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Prospective Study of Physical Activity and Risk of Developing a Stress Fracture among Preadolescent and Adolescent Females

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Abstract

Objective—To identify predictors of developing a stress fracture among adolescent females during a seven-year period.

Design—Prospective cohort study

Setting—Adolescent females living throughout the United States

Participants—6831 females, aged 9–15 years at baseline, in the Growing Up Today Study (GUTS), an ongoing prospective cohort study.

Main Exposures—Exposures were assessed by self-report questionnaires completed by adolescent girls in 1996, 1997, 1998, 1999, 2000, 2001, and 2003. The adolescent girl's history of stress fracture, including age when fracture occurred and site, were reported by their mothers, who are registered nurses, in 2004. Cox proportional hazards models were used in the analysis.

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Contributions of each author:
Study concept and design: Field, Gordon, Ramappa, Kocher.
Acquisition of data: Field.
Analysis and interpretation of data: Field.
Drafting of the manuscript: Field and Pierce.
Critical revision of the manuscript for important intellectual content: Field, Gordon, Pierce, Ramappa, Kocher.
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Main Outcome Measure—Incident stress fracture that occurred between 1997 and 2004.

Results—During seven years of follow-up, 267 females (3.9%) developed a stress fracture. Independent of age, age at menarche, family history of fracture, and hours per week of low and moderate impact activity, hours per week of running (relative risk (RR)=1.13, 95% confidence interval (CI) 1.04–1.23), basketball (RR=1.12, 95% CI 1.03–1.22) and cheerleading and gymnastics (RR=1.12, 95% CI 1.02–1.23) were significant predictors of developing a stress fracture. No other type of high impact activity was associated with an increased risk.

Conclusions—Females who engage in running, basketball, cheerleading, or gymnastics should be encouraged to include varied training in lower impact activities to decrease the cumulative amount of impact in order minimize their risk of stress fractures.

Introduction

During adolescence, more than half of adult bone calcium is acquired and peak bone mineral density (BMD), a major determinant of a woman's long-term risk of osteoporosis,[1,2] is thought to be achieved by early adulthood.[3,4] Although much of BMD is genetically determined,[5] physical activity is an important modifiable determinant of bone health. However, the relationship between activity and BMD is complex. Weight-bearing activity stimulates bone remodeling and thus increases bone density,[6,7] but very high levels of activity may be detrimental to bone health[8,9] and increase the risk of stress fracture.

Among females, other suspected risk factors for developing a stress fracture include disordered eating[10] and irregular menstrual cycles, both of which may result in a deficient estrogen status that can counteract the beneficial effects of exercise on bone density.[11–14] Delayed menarche has also been shown to be associated with deficits of the peripheral and axial skeleton, implicating estrogen deficiency as detrimental for bone accretion[15,16]. Although stress fractures are relatively uncommon, they affect as many as 20% of young women athletes and military recruits.[17]

Despite a growing concern about suboptimal bone health in adolescents, particularly among females and athletes, few prospective studies have been conducted[18] and most have used specialized samples so it is unclear to whom their results are generalizable. Moreover, few studies have been conducted in samples of adolescent athletes and no prospective studies have examined factors related to stress fractures in girls less than 18 years of age. Therefore, the prevalence and predictors of stress fracture among children and adolescents is essentially unknown. In addition, the results from studies of older adolescent girls have not been consistent with those of adult women.[19–24] As adolescence is a sensitive period for bone health, high levels of physical activity, particularly when accompanied by inadequate caloric intake, can result in suboptimal growth.[8] However, high levels of activity before puberty may result in greater bone density.[25–26] Thus, adolescence may be the most important period for examining factors predictive of stress fracture.

Although there is a dearth of prospective research on stress fracture, the results on gender differences from cross-sectional studies clearly demonstrate that female athletes have a much greater risk of sustaining stress fracture than do males. In a large retrospective study of 2,989 athletes seen over a 14-year period, Iwamoto and colleagues observed female track and field athletes to have a more than four-fold greater risk of developing stress fractures than their male counterparts.[27] Similar gender differences have been observed in Israeli military recruits.[28]

Athletic participation by females has increased dramatically since the "title IX" legislation was enacted in 1972. Current estimates are that 3 million females in the United States participate in high school sports,[29] but little is known about their risk of stress fracture. Because youth sports have become more specialized and training programs more rigorous and extended over multiple seasons, it is of critical importance to understand the activity patterns that increase risk of stress fracture. The aim of the present investigation was to assess the relationship between type and quantity of physical activity with the risk of developing a stress fracture over a seven-year period among more than 6831 preadolescent, adolescent, and young adult females in the Growing Up Today Study (GUTS).

