Effects of plyometric jump training on bone mass in adolescent girls

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ABSTRACT

WITZKE, K. A. and C. M. SNOW. Effects of plyometric jump training on bone mass in adolescent girls. *Med. Sci. Sports Exerc.*, Vol. 32, No. 6, pp. 1051–1057, 2000. **Purpose:** The purpose of this study was to investigate the effects of 9 months of plyometric jump training on bone mineral content (BMC), lower extremity performance, and static balance in adolescent girls (aged 14.6 ± 0.5 yr; 22.7 ± 14.0 months past menarche). **Methods:** Exercisers ($N = 25$) trained 30–45 min, three times per week, performing various exercises using weighted vests (squats, lunges, calf raises) and plyometrics (hopping, jumping, bounding, and box depth jumps). The program was designed to load the lower extremities. Controls ($N = 28$), matched to exercisers for age and months past menarche, maintained their usual activities. The following were assessed at baseline and 9 months: BMC, strength by isokinetic dynamometry, power (Wingate), and static balance. **Results:** Repeated measures ANOVA revealed no significant differences between groups for BMC, nor were the changes in anthropometric or performance variables, analyzed by MANOVA, significant. In follow-up analyses, *t*-tests for independent samples revealed that both groups experienced a significant ($P < 0.01$) increase in percent change in bone mass compared to zero, for the whole body (mean: 3.7% exercisers, 3.6% controls), femoral neck (4.5% vs 2.4%), lumbar spine (L2–4) (6.6% vs 5.3%), and femoral shaft (3.4% vs 2.3%), but only the exercisers improved BMC of the greater trochanter (3.1% vs 1.9%). Furthermore, the exercise group significantly improved knee extensor strength (14.7% vs 7.3%) and medial/lateral balance (38.1% vs 9.5%), whereas the control group demonstrated no changes. The variety of lateral movement activities performed by the exercise group may have contributed to the differences observed between groups for greater trochanter bone mineral density (BMD), leg strength, and medial/lateral balance. **Conclusion:** The trends observed in bone mass between groups suggest that plyometric jump training continued over a longer period of time during adolescent growth may increase peak bone mass. **Key Words:** HIGH-IMPACT, STRENGTH, POWER, BMC, BMD

Research has suggested that increasing bone mass during and immediately following growth may prove to be an important prevention strategy for osteoporosis (10,28,33,34). An increase of only 3–5% in bone mineral density (BMD) is estimated to result in as much as a 20–30% reduction in fracture risk (18). Weight-bearing exercise of high load intensity is a known osteogenic stimulus (21,22,35,36). In cross-sectional reports, children who participate in activities associated with higher loads have been shown to exhibit higher bone mass than children who participate in activities associated with lower loads or controls (12). Furthermore, there is evidence that the effects of exercise on bone, if imposed before or around the adolescent growth spurt, are more effective for increasing bone mass than if imposed after puberty (11,13,16).

To date, only two studies have reported results of exercise interventions during youth. Blimkie et al. (3) reported no changes in spine or total body bone mass in adolescent girls after 26 wk of resistance training, despite significant strength gains. By contrast, Morris et al. (25) reported increased bone mass in prepubescent girls after 10 months of resistance plus moderate intensity jump training. However, there are no reports on the effects of high intensity skeletal loading in adolescent girls.

There are substantial data that support high magnitude (intensity) loading as the most effective type of bone-building activity (15,16,23,26,29,33). Athletes whose skeletons are subjected to forces of high intensity, such as gymnasts, display significantly higher bone mass at the hip and spine compared with athletes who participate in activities associated with lower skeletal forces (29,33). Based upon the literature and preliminary studies in our laboratory, we define high intensity skeletal loading as ground reaction forces of greater than four times body weight, moderate intensity as two to four times body weight and low intensity as ground reaction forces less than two times body weight (14).

