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ORIGINAL RESEARCH

Dietary and Training Predictors of Stress Fractures in Female Runners

Laurel Wentz, Pei-Yang Liu, Jasminka Z. Ilich, and Emily M. Haymes

Purpose: To compare female runners with and without a history of stress fractures to determine possible predictors of such fractures. ***Methods:*** 27 female runners (age 18–40 yr) who had had at least 1 stress fracture were matched to a control sample of 32 female runners without a history of stress fractures. Bone mineral density (BMD) was measured by dual-energy X-ray absorptiometry (iDXA). Subjects answered questionnaires on stress-fracture history, training, menstrual status, and diet. ***Results:*** No significant differences were found in menstrual characteristics, diet and dairy intake, or bone measurements. Weekly servings of milk during middle school significantly predicted BMD at the femur ($p = .010$), femoral neck ($p = .002$), Ward's triangle ($p = .014$), and femoral shaft ($p = .005$). Number of menstrual cycles in the previous year predicted femoral-neck BMD ($p = .004$). Caffeine intake was negatively associated with BMD of the femur ($p = .010$), femoral neck ($p = .003$), trochanter ($p = .038$), and femoral shaft ($p = .035$). Weekly hours of training were negatively associated with total-body BMD ($p = .021$), total-body bone mineral content ($p = .028$), and lumbar-spine BMD ($p = .011$). Predictors for stress fractures included the number of years running, predominantly running on hard ground, irregular menstrual history, low total-body BMD, and low current dietary calcium intake when controlling for body-mass index (Nagelkerke $R^2 = .364$). ***Conclusions:*** Servings of milk during middle-school years were positively correlated with hip BMD, although current calcium intake, low BMD, irregular menstrual history, hard training surface, and long history of training duration were the most important predictors of stress fractures.

Keywords: bone mineral density, athletes, calcium intake, nutrition, menstrual irregularities, running on hard surface

An injury commonly experienced in distance running and track athletes is a stress fracture, which occurs when repetitive mechanical loading disrupts the balance between bone resorption and formation (Pepper, Akuthota, & McCarty, 2006). Risk factors that have been identified include female gender, poor biomechanics, overtraining, menstrual irregularity, low bone mineral density (BMD), disordered eating, inadequate calcium intake, and depressed serum levels of vitamin D (Wentz, Liu, Haymes, & Ilich, 2011). In spite of the accepted role of dietary calcium in achieving peak bone mass, inadequate calcium intake has not been clearly established as a risk factor for stress fractures.

Calcium intake has been established as a regulator of bone metabolism, especially important to adolescent growth and the attainment of peak bone density (Weaver, 2002). More-frequent consumption of milk during childhood and adolescence has been correlated with increased BMD in postmenopausal women (Kalkwarf, Khoury, & Lanphear, 2003; Teegarden, Lyle, Proulx, Johnston, & Weaver, 1999). Since reduced BMD has been found to be a risk factor for stress fractures (Myburgh, Hutchins, Fataar, Hough, & Noakes, 1990), inadequate adolescent calcium intake may contribute to the development of stress fractures through its influence on BMD. Limited research has found significant relationships between calcium intake and stress fractures, linking lower dairy intake with increased risk of stress fracture (Kelsey et al., 2007; Myburgh et al., 1990). Many investigations into the etiology of stress fractures focus on current dietary calcium intake in subjects who are at least 18 years of age, by which time they have accrued most of their peak bone mass. Furthermore, subjects who experienced stress fractures in the past may have increased their intake of dietary calcium in an effort to accelerate healing and prevent future occurrences (Guest & Barr, 2005).

Menstrual irregularities have also been linked to the development of stress fractures, likely due to the effect of estrogen deficiency on bone turnover (Bennell et al., 1996). In female athletes with and without stress fractures, reduced BMD in the spine and Ward's triangle was correlated with fewer menstrual cycles (Myburgh et al., 1990). Furthermore, athletes with menstrual irregularity may have coexistent behaviors characteristic of disordered eating, restricting their total calories, as well as many individual nutrients.

Wentz, Ilich, and Haymes are with the Dept. of Nutrition, Food and Exercise Sciences, Florida State University, Tallahassee, FL. Liu is with the School of Family and Consumer Sciences, University of Akron, Akron, OH.

