Correlates of Stress Fractures Among Preadolescent and Adolescent Girls

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ABSTRACT. Objective. Although stress fractures are a source of significant morbidity in active populations, particularly among young female athletes, the causes of stress fractures have not been explored among females <17 years of age or in the general population. The purpose of this study was to examine correlates of stress fractures in a large, population-based, national, cohort study of preadolescent and adolescent girls.

Methods. A cross-sectional analysis of data from 5461 girls, 11 to 17 years of age, in the Growing Up Today Study, an ongoing longitudinal study of the children of registered female nurses participating in Nurses’ Health Study II, was performed. Mothers self-reported information regarding their children’s histories of stress fractures on their 1998 annual questionnaire. Growing Up Today Study participants self-reported their weight and height, menarchal status, physical activity, dietary intake, and disordered eating habits on annual surveys.

Results. In 1998, the mean age of the participants was 13.9 years. Approximately 2.7% of the girls had a history of stress fracture, 16% engaged in disordered eating (using fasting, diet pills, laxatives, or vomiting to control weight), and 16% participated in ≥16 hours per week of moderate to vigorous activity. Age at menarche, z score of BMI in 1998, calcium intake, vitamin D intake, and daily dairy intake were all unrelated to stress fractures after controlling for age. Independent of age and BMI, girls who participated in ≥16 hours per week of activity in 1998 had 1.88 greater odds of a history of stress fracture than did girls who participated in <4 hours per week (95% confidence interval [CI]: 1.18–3.30). Girls who participated in ≥16 hours per week of activity were also more likely than their peers to engage in disordered eating (4.6% vs 2.8%); however, disordered eating did not have an independent association with stress fractures (odds ratio [OR]: 1.33; 95% CI: 0.61–2.99). Independent of age and BMI, each hour per week of high-impact activity significantly increased the risk of stress fracture (OR: 1.05; 95% CI: 1.02–1.09). Among the high-impact physical activities, only running (OR: 1.13; 95% CI: 1.05–1.22) and cheerleading/gymnastics (OR: 1.10; 95% CI: 1.01–1.21) were independently associated with greater odds of stress fracture.

Conclusions. These findings suggest that, although activity can be beneficial for bone health, there is a threshold over which the risk of stress fracture increases significantly among adolescent girls. High-impact activities, particularly running, cheerleading, and gymnastics, appear to be higher risk than other activities. Prospective studies are needed to explore the directionality of these relationships, as well as the role of menstrual history. In the meantime, clinicians should remain vigilant in identifying and treating disordered eating and menstrual irregularities among their highly active, young, female patients. Pediatrics 2005; 115:399–e406. URL: www.pediatrics.org/cgi/doi/10.1542/peds.2004-1868; epidemiology, female, adolescents, stress fracture, activity.

ABBREVIATIONS. GUTS, Growing Up Today Study; BMD, bone mineral density; OR, odds ratio; CI, confidence interval.

Stress fractures can be defined as skeletal defects that result from the repeated application of stress lower than that required to fracture a bone in a single loading. Often called fatigue or insufficiency fractures, they are relatively uncommon in general but are a source of significant morbidity in active populations, with annual incidence rates ranging as high as 20% in prospective studies of young female athletes and military recruits. In some cases, a stress fracture may be an indicator of inadequate bone mass. These fractures would be particularly important findings if noted during adolescence, a critical period for bone mass acquisition. More than one half of adult bone calcium is acquired during the teenage years and a woman’s peak bone mineral density (BMD), a major determinant of her long-term risk of osteoporosis, is thought to be achieved in early adulthood. Weight-bearing exercise is a major stimulus for skeletal remodeling, increased bone mineralization, and thus increased BMD. Therefore, maximization of peak BMD through participation in athletic activities during adolescence could assist in the prevention of osteoporosis later in these young women’s lives. Paradoxically, very high levels of activity may impair bone health. In addition, some female athletes who participate in high levels of activity resort to patterns of unhealthy eating, which may lead to irregular menstrual cycles and an ensuing state of low serum estrogen levels that can counteract the beneficial effects of exercise on BMD. This constellation of disordered eating, amenorrhea, and osteoporosis has come to be known as the “female athlete triad,” a...
To begin to assess which stress fractures may be markers of compromised bone health, one must understand the epidemiology and causes of these injuries. Although stress fractures cause considerable impairment, unfortunately little is known about the prevalence of or risk factors for stress fractures among young women. In a case-control study that included 38 adult female athletes, lower dietary calcium intake, current menstrual irregularity, lower use of oral contraceptives, and decreased bone density were identified as risk factors for stress fractures. 4 A large, cross-sectional survey of 2312 female active duty soldiers showed that a history of amenorrhea, smoking, white race, and a family history of osteoporosis were associated with a history of stress fracture. 18 In a case-control study, 27 female military recruits with stress fractures reported significantly higher levels of exercise and demonstrated lower femoral neck BMD than did 158 female subjects without fractures. 19

