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Age of menarche																
Low	8	33	39	6	25	7	22	2	8	24	18	13	9	4	11	20
Moderate	1	1	10	0	4	5	1	1	0	0	6	1	0	0	4	5
High	0	2	9	0	2	6	7	0	1	3	4	1	0	0	0	0
Oligomenorrhea/amenorrhea[d]																
Low	9	24	29	4	14	10	13	2	4	15	14	8	3	3	7	16
Moderate	0	5	8	1	4	3	2	1	1	2	2	2	3	1	1	0
High	0	1	10	0	3	3	1	0	0	2	5	1	1	0	1	0
Low BMD																
Low	9	35	48	6	30	18	30	2	8	27	27	14	9	4	13	24
Moderate	0	1	7	0	1	0	0	1	1	0	0	0	0	0	1	1
High	0	0	3	0	0	0	0	0	0	0	1	1	0	0	1	0
Stress reaction/fracture																
Low	7	33	36	6	28	13	25	3	8	25	25	14	8	4	13	24
Moderate	2	3	9	0	2	1	3	0	1	1	3	1	1	0	2	1
High	0	0	13	0	1	4	2	0	0	1	0	0	0	0	0	0

[a]BMD, bone mineral density; BMI, body mass index.
[b]Excluding athletes who also participated in cross-country (n = 16).
[c]With or without disordered eating/eating disorder.
[d]For the 239 athletes with known menstrual status, excluding 84 taking hormonal therapy.

Delayed Menarche

Nearly one-fourth of all athletes (74 of 323; 22.9%) had a history of delayed menarche (defined as first menstrual period at ≥15 years). The majority of athletes with delayed menarche were lean-sport athletes (64 of 74; 86.5% of the total) (Table 3), including a majority of gymnasts (11 of 18), one-third of cross-country runners (19 of 58) and

TABLE 4
Risk Categories for Subsequent BSI by Sport Participation Status[a]

Category	No. of Athletes	BSI, n (%)	Risk Ratio (95% CI)
All athletes			
Low risk	169	11 (4.7)	Reference population
Moderate risk	61	13 (16.9)	3.4 (1.5-7.8)
High risk	9	7 (63.6)	10.4 (4.4-24.7)
Cross-country runners			
Low risk	24	3 (12.5)	Reference population
Moderate risk	16	8 (50)	4.0 (1.2-12.8)
High risk	7	5 (71.4)	5.7 (1.5-13.8)
Athlete risk adjusting for cross-country participation and age			
Moderate risk			2.6 (1.3-5.5)
High risk			3.8 (1.8-8.0)

[a]95% CI, 95% confidence interval; BSI, bone stress injury.

sailing athletes (1 of 3), and over one-fourth of both swimmers/divers (10 of 28) and lacrosse athletes (8 of 30).

Oligomenorrhea/Amenorrhea

Excluding the 84 athletes taking hormonal therapy, one-fourth of all athletes (64 of 239; 26.8%) had oligomenorrhea (6-9 periods) or amenorrhea (<6 periods) in the past 12 months. This included 57.1% of tennis athletes (n = 4), 38.3% of cross-country runners (n = 18), 37.5% of gymnasts (n = 6), and 33.3% of sailing athletes (n = 1).

Low BMD

Nineteen athletes (5.9%) met criteria for low BMD (*Z*-scores < 1). Over one-half of these athletes (10 of 19; 52.6%) were cross-country runners.

History of Stress Fractures/Stress Reactions

Nearly 1 in 7 athletes (51 of 323; 15.8%) had a history of ≥1 stress fracture and/or stress reaction. These injuries were most common in cross-country (22; 37.3% of the total population), gymnastics (5; 27.8%), lacrosse (5; 16.7%), swimming/diving (3; 10.7%), and field hockey (3; 9.7%).

Prospective BSIs

Within the population of 239 athletes assigned to a risk category, 25 athletes sustained ≥1 BSI (25 of 239; 10.5%) after completion of both the PPE and the DXA scan. The prevalence of BSIs was highest in cross-country runners (16; 34%), followed by basketball players (2; 22.2%). One BSI occurred in each of the following sports: fencing, field hockey, softball, swimming/diving, synchronized swimming, track and field, and volleyball.