We hypothesized that female runners who had higher current calcium intake and whose dairy intake throughout the adolescent years was higher would be less prone to developing stress fractures. Therefore, the purpose of this study was to compare female runners with a history of stress fractures with matched runners with no history of stress fractures to determine whether there were differences in dairy intake during their adolescent years and current dietary calcium intake. Other possible predictors of stress fractures, including energy intake, BMD, menstrual irregularities, and duration and type of training, were considered, as well.

Methods

Subjects

Participants were recruited from local races, running clubs, and university cross-country teams using flyers, as well as through contacts with coaches and club officers. Female runners, age 18–40 years, who ran a minimum of 20 miles/week were recruited. Interested subjects were screened to ensure they were not pregnant and were free of chronic disease. For inclusion in the stress-fracture group, runners had to have had at least one stress fracture that had been confirmed by a diagnostic test by a medical professional. Once the sample of runners who had experienced at least one stress fracture was identified, control runners without a history of stress fracture were matched for race, age, weight, and fat-free mass (FFM). Subjects were not excluded based on menstrual status or use of oral contraceptives, but these variables were evaluated for consideration in statistical analysis. All study procedures were approved by the institutional review board at Florida State University, and all subjects provided written informed consent before participation.

Measurements

Subjects were measured in indoor clothes without shoes or jewelry. Height was measured using a wall-mounted stadiometer to the nearest 0.1 cm. Weight was measured on a digital scale to the nearest 0.1 kg, and body-mass index was calculated (kg/m^2). Dual-energy X-ray absorptiometry (iDXA) whole-body scans measured percent body fat, FFM, and fat mass. iDXA software was used to determine BMD (g/cm^2) and bone mineral content (BMC; g) of the whole body, lumbar spine, both proximal femurs (including total femur, Ward's triangle, femoral neck, trochanter, and femoral shaft), and the nondominant forearm (33% radius). All measurements were performed on the same Lunar iDXA machine (GE Medical Systems, Madison, WI) using standard manufacturer software (Encore 2006, version 9.1).

Subjects were asked to disclose their history of stress fractures, menstrual status, dietary intake, and training history. Current menstrual status was categorized as eumenorrheic (10–12 menses/year), oligomenorrheic (4–9 menses/year), or amenorrheic (0–3 menses/year). Following the procedures of Grimston, Sanborn, Miller, and Huffer (1990), the Menstrual History Index was calculated from the number of years subjects were menstruating regularly (years R), experiencing oligomenorrhea (years O), or amenorrhea (years A) for each age range to estimate the average number of menstrual cycles per year from menarche through current age. Women whose menstrual index was below 10 indicated that they had a history of menstrual irregularity.

$$\text{MHI} = \frac{11.5\left(\text{years R}\right)+7\left(\text{years O}\right)+1.5\left(\text{years A}\right)}{\text{current age-age at menarche}}$$

Retrospective analysis of calcium intake relied on dairy foods and supplements consumed during periods of subjects' lives from childhood through present. Subjects were asked to estimate weekly servings of dairy products consumed during elementary, middle, and high school; since leaving high school; and over the past year. Serving sizes for each dairy product were as follows: 8 fluid oz (1cup) of milk, 8 oz of yogurt, 1 oz of cheese, 1/2 cup of cottage cheese, 1/2 cup of ice cream. Subjects were shown food models representing these serving sizes to help them estimate their intake. This survey tool was generated based on the procedures of Myburgh et al. (1990). Subjects were also asked to list details of calcium, vitamin D, and multivitamin supplements consumed, including dosage and dates of use. Despite possible limitations that result from depending on memory recall to estimate dietary intake, it has been suggested that dairy products, especially milk, can be remembered with fair accuracy due to their stability in the diet (Kalkwarf et al., 2003).

To assess current dietary habits, subjects completed a 3-day food record. A registered dietitian instructed subjects on serving sizes with the use of food models and helpful reminders to produce accurate results. Dietary intake for calcium, energy, and all other nutrients was analyzed using NutriBase 7 (2007) software. Subjects were asked to include any supplements they consumed.