Few studies have been conducted with samples of adolescent athletes, and none have examined factors related to stress fractures among girls <17 years of age. Therefore, the prevalence of stress fractures among children and adolescents is essentially unknown. In addition, the results from studies of older adolescent girls have not been consistent with those from studies of adult women. 20–25 Bennell et al 22 conducted a retrospective study of 53 Australian female, track and field athletes 17 to 26 years of age and found that menstrual irregularities and restrictive eating behaviors were risk factors for stress fractures but low BMD was unrelated to fractures; however, in a prospective follow-up study of the same cohort, Bennell et al 23 found that lower bone density and a history of menstrual disturbances were significant predictors of stress fractures. A similar prospective study of 50 US collegiate, track and field athletes found that a history of stress fracture and low BMD were significant predictors of stress fractures but menstrual history was not. 25 Hormonal status, serum calcium and vitamin D levels, nutritional history, and white ethnicity were not identified as significant predictors of stress fractures. The inconsistencies among earlier studies and more recent investigations may be accounted for by differences between military and nonmilitary populations 23 and differences in sample size, with some of the studies being underpowered to detect significant differences in the proposed predictors of stress fractures. Moreover, those investigators studied exclusively athletes whose primary sport involved running, thus precluding conclusions about correlates of stress fractures in the wider population of older adolescent females, the majority of whom are neither runners nor particularly athletic. To assess the prevalence and correlates of stress fractures among adolescent girls in general, we examined cross-sectional data for 5461 participants in an ongoing national cohort study.

METHODS

Overview

The Growing Up Today Study (GUTS) was established by recruiting the children of women participating in Nurses’ Health Study II who were 9 to 14 years of age in 1989. With the use of Nurses’ Health Study II data, a detailed letter was sent to identified mothers who had children between the ages of 9 and 14 years. The purposes of GUTS were explained, and the mothers were asked to provide parental consent for their children to enroll. Additional details were reported previously. 26 Approximately 12% of the girls (N = 9039) and 58% of the boys (N = 7843) returned completed questionnaires, thereby assenting to participate in the cohort. The project was approved by the Human Subjects Committee at Brigham and Women’s Hospital; this study was approved by that committee and by the Committee on Clinical Investigation at Children’s Hospital Boston.

Measures

Self-reported physical activity, dietary intake, weight control behaviors, Tanner stage of development, weight, and height were assessed annually from 1996 through 1998. We calculated BMI values from self-reported weight and height information (weight [in kilograms]/height [in meters] squared) and calculated z scores on the basis of the Centers for Disease Control and Prevention growth charts (www.cdc.gov/growthcharts), which are gender specific. BMI values >3 SDs above the mean were excluded as outliers. In addition, BMI values of <12 for preadolescents or <12.5 for adolescents were excluded as being biologically implausible. Overweight was defined as a BMI ≥85th percentile for age and gender, whereas underweight was defined as a BMI <10th percentile. Drawings of the 5 Tanner stages of development of pubic hair were used for assessment of pubertal development.

