Female Athlete Triad Risk Factors Are More Strongly Associated With Trabecular-Rich Versus Cortical-Rich Bone Stress Injuries in Collegiate Athletes

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Background: Bone stress injuries (BSIs) are common in athletes. Risk factors for BSI may differ by skeletal anatomy and relative contribution of trabecular-rich and cortical-rich bone.

Hypothesis: We hypothesized that Female Athlete Triad (Triad) risk factors would be more strongly associated with BSIs sustained at trabecular-rich versus cortical-rich skeletal sites.

Study Design: Cohort study; Level of evidence, 2.

Methods: The study population comprised 321 female National Collegiate Athletic Association Division I athletes participating in 16 sports from 2008 to 2014. Triad risk factors and a Triad cumulative risk score were assessed using responses to preparticipation examination and dual energy x-ray absorptiometry to measure lumbar spine and whole-body bone mineral density (BMD). Sports-related BSIs were diagnosed by a physician and confirmed radiologically. Athletes were grouped into those sustaining a subsequent trabecular-rich BSI, a subsequent cortical-rich BSI, and those without a BSI. Data were analyzed with multinomial logistic regression adjusted for participation in cross-country running versus other sports.

Results: A total of 19 participants sustained a cortical-rich BSI (6%) and 10 sustained a trabecular-rich BSI (3%) over the course of collegiate sports participation. The Triad cumulative risk score was significantly related to both trabecular-rich and cortical-rich BSI. However, lower BMD and weight were associated with significantly greater risk for trabecular-rich than cortical-rich BSIs. For every value lower than 1 SD, the odds ratios (95% CIs) for trabecular-rich versus cortical-rich BSI were 3.08 (1.25-7.56) for spine BMD; 2.38 (1.22-4.64) for whole-body BMD; and 5.26 (1.48-18.70) for weight. Taller height was a significantly better predictor of cortical-rich than trabecular-rich BSI.

Conclusion: The Triad cumulative risk score was significantly associated with both trabecular-rich and cortical-rich BSI, but Triad-related risk factors appeared more strongly related to trabecular-rich BSI. In particular, low BMD and low weight were associated with significantly higher increases in the risk of trabecular-rich BSI than cortical-rich BSI. These findings suggest Triad risk factors are more common in athletes sustaining BSI in trabecular-rich than cortical-rich locations.

Keywords: biology of bone; epidemiology; female athlete; stress fracture

Sports participation is important for both musculoskeletal and overall health. However, some athletes may sustain overuse injuries, and understanding associated risk factors may guide more effective clinical care. Bone stress injuries (BSIs) are common overuse injuries to bone that are commonly seen in a sports medicine practice.[20] This form of injury is common in collegiate athletes. One report in National Collegiate Athletic Association (NCAA) athletes between the academic years of 2004 to 2005 and 2013 to 2014 identified that athletes sustained 671 cases of BSIs (5.70 per 100,000 athlete-exposure) and that injuries were more common in women than men.[14]

Risk factors for BSIs have been previously characterized and include female sex,[4,21] previous BSI,[8,19,21] menstrual dysfunction,[1,8,19] low body mass index (BMI), [19,22] low bone mineral density (BMD),[8] low vitamin D intake,[15] and biomechanical factors.[3] The Female Athlete Triad (Triad) is defined as the interrelationship of energy availability, menstrual function, and bone health, and each component is recognized to exist on a spectrum of health to disease.[5] Risk factors described by the Triad are importance for the overall health of the athlete including concern for risk of BSI.

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The overall influence of Triad risk factors can be quantified using the Triad Cumulative Risk Assessment score to assign an athlete to low-, moderate-, and high-risk category.[5] An earlier study in female collegiate athletes identified those classified as moderate or high risk had 2.6- and 3.8-fold increased risk for BSI compared with athletes assigned to the low-risk category.[16] These findings were consistent with previous studies that demonstrated higher cumulative risk for BSI with greater Triad risk factors.[2,19]

More recent research has focused on the understanding of risk factors for BSI by anatomic location. Bone is composed of cortical (dense and compact) and trabecular (honeycombed framework with open spaces) content,[13] and the relative contribution of each varies in the skeleton by anatomic location. Trabecular-rich bone may be more metabolically active and sensitive to changes in hormones contributing to lower bone mass, with previous work suggesting BSI in trabecular-rich sites (described as pelvis, femoral neck, and calcaneus) may be more common in athletes with lower BMD than cortical-rich sites of injury (such as the tibial and metatarsal bones).[10,17,18] Nattiv et al[12] reported that disordered eating, menstrual dysfunction, and middle- and long-distance running were significantly more associated with trabecular- than cortical-rich BSIs in female collegiate track and field athletes.