Blood was drawn approximately 10 days after the onset of the menses in the women who had regular menstrual cycles, during the late follicular phase of the ovarian cycle. Samples were collected in 5-ml Vacutainers and centrifuged at 3,000 rpm for 20 min. Serum was collected into 1.7-ml polypropylene microtubes (VWR, Suwannee, GA) and stored in a freezer at –20 °C until all serum samples were collected. Serum estradiol concentrations were measured using an enzyme immunoassay kit (ALPCO Immunoassays, Salem, NH). Assays were performed in duplicate. The intra-assay and interassay coefficients of variation were 4.6–9.3% and 6.2–10.1%, respectively.

Statistical Analysis

In a similar study published in this area, Guest and Barr (2005) selected power of .80 with an alpha level of .05 to calculate sample size. Effect size was calculated based on the work of Myburgh et al. (1990), resulting in a minimum sample size of 26 subjects for each group. Results were analyzed using SPSS (version 19). Descriptive statistics ($M \pm SD$) were computed for each variable collected for comparison between groups. Subjects in each group were matched for age, weight, and FFM. Student's t tests for independent variables were used to compare means for continuous variables between the groups. For categorical variables with nonnormally distributed means, chi-square analysis was used to detect differences between groups. Pearson's correlations were used in univariate analysis to determine associations between independent variables and BMD of the total body, total femur, femoral sites, spine, and nondominant forearm. Variables with strong correlations were entered into stepwise multiple linear regression to identify significant predictors for BMD in multiple-regression models. Variables were entered into logistic-regression analysis to create a model to predict the risk of stress fractures. Differences were considered significant at $p < .05$.

Results

Sixty-eight female runners were recruited for the study, ranging in age from 18 to 40 years. All subjects ran at least 20 miles/week. Twenty-seven subjects who had had at least one stress fracture diagnosed by a doctor made up the stress-fracture group. All women in this group identified their ethnicity as White, non-Hispanic. Eight subjects from the stress-fracture group were identified as having a history of multiple stress fractures; there were 44 stress fractures in 27 subjects. Most of the stress fractures had occurred in the tibia and fibula (47.7%), followed by the metatarsals (36.4%), femur (11.3%), calcaneus (2.3%), and spine (2.3%). From the remaining subjects, the control group matched for age, weight, FFM, and ethnicity was selected ($n = 32$). Demographic and bone characteristics of the two groups are presented in Table 1. No significant differences were observed between stress-fracture and control groups for BMD in total body; lumbar spine; femoral sites; and nondominant forearm, measured at 33% radius; or total-body BMC.

No differences were observed for training factors, prior menstrual history, current menstrual status, or use of oral contraceptives between subjects (Table 2). Regularly menstruating subjects visited the laboratory during their follicular phase, an average of 9.2 days after the start of their menses (range 5–14 days). Amenorrheic subjects visited the laboratory at random. No significant difference between groups was observed for serum estradiol.

Weekly servings of milk and dairy foods are illustrated in Figures 1 and 2. Dairy intake was analyzed as milk servings alone, as well as total dairy servings. No significant differences were observed between stress-fracture and control groups for servings of milk or total dairy intake for any life period.

Results of the 3-day food records reflecting current dietary intake are presented in Table 3. Two stress-fracture and one control subject failed to complete their 3-day food records and are not included in this analysis. Energy intake and macronutrients did not differ between

Table 1 Demographic and Bone Characteristics of Female Runners With and Without a History of Stress Fracture, *M* ± *SD*

Characteristic	Control ($n = 32$)	Stress fracture ($n = 27$)
Age (years)	23.1 ± 4.4	24.0 ± 5.5
Height (cm)	165.8 ± 4.7	166.4 ± 4.7
Weight (kg)	57.3 ± 6.3	57.5 ± 6.3
Fat-free mass (kg)	43.6 ± 4.3	43.6 ± 4.1
Body fat (%)	23.7 ± 4.9	23.8 ± 4.9
Body-mass index (kg/m^2)	20.8 ± 1.9	20.8 ± 2.2
Bone mineral density (g/cm^2)		
total body	1.162 ± 0.081	1.147 ± 0.069
lumbar spine (l2–l4)	1.189 ± 0.114	1.190 ± 0.118
total femur	1.128 ± 0.114	1.130 ± 0.104
femoral neck	1.135 ± 0.107	1.134 ± 0.104
Ward's triangle	1.038 ± 0.121	1.013 ± 0.138
trochanter	0.900 ± 0.114	0.900 ± 0.095
femoral shaft	1.334 ± 0.139	1.340 ± 0.137
33% radius	0.662 ± 0.058	0.652 ± 0.046
Total-body bone mineral content (g)	2,401.7 ± 245.4	2,380.3 ± 195.4