Weight control methods (dieting, exercise, self-induced vomiting, diet pills, and laxatives) were assessed with questions adapted from the Youth Risk Behavior Surveillance System questionnaire. 27 Girls who reported using any of these methods to control their weight during the past year were requested to state the frequency of the behavior (“less than once a month,” “1–3 times a month,” “once a week,” “2–6 times per week,” or “every day”). Purging was defined as using laxatives or vomiting at least monthly to control weight in 1995–1996, 1997–1998, or 1998–1999. Disordered eating was defined as using vomiting, laxatives, fasting, or diet pills at least monthly to control weight in 1995–1996, 1996–1997, 1997–1998, or 1998–1999. Dietary intake was assessed with the Youth/Adolescent Questionnaire, a validated, self-administered, semiquantitative, food frequency questionnaire assessing intake over the past year. 28 The questionnaire asked participants how often, on average, they consumed each of the 131 foods listed. Response categories for foods ranged from less than once per month to ≥4 times per day. Nutrient intake was computed by multiplying the frequency of consumption of the food by its nutrient content, as estimated from standard food composition sources.

Physical activity was assessed with 18 questions on the hours per week, within each of the 4 seasons, that a participant engaged in a specific activity (eg, volleyball or soccer). Hours per week of moderate or vigorous activity were computed as the sum of the average hours per week engaged in basketball, baseball, biking, dance/aerobics, hockey, running, swimming, skating, skateboarding, soccer, tennis, cheerleading/gymnastics, lifting weights, volleyball, or karate. Reports of an average of ≥40 hours per week were considered implausible and were therefore set to missing and not used in the analysis. High-impact activity was computed as the sum of the average hours per week engaged in basketball, running, soccer, tennis, cheerleading, or volleyball. Medium-impact activity was computed as the sum of the average hours per week engaged in baseball, dance/aerobics, hockey, or karate. Nonimpact activity was computed as the sum of the average hours per week engaged in biking, swimming, skating, skateboarding, or lifting weights.

Menstrual status was assessed annually from 1996 through 1998. Girls were asked whether their menstrual periods had started. Girls who marked “yes” were asked the age when periods began (age at menarche).

The primary outcome measure was a history of a stress fracture. The 1999 questionnaire to the mothers asked the question,
“Has a doctor ever said that this child had any of the following conditions?” The orthopedic conditions were tendinitis, stress fracture, Osgood-Schlatter syndrome, and anterior cruciate ligament tear.

Sample
Participants included 7864 girls who completed the 1998 questionnaire. Those who completed the abbreviated questionnaire sent to them did not return the more complete questionnaire (n = 973), were <9 or >14 years of age at baseline (1996) (n = 99), did not provide plausible information or were missing information on physical activity (n = 122) or weight or height in 1998 (n = 133), or whose mother did not complete the mother’s questionnaire (n = 1076) were excluded. After these exclusions, 5461 girls, 11 to 17 years of age in 1998, remained for analysis.

Data Analyses
All analyses were conducted with the SAS statistical software package.29 Generalized estimating equations (SAS proc genmod) were used for all multivariate analyses, to account for correlations between siblings. All statistical models assessing associations with a history of stress fracture controlled for age.

Hours per week of moderate or vigorous activity were initially divided into 8 groups, ie, <1, 1 to 3.9, 4 to 7.9, 8 to 11.9, 12 to 15.9, 16 to 19.9, 20 to 24.9, and ≥25 hours per week. Because of small group sizes, the top 3 categories were collapsed into 1 group for analyses, for a total of 6 groups. For multivariate analyses, the bottom 2 categories were also collapsed, making a total of 5 groups (<4, 4–7.9, 8–11.9, 12–15.9, and ≥16 hours per week). Participants who reported <4 hours per week of moderate or vigorous activity were used as the reference group. The Tanner stage of development was not included in the analysis because the majority of girls were in Tanner stage 4 or 5 (33% of girls were in Tanner stage 1 or 2). All P values were 2-sided, with P <.05 being considered statistically significant.

RESULTS
In 1998, the mean age of the girls was 13.9 years and 67.9% of the girls had achieved menarche. The mean BMI of the girls was 20.1 kg/m²; 7% of the girls were underweight and 15% were overweight. In addition, 3% of the girls engaged in disordered eating. Approximately 94% of the girls were white. Most girls participated in physical activity. Ninety-six percent of the girls engaged in ≥1 hour per week of moderate or vigorous activity, and 16% of the girls participated in ≥16 hours per week of activity (Table 1).