A comprehensive assessment of risk factors for BSIs for specific anatomic locations has not been adequately described in female collegiate athletes. Understanding the relative influence of anthropometric (eg, height, weight) and Triad risk factors to BSI by anatomy and classification of trabecular-rich and cortical-rich sites of injury may advance effective evaluation of risk factors and management of BSI in female collegiate athletes.

The purpose of this study was to evaluate the association of Triad risk factors in athletes who sustain trabecular-rich and cortical-rich BSIs. We hypothesized that Triad risk factors would be associated more strongly with BSIs sustained at trabecular-rich versus cortical-rich bone locations.

METHODS

This was a secondary data analysis of previous studies that aimed to characterize the health of NCAA Division I (DI) collegiate athletes.[16,17] The methodology and cohort for the current study have been previously described.[16,17] This research protocol received institutional review board approval.

Participants

The study population comprised 321 female-identifying NCAA DI athletes participating in 16 sports at Stanford University between 2008 and 2014. Before participation, written informed consent to participate in a healthy athlete database of bone density was obtained from each participant. Involvement in this database included consent to measure BMD and body composition with dual-energy x-ray absorptiometry (DXA; GE Lunar iDXA; GE Medical Systems Lunar). As standard of care to determine safety for sports participation, each athlete completed annual electronic preparticipation examination (ePPE; PrivIT patent 8.275.632) forms for medical clearance, as previously described.[16,17] These responses were reviewed to measure risk factors of interest. Participating athletes with completed DXA scans and ePPE forms (321 athletes) were included in this study. The outcome of subsequent BSIs was defined as BSIs that were sustained after completion of initial ePPE (if participant participated in multiple years) and DXA.

Triad Risk Factors

The Female Athlete Triad Coalition developed a metric in 2014 to determine cumulative risk of Triad (low, moderate, or high).[5] This Triad Risk Cumulative Assessment score (Triad cumulative risk score) is the sum of 6 scored criteria with each criterion assigned low (0 point), moderate (1 point), or high (2 points). This score was calculated for each athlete. The ePPE forms completed by each athlete included questions on sport participation, menstrual history, medication use, and medical history. The risk factors assessed from the ePPE forms were assigned and modified for low energy availability and oligomenorrhea/amenorrhea values, as shown in Table 1. All DXA scans were conducted by a single technician and the system was calibrated before each scan. Height and weight were measured using a stadiometer and digital scale at the same visit and used to calculate BMI. Areal BMD measurements included total body and lumbar spine (L1-L4) and were standardized to Z scores based on reference populations

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Ethical approval for this study was obtained from Stanford University (eProtocol ID 28057).

TABLE 1
Criteria to Assign to the Triad Cumulative Risk Score[a]

(1) Low energy availability with or without disordered eating or eating disorder
(a) Score = 0: No history of or current disordered eating or eating disorder
(b) Score = 1: History of disordered eating or eating disorder
(c) Score = 2: Current disordered eating or eating disorder
(2) BMI
(a) Score = 0: BMI $\geq$18.5 kg/m^2
(b) Score = 1: BMI 18.4 to 17.6 kg/m^2
(c) Score = 2: BMI $\leq$17.5 kg/m^2
(3) Age at menarche
(a) Score = 0: Menarche at <15 years
(b) Score = 1: Menarche at 15 years
(c) Score = 2: Menarche at $\geq$16 years
(4) Oligomenorrhea/amenorrhea (over past 12 months)
(a) Score = 0: >9 periods
(b) Score = 1: 6-9 periods
(c) Score = 2: <6 periods
(5) Previous stress reaction/stress fracture
(a) Score = 0: No history of stress reaction/stress fracture
(b) Score = 1: 1 previous stress reaction/stress fracture
(c) Score = 2: $\geq$2 stress reaction/fracture OR stress reaction/fracture in trabecular-rich location (pelvis, femoral neck, or calcaneus)
(6) Low BMD
(a) Score = 0: BMD Z score ≥ -1.0
(b) Score = 1: BMD Z score between -1 and -2
(c) Score = 2: BMD Z score $\leq$-2.0

[a]BMD, bone mineral density; BMI, body mass index.

determined by age, ethnicity, and sex of each athlete. The data were postprocessed with enCORE Version 14.1.