Methods

Overview

The Growing Up Today Study (GUTS) was established by recruiting the children of women participating in the Nurses' Health Study II (NHS II) who were 9 to 14 years of age in 1996. Using NHS II data, a detailed letter was sent to identified mothers who had children between the ages of 9 and 14. The purposes of GUTS were explained and they were asked to provide parental consent for their children to enroll. Additional details have been reported previously.[30] Approximately 68% of the girls (N = 9039) and 58% of the boys (N = 7843) returned completed questionnaires, thereby assenting to participate in the cohort. The GUTS project and the analyses using data from GUTS participants and their mothers in NHS II was approved by the Human Subject Committee at Brigham and Women's Hospital; this study was approved by that committee, as well as the Committee on Clinical Investigation at Children's Hospital Boston.

Measures

In the fall of 1996 through 2003, the GUTS participants received a questionnaire every 12–18 months assessing a variety of factors. Self-reported weight, height, and age at menarche were assessed on all questionnaires.

Body mass index (BMI) [wt (kg)/ht (m)^2] was calculated using self-reported weight and height information. Children were classified as overweight or obese based on the International Obesity Task Force (IOTF) cut-offs,[31] which are age- and gender-specific and provide comparability in assessing overweight and obesity from adolescence to adulthood. The validity of self-reported weight and height among preadolescents and adolescents has been investigated by several groups of researchers[32–34] and the results show that young people provide valid information on weight and height.

Menstrual status was assessed annually from 1996 through 2005. Girls were asked whether their menstrual periods had started. Girls who marked "yes" were asked the age when periods began (age at menarche).

Weight control behaviors were assessed with questions adapted from the Youth Risk Behavior Surveillance System questionnaire.[35] Purging was assessed with two questions, "During the past year, how often did you make yourself throw up to keep from gaining weight?" and "During the past year, how often did you take laxatives to keep from gaining weight?" The purging questions have been validated in the GUTS cohort. Among the girls, the specificity and negative predictive values of self-reported purging (0.87 and 0.99, respectively) were high, thereby demonstrating that the questionnaire did an excellent job at classifying females who did not purge.

Physical activity was assessed with 18 questions on hours per week within each of the 4 seasons that a participant engaged in a specific activity (e.g., volleyball, soccer). Hours per week of moderate and vigorous activity was computed as the sum of average hours per week engaged in basketball, baseball, biking, dance/aerobics, hockey, running, swimming, skating, skateboarding, soccer, tennis, cheerleading/gymnastics, lifting weights, volleyball, and karate (Copies of the questionnaire can be seen at http://gutsblog.com/links/questionnaires.html). Reports of an average of > 40 hours per week were considered implausible and therefore set to missing and not used in the analysis. High impact activity was computed as the sum of average hours per week engaged in basketball, running, soccer, tennis, cheerleading, and volleyball. Medium impact activity was computed as the sum of average hours per week engaged in baseball, dance/aerobics, hockey, and karate.[36] Non impact activity was computed as the sum of average hours per week engaged in biking, swimming, skating, skateboarding, and lifting weights.

History of low bone density and osteoporosis was collected in 2005 as part of the Nurses' Health Study II. Girls whose mothers reported a history of low bone density or osteoporosis were classified as having a family history of low bone density or osteoporosis.

Outcome

The outcome was incident stress fracture. In 2004, the mothers of the GUTS participants, who are registered nurses participating in the ongoing Nurses' Health Study II, were sent a brief questionnaire. They were asked whether a doctor has ever said that their child had a stress fracture. If the mother indicated that her child had a history of stress fracture, she was asked to report the age at diagnosis, site (foot, arm, leg, wrist, or other), whether the stress fracture was sports-related, and the time off from playing sports (no time off, < 1 month, 1–2 months, or 3 or more months). Cases were defined as GUTS participants whose mother reported that they were diagnosed with a stress fracture at an age older than when they entered the GUTS cohort in fall of 1996. Children who were the same age at diagnosis and entry into GUTS were classified as prevalent cases and were not included in the analysis. Reports of a stress fracture without an age at diagnosis were excluded from the analysis since it would be impossible to know whether the cases occurred in the eligible time frame.

Sample

Participants included 9039 girls who completed one or more questionnaires. Girls were excluded if their mother did not respond to the 2004 mothers questionnaire (n=2109), the mother reported that her daughter had a stress fracture in 1996 (n=58) or did not report information on stress fracture (n=41). Furthermore the girl was excluded if she did not provide plausible information or was missing information on physical activity, or were missing plausible information on weight or height. After these exclusions, 6831 girls, age 9 to 15 years in 1996, remained for analysis.

