Impact of a School-Based Physical Activity Intervention on Fitness and Bone in Adolescent Females

Margaret Schneider, Genevieve F. Dunton, Stan Bassin, Dan J. Graham, Alon Eliakim, and Dan M. Cooper

Background: Many female adolescents participate in insufficient physical activity to maintain cardiovascular fitness and promote optimal bone growth. This study evaluates the impact of a school-based intervention on fitness, activity, and bone among adolescent females. *Methods:* Subjects were assigned to an intervention ($n = 63$) or comparison ($n = 59$) group, and underwent assessments of cardiovascular fitness (VO_{2peak}), physical activity, body composition, bone mineral density (BMD), bone mineral content (BMC), and serum markers of bone turnover at baseline and at the end of each of two school semesters. *Results:* The intervention increased physical activity, VO_{2peak}, and BMC for the thoracic spine (P values < 0.05). Bone turnover markers were not affected. In longitudinal analyses of the combined groups, improvements in cardiovascular fitness predicted increased bone formation ($P < 0.01$) and bone resorption ($P < 0.05$). *Conclusion:* A school-based intervention for adolescent females effectively increased physical activity, cardiovascular fitness, and thoracic spine BMC.

Key Words: bone density, bone development, exercise, physical education and training, physical fitness, school health services, adolescent

Epidemiological trends among adolescent females in the US suggest that the future health of the current generation is seriously at risk owing to the effects of physical inactivity. Data from the Youth Behavioral Risk Factor Survey[1] indicate that 37% of 9th grade females and 54% of 12th grade females are insufficiently active to maintain cardiovascular fitness. Among adults, physical inactivity increases the risk of obesity,[2] diabetes,[3] and osteoporosis.[4] Given that activity patterns established in youth tend to track into adulthood,[5,6] it is critical that steps be taken to reverse the downward trend in physical activity presently evidenced among adolescents in general and adolescent females in particular.

Schneider, Bassin, Graham, and Cooper are with the University of California at Irvine, Irvine, CA 92697. Schneider is with the Dept of Planning, Policy, and Design; Graham is with the Dept of Psychology and Social Behavior; Bassin is with the Dept of Medicine; and Cooper is with the Dept of Pediatrics. Dunton is with the Dept of Preventive Medicine, University of Southern California, Los Angeles, CA 90033. Eliakim is with the Dept of Pediatrics, Tel Aviv University, Ramat Aviv, Israel.

Schools offer a natural environment for intervening to increase physical activity among adolescents, and a number of studies support the efficacy of school-based programs for doing so.[7-9] Most of these studies have been implemented and evaluated on a school-wide basis, rather than targeting high-risk groups, although a few have targeted overweight children.[7,10] Within the literature, there has been very little work addressing the needs of female adolescents who are insufficiently active to maintain or promote physical fitness; a subgroup at heightened risk for a future sedentary lifestyle and its associated health problems. Thus, the present research set out to determine whether a school-based intervention to promote physical activity and physical fitness would be effective among insufficiently active adolescent females.

The Task Force on Community Preventive Services[11] has strongly recommended using physical education (PE) classes to promote physical activity and fitness in school-age youth, and several studies involving curricular change in PE have published encouraging but generally modest findings.[7,9,12] For example, an 8-wk school-based intervention with junior high school students[9] had small but positive effects on cardiovascular fitness. A 16-wk school-based intervention for overweight and low-active high school females[7] resulted in a positive shift in stage of change for exercise but had no effect on levels of physical activity. Another study of low-active female adolescents[12] found that a one-semester PE-based intervention increased vigorous physical activity and maintained cardiovascular fitness. An intervention of a longer duration may be required to demonstrate an absolute increase in fitness within adolescent females who are insufficiently active to maintain physical fitness.

School-based interventions also have been associated with significant increases in bone density[13] and improved bone mineral content[14] in children, but the osteogenic effects of exercise in post-pubertal adolescents are less well documented. Some researchers[15,16] have suggested that the "window of opportunity" for enhancing bone growth with physical activity has largely closed by mid- to late-adolescence; yet a few trials have produced suggestive evidence that vigorous activity is capable of enhancing bone growth in post-pubertal adolescents.[17,18] These initial findings regarding the role of physical activity in bone development among post-pubertal adolescents are not compelling, however, and further investigation is warranted to determine whether increasing activity in post-pubertal adolescents will have a beneficial impact on bone.