Approximately 2.7% of the girls (149 of 5461 girls) had a history of stress fracture. Age exhibited a J-shaped relationship with a history of stress fracture (Fig 1). Slightly more than 2% of 11- and 12-year-old subjects had a history of stress fracture, whereas 3.9% of 15-year-old subjects and 4.6% of 16-year-old subjects had a history of stress fracture. Stress fracture prevalence increased markedly at the highest levels of moderate or vigorous activity (Fig 2). The prevalence of stress fracture was approximately 2% to 3% for all categories of activity at <16 hours per week; however, 5% of girls who participated in ≥16 hours per week had a history of stress fracture.

In a bivariate analysis, being overweight appeared protective against stress fracture (1.7% of overweight girls and 2.9% of normal-weight girls had a stress fracture, P = .056). After adjustment for age, being overweight had an inverse but nonsignificant association with stress fracture (overweight versus normal-weight odds ratio [OR]: 0.62; 95% confidence interval [CI]: 0.36–1.07). Being underweight was unrelated to a history of fracture (underweight versus normal-weight OR: 0.76; 95% CI: 0.36–1.59). Girls who participated in ≥16 hours per week of activity were more likely than their peers (4.2% vs 2.8%, P < .03) to engage in disordered eating (using fasting, diet pills, laxatives, or vomiting to control weight); however, neither disordered eating (age-adjusted OR: 1.33; 95% CI: 0.61–2.89) nor purging (ie, using vomiting or laxatives to control weight) (age-adjusted OR: 0.63; 95% CI: 0.09–4.34) had an independent association with a history of stress fracture. Age at menarche (age-adjusted OR: 0.99; 95% CI: 0.84–1.17), quartile of calcium intake (age-adjusted OR: 1.06; 95% CI: 0.91–1.24), quartile of vitamin D intake

TABLE 1. Age, Maturational Stage, Dietary Intake, and Activity of 5461 Girls in GUTS in 1998

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD) age, y</th>
<th>Mean (SD) BMI, kg/m²</th>
<th>Mean (SD) BMI z score</th>
<th>Mean (SD) age at menarche, y</th>
<th>% Postmenarcheal</th>
<th>% Underweight</th>
<th>% Overweight</th>
<th>% Disordered eating</th>
<th>Mean (SD) calcium intake, mg/d</th>
<th>Mean (SD) vitamin D intake, IU/d</th>
<th>Mean (SD) daily servings of dairy</th>
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<td></td>
<td>13.9 (1.6)</td>
<td>20.1 (3.3)</td>
<td>0.1 (0.9)</td>
<td>12.0 (1.1)</td>
<td>67.8 (n = 3638)</td>
<td>7.1 (n = 386)</td>
<td>14.9 (n = 814)</td>
<td>3.1 (n = 172)</td>
<td>1121 (491)</td>
<td>314 (218)</td>
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<td>% with moderate or vigorous activity of*</td>
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<td>&lt;1 h/wk</td>
<td>3.7 (n = 204)</td>
<td>17.5 (n = 957)</td>
<td>27.5 (n = 1503)</td>
<td>21.2 (n = 1156)</td>
<td>14.3 (n = 782)</td>
<td>7.9 (n = 433)</td>
<td>5.0 (n = 274)</td>
<td>2.8 (n = 155)</td>
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<td>8–11.9 h/wk</td>
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<td>16–19.9 h/wk</td>
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<td>20–24.9 h/wk</td>
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<td>≥25 h/wk</td>
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</table>
| Mean (SD) time of nonimpact activity, h/wk | 3.6 (3.3) | 1.7 (2.3) | 4.2 (4.2) | 0.056. After adjustment for age, being overweight had an inverse but nonsignificant association with stress fracture (overweight versus normal-weight odds ratio [OR]: 0.62; 95% confidence interval [CI]: 0.36–1.07). Being underweight was unrelated to a history of fracture (underweight versus normal-weight OR: 0.76; 95% CI: 0.36–1.59). Girls who participated in ≥16 hours per week of activity were more likely than their peers (4.2% vs 2.8%, P < .03) to engage in disordered eating (using fasting, diet pills, laxatives, or vomiting to control weight); however, neither disordered eating (age-adjusted OR: 1.33; 95% CI: 0.61–2.89) nor purging (ie, using vomiting or laxatives to control weight) (age-adjusted OR: 0.63; 95% CI: 0.09–4.34) had an independent association with a history of stress fracture. Age at menarche (age-adjusted OR: 0.99; 95% CI: 0.84–1.17), quartile of calcium intake (age-adjusted OR: 1.06; 95% CI: 0.91–1.24), quartile of vitamin D intake...
(age-adjusted OR: 1.00; 95% CI: 0.86–1.16), and servings per day of dairy products (age-adjusted OR: 1.00; 95% CI: 0.87–1.15) were also unrelated to stress fracture.