Note. Statistical analysis was conducted using an independent Student's t test. No differences were observed at $p < .05$.

Table 2 Training and Menstrual Characteristics of Female Runners With and Without a History of Stress Fracture

Characteristic	Control (*n* = 32)	Stress fracture (*n* = 27)
Length of time running (years)	5.3 ± 2.9	6.6 ± 2.9
Days run per week	5.8 ± 1.1	5.8 ± 1.1
Running distance (miles/week)	35.8 ± 9.9	37.8 ± 11.4
Running pace (min/mile)	7.9 ± 0.7	7.6 ± 0.4
Hours trained per week (hr)	8.5 ± 1.8	9.2 ± 1.5
Primary running surface (%)		
hard ground	14.5 ± 0.6	22.2 ± 0.9
soft ground	16.4 ± 0.6	18.1 ± 0.9
asphalt	22.3 ± 0.9	17.1 ± 0.9
concrete	17.5 ± 0.8	14.5 ± 0.8
grass	14.9 ± 0.6	15.8 ± 0.7
artificial track	10.3 ± 0.3	8.6 ± 0.3
treadmill	4.1 ± 0.4	3.6 ± 0.4
Age of menarche (years)	12.9 ± 1.8	13.6 ± 1.6
Current menstrual status (% subjects)		
eumenorrheic	68.8	63.0
oligomenorrheic	25.0	33.3
amenorrheic	6.2	3.7
Oral contraceptive use (% subjects)	25.0	40.3
MHI	9.2 ± 2.9	8.9 ± 2.5
MHI category (% subjects)		
regular	53.1	40.7
irregular	46.9	59.3
Serum estradiol (pg/ml)	89.0 ± 50.2	113.2 ± 60.7

Note. MHI = menstrual history index (average number of menstrual cycles/year in menstruation lifetime). Data are *M* ± *SD* unless stated otherwise. Statistical analysis was conducted using the independent Student's *t* test for continuous variables and chi-square for categorical variables. No differences were observed at $p < .05$.

groups, even after comparing energy per kilogram FFM or percent of calories from macronutrients. Calcium and vitamin D intake were calculated from dietary records alone and from dietary records plus supplement intake (calcium, vitamin D, and multivitamin supplements) as total intakes. There was a trend ($p = .077$) for greater dietary calcium intake in the control group. Significantly more stress-fracture subjects were consuming a calcium and/or vitamin D supplement ($p = .044$), although no differences were observed in total calcium or vitamin D intake. There were no significant differences in fiber, caffeine, or alcohol intake.

Total-femur BMD was positively associated with servings of milk during middle school ($p = .010$) and inversely associated with current caffeine intake ($p = .010$) and subjects' average training mile pace ($p = .039$; Table 4). Femoral-neck BMD was positively associated with servings of milk during middle school ($p = .002$) and number of menstrual cycles in the past year ($p = .004$) and inversely associated with caffeine intake ($p = .003$). Ward's triangle BMD was associated only with servings of milk during middle school ($p = .014$). Trochanter BMD was positively associated with estradiol ($p = .009$) and inversely associated with caffeine intake ($p = .038$). Femoral-shaft BMD was positively associated with servings of milk during middle school ($p = .005$) and inversely associated with caffeine intake ($p = .035$).

Logistic-regression analysis was used to construct a model designed to predict risk of stress fractures. The final model, controlled for body-mass index, is presented in Table 5 and was able to correctly classify 75.0% of subjects as stress-fracture or control. According to this model, stress-fracture risk was predicted by longer running history, irregular menstrual history, lower dietary calcium intake, lower total-body BMD, and training predominantly on a hard surface.