A multifaceted PE-based intervention was designed to increase physical activity and improve physical fitness among post-pubertal adolescent females. The program combined supervised physical activity with an educational component that encouraged subjects to increase their out-of-school activity. Moreover, in order to examine the population for whom increased activity is the most relevant, we focused on insufficiently active female adolescents with relatively low cardiovascular fitness. Thus, the present study investigates the potential for intervening during post-pubertal adolescence to enhance physical activity participation and physical fitness among insufficiently active adolescent females. Secondary outcomes included body composition (percent body fat, lean body mass, and bone mass) and serum indicators of bone turnover.

Methods

Study Design

Two public high schools within a single school district participated in the study. Both schools were similar in terms of facilities and equipment available to the students, and in terms of the structure of the physical education programs. One school was assigned, based on convenience factors, to receive the intervention, and the other functioned as a comparison group. Students were recruited after the assignment of schools to groups, and so were informed in advance whether or not they would be participating in the intervention. To maintain a manageable class size for the intervention, the study was conducted over three consecutive school years, involving sequential cohorts of $n = 43$ (year 1; 22 intervention and 21 comparison), $n = 39$ (year 2; 20 intervention and 19 comparison) and $n = 40$ (year 3; 21 intervention and 19 comparison). The comparison group received no instructions with regard to physical activity, and school records were reviewed to document enrollment in PE.

To minimize group differences in calcium consumption, each subject was asked to consume one flavored 500 mg calcium chew (Viactive) per day. Average daily dietary calcium intake estimates range between 850 to 1200 mg for adolescents[19] and pilot data for this study indicated a mean daily dietary calcium intake of 800 mg among insufficiently active adolescent females (unpublished data). Therefore, a supplement of 500 mg was determined to sufficiently boost subjects' average daily intake to the recommended level of 1300 mg.[20]

Assessments were conducted at a university-based general clinical research center at baseline (summer), semester 1 (the end of fall semester) and semester 2 (the end of spring semester). Intensity and duration of the supervised exercise sessions were estimated using periodic heart rate monitoring. Dietary calcium consumption was measured at baseline and semester 2, and compliance with calcium supplementation was assessed monthly via telephone call. Study subjects received monetary compensation for completing the clinic assessments, and schools awarded community service credit to subjects who completed all three clinical assessments. The study protocol was reviewed and approved by the university's institutional review board, and all subjects and their parent or guardian provided written informed consent.

Recruitment and Setting.   The two participating schools were similar demo-graphically (see Table 1). Subject inclusion criteria were: 1) enrollment in the 10th or 11th grade; 2) fewer than three 20-min bouts per week of vigorous physical activity and fewer than five 30-min bouts per week of moderate physical activity; 3) VO_{2peak} at or below age-specific 75th percentile; 4) ability to exercise without restrictions; 5) eumennorheic; and 6) not taking any medications known to influence bone health (e.g., steroids).

At baseline, 146 eligible subjects enrolled in the study [$n = 79$ (intervention); $n = 67$ (comparison)]. Subsequently, 6 students in each condition changed schools, and so dropped out of the study. Fifteen intervention students were removed from the study because they missed more than 10 d of the PE class in the first 2 months

Table 1   Comparability of Participating Schools

	Intervention	Comparison
API score[*]	795	789
Low-income indicator[†]	10%	10%
Ethnicity		
African American	2%	1%
Asian American/Pacific Islander	11%	15%
Latino/Hispanic	16%	22%
White/European American/Other	72%	61%

Note. [*]API = Academic Performance Indicator; the state's method of combining test scores across all subjects and grade levels.

[†]Percent of students qualified to receive free or reduced-price meal subsidy.

of the study ($n = 6$) or because they exhibited a negative attitude that threatened to influence other students' participation in class activities ($n = 9$). One intervention student was dropped because she joined a sports team, and two comparison group subjects discontinued participation. Final analyses were conducted on 122 adolescent females [$n = 63$ (intervention); $n = 59$ (comparison)].