The age of the participants was strongly associated with a history of stress fracture in all multivariate models tested (Tables 2–4), with a 27% to 29% increase in the odds of stress fracture for every year over 11 years of age in 1998. The BMI z score was not associated with stress fracture (age-adjusted OR: 0.91; 95% CI: 0.78–1.07), and inclusion of it in the multivariate models did not change substantially the effect estimates for other covariates (Table 2); therefore, the BMI z score was not included in the final statistical models. Being postmenarcheal in 1998 appeared to confer protection against stress fracture (age-adjusted OR: 0.61; 95% CI: 0.40–0.95) and remained significant in most models (Tables 2–4).

The association between the quantity of moderate or vigorous activity and stress fracture was complex. Compared with girls participating in <4 hours per week of moderate or vigorous activity, girls participating in ≥16 hours per week had a significantly higher risk of stress fracture (OR: 1.88; 95% CI: 1.18–3.03) (Table 2). There was no evidence that girls participating in 8 to 11.9 hours per week or 12 to 15.9 hours per week of activity had any increase in the risk of stress fracture.

High-impact physical activity (basketball, running, soccer, tennis, cheerleading, or volleyball) was associated with a small but significantly increased odds of stress fracture (OR per hour of activity: 1.06; 95% CI: 1.00–1.12).

**TABLE 2.** Associations of Age, BMI, Menarcheal Status, and Activity With a History of Stress Fracture Among the Girls in GUTS

<table>
<thead>
<tr>
<th></th>
<th>OR, Adjusted for Age (95% CI)</th>
<th>OR, Adjusted for All Covariates in Model (95% CI)</th>
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<tbody>
<tr>
<td>Age</td>
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<tr>
<td>BMI z score</td>
<td>0.91 (0.78–1.07)</td>
<td>0.97 (0.81–1.16)</td>
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<tr>
<td>Postmenarcheal</td>
<td>0.61 (0.40–0.95)</td>
<td>0.62 (0.38–0.99)</td>
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<td>&lt;4 h/wk of activity*</td>
<td>1.00 (referent)</td>
<td>1.00 (referent)</td>
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<tr>
<td>4–7.9 h/wk of activity</td>
<td>0.71 (0.41–1.21)</td>
<td>0.66 (0.39–1.14)</td>
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<tr>
<td>8–11.9 h/wk of activity</td>
<td>0.94 (0.55–1.60)</td>
<td>0.90 (0.53–1.52)</td>
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<tr>
<td>12–15.9 h/wk of activity</td>
<td>0.94 (0.53–1.70)</td>
<td>0.89 (0.50–1.60)</td>
</tr>
<tr>
<td>≥16 h/wk of activity</td>
<td>1.86 (1.16–3.00)</td>
<td>1.88 (1.18–3.03)</td>
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</table>

There were 146 cases among 5219 girls with complete data. The ORs are from a generalized estimating equation model that adjusted for the covariates listed in the table. Information on correlates came from the 1998 GUTS questionnaire.

* Sum of basketball, baseball, biking, dance/aerobics, hockey, running, swimming, skating, skateboarding, soccer, tennis, cheerleading, lifting weights, volleyball, and karate.
CI: 1.03–1.10) (Table 3). Among the high-impact
physical activities, only running (OR: 1.13; 95% CI:
1.05–1.22) and cheerleading/gymnastics (OR: 1.10;
95% CI: 1.01–1.21) were associated independently
with greater odds of stress fracture (Table 4).

