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ORIGINAL RESEARCH

ASSOCIATIONS BETWEEN THE FEMALE ATHLETE TRIAD AND INJURY AMONG HIGH SCHOOL RUNNERS

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ABSTRACT

Purpose/Background: During the 2013-14 school year, over 763,000 female athletes participated in interscholastic running sports in the United States. Recent studies have indicated associations between the female athlete triad (Triad) and stress fracture or other musculoskeletal injuries in elite or collegiate female running populations. Little is known about these relationships in an adolescent interscholastic running population. The purpose of this study was to determine the associations between Triad and risk of lower extremity musculoskeletal injury among adolescent runners.

Methods: Eighty-nine female athletes competing in interscholastic cross-country and track in southern California were followed, prospectively. The runners were monitored throughout their respective sport season for lower extremity musculoskeletal injuries. Data collected included daily injury reports, Eating Disorder Examination Questionnaire (EDE-Q) that assessed disordered eating attitudes/behaviors, a questionnaire on menstrual history and demographic characteristics, a dual-energy x-ray absorptiometry scan that measured whole-body bone mineral density (BMD) and body composition (lean tissue and fat mass), and anthropometric measurements.

Results: Thirty-eight runners (42.7%) incurred at least one lower extremity musculoskeletal injury. In the BMD Z-score ≤ -1 standard deviation (SD) adjusted model, low BMD relative to age (BMD Z-score of ≤ -1SD) was significantly associated (Odds Ratio [OR] = 4.6, 95% confidence interval [CI]: 1.5-13.3) with an increased occurrence of musculoskeletal injury during the interscholastic sport season. In the BMD Z-score ≤ -2 SDs adjusted model, a history of oligo/amenorrhea was significantly associated (OR = 4.1, 95% CI: 1.2-13.5) with increased musculoskeletal injury occurrence.

Conclusion: Oligo/amenorrhea and low BMD were associated with musculoskeletal injuries among the female interscholastic cross-country and track runners.

Clinical Relevance: Regular, close monitoring of adolescent female runners during seasonal and off-season training may be warranted, so that potential problems can be recognized and addressed promptly in order to minimize the risk of running injury.

Level Of Evidence: 2

Keywords: Adolescent runners, bone mineral density, disordered eating, females, menstrual dysfunction, musculoskeletal injuries.

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INTRODUCTION

Over 763,000 female athletes participated in interscholastic cross-country and indoor/outdoor track and field in the United States during the 2013-2014 school year.[1] While many benefits can be gained from participation in these sports, the increased involvement among girls may also present a greater risk for musculoskeletal injury. Prospective studies have reported a cumulative seasonal incidence of injury for girls' interscholastic track and field runners and cross-country runners ranging from 34.0% to 52.0%.[2,3]

Over the past two decades there has been increased evidence that three interrelated conditions that comprise the female athlete triad (Triad): low energy availability (EA), with or without disordered eating; menstrual dysfunction; and low bone mineral density (BMD), may place a female runner at greater risk for musculoskeletal injury, especially for stress fracture.[4-12] Menstrual dysfunction has been associated with increased risk of stress fracture or other bone stress injuries in collegiate athletes,[13] competitive club track and field athletes[7-9] and adult runners.[10] In addition, menstrual dysfunction has been linked with greater interruption of training due to musculoskeletal injuries among women endurance runners.[14] The relationship between low BMD and stress fracture has been observed among young adults participating in competitive or collegiate cross-country and track and field events.[9-11,13] Disordered eating behaviors such as restrictive eating patterns, dieting, and carefulness about weight have increased the likelihood of stress fracture occurrence in competitive club track and field athletes.[8]