Intervention.   The intervention goal was to increase students' levels of physical activity through supervised in-class activity, health education, and Internet-based self-monitoring. The intervention class met 5 d per week for 60 min each day (approximately 40 min of activity time). One day per week was devoted to an educational discussion related to the health benefits of exercise and strategies for adopting an active lifestyle. Supervised activities were selected based on student input, and included a variety of aerobic (3 times per week, including aerobic dance, kickboxing, and brisk walking) and strength-building (1 time per week, including weightlifting and yoga) activities. A detailed description of the class has been provided elsewhere.[8]

Measures

Cardiovascular Fitness.   Cardiovascular fitness was obtained through a ramp-type progressive exercise test on an electronically-braked cycle ergometer. Subjects were encouraged to maintain a pedaling rate of 70 rpm during the test phase of the protocol. The ramp power output increased continuously until subjects reached voluntary fatigue. The test portion of the protocol lasted between 8 to 12 min. Each test was followed by an appropriate cool-down period. Peak oxygen consumption (VO_{2peak} in L/min and VO_{2peak} in mL · min^{-1} · kg^{-1}) was obtained using the SensorMedics Vmax 229 metabolic cart (SensorMedics, Yorba Linda, CA), through a method designed for children and adolescents.[21] Gas exchange was measured breath-by-breath throughout the exercise protocol.[22]

As noted by Vanhees et al.[23] "in the laboratory, exercise capacity is preferentially assessed through maximal incremental exercise testing. . . The peak oxygen uptake is the gold standard in the assessment of exercise tolerance." (p. 102) The

majority of the activities practiced by the intervention subjects in this study were intended to increase cardiovascular fitness; thus, we believe that the cycle ergometer test was appropriate for assessing whether improvements in fitness had occurred as a result of the intervention.

Physical Activity.   Self-reported physical activity was measured using a 3-Day Physical Activity Recall (3DPAR) validated by Motl, Dishman, Dowda, and Pate.[24] Activities were converted into metabolic equivalents (METs) using the compendium published by Ainsworth et al.,[25] and grouped to calculate the average daily minutes spent engaged in moderate (between 3 and 6 METs) and vigorous (greater than 6 METs) activity. Steps were taken to ensure that the 3DPAR excluded any supervised activity that was part of the intervention.

Bone Mass and Body Composition.   Percent body fat, lean body mass and bone mass [i.e., bone mineral content (BMC in g) and bone mineral density (BMD in g/cm^2)] were assessed by dual X-ray absorptiometry (DEXA) using a hologic QDR 4500 densitometer (Hologic, Inc. Bedford, MA). A series of scans were performed by a licensed X-ray technician and analyzed using software designed for a pediatric population. Standard procedures were employed to yield BMC and BMD values for the following regions: lumbar spine (L1-L4), hip, total body, thoracic spine, femoral neck, and trochanter. Subjects were scanned in a hospital patient gown while lying flat on their backs. On each day of testing, the DEXA machine was calibrated using the procedures provided by the manufacturer. Height was measured to the nearest 0.01 cm using a stadiometer and weight was measured to the nearest 0.1 kg using a calibrated scale.

Bone Turnover.   Subjects had blood drawn from an antecubital vein to assess levels of serum indicators of bone turnover. Serum was immediately isolated and small aliquots prepared and stored at –80 °C until needed. Bone formation was measured using ELISAs for osteocalcin (sensitivity 0.4 ng/mL), bone-specific alkaline phosphatase (BSAP, sensitivity 0.7 U/L), and C-terminal procollagen peptide (CICP, sensitivity 0.2 ng/mL). Bone resorption was measured using ELISAs for deoxypyridinoline cross-links (PYD, sensitivity 0.4 nM/L). All assay kits were obtained from QUIDEL, Inc., Santa Clara, CA.

Intensity and Duration of PE Class Activity.   Heart rates were monitored for one class period every other week within the intervention class using a Polar heart rate monitor. This device consists of an elastic belt, worn around the lower portion of the chest, and a watch-like receiver worn on the wrist. Monitors recorded average heart rate and number of minutes at or above 120 beats per min. Monitoring sessions varied by day of the week in order to obtain an equal representation of the different class activities. Students participated in the monitoring on a rotating basis.