Data Analysis

All analyses were conducted with the SAS statistical software package.[37] Cox proportional hazards models were used for all multivariate analyses. Statistical models controlled for age and maternal history of low bone density or osteoporosis.

Hours per week of moderate or vigorous activity was initially divided into 8 groups: less than 1, 1–3.9, 4–7.9, 8–11.9, 12–15.9, 16–19.9, 20–24.9, and ≥ 25 hours per week. Due to small group sizes, for the purpose of analysis the highest 3 categories were collapsed into one group, for a total of 6 groups. For multivariate analyses, the lowest 2 categories were also collapsed, giving 5 total groups (< 4, 4–7.9, 8–11.9, 12–15.9, and ≥ 16 hours per week). Participants who reported < 4 hours/week of moderate or vigorous activity were used as the reference group. All p-values are two-sided, with $p < .05$ considered statistically significant.

Results

In 1996, the mean age of the girls was 11.6 years and 44.1% of the girls had achieved menarche. The mean BMI of the girls was 19.0 kg/m^2; 8.6% of the girls were underweight and 19.8% were overweight or obese. Approximately 2.5% of the girls engaged in disordered eating. More than 96% of the girls engaged in at least 4 hours per week of some form of activity, including walking (Table 1).

During seven years of follow-up, 267 females (3.9%) developed a stress fracture. The older a girl was at menarche, the higher her risk of developing a stress fracture. Each one year delay in onset of menarche was associated with an approximate 30% increase in risk (odds ratio (OR)=1.32 95% confidence interval (CI) 1.11–1.57). Family history of osteoporosis or low bone density was strongly related to the risk of incident stress fracture. Females reporting a family history were almost two times more likely to develop a stress fracture (OR=1.95, 95% CI 1.24–3.07). In addition, risk of stress fracture increased with time spent engaged in physical activity (Table 2). Adjusting for age, age at menarche, and history of low bone density increased the associations. Girls who engaged in eight or more hours of activity per week were twice as likely as their peers who engaged in less than four hours of activity to develop a stress fracture.

The association of hours per week of moderate or vigorous activity with risk of developing a stress fracture was driven by impact activities (Table 3). Neither non-impact (OR=0.98, 95% CI 0.93–1.04) nor medium (OR=1.01, 95% CI 0.94–1.09) activity was predictive of risk, but each hour of high impact activity (e.g., basketball, running, soccer, tennis, cheerleading, and volleyball) increased the risk of stress fracture by approximately 8% (OR=1.08, 95% CI 1.05–1.12).

When considered individually, risk of stress fracture was associated with only three types of high impact activity. Running (OR = 1.13, 95% CI: 1.04–1.23), basketball (OR=1.12, 95% CI 1.03–1.22), and cheerleading/gymnastics (OR = 1.12, 95% CI: 1.02–1.23) were the only activities independently predictive of developing a stress fracture (Table 4).

Being underweight (OR=1.35, p=0.40), overweight (OR=0.96, p=0.90) or engaging in disordered eating (OR=0.92, p=0.88) were not associated with the risk of developing a stress fracture.

Comment

Our study, which is the first large general population-based study of incident stress fractures among adolescent and young adult girls, found that approximately 4% of the girls developed a stress fracture. Because it is the first prospective study in a general population sample, it is difficult to compare our results with estimates from other studies. Not surprisingly, we observed a lower incidence than has been observed in smaller studies of collegiate athletes[38], who represent a high risk group.

Age at menarche was a significant predictor of risk of developing a stress fracture. The older a girl was when menses began, the higher her risk. This result was not unexpected since there is a pronounced increase in BMD towards the end of the pubertal growth spurt, which is typically when menses begin.[2] BMD is one of the main determinants of a bone's ability to withstand loading.[2,17] Moreover, a later age at menarche would cause a prolonged period of low serum estrogen, which should increase the risk of developing a stress fracture. However, the results from other studies have been mixed. Bennell and colleagues prospectively studied a small sample of young adult female track-and-field athletes and found that lower bone density and a history of menstrual disturbances were significant predictors of stress fracture.