While the relationships between Triad components and injury observed in adult runners is becoming increasingly known, limited evidence exists on the likelihood of injury among high school runners who, because of their younger age, have not had as long duration of exposure to the adverse consequences of disordered eating, menstrual dysfunction and low bone density. Austin et al.[15] found associations between exercise related leg pain and abnormal menstrual function history during the season among high school cross-country runners. Tenforde et al.[16] reported that late menarche (age >15) was associated with stress fracture among high school runners. Rauh et al.[17] previously reported relationships between all three components and musculoskeletal injury among varsity high school athletes representing multiple sports but did not report these relationships by specific sport. Thus, the purpose of this study was to prospectively examine the associations between the Triad components, as defined in the 1997 American College of Sports Medicine (ACSM) Position Stand[18] (updated in 2007)[12] and risk of running-related injury among a cohort of competitive high school female cross-country runners and track and field athletes. Runners with disordered eating, menstrual dysfunction, and/or low BMD were expected to have a higher likelihood of injury. Additionally, as shin-related injury is common among female cross-country runners and track and field athletes,[3,6,19] BMD at the tibia/fibula was assessed to determine differences between injured and noninjured athletes. It was hypothesized that runners with a lower tibial/fibular BMD would have a higher likelihood of injury, particularly at the shin/calf region.

METHODS

The initial subject sample consisted of 95 female runners who competed in cross-country (n=33) and track and field (n=62) from six high schools in southern California during the 2003-04 interscholastic school year. Participants were 13 to 18 years old who had experienced menarche. Those who had not begun to menstruate were required to be 15 to 18 years old to participate. Six runners who had reported taking medications known to affect menstrual status or BMD[12] (e.g., birth control use, steroid inhalers for asthma) were excluded from the study analyses. The runners completed questionnaires regarding eating behaviors and menstrual history, and were measured, without shoes, for height and weight to the nearest 0.5in and 0.5lb, respectively, using a digital scale (Health-O-Meter; Sunbeam Products, Inc, Bridgeview, IL). One research assistant per 6-8 runners reviewed the Eating Disorder Examination Questionnaire response scale and questions deemed more difficult to interpret, defined terminology, e.g., binge episode, then remained in the room to assist runners who requested further clarification as they completed the questionnaires individually. The runners then received a dual-energy x-ray absorptiometry (DXA) scan for areal BMD ($g \cdot cm^{-2}$) at the spine (L1-L4), proximal femur, tibia/fibula, as well as whole-body BMD, body fat percent, and lean mass measurements.

The study was approved by the San Diego State University's Institutional Review Board. Written parental consent and athlete assent were provided by study participants.

Data Collection

Injury. Prior to each 15-week sport season, coaches and athletic trainers were trained on using the Athletic Health Care System Daily Injury Report (DIR) form.[3,19] From the first official day of practice until the last regular or post-season competition, coaches/athletic trainers recorded each athlete's daily participation at practices and competitive events, and absences and limitations of participation because of injury. An injury was defined as any reported muscle, joint or bone problem/injury of the back or lower extremity (i.e., hip, thigh, knee, shin, calf, ankle, foot) resulting from participation in a practice or competitive event and requiring the runner to be removed from a practice or competitive event or to miss a subsequent one.[3,19] Injuries that did not occur during participation, or were unrelated to running, were excluded. A day lost to injury was any day in which the runner was not able or permitted to participate in an unrestricted manner. Three time-loss classifications were used to assess injury severity: 1) Minor: 1–7 days missed, 2) Moderate: 8–21 days missed, and 3) Major: 22 days or more missed.[17,20] For injured runners, coaches/athletic trainers recorded the body part injured (e.g., knee).[19] The study research team met with the coaches and athletic trainers biweekly and collected the injury reports on a monthly basis. The DIR was reviewed and compared to the team's practice and competition schedule to ensure accurate and complete reporting.