Athletes assigned to the higher risk categories were more likely to develop a prospective BSI (Table 4). Among low-risk athletes, 9 of 169 (5.3%) sustained a BSI, increasing to 11 of 61 moderate-risk athletes (18%) and 5 of 9 high-risk athletes (55.6%). This corresponds to an RR of 3.4 (95% CI, 1.5-7.8) for moderate- compared with low-risk athletes and to an RR of 10.4 (95% CI, 4.4-24.7) for high- compared with low-risk athletes. However, because cross-country runners had the highest prevalence of prospective BSIs, these estimates are artificially inflated as a result of confounding by sport. When we adjusted for cross-country participation and age, we found that the RR was 2.6 (95% CI, 1.3-5.5) for moderate- versus low-risk athletes and 3.8 (95% CI, 1.8-8.0) for high- versus low-risk athletes (Table 4).

We also examined the association between the assigned risk category and BSIs within sports and for groups of sports (lean vs nonlean). Among cross-country runners, 3 of 24 low-risk runners (12.5%) sustained a BSI, compared with 8 of 16 moderate-risk athletes (50%) and 5 of 7 high-risk athletes (71.4%). This corresponds to an RR of 4.0 (95% CI, 1.2-12.8) for moderate- versus low-risk runners and 5.7 (95% CI, 1.8-18.2) for high- versus low-risk runners. We did not observe a strong association between risk category and BSI when we analyzed all sports excluding cross-country, but this may be because of the small number of fractures (n = 9) and the small number of high-risk athletes (n = 2, none of whom fractured). When we narrowed the analysis to just lean sports, excluding cross-country, moderate- to high-risk athletes had a 2.7-fold increased rate of BSIs compared with low-risk athletes, but the numbers were too small to draw conclusions: 2 of 37 moderate- to high-risk athletes (5.4%) sustained a BSI compared with 2 of 98 of low-risk athletes (2.0%).

Nearly all BSIs involved bone in the lower extremities, except 1 ulna BSI in a softball player. The anatomic distribution of BSIs differed by risk category (Table 5). Of 9 low-risk athletes with BSI, 7 athletes had ≥1 BSI at the time of injury in the foot, including the metatarsus (n = 4), tarsal navicular bone (n = 2), cuboid (n = 1), and talus (n = 1); 2 were in nonfoot locations (n = 1 each in the femoral neck and ulna). Moderate-risk athletes had a higher number of nonfoot localized BSIs, including in the sacrum (n = 5), tibia (n = 2), and femur (n = 1); 4 BSIs were in the foot (n = 2 in the metatarsus and 1 each in the calcaneus and talus). High-risk athletes had BSIs in the pelvis (n = 1

TABLE 5
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)

[a]95% CI, 95% confidence interval; BSI, bone stress injury.

each in the sacrum and ilium), femur (n = 2), and tibia (n = 1) and no fractures in the foot.

The time from completion of both the DXA scan and PPE to sustaining a BSI was similar between risk groups; average time to fracture was 1.02 years, 0.98 years, and 0.86 years for the low-, moderate-, and high-risk groups, respectively. The overall median time to BSI was 0.63 years.

We examined the independent effects of the individual components of the total risk score using multivariate Poisson regression with robust standard errors. We found that older age (P = .0303), participation in cross-country (P = .0002), oligomenorrhea/amenorrhea score (P = .0069), and prior stress/fracture reaction score (P = .0315) were independent predictors of a prospective BSI (pseudo R^2 = 31.3%).

DISCUSSION

To our knowledge, our investigation is the first to report the prevalence of athletes within the low-, moderate-, and high-risk category classifications using the 2014 Female Athlete Triad Coalition guidelines. We identified that 29% of athletes were classified as having moderate or high risk. Those athletes belonging to the higher risk categories had a significantly increased risk for sustaining a subsequent BSI. Results from this investigation suggest that using the risk assessment scores may help identify athletes at increased risk for BSIs. Our findings support guideline recommendations that athletes with elevated triad risk categories should receive active medical treatment, including a nutrition evaluation to determine adequate EA and a workup for menstrual dysfunction. The goal of screening for and actively managing triad risk factors may help reduce risk for adverse health consequences, including subsequently developing a BSI.[5] Because an athlete who sustains a BSI loses significant time to sports participation, an athlete who is categorized as having moderate or high risk may be motivated to engage in active management of the triad to facilitate continued successful participation in her sport.