At the time of survey completion, 86 athletes reported hormonal contraceptive use. These athletes did not receive an oligomenorrhea/amenorrhea score or a total Triad risk score and were excluded from all analyses that involved either of these predictors.

Bone Stress Injury

SIs that occurred within 1 year of each athlete's completion of a DXA scan and an ePPE form were identified through chart review. Electronic medical records were searched by 2 reviewers using the search terms "bone," "stress," "fracture," "injury," "osseous abnormality," "bone marrow edema," and "stress reaction." Inclusion of BSIs consisted of injuries diagnosed by a physician, confirmed radiologically by the treating physician and credited to participation in her respective sport; BSIs that were not attributed to sport participation (ie, trauma, occurred outside of sport) were excluded. Any possible BSI identified through chart review was subsequently reviewed by a single board-certified sports medicine physician (A.S.T.). Once confirmed, BSIs were categorized by location in trabecular-rich (pelvis, femoral neck, or calcaneus) or cortical-rich (tibia, fibula, femur, foot bones) bone.[10,12,16,18]

Data Analysis

Data were inputted manually into Research Electronic Database Capture (REDCap, Vanderbilt University, Nashville, TN)–a secure, web-based research data storage application.[6,7] A subset of 10% of data was double-entered with less than 0.01% matching error.

Statistical analysis was conducted using SAS Version 9.4 (SAS Institute). Means and standard deviations were calculated for participant baseline descriptive statistics. Odds ratios (ORs) and 95% CIs were calculated from multinomial logistic regression (outcomes: no BSI, cortical-rich BSI, or trabecular-rich BSI) and adjusted for cross-country participation (versus other sports) to assess the association between Triad risk factors and trabecular- versus cortical-rich BSIs. This adjustment for cross-country participation was made given this sport's high BSI incidence and high prevalence of Triad risk factors. We also stratified all analyses on cross-country participation. $P < .05$ was used as the threshold for statistical significance.

RESULTS

Study Participants

A total of 321 NCAA DI athletes who completed both DXA scans and ePPE forms were included in this analysis. The 86 athletes who were on hormonal contraceptives were omitted from analyses involving oligomenorrhea score or Triad cumulative risk score. Table 2 shows the anthropometric characteristics, Triad risk factors, and distance running sport participation of the cohort. The average Triad cumulative risk score was 1.12 ± 1.73; and 58 participants (n = 18.1%) were cross-country runners.

TABLE 2
Athlete Characteristics (N = 321)[a]

Variable	Value
Anthropometric characteristics	
White/non-Hispanic	231 (72.0)
Non-White	90 (28.0)
Age, y	19.8 ± 1.2
Height, m	1.7 ± 0.1
Weight, kg	66.1 ± 11.0
BMI, kg/m^2	22.9 ± 2.7
Percentage body fat	24.0 ± 5.5
Spine BMD, g/cm^2	1.30 ± 0.17
Spine *Z* score	0.76 ± 1.26
Total BMD, g/cm^2	1.22 ± 0.13
Total *Z* score	1.02 ± 1.01
Elevated Triad risk factor[b]	
Low energy availability	7 (2.2)
Low BMI	7 (2.2)
Delayed menarche	74 (23)
Oligomenorrhea/amenorrhea[c]	61/235 (26)
Low BMD	25 (7.8)
Previous stress reaction/stress fracture	50 (15.6)
Triad cumulative risk score[d]	1.12 ± 1.73
Sport participation	
Cross-country runners	58 (18.1)
Other athletes	263 (81.9)

[a]Data are reported as mean ± SD or No. (%). BMD, bone mineral density; BMI, body mass index.

[b]Elevated Triad risk category includes total portion of population studied meeting moderate or high risk (scores of 1 or 2 versus 0).

[c]Value unable to be determined in 86 athletes due to current use of hormonal contraception.