Eating Attitudes and Behaviors. Near the beginning of the season, each runner completed the Eating Disorder Examination Questionnaire (EDE-Q) to identify disordered eating attitudes and behaviors.[21,22] The EDE-Q, a shorter version of the Eating Disorder Examination and designed for self-report,[23] is comprised of four subscales: weight concern, shape concern, eating concern, dietary restraint, and a global score. Scores ranging from 0 to 6 on a Likert scale correspond to the number of days over the past four weeks the respondent has experienced a specific attitude, feeling or behavior. The EDE-Q also assesses pathogenic eating behaviors, including binge eating, self-induced vomiting, and use of laxatives, diuretics, or diet pills to control body weight. The EDE-Q has high internal consistency, and moderate to high concurrent and criterion validity.[22-24] Additionally, the EDE-Q addresses a specific time frame and specifically assesses the frequency of eating behaviors. Strong test-rest and interrater reliability of the EDE-Q has been shown in adolescent female athletes.[25] Runners were classified as having disordered eating (DE) if they had a mean score of ≥4.0 on the weight concern, shape concern, eating concern, or dietary restraint subscales, or had a mean global score of ≥4.0, or if they reported engaging in any pathogenic behavior two or more times in the past four weeks.[21,25]

Menstrual Status. Following administration of the EDE-Q, the runners completed a menstrual status/history questionnaire, which was derived from an athletic pre-participation medical history form developed to screen for presence of female athlete triad components.[26] The criteria for classifying runners with menstrual dysfunction were: primary amenorrhea (no onset of menses by age 15 years), secondary amenorrhea (cessation of menstrual cycles for ≥3 consecutive months in the past year), or oligomenorrhea (menstrual cycles occurring at intervals >35 days during the past year, after onset of menses by age 15 years).[12] For analyses purposes, girls meeting any of these criteria were combined into a single menstrual dysfunction (oligo/amenorrheic) group and compared to girls with normal menses (eumenorrheic).

Bone Mineral Density (BMD). Two to four weeks following the completion of the questionnaires, areal BMD ($g \cdot cm^{-2}$) at the spine (L1-L4), proximal femur, tibia/fibula (condyles of tibia to tibial and fibular malleoli) as well as whole-body, and body composition (percent fat and lean tissue mass) were assessed by DXA using a Lunar DPX-NT densitometer (Manufacturer, Madison, WI). Quality assurance (QA) tests were performed each morning of testing. The coefficient of variation in BMD in the study laboratory (30 subjects measured twice) was 0.6% for the total hip, 1.2% for the spine (L1-L4), and 0.99% for whole-body, indicating excellent precision.

Runners were categorized as having low BMD for age if their BMD Z-score (number of standard deviations

[SD] above or below the mean for the patient's age, sex and ethnicity) at the spine or whole-body was 1 SD or 2 SDs below the age-matched, gender-specific reference data from the GE/Lunar pediatric data base (BMD Z-score of ≤ -1 or ≤ -2).[12,27,28] Both BMD Z-score levels were examined to determine severity of low BMD because athletes in impact sports should normally be expected to have BMD values approximately 15% higher than non-athletes;[12] thus BMD Z-scores between -1 and -2 should be cause for concern.[29]

Statistical Methods

Independent *t*-tests and the chi-square test compared demographic, physical and menstrual history characteristics between injured and non-injured runners. As body mass has been reported to influence scores on eating attitudes questionnaires,[30] analysis of covariance (ANCOVA) controlled for body mass index (BMI, ($kg*m^{-2}$)) when comparing the mean EDE-Q scores between injured and non-injured runners. ANCOVA was also controlled for chronological age, gynecological age (chronological age minus age at menarche), and BMI when comparing BMD of injured and non-injured runners, as these variables are associated with BMD.

For multivariable analyses, the measure of association was the adjusted odds ratios (AOR) and 95% confidence intervals (95% CI), which were generated from a multiple logistic regression analysis.[31] Items in the logistic regression model analyses included disordered eating, menstrual status, BMD, and factors suspected to confound the relationships including chronological age, lean tissue mass, and gynecological age. Adjusted models were conducted for the ≤ -1 SD and ≤ -2 SDs BMD group levels. For all of the statistical analyses, the alpha level was set a priori at 0.05. All analyses were conducted with SPSS (version 20.0; SPSS Inc, Chicago, IL).