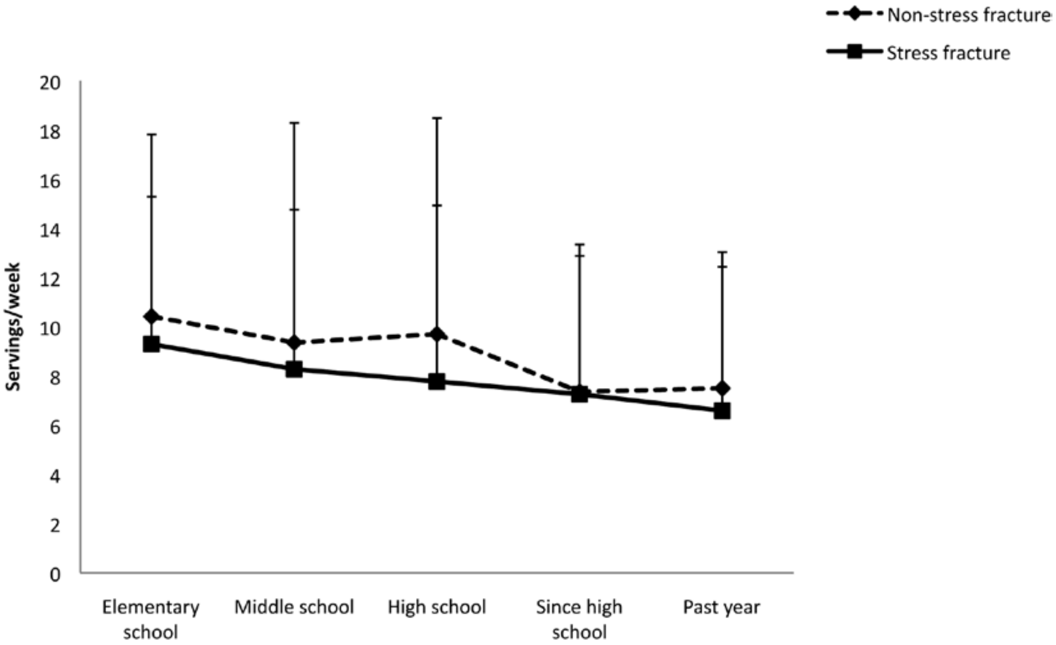

Figure 1 — Weekly servings of milk estimated at different periods of subjects' lives. One serving of milk was 8 fluid oz.