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22 Whereas, a prospective study of 50 U.S. collegiate track and field athletes found that menstrual history was not predictive of stress fracture[24] and other studies have been too small to detect associations.[39,40]

Despite our large sample size, we did not observe associations between weight status (i.e., being underweight or overweight) or disordered eating with risk of stress fracture. Thus, our results are not consistent with those from some previous cross-sectional[41] and case-control[40] studies. Barrack et al.[42] failed to observe an association between disordered eating and low BMD among adolescent females. Since low BMD is related to fracture risk in children,[43] our findings are consistent with several other studies not findings an association between disordered eating and stress fracture or high risk of stress fracture. Moreover, only lowest adult weight, but not current weight, was associated with risk of stress fracture in a prospective study of 3,758 female military recruits undergoing basic training.[44] It is possible that we did not observe an association with disordered eating or body weight because we had a relatively small number of females who were underweight or engaging in disordered eating, and we controlled for family history of low bone density and osteoporosis, which others have found to be a strong predictor of risk.[40] Approximately 80% of the variability in BMD is attributable to genetic factors.[2] Thus if the risk associated with being underweight is small and correlated with the weight and family history of the mother, controlling for family history would attenuate the association with stress fracture.

Our strongest findings relate to the association between physical activity and fracture risk. These results have important practical implications. We observed that girls engaging in eight or more hours of activity per week were about twice as likely as their less active peers to develop a stress fracture. The association was driven by hours per week engaged in three activities: running, basketball, and cheerleading/gymnastics. These results are consistent with other studies that have observed high rates of stress fracture among collegiate female runners.[45] Previous studies of gymnasts and cheerleaders have been too small to have sufficient statistical power, but there is a biological plausibility to such an association. Cheerleading and gymnastics involve repeatedly jumping and landing, which cause particularly high stresses on bone 46, thus there is physiological support for our observed association. Our results imply that clinicians, athletic trainers, coaches, and others who supervise athletic programs for young female runners, basketball players, gymnasts, and cheerleaders should promote including varied training in non- or intermediate impact activities to decrease the cumulative amount of impact, as well as reducing the hours spent training in their high-impact sport.

There are several limitations to this study. Our cohort is > 90% white and thus it is not clear whether the results are generalizable to non-Caucasian female adolescents and young adults. However, Caucasians are at high risk for stress fracture 47 and are thus an important group to study. In addition, we relied on self-reports from the mothers of the participants to ascertain stress fracture. This may have resulted in some misclassification with small numbers of individuals mistakenly included as cases and a small number of cases that the mother did not know about and, therefore, did not report. However, requiring radiographic confirmation, which would been extremely difficult to obtain in this sample which lives throughout the US, might also result in some misclassification because of the difficulty in distinguishing stress fractures from stress reactions. Nevertheless, the misclassification due to self-reported stress fracture likely slightly biased our results towards the null. Also we did not have information on some of the other predictors of stress fracture, such as factors related to biomechanics and bone microarchitecture. The strengths of the study, however, far outweigh the limitations. This is the first large prospective study of stress fracture. Moreover, this is the largest prospective study of adolescents. Another strength is that exposure information was collected every 12–24 months and was ascertained before the onset of the stress fracture. We also had information on the mother's history of low bone density and osteoporosis, as well as information from the participant on age at menarche, body weight, disordered eating, and physical activity.

Our study observed that high impact activities, specifically basketball, running and gymnastics/cheerleading, significantly increase risk for stress fracture among adolescent girls. Thus, there is a need to establish training programs that are rigorous and competitive, but include varied training in lower impact activities to decrease the cumulative amount of impact in order to reduce the risk of stress fracture.

More research is needed to understand whether dietary intake, disordered eating, and weight history affects risk. Physical activity during childhood and moderate activity during adolescence may increase bone density and thus help to protect against osteoporosis in adulthood. Therefore, clinicians, parents, and coaches should continue to promote activity to young girls, but should make sure that training hours are not excessive and thereby, not compromising bone health. This is particularly critical since youth sports have moved away from playing a different sport in each seasons to focusing on a single sport throughout the year.

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Table 1

Baseline demographics and lifestyle characteristics of 6831 preadolescent, adolescent, and young adult females in the Growing Up Today Study