Dietary Intake.   Daily caloric consumption in kilocalories and daily calcium consumption were measured with a 3-d diet diary (one weekend day and two weekdays) at baseline and semester 2. Registered dieticians trained subjects to complete the diary, contacted each subject midway through the assessment period to answer questions, and reviewed diaries with subjects upon completion. Data were analyzed using First Database Nutrition Pro.

Calcium Supplementation Compliance.   Compliance with calcium supplementation was assessed monthly via a telephone call. Researchers asked subjects to report the number of days in the past week that the calcium supplement was taken (0 to 7 d). Average compliance was calculated for the 9-month intervention.

Data Analyses

Non-normal distributions required transformation of several variables prior to analyses: moderate activity (square root transform); vigorous activity (dichotomized into "some" and "none"); CICP and trochanter BMC (log transforms). To account for the dependence of observations within each study group, baseline comparisons and group × time interactions were assessed using multi-level random coefficient modeling (HLM, version 6.0, Scientific Software International, Lincolnwood, IL).[26,27] The extent to which the intervention influenced vigorous activity ("some" versus "none") was tested using the hierarchical generalized linear model (HGLM*)* function, a non-linear analysis for binary outcomes using the Bernoulli distribution. All multi-level models controlled for cohort (i.e., year 1, year 2, or year 3) and ethnicity. Additional covariates included baseline percent body fat (for models testing baseline group differences and the group × time interactions for moderate, vigorous, and VO_{2peak}), height and weight (for models testing baseline group differences in BMC, BMD, and serum indicators of bone turnover), and changes in height and weight (for models testing group × time interactions for BMC, BMD, and serum indicators of bone turnover). A more conservative approach of using robust standard errors was taken for all analyses owing to the fact that many of the outcome variables were moderately skewed. Multiple regressions examined whether individual improvements in cardiovascular fitness and physical activity predicted beneficial changes in secondary outcomes when the intervention and comparison groups were combined ($N = 122$). These analyses also controlled for changes in height and weight.

Results

Descriptive Statistics

Subject Characteristics.   At baseline, intervention ($n = 63$) and comparison ($n = 59$) groups were comparable in age (mean = 15.04, standard deviation = 0.79), height (mean = 1.62 m, standard deviation = 0.57), weight (mean = 60.80 kg, standard deviation = 11.90), BMI (mean = 23.22, standard deviation = 4.54), GPA (mean = 3.24, standard deviation = 0.76), self-reported health (single item, range 1 to 5; mean = 2.98, standard deviation = 0.81), average daily caloric consumption (mean = 1495.34 kcal, standard deviation = 438.67), and daily calcium intake (mean = 797 mg, standard deviation = 387). There were no group differences in physical activity or cardiovascular fitness, but the intervention group was heavier and had higher body fat (Table 2). The intervention group also included a greater proportion of non-Hispanic whites (68% vs. 49%; χ^2(df = 1) = 4.03, $P < 0.05$). The overall study sample was diverse, with 57% non-Hispanic white, 20% Hispanic, 17% Asian, and 6% "other." The three cohorts were comparable in terms of the

Table 2 Group-by-Time Interactions for Body Composition, Physical Activity, and Cardiovascular Fitness

	Intervention (n = 63)			Comparison (n = 59)			Base-line Diff. P	Group x Time P
	Baseline M (SD)	Semester 1 M (SD)	Semester 2 M (SD)	Baseline M (SD)	Semester 1 M (SD)	Semester 2 M (SD)		
Height (m)	1.62 (0.06)	1.62 (0.06)	1.62 (0.06)	1.62 (0.06)	1.62 (0.06)	1.62 (0.06)	0.33	0.15
Weight (kg)	62.60 (13.40)	63.29 (14.06)	64.20 (14.17)	58.88 (9.80)	59.17 (9.91)	59.03 (10.03)	0.04	0.04
BMI percentile	69.07 (28.82)	68.38 (28.97)	69.31 (28.40)	63.14 (25.02)	62.13 (26.18)	59.42 (26.67)	0.10	0.04
Body fat (%)*	33.06 (6.30)	32.51 (6.40)	33.19 (6.55)	31.17 (5.35)	30.72 (5.70)	30.76 (6.02)	0.02	0.45
Lean body mass (g)	40530 (5521)	41172 (3070)	41338 (4810)	39224 (3406)	39525 (3856)	39734 (9103)	0.28	0.40
VO_{2peak} (L/min)	1.41 (0.28)	1.44 (0.27)	1.52 (0.27)	1.39 (0.26)	1.29 (0.25)	1.33 (0.21)	0.84	0.001
VO_{2peak} (mL$^{-1} \cdot$ min$^{-1} \cdot$ kg^{-1})	23.19 (4.81)	23.20 (4.59)	24.17 (4.53)	23.71 (4.19)	22.11 (4.14)	22.85 (3.61)	0.83	0.02
Moderate (min)[†]	75.07 (77.99)	51.26 (61.55)	70.63 (61.11)	86.61 (70.96)	46.44 (56.28)	55.76 (68.96)	0.24	0.04
Vigorous (%)[‡]	59.7	67.7	84.1	44.1	45.8	57.6	0.12[§]	0.001