[d]Triad cumulative risk score values in 235 participants, as 86 were on hormonal contraceptives and could not have complete score calculated.

Characteristics Associated With Trabecular-Rich Versus Cortical-Rich BSI

In athletes with completed Triad cumulative risk scores, 29 athletes sustained a BSI with median time 0.63 years from time of risk factor assessment.[16] Of these 29 athletes, 19 (65.5%) were located in cortical-rich bones and 10 (34.5%) in trabecular-rich bone. The most common site of cortical-rich BSIs was a metatarsal bone and for trabecular-rich BSIs was the sacrum. Table 3 presents athlete and Triad characteristics stratified by BSI group (trabecular-rich, cortical-rich, or no BSI). The groups were similar in age, but the BSI groups included more runners than the no-BSI group. The trabecular-rich group had lower weight, BMI, and spine and whole-body BMD than the cortical-rich and no-BSI groups; the cortical-rich group was taller than the trabecular-rich and no-BSI groups. The Triad cumulative risk score was higher in the cortical-rich group (mean, 2.44) than the no-BSI group (0.92) and highest in the trabecular-rich group (3.56). Higher percentages of the cortical-rich group (63.2%) and the trabecular-rich group (50%) had sustained previous BSI compared with the no-BSI group (11.3%).

We then used multinomial logistic regression to compare the BSI groups, adjusting for the differences in cross-country running participation (Table 4). The Triad cumulative risk score was associated with a significantly elevated risk of sustaining either a trabecular-rich or cortical-rich BSI (OR [95% CI]: 1.51 [1.13-2.02] for trabecular-rich versus no-BSI and 1.37 [1.07-1.76] for cortical-rich versus no-BSI; $P < .05$ for both). However, lower whole-body BMD, lower spine BMD, and lower weight were associated more strongly with trabecular-rich than cortical-rich BSI (OR [95% CI]: 2.38 [1.22-4.64],

TABLE 3
Athlete Characteristics for the no-BSI, Cortical-Rich BSI, and Trabecular-Rich BSI Groups[a]

	No BSI (n = 292)	Cortical-Rich BSI (n = 19)	Trabecular-Rich BSI (n = 10)
Age, y	19.8 ± 1.2	19.8 ± 1.1	19.8 ± 1.3
Height, m	1.69 ± 0.08	1.74 ± 0.08	1.66 ± 0.07
Weight, kg	66.5 ± 10.9	65.6 ± 12.7	55.0 ± 5.8
BMI, kg/m^2	23.1 ± 2.7	21.5 ± 2.9	19.8 ± 1.4
Spine BMD *Z* score	0.84 ± 1.22	0.48 ± 1.51	−0.87± 1.05
Whole-body BMD *Z* score	1.03 ± 0.99	1.39 ± 0.92	−0.06 ± 1.11
Triad cumulative risk score[b]	0.92 ± 1.50	2.44 ± 2.71	3.56 ± 1.81
Low energy availability[c]	5 (1.7)	1 (5.3)	1 (10)
Low BMI (<18.5 kg/m^2)	3 (1.0)	1 (5.3)	3 (30)
Delayed menarche (≥15 y)	62 (21.2)	7 (36.8)	5 (50)
Oligomenorrhea/amenorrhea (n = 235)[b]	48 (22.9)	6 (37.5)	7 (77.8)
Low BMD (*Z* score <-1)	18 (6.2)	3 (15.8)	4 (40)
Previous stress reaction/stress fracture	33 (11.3)	12 (63.2)	5 (50)
Cross-country runner	38 (13)	12 (63.2)	8 (80)

[a]Data are reported as mean ± SD or No. (%). BMD, bone mineral density; BMI, body mass index; BSI, bone stress injury.

[b]Sample sizes for the Triad cumulative risk score and oligomenorrhea/amenorrhea were 210 in the no-BSI group, 16 in the cortical-rich BSI group, and 9 in the trabecular-rich BSI group.

[c]Low energy availability was defined as previous or current disordered eating or eating disorder.