DISCUSSION
This study is the first of which we are aware to
report a lifetime prevalence of stress fracture (2.7%)
among a large, general-population sample of adoles-
cent girls living throughout the United States. Be-
cause this is the first general-population sample
study, it is difficult to compare our results with es-
timates from other studies. Studies of collegiate ath-
letes estimated that the annual incidence of stress
fractures among late adolescent and young adult
female athletes is between 2.7% and 6.9%.30–32 The
largest cohort studies of stress fracture have been
among women in the US military and observed in-
cidence rates among adult female recruits during
basic training to be between 1.1% and 3.4%.33,34 Al-
though the mothers of the GUTS participants were
registered nurses and thereby potentially more accu-
rate than lay persons in providing information re-
garding medical conditions, relying on maternal rec-
collections of stress fracture diagnoses still might have
resulted in an underestimate of the true prevalence
of stress fractures in our sample. Alternatively, chil-
dren of nurses might have greater access to medical
care than other children and thus might be more
likely to be diagnosed as having a stress fracture.
Therefore, the prevalence of stress fractures in our
sample might be higher than it would have been had
we chosen to study a group of girls with less access
to medical care. However, our results are consistent
with those from other published studies that used medical records,30,31 direct monitoring,32–34 and ra-
diographic confirmation of stress fractures.20

The age of the participants was the most consistent
correlate of stress fractures in this sample. This is
most likely because age might be a proxy for expo-
sure time; the older an adolescent girl is, the longer
she might have been participating in risk-associated
activities and the greater the chance that she has
sustained a stress fracture. Alternatively, it could be
that the older girls had begun to participate in high
school sports or other higher levels of competition, in
which the intensity of the training sessions (a vari-
able not assessed in the GUTS) is greater than the
intensity of training sessions for girls at younger
ages.

Menarche (the onset of menstrual periods) occurs
near the end of the pubertal growth spurt, which is
accompanied by rapid increases in bone mass and
BMD.6 BMD is one of the main determinants of a
bone’s ability to withstand loading.2,6 Girls in this
study who had achieved menses had decreased odds
of stress fracture, which was possibly related to in-
creased bone mass, although BMD was not mea-
sured in this cohort. Because menarche had not oc-
curred for a nontrivial percentage of this sample, we
must interpret associations of age at menarche with
stress fracture that appear nonsignificant very cau-
tiously. In a cohort of older adolescent, Australian,
track and field athletes, age at menarche was an independent risk factor for stress fracture, with younger ages providing significant protection.23 Other studies have not replicated this finding consistently, although none has suggested an inverse relationship between age at menarche and risk of stress fracture.25 Numerous small studies also suggested consistently that stress fractures are less common among athletes with regular menses,32 although the studies were not large enough to have adequate statistical power to allow firm conclusions. The presumed mechanism through which regular menses would offer protection against stress fracture is the improved BMD associated with an endogenous eustrogenic state.

Although clinicians and public health officials also target disordered eating, low calcium intake, low vitamin D intake, and fewer servings per day of dairy products as behaviors that can potentially be changed to improve bone mass and prevent future osteoporosis, none of these factors was significantly associated with a history of stress fracture in our sample. Because 50% to 85% of the variability in BMD is attributable to genetic factors,6 any negative effects of these modifiable correlates on BMD might not have been large enough to affect stress fracture risk.

Identification of a threshold quantity of activity at which the risk of stress fracture increases would be valuable for clinicians, athletic trainers, coaches, and others guiding athletes in their training regimens. Because stress fractures result from repetitive stress loading,1 training volume (ie, amount of exercise), which is related directly to the number of repeated applications (or “strain cycles”), is a key component in the pathophysiologic development of stress fractures.2 Our finding of increased odds of stress fractures with ≥16 hours per week of moderate or vigorous activity requires additional refinement to define the “breakpoint” for increased odds of stress fracture, because higher strata of weekly exercise amounts contained too few participants with a history of stress fracture to allow meaningful associations. Prospective studies that can establish temporal directionality are also needed. Because this study was cross-sectional, it is impossible to identify whether the reported activity preceded the stress fractures. Because the activity reports were from 1998 and the mothers’ questionnaire reported any stress fracture diagnosis up to 1999, it is possible that some of the activity assessments reflected a period after the stress fracture diagnosis had been made. It is likely that participants would have moderated their training volumes after a stress fracture diagnosis. Therefore, our effect estimate for the association between hours per week of activity and the risk of stress fracture might have underestimated the true association. The true breakpoint might have occurred at a volume of >16 hours per week, reflecting preinjury activity levels.