Mean (S.D.) age (years)	12.0 (1.6)
Mean (SD) body mass index (kg/m^2)	19.0 (3.3)
Mean (SD) age at menarche (years)	11.8 (1.0)
% Post-menarcheal	44.1% (n=3008)
% Underweight	8.6% (n=570)
% Overweight or obese	19.8% (n=1309)
% Disordered eating	2.5% (n=169)
% Maternal history of low bone density or osteoporosis	10.4% (n=707)
Hours per week of moderate or vigorous activity[a]	
< 1 hour/week	0.2% (n=12)
1–3.9 hrs/wk	3.4% (n=222)
4–7.9 hrs/wk	14.0% (n=918)
8–11.9 hrs/wk	19.9% (n=1310)
12–15.9 hrs/wk	18.8% (n=1239)
16–19.9 hrs/wk	15.0% (n=988)
20–24.9 hrs/wk	11.2% (n=734)
> 25 hrs	15.7% (n=1033)
Mean (SD) hours/week of non impact activity	4.7 (3.3)
Mean (SD) hours/week of intermediate impact activity	2.2 (2.4)
Mean (SD) hours/week of high impact activity[b]	5.2 (4.1)

[a] Sum of basketball, baseball, biking, dance/aerobics, hockey, running, swimming, skating, skateboarding, soccer, tennis, cheerleading, lifting weights, volleyball, and karate.

[b] Sum of basketball, running, soccer, tennis, cheerleading, and volleyball.

Table 2

Associations of age at menarche and activity with incident stress fracture among 6831 females in GUTS

	Hazard ratio, adjusted for age and family history (95% confidence interval)	Hazard ratio, fully adjusted[a] (95% confidence interval)
Age at menarche (years)	1.32 (1.11–1.57)	1.34 (1.12–1.62)
< 4 hours/wk of activity[b]	1.00 (Referent)	1.00 (Referent)
4–7.9 hours/wk of activity	1.27 (0.67–2.43)	1.40 (0.70–2.80)
8–11.9 hours/wk of activity	1.65 (0.88–3.11)	1.94 (0.98–3.83)
12–15.9 hours/wk of activity	2.41 (1.28–4.54)	2.78 (1.41–5.47)
≥ 16 hours/wk of activity	2.67 (1.46–4.85)	2.65 (1.37–5.12)

[a]Hazard ratios above are from Cox proportional hazards models adjusted for age, BMI, maternal history of low bone density or osteoporosis, and the covariates listed in the column.

[b]Sum of basketball, baseball, biking, dance/aerobics, hockey, running, swimming, skating, skateboarding, soccer, tennis, cheerleading, lifting weights, volleyball, and karate.

Table 3

Association of non-, medium, and high impact activity with incident stress fracture among females in GUTS

	Hazard ratio, adjusted for age and family history (95% CI)	HR, adjusted for all covariates in model[a] (95% CI)
Age of menarche	1.32 (1.11–1.57)	1.34 (1.11–1.61)
Non-impact activity[b] (hrs/wk)	0.98 (0.92–1.03)	0.98 (0.93–1.04)
Medium impact activity[c] (hrs/wk)	1.02 (0.95–1.09)	1.01 (0.94–1.09)
High impact activity[d] (hrs/wk)	1.09 (1.06–1.13)	1.08 (1.05–1.12)

[a] Hazard ratios above are from Cox proportional hazards models adjusted for age, BMI, age, maternal history of low bone density or osteoporosis, and the covariates listed in the column. and the covariates listed in the table.

[b] Sum of biking, swimming, skating, skateboarding, and lifting weights

[c] Sum of baseball, dance/aerobics, hockey, and karate.

[d] Sum of basketball, running, soccer, tennis, cheerleading, and volleyball.

Table 4

Association of type of activity with incident stress fracture among females in GUTS

	Hazard ratio, adjusted for age and family history (95% confidence interval)	HR, adjusted for all covariates in model[a] (95% CI)
Age at menarche	1.32 (1.11–1.57)	1.35 (1.12–1.63)
Family history	1.95 (1.24–3.07)	1.81 (1.10–2.99)
Non-impact activity (hrs/wk)	0.98 (0.92–1.03)	0.96 (0.90–1.02)
Medium impact activity (hrs/wk)	1.02 (0.95–1.09)	0.99 (0.92–1.07)
Running (hrs/wk)	1.14 (1.06–1.22)	1.13 (1.04–1.23)
Basketball (hrs/wk)	1.19 (1.10–1.28)	1.12 (1.03–1.23)
Soccer (hrs/wk)	1.09 (1.01–1.18)	1.05 (0.96–1.15)
Cheerleading or gymnastics (hrs/wk)	1.12 (1.04–1.21)	1.12 (1.02–1.22)
Tennis (hrs/wk)	0.85 (0.66–1.10)	0.86 (0.66–1.12)
Volleyball (hrs/wk)	1.07 (0.96–1.20)	1.04 (0.92–1.18)

[a]Hazard ratios above are from Cox proportional hazards models adjusted for age, BMI, family history of low bone density or osteoporosis, and the covariates listed in the table