TABLE 4
ORs From Multinomial Logistic Regression Model Relating Triad Risk Factors to Risk of Prospective Trabecular-Rich or Cortical-Rich BSI[a]

	Trabecular-Rich BSI vs Cortical-Rich BSI		Trabecular-Rich BSI vs No BSI		Cortical-Rich BSI vs No BSI	
Characteristic[b]	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Spine BMD (per SD)	3.08 (1.25-7.56)	**.014**	3.82 (1.67-8.77)	**.0016**	1.24 (0.76-2.04)	.39
Total BMD (per SD)	2.38 (1.22-4.64)	**.011**	1.84 (1.20-2.81)	**.0052**	0.77 (0.45-1.33)	.35
Overall Triad cumulative risk score (per point)	1.10 (0.82-1.47)	.52	1.51 (1.13-2.02)	**.0059**	1.37 (1.07-1.76)	**.014**
Oligomenorrhea risk score (per point)	1.68 (0.65-4.31)	.28	3.08 (1.33-7.11)	**.0086**	1.84 (0.95-3.55)	.071
Previous BSI risk score (per point)	1.01 (0.42-2.46)	.98	3.19 (1.41-7.22)	**.0054**	3.16 (1.68-5.95)	**.0004**
BMD risk score (per point)	1.92 (0.56-6.58)	.30	3.16 (1.09-9.15)	**.034**	1.65 (0.58-4.71)	.35
Menarche risk score (per point)	1.24 (0.50-3.06)	.64	2.13 (0.96-4.73)	.064	1.71 (0.92-3.18)	.089
Stress reaction/stress fracture risk score (per point)	1.87 (0.39-9.07)	.44	3.20 (0.76-13.53)	.11	1.71 (0.36-8.08)	.50
Low energy availability risk score (per point)	1.38 (0.30-6.31)	.68	2.64 (0.63-11.07)	.19	1.91 (0.49-7.44)	.35
Weight (per SD lower)	5.26 (1.48-18.70)	**.01**	4.55 (1.37-15.09)	**.013**	0.86 (0.53 -1.42)	.57
Height (per SD higher)	0.28 (0.10-0.78)	**.015**	0.59 (0.23-1.50)	.27	2.14 (1.24-3.69)	**.0064**
BMI (per SD lower)	2.61 (0.82-8.30)	.10	3.95 (1.34-11.60)	**.013**	1.51 (0.85-2.70)	.16
Percentage body fat (per SD lower)	1.35 (0.57-3.23)	.50	1.57 (0.73-3.37)	.25	1.16 (0.68-1.98)	.59

[a]Models are adjusted for cross-country running versus other sports. Boldface *P* values indicate statistical significance ($P < .05$). BMD, bone mineral density; BMI, body mass index; BSI, bone stress injury; OR, odds ratio.

[b]Overall Triad cumulative risk score is on a 0-to-12 point scale; individual Triad risk factor scores are on a 0-to-2 scale; BMD and body measures are in SD units.

3.08 [1.25-7.56], and 5.26 [1.48-18.70], respectively; $P < 0.05$ for all) (Table 4). The Triad-related risk factors of menstrual dysfunction (delayed menarche, oligomenorrhea), low energy availability, low BMI, and lower percentage body fat had qualitatively stronger associations with trabecular-rich BSI risk as evidenced by the elevated ORs for trabecular-rich versus cortical-rich BSI, although these did not reach statistical significance (Table 4). The only Triad-related risk factor that did not have an elevated OR for trabecular-rich versus cortical-rich BSI was history of BSI (OR [95% CI], 1.01 [0.42-2.46]). The only characteristic found to be a better predictor of cortical-rich BSIs compared with trabecular-rich BSIs was taller height (OR [95% CI]: 0.28 [0.10-0.78]; $P = .015$) (Table 4).

We found similar results when we stratified on cross-country running participation rather than adjusting for it (Appendix Tables A1 and A2).

DISCUSSION

The purpose of this study was to characterize differences in risk factors by anatomic location of BSI. Similar to previous findings,[16,17] the Triad cumulative risk score was significantly related to both trabecular and cortical-rich BSI. However, low BMD, low BMI, and low weight were significantly more related to trabecular-rich BSI. All other Triad-related risk factors, with the exception of BSI history, had qualitatively larger associations with trabecular-rich than cortical-rich BSI. Taller height was a risk factor for cortical BSI. Collectively, these findings substantiate earlier work that suggests BSI risk factors may be different by anatomic location and relative bone composition.