Similarly, it is unknown whether girls with stress fractures might have changed activity types after their diagnoses. Girls with stress fractures or even their precursors, ie, symptomatic stress reactions, might have chosen to switch to lower-impact activities; therefore, our results might underestimate the true effects of high-impact activities. The increased odds of stress fracture with running in this study were consistent with the results of other reports that showed high incidence rates for stress fractures among collegiate female runners.30 Sample sizes for gymnastics in other studies were too small to allow comparisons. It is biologically plausible that these activities are most strongly associated with stress fractures, because the load applied to bone can equal 2 to 5 times body weight for jogging or running36 and up to 12 times body weight for jumping and landing,37 which are repetitive maneuvers in cheerleading and gymnastics.

Finally, recent evidence38 reemphasized the observation that stress fractures result from an imbalance between the microfractures caused by repeated loading cycles and the bone’s own responses to remodel the damaged region.39,40 Because remodeling is a constant dynamic process, it may be inadequate acceleration of this process that results in stress fractures. Therefore, the more relevant activity parameter is likely to be the rate of increase in exercise volume, not the total volume itself. Our inability to date the stress fractures in this study precluded us from investigating this issue.

A limitation of this study was that the cohort was >90% white and was thus not representative of the US adolescent population. This limitation is mitigated because whites are a group at increased risk of stress fractures.33 Therefore, the GUTS cohort represents an enriched sample in which to study this particular injury. Because the participants were children of registered nurses, the sample might underestimate female subjects of low socioeconomic status, potentially limiting the generalizability to female subjects of middle and upper socioeconomic status. Moreover, the high levels of physical activity demonstrated in this cohort contrast with the consistent findings of low and declining levels of physical activity among adolescent girls in other national surveys.41 Therefore, the estimated levels of activity we observed might not be generalizable to a general sample of adolescent female subjects. The strength of the association between the activity level and the risk of stress fracture should be generalizable, but other studies might observe lower rates of stress fractures because of having fewer girls who are highly active.

Although BMI and age- and gender-specific BMI percentile are used widely as proxy measures of weight status and body fatness, it is important to remember that highly active people who have substantial muscle mass may weigh slightly more than the standard for their height, despite having low body fat levels. Therefore, some girls might have been overweight according to the Centers for Disease Control and Prevention pediatric cutoff values but not overweight. Although the correlations between BMI, BMI percentile, and body fat are very high,42-44 BMI is not a direct measure of body fatness; therefore, there is some misclassification when weight status is based on BMI alone, because BMI does not take into account lean body mass. The result of this misclassifi-
fication might have been underestimation of the true association between weight status and risk of stress fracture. Another limitation was the lack of radiographic confirmation of stress fractures in this study, which could have resulted in overestimation of the prevalence of true stress fractures because of the difficulty of distinguishing them from stress reactions or other overuse injuries on the basis of clinical findings alone. If possible, future studies should define the outcome, namely, stress fracture, on the basis of objective findings and should specify the body part injured. Most importantly, the temporal relationship between stress fracture and activity should be clarified by assessing when the injury occurred and assessing the exposures before the diagnosis of stress fracture.

It is disturbing that highly active girls were more likely than their less-active peers to engage in disordered eating practices. This association may be attributable to girls using physical activity, as well as disordered eating, as a means to achieve a certain ideal body image. Although we did not observe an association between stress fractures and disordered eating, it is possible that the lack of association was attributable to a lack of statistical power rather than a true lack of association. Therefore, clinicians should be advised to maintain their vigilance in screening their athletic and apparently healthy young female patients.

Given the significant gaps in knowledge about risk factors for stress fractures among active adolescent girls across a range of impact-loading sports, the results of this study provide critical information regarding the roles that amount and type of exercise play in the development of stress fractures in this population. The results provide preliminary information on how much exercise may be deleterious to skeletal health. Future studies should identify when the stress fracture occurred, so that only activity levels before the fracture are used in analyses trying to establish the point at which activity levels start to increase the risk of fracture. Moreover, future studies that examine more closely the amounts and types of weekly exercise, the types of training surfaces, and the menstrual history associated with stress fractures should help determine whether these injuries can be prevented and help identify whether some stress fractures should be considered markers of low bone mass and subsequent increased risk of long-term osteoporosis.

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