Note. All multi-level models controlled for cohort and ethnicity. Models predicting VO_{2peak}, moderate activity, and vigorous activity also controlled for baseline fat. Non-adjusted means are presented. Robust standard errors were used in all analyses.

*Percent body fat as measured by DEXA.

[†] Average daily minutes expended in moderate activity. For clarity of interpretation, nontransformed values are presented.

[‡] Percent of participants reporting at least some vigorous activity.

[§] Estimated using HGLM, a non-linear analysis for binary outcomes using the Bernoulli distribution.

major study variables. Subjects who completed the study reported better overall health [$t(145) = 2.11$, $P < 0.05$] and a higher GPA [$t(136) = 4.21$, $P < 0.001$] at baseline than subjects who did not.

Participation in Physical Education Within the Comparison Group. Twenty-four percent ($n = 14$) of the comparison group subjects were enrolled in PE for one semester, and 76% ($n = 44$) were enrolled in PE for two semesters during the intervention year (data were missing for one comparison subject). ANOVAs showed that whether comparison group subjects were enrolled in PE for one or two semesters had no effect on change over time in any of the study outcome variables (P values > 0.05).

Intensity and Duration of PE Class Activity. Heart rate data were collected for 62 of the 63 intervention subjects on approximately four separate occasions. On average, subjects exercised at or above 120 beats per min for 18.66 min (standard deviation = 11.64) per session. In addition, we calculated the average mean heart rate achieved during each exercise session across all subjects. The average mean heart rate was 128.73 beats per min (standard deviation = 17.09). Monitors were worn for an average of 34.10 (standard deviation = 8.79) min per class, with the remaining time being devoted to fitting the chest straps and wrist units onto subjects.

Calcium Intake and Compliance. Daily dietary calcium intake decreased by about 20 mg in both the intervention and the comparison groups; there was no significant difference between the two groups ($P > 0.10$). Similarly, overall compliance with daily calcium supplementation was comparable between groups, with subjects reporting consuming the supplement an average of 5 d per week.

Effect of the Intervention

Cardiovascular Fitness, Physical Activity, and Body Composition. Improvements in VO_{2peak} and vigorous activity were significantly larger for the intervention group (Table 2; P values < 0.001). Results of the analysis did not change when VO_{2peak} mL $\cdot$ min^{-1} $\cdot$ kg^{-1} was used as the dependent variable. Within the intervention group, participation in vigorous activity increased from 59% at baseline to 84% at semester 2. In addition, average daily minutes in moderate activity remained stable in the intervention group, whereas average minutes of moderate activity declined in the comparison group ($P = 0.04$). The intervention group experienced a significantly larger weight increase between baseline and semester 2 ($P = 0.04$); yet, changes in height, percent body fat, and lean body mass were similar across groups.

Bone Mass and Turnover. Of the six bone regions evaluated, the effect of the intervention on BMC for the thoracic spine was significant [$t(115) = 2.15$, $P = 0.032$]. Within the intervention group, thoracic BMC increased 6.3% [(102.59 g (standard deviation = 16.91) to 108.05 g (standard deviation = 18.62)], as opposed to a 1.4% increase within the comparison group [(99.11 g (standard deviation = 16.33) to 100.41 g (standard deviation = 15.47)]. None of the measures of BMD were significantly affected by the intervention; nor were any of the serum indicators of bone formation differentially affected by the intervention.