The finding of higher Triad cumulative risk score associated with BSI, particularly in trabecular-rich bones, is consistent with previous reports in exercising women and high school–age runners.[2,19] The influence of low energy availability on sex hormones such as estradiol that affect menstrual function and impaired skeletal health has been described in the Triad and Relative Energy Deficiency in Sport.[11] Previous report using an overlapping athlete population identified those athletes with trabecular-rich BSI had were more likely to be assigned to the moderate- and high-risk categories using the Triad cumulative risk score.[16] The stronger associations of lower BMD and weight with trabecular-rich versus cortical BSI builds on observations in other cohorts including female athletes and male runners.[10,18] Collectively, these findings advance our understanding of biological risk factors for BSI at certain anatomic sites, including BSI sustained in the femoral neck and pelvis, which are both grouped as "trabecular-rich" sites of BSI in our study. Screening and management of biological risk factors may optimize health of athletes and represent an area of future translational research to understand biological pathophysiology of BSI by anatomic location. While Triad risk factors should be characterized during preparticipation physical examinations, obtaining Triad risk factors and consideration for bone density measures through DXA would be advised, particularly in athletes who sustain a trabecular-rich site of BSI.[5]

Height was positively correlated with cortical-rich BSIs, a finding that has not been reported in other studies; the observation in this cohort may alternatively be explained by confounding by sport. Though our analyses adjusted for cross-country running versus other sports, we were unable to adjust for participation in other specific sports due to limited sample sizes. Basketball players sustained the second highest prevalence of BSIs with injuries to the foot (n = 2 of 9 basketball players; 22.2%), yet basketball players did not commonly have risk factors of the Triad. Rizzone et al[14] found that of BSIs reported for NCAA DI female athletes over a decade, 34.5% were in female basketball players and, of those BSIs, at least 83.6% were in cortical-rich bone.

Limitations

This study has some limitations. The data collected from ePPE forms were retrospective and self-reported, which may have affected reliability. Participants may have intentionally underreported Triad-related risk factors or unintentionally misreported their medical histories. Some of the associations may have been affected by confounding by sport, such as height in basketball players. The use of hormonal contraceptives led to missing data on oligomenorrhea/amenorrhea status. However, this limitation is consistent with the challenges in clinical practice for obtaining accurate menstrual history due to influence of hormones on menstrual status. Further, the use of oral contraceptive pills has inconclusive influence on fracture risk[9] and is not recommended to address menstrual disturbances in athletes resulting from low energy availability.[5,11] There may also be selection bias in this cohort, as it is composed of any NCAA DI female athlete at this institution who chose to volunteer for a DXA scan. Last, although this data set represents a variety of sports, it only represented a single West Coast university with DI sports, comprising different sample sizes for each sport, and therefore may not be generalizable to all female collegiate athletes. Characterizing certain risk factors in this population was further limited as athletes using hormonal contraception were excluded from some analyses due to an inability to accurately assess menstrual status.

CONCLUSION

In this study, we identified differences in risk factors associated with BSI by anatomy. Given the strong association observed between Triad-related risk factors with BSIs, particularly in trabecular-rich bone, clinicians should ensure adequate screening and management of these health issues in efforts to prevent BSIs. Prevention of BSIs in cortical-rich bones may require clinicians to address a wider set of risk factors, potentially including biomechanics and management of bone loading.

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APPENDIX

TABLE A1

ORs From Multinomial Logistic Regression Model Relating Triad Risk Factors to Risk of Prospective Trabecular-Rich or Cortical-Rich BSI Stratified for Cross-Country Runners (n = 58)[a]