We identified that sports emphasizing leanness, including cross-country, gymnastics, and lacrosse, had the greatest proportion of athletes in the moderate- and high-risk categories. Our findings are consistent with prior reports that suggested female athletes and active women in lean sports have a higher prevalence of individual and combined components of the triad compared with nonlean sports.[8,23]

Of the 16 sports included in this investigation, cross-country runners had the greatest proportion of BSIs (16 of 25 overall BSIs). Compared with cross-country runners categorized as low risk, runners classified as moderate and high risk had a 4-fold and 5.7-fold increased risk for BSIs, respectively. In addition, a large proportion of moderate-risk (8 of 16; 50%) and high-risk (5 of 7; 71.4%) cross-country runners sustained a BSI. Therefore, cross-country runners may be a population of athletes with a high prevalence of triad risk factors and associated BSIs and may require special attention to address these health concerns. One explanation for the high number of BSIs in cross-country runners is that these athletes may also participate in track and field. Given the retrospective nature of this investigation and the limited number of athletes studied, we cannot fully account for multisport participation in our analysis and total athletic exposure risk for injury. The influence on how multiple sports participation for athletes modulates BSI risk either directly or through behaviors associated with the triad requires further exploration.

Independent risk factors for BSIs identified in our investigation include participation in cross-country, prior stress fracture/reaction, history of oligomenorrhea/amenorrhea, and older age. Cross-country was previously identified as a sport with a high risk for stress fracture in younger athletes[4,6] and college-aged runners.[3,21] In addition, prior fracture has been shown to place athletes at increased risk for future stress fracture.[10,17,22] Menstrual history including oligomenorrhea/amenorrhea and late menarche has been shown to increase the risk for injury.[6,17,22] Although younger age has been associated with an increased risk for BSIs in other investigations,[10,16] we postulate that older athletes may have a greater cumulative effect of triad risk factors on bone strength that may explain the increased risk for BSIs.

The anatomic distribution of BSIs in the triad low-risk category group was primarily in cortical bones within the foot compared with the triad moderate- and high-risk category groups that had a large number of stress fractures in bones with greater cancellous composition, including the pelvis and femoral neck. Why is there an observed difference in anatomy of fracture location based on risk category? We postulate that both biological and biomechanical risk factors contribute to BSIs in athletes. Athletes in triad low-risk categories, including basketball players, may be at higher risk for repetitive overuse BSIs in the cortical bone locations, owing to the high impact demands of the sport. By contrast, cross-country runners may be more predisposed to fractures with greater cancellous bone composition such as the sacrum, owing to impaired bone health in cancellous bone sites associated with the triad. Limited research suggested that cancellous bone fractures are more likely associated with lower BMD compared with fractures in cortical locations.[14] The relative contribution of both biological risk factors including the triad and biomechanical factors that contribute to BSIs by anatomy deserves further research exploration to optimize treatment for athletes.

Menstrual dysfunction was the most prevalent risk factor identified within the athlete population. Delayed menarche and oligomenorrhea/amenorrhea were seen in a large number of lean-sport athletes. These findings are not surprising, given that prior reports have described a high prevalence of menstrual dysfunction in collegiate athletes participating in sports emphasizing leanness, including cross-country, swimming/diving, and field hockey.[2]

The primary cause of the triad is postulated to result from low EA.[19] EA is defined as the difference in energy intake and estimated energy expenditure, standardized to fat free mass; low EA has been suggested to exist more commonly in athletes in endurance sports because of the metabolic demands of the sport.[12] In our investigation, few athletes reported a history of disordered eating or eating disorders. The low prevalence may reflect the limitation of self-report from athletes who may not disclose a prior eating disorder or current disordered eating. Other questions included on the PPE do ask about dietary behaviors; however, we are not aware of research to validate these questions in relationship to disordered eating/eating disorders or low EA. A clinical survey tool to determine EA and disordered eating/eating disorders would add to the PPE in screening athletes at risk for the triad. For example, the Eating Disorders Examination Questionnaire is a self-report questionnaire validated in students and adults, including female individuals in college.[13] Because low EA may be inadvertent,[12] addressing nutrition demands to ensure adequate EA could help manage treatment for athletes with the triad.