RESULTS

Characteristics of Runners

Thirty-eight (42.7%) of the 89 runners incurred 65 running-related injuries during their respective sport season. The mean characteristics for continuous variables (age, height, weight, BMI, lean tissue mass, total body fat percent) are reported in Table 1. Those who incurred injuries were not statistically significantly different from those without injury on any of the continuous demographic or physical characteristics ($p > 0.05$). The sample included a racial/ethnic distribution of 43.8% Caucasian, 24.7% Latina, 20.2% African American, 9.0% Asian/Pacific Islander, and 2.3% 'other' race/ethnicity. Chi-square analysis indicated that the racial/ethnic distribution by injury status was not statistically significant ($p = 0.98$).

Musculoskeletal Injuries

The most common sites of injury were the lower leg (shin/calf) (46.2%) knee (15.4%), hip (15.4%) and

Table 1. *Means and Standard Deviations of Selected Demographic and Physical Characteristics of Sample by Musculoskeletal Injury Status.*

Characteristics	Total (N= 89) Mean	(SD)	Injured (N = 38) Mean	(SD)	Non-injured (N =51) Mean	(SD)	p-value*
Age	15.5	(1.3)	15.7	(1.3)	15.4	(1.3)	0.45
Height (cm)	163.9	(6.6)	164.3	(6.0)	163.6	(7.1)	0.63
Weight (kg)	57.9	(8.0)	58.0	(8.1)	57.8	(8.1)	0.88
BMI ($kg*m^{-2}$)	21.6	(2.7)	21.5	(2.5)	21.6	(2.9)	0.83
Lean tissue mass (kg)	38.9	(4.3)	38.9	(4.5)	38.9	(4.2)	0.95
Body fatness (%)	26.0	(6.8)	26.7	(6.2)	25.5	(7.2)	0.41
Age at menarche (y)	12.3	(1.1)	12.3	(1.1)	12.3	(1.1)	0.91
Gynecological age (y) †	3.2	(1.7)	3.3	(1.8)	3.1	(1.6)	0.51
Menses past year (#)	10.9	(2.3)	11.1	(2.0)	10.8	(2.5)	0.49

*Between injured and non-injured mean values, Independent t-test.
†Gynecological age: Chronological age – menarcheal age.

foot (12.3%). (Table 2) Most injuries were minor ([1-7 days lost], 58.5%) in severity followed by moderate ([8-21 day lost], 27.7%) and severe ([22 or more days lost], 13.8%) injuries.

Menstrual Dysfunction, Disordered Eating & BMD Mean Values by Injury Status

At baseline, among all runners, 11.2%, 21.3%, and 32.6% met the criteria for disordered eating, menstrual dysfunction, and low BMD, respectively. Overall, while runners reporting oligo/amenorrhea during the past year had a significantly older menarcheal age than runners reporting normal menses (mean [SD] = 13.1 [1.2] vs. 12.1 [1.0], p = 0.001), the mean characteristics for menarcheal age were not statistically significantly different from those with or without injury. (Table 1) After adjusting for BMI, injured runners reported significantly higher mean scores than for EDE-Q subscales for weight concern (p = 0.002) and shape concern (p = 0.004), and global score (p = 0.005) than non-injured runners (Table 3). Overall, a low percent of pathologic behaviors such as binging (3.4%), vomiting (3.4%), laxative use (2.2%), and diuretic use (0.0%) was reported by the runners (via the EDE-Q) and no significant differences were observed between injured and non-injured runners (p > 0.05). Injured runners had significantly lower BMD at the spine (p = 0.009), total hip (p = 0.03), and whole-body (p = 0.04) as compared to non-injured runners after adjusting for lean tissue mass, chronological and gynecological age. While injured runners had lower BMD than non-injured runners at the tibia/fibula, the difference was not statistically significant (p = 0.08). After adjusting for gynecological age and lean tissue mass, injured runners had significantly lower BMD Z-score at the spine than non-injured runners (p = 0.02).