	Trabecular-Rich BSI vs Cortical-Rich BSI		Trabecular-Rich BSI vs No BSI		Cortical-rich BSI vs No BSI	
Characteristic	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Spine BMD (per SD)	2.90 (1.24-6.76)	**.039**	2.90 (1.24-6.76)	**.014**	1.07 (0.58-1.97)	.94
Total BMD (per SD)	3.25 (1.06-10.00)	**.039**	3.34 (1.24-9.01)	**.017**	1.03 (0.50-2.14)	.35
Overall Triad cumulative risk score (per point)	1.09 (0.80-1.50)	.58	1.52 (1.08-2.15)	**.016**	1.39 (1.01-1.93)	.043
Oligomenorrhea risk score (per point)	1.53 (0.50-4.74)	.46	2.31 (0.87-6.12)	.093	1.51 (0.60-3.80)	.39
Previous BSI risk score (per point)	1.01 (0.42-2.46)	.98	4.78 (1.72-13.26)	**.0026**	4.78 (1.93-11.84)	**.00072**
BMD risk score (per point)	1.81 (0.45-7.31)	.41	2.64 (0.79-8.85)	.115	1.46 (0.41-5.17)	.56
Menarche risk score (per point)	1.40 (0.50-3.94)	.53	3.28 (1.23-8.74)	**.017**	2.35 (0.98-5.63)	.055
Stress reaction/stress fracture risk score (per point)	1.85 (0.38-8.96)	.44	3.28 (0.76-14.17)	.11	1.77 (0.37-8.55)	.48
Low energy availability risk score (per point)	1.28 (0.28-5.93)	.75	3.90 (0.56-26.98)	.17	3.05 (0.45-20.71)	.25
Weight (per SD lower)	3.47 (0.75-16.13)	.11	4.95 (1.17-20.83)	**.030**	1.43 (0.62-3.26)	.40
Height (per SD higher)	0.40 (0.11-1.44)	.16	0.78 (0.25-2.42)	.67	1.93 (0.85-4.42)	.12
BMI (per SD lower)	2.14 (0.50-9.09)	.30	5.59 (1.39-22.73)	**.015**	2.62 (1.00-6.85)	.050
Percentage body fat (per SD lower)	1.21 (0.43-3.38)	.71	1.52 (0.63-3.72)	.35	1.26 (0.61-2.61)	.54

[a]Models are stratified for cross-country runners. Boldface *P* values indicate statistical significance ($P < .05$). BMD, bone mineral density; BMI, body mass index; BSI, bone stress injury; OR, odds ratio.

TABLE A2

ORs From Multinomial Logistic Regression Model Relating Triad Risk Factors to Risk of Prospective Trabecular-Rich or Cortical-Rich BSI Stratified for Non–Cross Country Runners (n = 263)[a]

	Trabecular-Rich BSI vs Cortical-Rich BSI		Trabecular-Rich BSI vs No BSI		Cortical-Rich BSI vs No BSI	
Characteristic	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Spine BMD (per SD)	10.20 (0.70-142.86)	.089	15.63 (1.20-200.00)	**.036**	1.54 (0.67-3.52)	.31
Total BMD (per SD)	2.72 (1.01-7.35)	**.048**	1.55 (0.90-2.67)	.11	0.57 (0.25-1.32)	.19
Overall Triad cumulative risk score (per point)	1.12 (0.51-2.50)	.78	1.50 (0.74-3.02)	.26	1.33 (0.87-2.05)	.19
Oligomenorrhea risk score (per point)	2.96 (0.39-22.63)	.30	6.24 (0.97-40.05)	.054	2.11 (0.85-5.26)	.11
Previous BSI risk score (per point)	—	—	—	—	1.79 (0.51-6.27)	.37
BMD risk score (per point)	2.65 (0.22-32.01)	.44	5.03 (0.77-32.95)	.09	1.90 (0.32-11.17)	.48
Menarche risk score (per point)	—	—	—	—	1.29 (0.46-3.59)	.96
Stress reaction/stress fracture risk score (per point)	—	—	—	—	—	—
Low energy availability risk score (per point)	—	—	—	—	—	—
Weight (per SD lower)	8.70 (0.87-83.33)	.065	5.03 (0.55-45.45)	.15	0.58 (0.31-1.07)	.083
Height (per SD higher)	0.15 (0.03-0.87)	**.034**	0.35 (0.07-1.76)	.20	2.37 (1.14-4.94)	**.021**
BMI (per SD lower)	2.95 (0.37-23.81)	.31	2.67 (0.38-18.87)	.32	0.91 (0.43-1.93)	.80
Percentage body fat (per SD lower)	1.73 (0.31-9.62)	.53	1.80 (0.39-8.26)	.45	1.04 (0.47-2.30)	.93

[a]Models are stratified for non–cross country runners. Boldface *P* values indicate statistical significance ($P < .05$). Dashes indicate areas unable to be estimated. BMD, bone mineral density; BMI, body mass index; BSI, bone stress injury; OR, odds ratio.