Longitudinal Relationships Among Fitness, Physical Activity, and Secondary Outcomes

Changes in cardiovascular fitness across the combined groups ($N = 122$) were positively related to changes in BSAP ($\beta = 0.172$, $P = 0.004$) and PYD ($\beta = 0.156$, $P = 0.025$). No other relationships between changes in physical activity/fitness and changes in secondary outcomes emerged.

Discussion

A school-based physical activity promotion intervention successfully enhanced physical activity and physical fitness within a group of adolescent females who exhibited low levels of physical activity and fitness at baseline. The two-semester intervention, consisting of a special PE class and Internet-based self-monitoring was found to significantly impact participation in both moderate and vigorous physical activity and to improve cardiovascular fitness as compared to a non-intervention comparison group. The intervention had very little effect, however, on bone development, with only one of the six measures of BMC and none of the measures of BMD showing any improvement. Importantly, the majority of the comparison group subjects were enrolled in regular PE classes for the duration of the intervention, suggesting that the intervention was effective in promoting activity and cardiovascular fitness changes as compared to traditional PE. Overall, the intervention was effective in influencing key behavioral and physiological outcomes in a population at high risk for becoming sedentary, overweight adults, but was less effective for enhancing bone health.

Prior research indicated that a one-semester intervention was not sufficient to improve cardiovascular fitness among insufficiently active adolescent females.[12] The current study shows that fitness levels can be significantly increased over the course of a sustained two-semester intervention. The fact that fitness primarily increased in the later months of the intervention highlights the importance of sustained interventions among insufficiently active populations. Neumark-Sztainer et al. (2003) found that a 4-month school-based intervention did not increase physical activity among low-active high school girls, and the duration of school-based programs shown to successfully impact fitness and activity is typically 6 months or more.[28]

It is interesting to note that whereas there was a small increase over time in weight and BMI in the intervention group, relative to the comparison group, there was no differential change in percent body fat. Visual inspection of the pattern of change in lean body mass (LBM) suggests that the intervention group may have experienced a larger increase in muscle mass, although this increase was not large enough to reach statistical significance (perhaps owing to the large standard deviation in LBM). We hypothesize, therefore, that the intervention stimulated greater increases in muscle mass through increased activity, and that the weight gain evidenced in the intervention group was due to enhanced LBM.

In terms of the secondary outcomes investigated, the results are ambiguous. On the one hand, the magnitude of the change in thoracic spine BMC (6% in the intervention vs. 1% in the comparison group) is comparable to or even greater than the changes in bone mass found by investigators working with pre-pubertal girls.

For example, McKelvie et al.[14] found a difference of 2 to 4% in BMC between girls who engaged in high-impact jumping three times per week for 2 y and a control group, and Heinonen et al.[15] found a difference of 3 to 4% in BMC between girls in a 9-month step aerobic program and a control group. On the other hand, the present intervention resulted in a significant change in bone development in only one of the six skeletal regions analyzed. Moreover, there was no significant impact of the intervention on the serum indicators of bone turnover. These findings suggest that the effect of the intervention on bone development overall was limited in scope.

The minimal impact on bone does not appear to be attributable to problems with intervention fidelity. Based on heart rate monitoring, in-class activities were sufficiently intense to elevate subjects' heart rates to at least 60% of their maximum level for close to 20 min four times per week. Subjects also increased their vigorous activity outside the supervised setting. The most compelling evidence for the effectiveness of the intervention, however, is provided by group differences in cardiovascular fitness. Over the course of the 9 months, intervention group subjects increased cardiovascular fitness by 8%, whereas the control group decreased fitness by 4%.

Our findings are in line with controlled studies of young adult females that have failed to yield substantial improvements in bone parameters as a result of increased physical activity.[29,30] As suggested by previous authors, these results are likely due to a limited developmental window of opportunity when exercise is able to effectively influence bone growth.[31] Heinonen et al.[15] propose that exercise-related effects on bone are restricted to periods of rapid body growth (i.e., early and middle adolescence) when levels of insulin-like growth factor 1 (IGF-1), growth factor, estrogen, and androgen are high. In terms of reducing the risk of osteoporosis, then, it would appear that the most effective time to increase physical activity, at least among girls, would be in the pre-menarchal years.