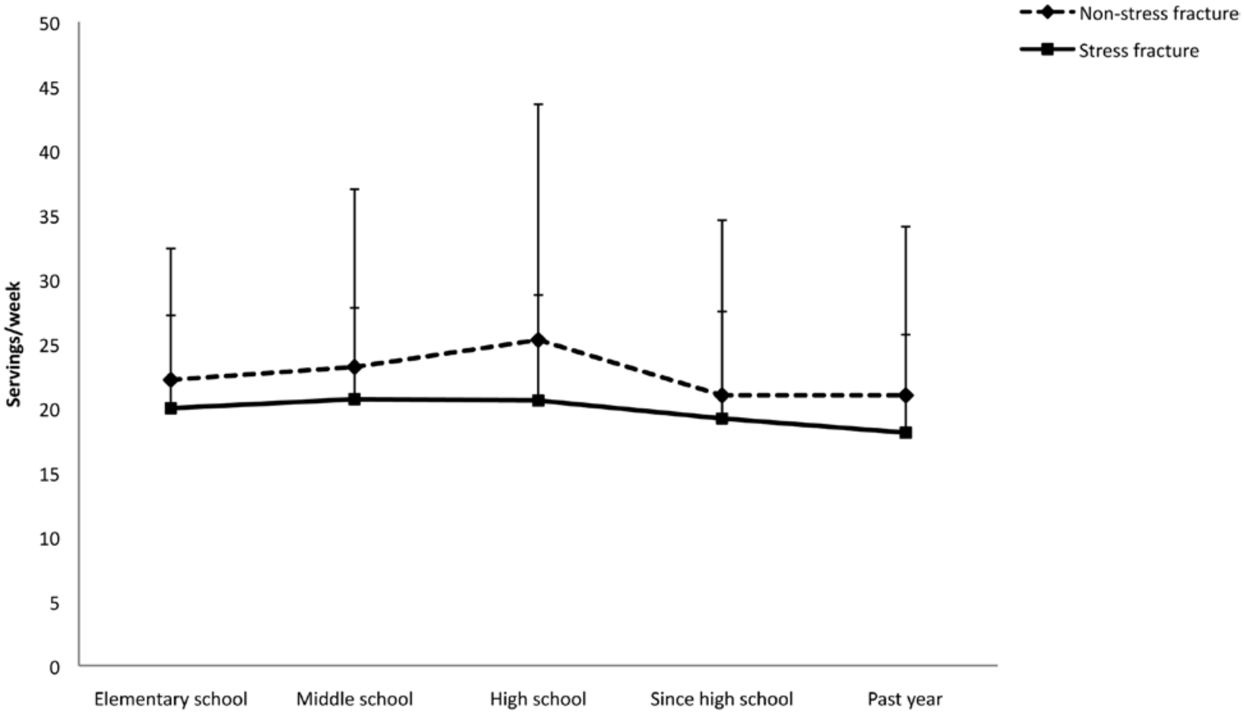

Figure 2 — Weekly servings of total dairy intake estimated at different periods of subjects' lives. Total dairy servings were calculated as the sum of weekly servings of milk (8 fluid oz), yogurt (8 oz), cheese (1 oz), cottage cheese (1/2 cup), or ice cream (1/2 cup).

Table 3 Current Daily Energy and Nutrient Intakes (Means From 3-Day Food Records) of Female Runners With and Without a History of Stress Fracture

Nutrient	Control (n = 31)	Stress fracture (n = 25)
Energy (kcal)	2,148 ± 723	1,983 ± 534
Energy per kg fat-free mass (kcal/kg)	49.6 ± 15.6	46.0 ± 12.5
Protein (g)	92 ± 28	91 ± 34
% energy	17.8 ± 4.0	18.4 ± 4.2
Carbohydrate (g)	298 ± 105	273 ± 73
% energy	55.4 ± 6.4	55.4 ± 7.9
Fat (g)	68 ± 28	63 ± 26
% energy	28.2 ± 5.6	28.1 ± 7.0
Calcium from diet (mg)	1,111 ± 491	904 ± 330
Total calcium: diet + supplements (mg)	1,464 ± 993	1,320 ± 579
Vitamin D from diet (IU)	146 ± 112	125 ± 90
Total vitamin D: diet + supplements (IU)	750 ± 838	814 ± 1041
Fiber (g)	28 ± 11	28 ± 10
Caffeine (mg)	47 ± 69	66 ± 91
Alcohol (g)	3.5 ± 8.3	2.3 ± 5.3
Calcium and vitamin D supplements (% subjects)	25.8*	52.0
Multivitamin (% subjects)	64.5	44.0

Note. Data are $M \pm SD$ unless stated otherwise. Three subjects failed to return their 3-day food records and are not included in this analysis. Statistical analysis was conducted using the independent Student t test for continuous variables and Chi-square for categorical variables.

*$p < .05$.

Table 4 Multiple Linear Regression to Predict Bone Mineral Density (BMD) of Skeletal Sites and Total-Body Bone Mineral Content (BMC) in All Women (N = 59)

Dependent variable	Explanatory variables	p	$\%R^2_{adj}$ of model
Total-body bone mineral density	Hours trained per week	.021	31.0
Total-body bone mineral content	Hours trained per week	.028	52.9
Lumbar-spine bone mineral density	Hours trained per week	.011	24.8
33% radius bone mineral density	Days run per week	.034	30.1
Total femur bone mineral density	Milk servings during middle school	.010	41.3
	Caffeine	.010	
	Running pace	.039	
Femoral-neck bone mineral density	Milk servings during middle school	.002	48.1
	Caffeine	.003	
	Menstrual cycles per year	.004	
Ward's triangle bone mineral density	Milk servings during middle school	.014	13.1
Trochanter bone mineral content	Caffeine	.038	35.5
	Estradiol	.009	
Femoral-shaft bone mineral density	Milk servings during middle school	.005	39.0
	Caffeine	.035	

Note. Models controlled for weight, height, and age of menarche. Running pace is defined as subjects' average training mile pace in min/mile.