Risk factors for Musculoskeletal injury

After adjusting for gynecological age, lean tissue mass, and all Triad components (disordered eating, oligo/amenorrhea, low BMD), low BMD (BMD Z-score of ≤ -1.0 SD) was significantly associated with running related injury in the final BMD Z-score ≤ -1 SD logistic regression model (Table 4). However, in the final BMD Z-score ≤ -2 SDs logistic regression model, oligo/amenorrhea was associated with running-related injury.

Risk factors and tibular/fibular injury. While runners who incurred any shin injury had lower tibial/fibular BMD values (1.146 ± 0.110) than runners who did not incur a shin injury (1.169 ± 0.111), the difference was not statistically significant after adjusting for gynecological age, lean tissue mass, and oligo/amenorrhea (p = 0.30).

DISCUSSION

The purpose of this study was to determine if components of the female athlete triad, as defined in the 1997 ACSM position stand,[18] were associated with lower extremity musculoskeletal injury in a cohort of competitive female high school runners. The current study's results indicated that runners who reported oligo/amenorrhea during the past year, or whose BMD was lower than expected for their age

Table 2. *Incidence and severity of musculoskeletal injury (n = 65) by body location in 38 injured high school cross-country runners.*

Body Location	Number of Injuries	(%)	Average Days Lost due to Injury	Range of Days Lost Due to Injury	Percent of Minor Injuries*	Percent of Moderate Injuries†	Percent of Major Injuries‡
Lower back	1	1.5	61.0	61.0	0.0	0.0	100.0
Hip/Pelvis	10	15.4	5.2	2 to 12	60.0	40.0	0.0
Thigh	4	6.2	15.8	5 to 48	75.0	0.0	25.0
Knee	10	15.4	7.2	1 to 21	60.0	40.0	0.0
Lower leg	30	46.2	15.5	1 to 55	50.0	26.7	23.3
Ankle	2	3.1	3.0	3.0	100.0	0.0	0.0
Foot	8	12.3	7.0	1 to 19	75.0	25.0	0.0
Total	65				58.5	27.7	13.8

Time Lost Categories:[17,20]

*Minor: 1 to 7 days lost from running participation.

†Moderate: 8 to 21 days lost from running participation.

‡Major: 22 or more days lost from running participation.

Table 3. *EDE-Q and Bone Mineral Density by Musculoskeletal Injury Status.*

Characteristic	Total (N=89) Mean (SD)	Injured (N=38) Mean (SD)	Non-injured (N=51) Mean (SD)	p-value
EDE-Q subscale*				
Weight concern	1.47 (1.22)	1.90 (1.28)	1.16 (1.09)	**0.002**
Shape concern	1.78 (1.31)	2.22 (1.42)	1.45 (1.13)	**0.004**
Eating concern	0.62 (0.78)	0.80 (0.94)	0.48 (0.62)	0.06
Dietary restraint	1.00 (1.24)	1.27 (1.33)	0.80 (1.15)	0.07
Global score	1.23 (0.98)	1.55 (1.07)	0.99 (0.86)	**0.005**
Bone mineral density, g/cm^{2}†				
Spine (L1-L4)	1.137 (0.133)	1.107 (0.146)	1.160 (0.119)	**0.009**
Total hip	1.104 (0.121)	1.075 (0.125)	1.126 (0.115)	**0.03**
Femoral neck	1.120 (0.118)	1.102 (0.125)	1.133 (0.112)	0.17
Trochanter	0.899 (0.115)	0.875 (0.115)	0.916 (0.113)	0.06
Whole-body	1.152 (0.086)	1.136 (0.086)	1.163 (0.085)	**0.04**
Tibia/Fibula‡	1.164 (0.110)	0.146 (0.101)	0.178 (0.116)	0.08
Z-score§				
Spine	-0.17 (1.30)	-0.48 (1.46)	0.07 (1.14)	**0.02**
Whole-body	0.47 (1.02)	0.27 (1.02)	0.61 (1.00)	0.06

EDE-Q, Eating Disorder Examination Questionnaire.