In addition, our report highlights other challenges with generating a risk assessment score using the currently endorsed PPE (version 2010).[20] In particular, the question "How many periods have you had in the last 12 months?" does not capture the history of oligomenorrhea/amenorrhea in an athlete who may have regular menses within 1 year of completing the PPE. Furthermore, athletes who are taking hormonal therapy cannot be accurately assessed for presence of oligomenorrhea/amenorrhea using the published criteria. We recommend that sports medicine organizations consider modifying this question to better capture prior history of oligomenorrhea/amenorrhea and facilitate applying the risk assessment score to the female athlete population during PPE. Additionally, we recommend that each athlete be consistently asked why she is taking hormonal therapy because this may have been previously prescribed for menstrual dysfunction related to the triad.

Limitations of this investigation include the retrospective study design and self-report for most risk factors within sports at 1 university. We postulate that athletes would be more likely to underreport triad risk factors including eating disorders, so our report may underestimate the true prevalence of athletes belonging to the moderate- and high-risk categories. We were unable to calculate EA for each athlete; absence of EA status may result in fewer athletes being assigned to the triad moderate- or high-risk categories. The updated *Diagnostic and Statistical Manual of Mental Disorders* (5th edition) criteria are more inclusive than the criteria used when athletes were queried about eating disorders, leading to potential underreporting of current diagnosed forms of eating disorders. Despite these limitations, 29% of athletes were categorized as moderate or high risk. Resources for collegiate athletes should include dietary assessment to ensure adequate EA. In addition, athletes should have access to sports medicine professionals with experience in management of the triad to optimize the health of these athletes. Another potential limitation is self-selection by athletes who chose to participate in DXA screening. The DXA data were obtained from a study open to all athletes and were intended to represent a representative sample of collegiate athletes. The ePPEs were not collected on the same day as DXA, although DXA data would not be expected to change significantly within the average time between collection of both the ePPE and DXA to generating the triad risk assessment scores. Additionally, cross-country runners represented a large portion of the overall sample with BSIs and had a high prevalence of moderate- and high-risk athletes. However, the association between the moderate- and high-risk categories and BSIs persisted even after adjusting for participation in cross-country. DXA is a commonly used screening method for bone health but does not assess bone microstructure or geometry, so we cannot fully account for other anatomic factors including bone geometric properties that may predict BSI risk. Each BSI was determined using chart review of available records within our institution. Therefore, some BSIs may not have been captured, although this is less likely given that BSIs were queried on annual PPE questionnaires. The prevalence of eating disorders, menstrual dysfunction, low BMD, and BSIs in our study is similar to reports within a larger cohort of 797 collegiate athletes.[15]

In summary, we report the proportion of athletes belonging to risk categories within a large sample of female NCAA Division I athletes. More than 29% of all athletes in this population were classified into moderate- or high-risk categories, and the prevalence was higher in sports emphasizing leanness, including cross-country, gymnastics, lacrosse, and swimming/diving. Sports medicine professionals should incorporate the risk assessment score into standard PPE practice and should consider expanding screening during PPE to include a full menstrual history, reasons for hormonal therapy use, and questions about EA and disordered eating to ensure that accurate triad risk assessment scores are obtained. The elevated risk for BSIs with higher triad risk assessment scores from our investigation adds to the literature demonstrating detrimental effects of the triad, including longer time for return to sports after sustaining a BSI with higher risk assessment scores[11] and performance decrements with negative energy balance.[24] By identifying athletes at elevated risk categories, sports medicine providers can better guide management and ensure that the health of each athlete is addressed in a comprehensive manner.

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