Table 5 Logistic-Regression Model to Predict Risk of Stress Fracture in All Women (N = 59)

Variable	β	Wald	p	Odds ratio (95% CI)
Calcium from diet (mg)	–0.002	3.931	.047	0.998 (0.996, 1.000)
Menstrual History Index category (irregular or regular)	–1.391	3.911	.048	0.249 (0.063, 0.988)
Length of time running (years)	0.253	3.853	.050	1.288 (1.000, 1.658)
Total-body bone mineral density (g/cm^2)	–11.319	3.638	.056	0.00001 (0, 1.367)
Hard ground (% running surface)	0.032	3.649	.056	1.032 (0.999, 1.066)
Body-mass index (kg/m^2)	0.216	1.244	.265	1.241 (0.849, 1.814)
Model Nagelkerke R^2			.364	
Model classification (%)			75.0	

Discussion

This study compared female runners with a history of stress fracture with matched runners who had no history of stress fracture to determine if differences existed in diet, BMD, menstrual irregularity, and amount and type of training. No significant group differences were observed for measured variables, although statistical analysis showed an increased risk for stress fracture in women with longer running history, higher percentage of hard-ground running, low dietary calcium intake, lower total-body BMD, and history of irregular menstrual cycles. Milk intake during early adolescence, specifically middle school, was highly correlated with BMD at multiple skeletal sites, while caffeine intake and training variables were negatively correlated with BMD.

No differences in BMD were observed at any skeletal site between control and stress-fracture groups. The BMD levels in our study exceed those found in similar-age female cross-country runners for all sites measured (Kelsey et al., 2007; Nieves et al., 2010). Total-body BMD was included as a variable in the logistic model for stress-fracture prediction, reaching a borderline significance. Results from this retrospective study differ from those of prospective studies of competitive runners in which BMD differences were detected between groups (Bennell et al., 1996; Nattiv et al., 2000) or low total-body BMC increased the risk for stress fractures (Kelsey et al., 2007). Those subjects were not matched for weight or FFM given their prospective designs, which allowed them to be assessed for BMD and BMC before stress-fracture development rather than after they may have made dietary or training adjustments. One retrospective analysis did detect significant differences in BMD of the spine, femoral neck, Ward's triangle, trochanter, and total femur (Myburgh et al., 1990).

Our results indicated that hours of training per week were negatively correlated with total-body and lumbar-spine BMD and total-body BMC. Compared with athletes from other sports, runners tend to have lower BMD, owing to a combination of dietary deficiencies and inferior osteogenic stimulus (Mudd, Fornetti, & Pivarnik, 2007). Data collected from endurance runners have shown that weekly running distances were negatively correlated with lumbar-spine (Hind, Truscott, & Evans, 2006) and femoral-neck BMD (Burrows, Nevill, Bird, & Simpson, 2003). One mechanism to explain the negative effect of activity on BMD is that runners who exercise longer hours or run more miles per week are at greater risk for energy deficiency, which reduces their estrogen levels. This hypothesis is supported by our study, as we found that serum estradiol was positively correlated with BMD. Extensive training combined with inadequate energy intake leads to elevated bone turnover with greater increases in bone resorption, leading eventually to reduced BMD (Ihle & Loucks, 2004).

Although current menstrual characteristics did not differ between groups, history of an irregular menstrual cycle was a significant predictor of stress fractures in the logistic-regression model. Older age at menarche and fewer menses in the past year have been linked to increased risk for stress fractures in elite athletes (Bennell et al., 1996; Carbon et al.,1990). Menstrual irregularity is generally considered a risk factor for stress fractures due to its role in lowering BMD. In the multiple-regression model, we found that the number of menstrual cycles in the past year and servings of milk during middle school were significant positive predictors for femoral-neck BMD, with caffeine intake a negative predictor.