*EDE-Q subscales were used to classify runners with disordered eating. Comparisons between injured and non-injured runners were adjusted for body mass index; Analysis of Covariance.

†Comparisons between injured and non-injured runners were adjusted for chronological age, gynecological age (chronological age minus age at menarche), lean tissue mass; Analyses of Covariance.

‡Condyles of tibia to tibial and fibular malleoli.

§Comparisons between injured and non-injured runners were adjusted for gynecological age, lean tissue mass (kg); Analyses of Covariance.

based on reference norms (BMD Z-score ≤ -1.0), were at increased risk of injury. While there have been two previous prospective studies on associations between all three Triad components and musculoskeletal injury in collegiate or competitive club running populations,[9,10] to the authors' knowledge, this is the first study to report these relationships specific to female high school runners. The prospective design allowed the status of each runner's Triad component to be determined along the Triad spectrum before injuries occurred, which strengthened the study design by decreasing the likelihood of recall or measurement bias.[31]

Injuries

Thirty-eight (42.7%) runners reported incurring at least one running-related injury to the lower extremities that resulted in a missed practice or competitive event. This finding supports previous reports that female high school distance runners have a high annual-season injury risk and that most will incur an injury considered minor in severity.[2,3,19.] As over 40% of the injuries caused the runners to miss a week or more of practices and/or competitive events indicates that more investigation is needed to determine the reasons for the greater disability at some body locations.

Menstrual Dysfunction and Injury

The current study's finding that oligo/amenorrhea was associated with lower extremity musculoskeletal running-related injury is consistent with data reported by Austin et al in their study of female high school cross country runners.[15] The results from Austin et al and the current study have a two-fold importance. First, they support findings from prior

Table 4. *Adjusted Odds Ratios for Musculoskeletal Injury by Disordered Eating Status, Menstrual Status, and Low Bone Mineral Density Level.*

	Musculoskeletal Injury			
	BMD Z-score ≤ -1 SD		BMD Z-score ≤ -2 SDs	
Risk Factor	AOR*	95% CI	AOR*	95% CI
Disordered eating status				
Normal (EDE-Q <4.0)	1.0		1.0	
Elevated (EDE-Q ≥4.0)	1.9	0.4-8.6	1.9	0.5-8.2
Menstrual status				
Eumenorrheic	1.0		1.0	
Oligo/amenorrheic†	2.8	0.8-9.8	**4.1**	**1.2-13.5**
Bone mineral density Z-scores				
Normal (Z-score > -1 SD)	1.0			
Low (Z-score ≤ -1 SD)	**4.6**	**1.5-13.3**	-----	-----
Normal (Z-score > -2 SDs)			1.0	
Low (Z-score ≤ -2 SDs)	-----	-----	5.9	0.9-37.9

AOR, Adjusted Odds Ratio; 95% CI, 95% Confidence interval; EDE-Q, Eating Disorder Examination Questionnaire.

*Adjusted for all variables in the table plus gynecologic age (chronological age minus age at menarche), and lean tissue mass.

†Oligo/amenorrhea: athletes who reported primary amenorrhea, oligomenorrhea, secondary amenorrhea.