The finding that individual gains in cardiovascular fitness were associated with greater bone turnover—as indicated by significant increases in serum markers—raises some interesting questions. Among older women, increased bone turnover has been related to a greater risk for osteoporotic fracture.[32] Among female adolescents, however, higher levels of formation and resorption markers have been associated with increased BMD.[33] The evidence for a relationship between increased concentrations of serum markers of bone turnover and enhanced bone density is not compelling, however, and additional research is necessary to determine whether higher circulating levels of PYD and BSAP are predictive of enhanced bone growth among adolescents.

The strengths of this study include the longitudinal design, use of standardized and clinical measures, and the focus on insufficiently active female adolescents. Nevertheless, the lack of random assignment and selective attrition are limitations that should be acknowledged. With respect to most of the major study criteria, the intervention and comparison groups were comparable at baseline, and we controlled statistically for those differences that did emerge. Moreover, the two schools that participated in the study were similar based on publicly available demographic and academic performance statistics. Nevertheless, there may have been unmeasured differences between the two groups or in the two school environments that affected the findings. In terms of attrition, we took a proactive approach to the intervention subjects, and terminated participation for individuals who either were absent

from school an unusually high number of days (thus limiting their exposure to the intervention) or manifested a behavior pattern in the intervention class that threatened to disrupt the intervention for other subjects. This proactive approach may have increased our probability of having an impact on cardiovascular fitness among those who completed the study, and may therefore limit the generalizability of the findings.

Overall, a school-based physical activity intervention significantly increased levels of physical activity and fitness, had only minimal effects on bone development, and had no effect on body composition among insufficiently active, post-pubertal adolescent females. These findings support the use of specialized PE classes (because we found that regular PE classes were ineffective) as an appropriate venue for promoting physical activity among insufficiently active adolescent females, and highlight the possibility that physical activity may have minimal impact on bone development in post-pubertal females.

Acknowledgments

References

1. CDC. Surveillance Summaries. *MMWR*. May 21 2004;53(SS-2).
2. Jacicik J, Otto A. Physical activity considerations for the treatment and prevention of obesity. *Am J Clin Nutr*. 2005;82:226S-229S.
3. Kriska A. Can a physically active lifestyle prevent Type 2 diabetes. *Exerc Sport Sci Rev*. 2003;31:132-137.
4. Todd J, Robinson R. Osteoporosis and exercise. *Postgrad Med J*. 2003;79:320-323.
5. Paavola M, Vartiainen E, Haukkala A. Smoking, alcohol use, and physical activity: A 13-year longitudinal study ranging from adolescence into adulthood. *J Adolesc Health*. 2004;35:238-244.
6. Kelder S, Perry C, Klepp K, Lytle L. Longitudinal tracking of adolescent smoking, physical activity, and food choice behaviors. *Am J Public Health*. 1994;84:1121-1126.
7. Neumark-Sztainer D, Story M, Hannan PJ, Rex J. New Moves: a school-based obesity prevention program for adolescent girls. *Prev Med*. 2003;37:41-51.
8. Jamner MS, Spruijt-Metz D, Bassin S, Cooper DM. A controlled evaluation of a school-based intervention to promote physical activity among sedentary adolescent females: Project FAB. *J Adolesc Health*. 2004;34:279-289.
9. McMurray R, Harrell J, Bangdiwala S, Bradley C, Deng S, Levine A. A school-based intervention can reduce body fat and blood pressure in young adolescents. *J Adolesc Health*. 2002;31:125-132.
10. Carrel A, Clark R, Peterson S, Nemeth B, Sullivan J, Allen D. Improvement of fitness, body composition, and insulin sensitivity in overweight children in a school-based exercise program: a randomized, controlled study. *Arch Pediatr Adolesc Med*. 2005;159:963-968.

11. Kahn E, Ramsey L, Brownson R, et al. The effectiveness of interventions to increase physical activity: a systematic review. *Am J Prev Med*. 2002;22(4S):73-107.

12. Jamner MS, Spruijt-Metz D, Bassin S, Cooper DM. A controlled evaluation of a school-based intervention to promote physical activity among sedentary adolescent females: Project FAB. *J Adolesc Health*. 2004/4 2004;34:279-289.

13. McKay HA, Petit MA, Schutz RW, Prior JC, Barr SI, Khan KM. Augmented trochanteric bone mineral density after modified physical education classes: A randomized school-based exercise intervention study in prepubescent and early pubescent children. *J Pediatr*. 2000;136:156-162.