No differences between groups emerged in milk or total dairy intake in periods from elementary school through the past year. Although these data were collected retrospectively, reinterview of subjects from previous research has shown that dietary-history recalls provided accurate estimates of diet (Byers, Marshall, Athony, Fiedler, & Zielezny, 1987). Dairy servings over the past year were significantly correlated with current dietary calcium intake and vitamin D intake, indicating that our survey data were consistent with the 3-day food records. Our results differ from those of Myburgh et al. (1990), who found that subjects with stress fractures had consumed fewer weekly servings of dairy products since leaving high school than had non-stress-fracture subjects. Two prospective studies that surveyed calcium and dairy servings before stress-fracture development found that increased dairy consumption reduced the risk of stress fractures (Kelsey et al., 2007; Nieves et al., 2010). In those studies, subjects who developed stress fractures also had lower BMD (Myburgh et al., 1990) or BMC (Kelsey et al., 2007) than non-stress-fracture subjects, while we observed no differences in BMD, which may explain why dairy servings were not a significant predictor of stress fracture.

While we did not find the anticipated differences between servings of dairy products, we did note that servings of milk during middle school were a significant predictor for BMD in the total femur, femoral neck, Ward's triangle, and femoral shaft. Research that focused on previous milk intake in young women has also found servings of milk during adolescence were linked to current BMD (Kalkwarf et al., 2003; Teegarden et al., 1999). These results support the claim that greater calcium intake during adolescence improves attainment of peak bone mass.

In our logistic-regression model, higher dietary calcium intakes were protective against stress fractures, which agrees with research suggesting that dietary calcium intake is protective against stress fractures beyond its association with BMD (Kelsey et al., 2007). A clinical trial in female naval recruits found that supplementing calcium and vitamin D reduced stress-fracture incidence (Lappe et al., 2008). Two prospective studies found that low calcium intake increased the risk for stress fracture (Kelsey et al., 2007; Nieves et al., 2010).

Although total energy and macronutrients were not correlated with BMD, caffeine was negatively correlated with BMD of total femur, femoral neck, trochanter, and femoral shaft. In rats, caffeine stimulated the formation of osteoclasts, which resulted in lower BMD in the lumbar spine, femur, and tibia than in caffeine-free controls (Liu et al., 2011). Human studies remain inconclusive, as some show a negative effect of caffeine on BMD in postmenopausal women (Ilich, Brownbill, Tamborini, & Crncevic-Orlic, 2002), while others show no effect in young women (Ruffing et al., 2007) or postmenopausal women (Lloyd, Rollings, Eggli, Kieselhorst, & Chinchilli, 1997).

Two training variables, the number of years subjects had been running regularly and the surface on which they trained, were predictors for stress fractures in the logistic-regression model. Given the retrospective design, a longer history of running corresponded to greater opportunity to develop a stress fracture. Running predominantly on hard ground, defined as dirt trails, increased the risk of stress fractures. Other research has evaluated surface, showing that running on an outdoor track (Laker, Saint-Phard, Tyburski, & van Dorsten, 2007) or treadmill (Milgrom et al., 2003) was protective against stress-fracture development compared with trail or road running. It is possible the uneven surface of the hard ground led to muscle fatigue, thereby altering the load on bone (Pepper et al., 2006).

Limitations of our study include respective design, which required self-reporting of stress-fracture history and allowed subjects to alter habits postinjury, potentially clouding differences between groups. In addition, dairy intake was collected retrospectively and was therefore subject to error in memory. Dietary intake was self-recorded in food diaries, which depended on portion estimates by subjects. Finally, the complex etiology of stress fractures makes it difficult to isolate specific risk factors.

Conclusions

This study failed to show differences between stress-fracture subjects and matched control subjects in BMD, serum estradiol, menstrual characteristics, current dietary intake, or previous dairy intake. In logistic regression, stress-fracture risk was increased by the combination of lower dietary calcium intake, history of menstrual irregularity, lower BMD, longer history of running, and running predominantly on hard ground. Despite no difference in dairy intake, servings of milk during middle school were a significant predictor for femur BMD sites, thereby supporting the claim that adolescent calcium intake has significant influence on bone development. Therefore, adolescent female athletes should aim to optimize their diet to include sources of calcium to support bone growth and adequate calories to maintain menstrual function to reduce their risk of stress fractures.

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