studies of high school and collegiate runners, competitive club track runners, and recreational runners where menstrual dysfunction has been associated with injury.[7-11,13,16] Second, they provide evidence that menstrual dysfunction may play a role in the increased likelihood of injury in a younger female running population. This study's finding of an association between oligo/amenorrhea and lower extremity musculoskeletal running-related injury is notable, as past studies that have examined the role of menstrual dysfunction have primarily focused on stress fractures or bone stress-related injuries.[7-11,13,16] The current study included all injuries regardless of bone- or non-bone-related injuries. While the mechanisms for both types of injuries are not fully clear, there have been reports of a direct negative effect of dietary restriction on hormones that regulate menstrual function and on markers of bone turnover.[32] Further, other reports have indicated that physiologic adaptations evident of energy deficiency, including decreased circulating IGF-I, thyroid hormone, and leptin, and increased cortisol, are associated with amenorrhea and are indicative of a suppressed anabolic state.[32-35] While there is no published literature to the authors' knowledge, the same hormonal profile that disrupts normal bone metabolism may also affect the health of other tissues, including muscle and connective tissue, which may explain the relationship between oligo/amenorrhea and non–bone-related (e.g., muscle strain) injuries. Several prospective studies have reported a relationship between older menarcheal age and stress fracture in competitive adult cross-country runners and club track and field athletes.[9,10] Tenforde et al.[16] also reported that high school runners who incurred a stress fracture had an older menarcheal age on average than runners without stress fracture. In the current study, however, a relationship between menarcheal age and injury was not observed. This finding may be attributable in part to that the difference in menarcheal age between injured and non-injured runners was only one year.

BMD and Injury

When the risk of injury was examined by BMD Z-scores, runners with low BMD were found to be at a 5- and 6-fold increased risk of injury at -1 SD and -2 SDs, respectively. This finding supports those reported by Kelsey et al.[10] who found an association between stress fracture and low hip BMD in young female cross-country runners. The current study's finding also concurs with reports of several prospective and retrospective studies whose authors[9,10,11,13] found relationships between low BMD and stress fracture or other musculoskeletal injury among runners. This study's finding that injured runners had lower mean lumbar spine BMD is consistent with findings of authors who have reported associations between lower lumbar spine[9-11] or hip BMD[11] and increased risk of stress fracture in competitive, adult, or track and field athletes. Further, although non-statistically significant trends were observed, the injured runners had lower mean femoral neck, trochanter, and whole-body BMD than uninjured runners. As musculoskeletal-related injuries to the shin were expected to be the most common injury observed in this running population,[3,19] the runners' tibia/fibula BMD was evaluated. While the levels of tibial/fibular BMD of the injured runners were lower than the non-injured runners, the finding was not significant. This finding, as well as the lower levels of BMD observed at the lumbar spine, proximal femur, total hip, femoral neck and trochanter in the injured runners, suggests that low BMD, directly or indirectly, may increase a female high school runner's susceptibility to a bone or non–bone related injury. Therefore, behaviors that promote optimal bone mineral accrual in high school runners may also serve a protective role in minimizing the incidence of non–bone related injury.[17]

Disordered Eating and Injury

The adjusted mean scores for all disordered eating subscales and the global scale were higher among injured runners than uninjured runners. While this finding supports results from several previous studies in high school[17,36] and collegiate[37] athletes, the mean scores for the injured runners in the current study were generally within the normal range for eating behavior and attitudes. Further, in the adjusted estimates, the percentages of runners of having a disordered eating or attitude concern (weight, shape, eating, dietary restraint) were also higher among the runners incurring a lower extremity musculoskeletal injury than the runners not reporting a lower extremity musculoskeletal injury, but these findings were also non-significant. While these findings are non-statistically significant, the patterns of unhealthy eating attitudes and behaviors among the injured runners are important because several studies have reported that dietary restraint behaviors or restricted caloric intake may lead to amenorrhea, decreased bone formation and/or increased bone resorption, low BMD, or increased likelihood of stress fracture.[8,24,38] The current study's findings that only a small percentage of runners reported disordered eating behaviors and attitudes in the current study raises the important speculation that the runners may not be aware of the importance of the energy intake level needed to support their high energy expenditure. Alternatively, the low number of runners reporting DE may be attributed to them not reporting truthfully on the EDE-Q for reasons that include the belief that they need to be lighter for increased performance, or fear of possible consequences of revealing disordered eating. Further study is needed to examine the truthfulness and validity of adolescent's reports on eating behaviors and attitudes using the EDE-Q.