14. MacKelvie KJ, Khan KM, Petit MA, Janssen PA, McKay HA. A school-based exercise intervention elicits substantial bone health benefits: A 2-year randomized controlled trial in girls. *Pediatrics*. 2003;112:447-452.

15. Heinonen A, Sievanen H, Kannus P, Oja P, Pasanen M, Vuori I. High impact exercise and the bones of growing girls: A 9-month controlled trial. *Osteoporosis Int*. 2000;11:1010-1017.

16. Witzke KA, Snow CM. Effects of plyometric jump training on bone mass in adolescent girls. *Med Sci Sports Exerc*. 2000;32:1051-1057.

17. Sundberg M, Gardsell P, Johnell O, et al. Peripubertal moderate exercise increases bone mass in boys but not in girls: A population-based intervention study. *Osteoporosis Int*. 2001;12:230-238.

18. Stear SJ, Prentice A, Jones SC, Cole TJ. Effect of a calcium and exercise intervention on the bone mineral status of 16-18-y-old adolescent girls. *Am J Clin Nutr*. 2003;77:985-992.

19. Novotny R, Boushey C, Bock MA, et al. Calcium intake of Asian, Hispanic, and white youth. *J Am Coll Nutr*. 2003;22:64-70.

20. US Dept of Health and Human Services and US Dept of Agriculture. *Dietary Guidelines for Americans,* 2005, 6th edition.

21. Cooper DM, Weiler-Ravell D, Whipp BJ, Wasserman K. Aerobic parameters of exercise as a function of body size during growth in children. *J Appl Physiol*. 1984;56:628-634.

22. Beaver WL, Lamarra N, Wasserman K. Breath-by-breath measurement of true alveolar gas exchange. *J Appl Physiol*. 1981;51:1662-1675.

23. Vanhees L, Lefevre J, Philippaerts R, et al. How to assess physical activity? How to assess physical fitness? *Eur J Cardiovasc Prev Rehabil*. 2005;12:102-114.

24. Motl RW, Dishman RK, Dowda M, Pate RR. Factorial validity and invariance of a self-report measure of physical activity among adolescent girls. *Res Q Exerc Sport*. 2004;75:259-271.

25. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: An update of activity codes and MET intensities. *Med Sci Sports Exerc*. 2000;32(9S): S498-S504.

26. Raudenbush SW, Bryk AS. Hierarchical linear models: Applications and data analysis methods. Thousand Oaks, CA: Sage Publications;1992.

27. Raudenbush SW, Bryk AS, Cheong YF, Congdon R. HLM 5: Hierarchical linear and nonlinear modeling. Lincolnwood, IL: Scientific Software International; 2000.

28. Luepker R, Perry C, McKinlay S, et al. Outcomes of a field trial to improve children's dietary patterns and physical activity: The Child and Adolescent Trial for Cardiovascular Health (CATCH). *JAMA*. 1996;275:768-776.

29. Vuori I, Heinonen A, Sievanen H, Kannus P, Pasanen M, Oja P. Effects of unilateral strength training and detraining on bone mineral density and content in young women: A study of mechanical loading and deloading on human bones. *Calcified Tissue Int*. 1994;55:59-67.

30. Snow-Harter C, Bouxsein ML, Lewis BT, Carter DR, Marcus R. Effects of resistance and endurance exercise on bone mineral status of young women: A randomized exercise intervention trial. *J Bone Min Res*. 1992;7:761-769.
31. MacKelvie KJ, Khan KM, McKay HA. Is there a critical period for bone response to weight-bearing exercise in children and adolescents? a systematic review. *Br J Sports Med*. 2000;36:250-257.
32. Sornay-Rendu E, Munoz F, Garnero P, Duboeuf F, Delmas PD. Identification of osteopenic women at high risk of fracture: the OFELY study. *J Bone Miner Res*. 2005;20:1813-1819.
33. Lehtonen-Veromaa M, Mottonen T, Irjala K, Nuotio I, Leino A, Viikari J. A 1-year prospective study on the relationship between physical activity, markers of bone metabolism, and bone acquisition in peripubertal girls. *J Clin Endocr Metab*. 2000;85:3726-3732.