Limitations

Several limitations of the current study should be noted. First, the study data were collected before the revised ACSM position stand[12] was published. At that time, the Triad was more narrowly defined in terms of disordered eating/eating disorders[18] rather than the current broader definition of energy availability[12] which requires measurement of both energy intake and exercise energy expenditure in order to calculate energy availability. Thus, the relationship between energy availability, with or without disordered eating, and lower extremity musculoskeletal injury was not examined. Second, self-reported menstrual status data was also used instead of laboratory measures. Interpreting menstrual data is difficult, especially in those runners who report oligomenorrhea, which is not uncommon in the first few years after menarche.[39] However, approximately 90% of girls attain regular cycles within two years of menarche.[40,41] Thus, at a mean age of 15.5 years and onset of menarche at 12.3 years, it would be expected that most of the runners in the study sample would have attained regular menstrual cycles unless they truly had a menstrual disturbance. Further, the current study's data was reliable[25] and consistent with those reported in prior studies where menstrual status was measured by self-report in high school, collegiate, and elite athletes. Third, data on runners' training mileage was not collected. Increased running mileage has been associated with low BMD,[42] and low BMD has been related to injury.[9-11,13] Thus, future studies involving adolescent runners should assess the relationships between running mileage, Triad components, and injury. Finally, while the coaches' reports regarding injured body site were believed to be accurate due to the education the coaches received about running injuries and how to report them, [19] the accuracy of their reports on injury type (e.g., sprain, strain, stress reaction) was less certain without a clinician's diagnosis to confirm them. Thus, results regarding injury type were not reported as this may have increased the likelihood for misclassification.[31]

Future Directions

Several recommendations are suggested for future research. First, while there has been increasing evidence for the causal mechanisms in how low energy availability and/or menstrual irregularity play a role in low BMD and stress fracture injuries, less is known on the causality mechanisms of these factors and lower extremity non bone-related musculoskeletal injuries. Presently, the authors of this study speculate that components of the Triad contribute to the occurrence of musculoskeletal injury by decreasing the musculoskeletal tissues' ability (e.g., weaken) to withstand stresses caused by factors such as excessive pronation or other biomechanical defects, training error (e.g., too much mileage too soon).[19,43] Second, further examination into the influence of Triad components on decisions to return athletes to sport participation following injury is recommended. Previous reports provide evidence that Triad components may delay or impede healing time of both bone and soft tissues,[44,45] such that return to play too soon may make them more susceptible to re-injury. Third, more prospective studies with larger sample sizes of interscholastic runners are needed. Prior to recent reports, most studies have used cross-sectional designs with smaller sample sizes. Thus, the ability to look at the temporal relationship between Triad components and risk of injury has not been adequately evaluated. Fourth, as recommended by the 2007 ACSM Triad position stand,[12] future investigators should evaluate the association between energy availability, with and without eating disorders or disordered eating, and running-related injuries, using valid and reliable measures that will capture the runners' energy intake and exercise energy expenditure. Finally, intervention studies designed to educate high school runners, their parents, coaches, and sports health care professionals on the causes and adverse effects of the Triad, and to promote healthy eating and training behaviors are warranted as recent studies indicate that knowledge and awareness of detrimental effects of the Triad are lacking in these groups.[46,47]

Conclusions

In this prospective study of 89 interscholastic female distance runners, oligomenorrhea/amenorrhea and low BMD were associated with lower extremity musculoskeletal injury. Causes of menstrual dysfunction and low BMD are multifactorial, so runners suspected of having menstrual dysfunction or low BMD should be referred to their physician for further examination. While the focus on identifying menstrual dysfunction has primarily been assessed during pre-participation exams, regular and close monitoring of adolescent female runners during season and off-season training appears warranted, especially with regard to reassessment when making important decisions prior to allowing a runner to return to training and competition after incurring a musculoskeletal injury.

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