The aim of this study was to evaluate the effects of 9 months of high intensity jump training, using plyometrics, on the musculoskeletal system in adolescent girls. Plyometric jump training is associated with high ground reaction forces (four to 7 times body weight) and includes a wide variety of exercises specifically designed to increase muscular strength and power of the lower extremities. These activities are based on the premise that increasing eccentric preload on a muscle induces the myotatic stretch reflex and

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may cause a more forceful concentric contraction. Plyometrics range in difficulty and intensity level, from simple stationary jumping to traveling drills such as hopping and bounding, to very high-intensity depth jumps from boxes of varying heights. Depth jumps have been shown to produce ground reaction forces of up to seven times body weight (5). An inherent benefit of utilizing plyometrics in a training study such as this one is that they require little equipment, small blocks of time, and are safe for children and young adults to perform (6). Plyometric jump training has been shown to safely and effectively improve lower body strength and power in young, high school-aged women (17), but its effect on bone density has yet to be determined. A proper progression of exercises is important to ensure proper body mechanics during execution and landing. Thus, the 9-month intervention included a combined program of lower body resistance plus moderate intensity plyometrics during the initial 3 months of exercise. As a result of the plyometric jump training, we hypothesized that the improvements in bone mass, balance, and leg strength would be greater than those observed in a matched control group.

METHODS

Subjects

Fifty-six freshmen girls (aged 14.6 ± 0.5 yr; 22.7 ± 14.0 months past menarche) were recruited from two local high schools to participate in the program (exercisers, $N = 27$; controls, $N = 29$). Given that the 9-month exercise training program was incorporated into their daily schedule as a one-credit physical education class, the girls were recruited specifically for the exercise group. After formation of this group, control subjects were then recruited from the high schools and matched by age and months past menarche with exercisers. All subjects were apparently healthy, postpubertal girls between the ages of 13 and 15 yr. Subjects were excluded for metabolic disease (diabetes, thyroid conditions), respiratory disease, and orthopedic problems (significant disability of knee, ankle, or hip) that would interfere with their participation in the exercises. Control subjects were recruited and matched by age and months past menarche subsequent to the formation of the exercise group. Written informed consent from the girls and their parents was obtained. This study was approved by the Institutional Review Board at Oregon State University, and by the State of Oregon Board of Radiology.

Assessments

All subjects completed a comprehensive health and activity questionnaire, a 100-item Block food frequency questionnaire, and were tested on the following variables: BMC, muscular strength, muscular power, and static balance.

Health and Block food frequency questionnaires. Subjects completed a computer-scored 100-item Block Food Frequency Questionnaire designed for use by the National Cancer Institute (4) to obtain values for daily caloric consumption, calcium, and ratios of calcium:protein and calcium:phosphorus. Health information included onset of menses and menstrual cycle history.

Bone mass measurements. BMC was assessed by dual energy x-ray absorptiometry (Hologic QDR 1000/W, Waltham, MA) for the whole body, lumbar spine (L2–4), proximal femur (femoral neck and greater trochanter), and femoral mid-shaft. Precision error in our lab is <1.0% for lumbar spine and 1.0% for regions of the proximal femur and whole body BMC. The mid-femoral shaft scan was begun at the distal femur, one-third the distance from the proximal patella to the inguinal crease, measured with the subject lying on the table. The scan length was set at 4.0 inches. In-house coefficient of variation (CV) for femoral shaft BMC is 1.2%. Bone-free lean body mass and fat mass (CV = 1.2%) were obtained from the whole body scan. All bone scans and analyses were performed by the same technician. BMC was evaluated instead of BMD because in the growing skeleton BMD does not accurately correct for changing bone geometry. However, BMC is a good measure of the structural properties of bone, capturing both the material and geometric properties.

Muscular strength. Gravity corrected (9) isokinetic strength of the left knee extensors was determined (KinCom 500H, Knoxville, TN) as an evaluative measure of the training program. This instrument has been shown to provide valid and reliable (r = 0.95) measures of muscle strength (8). In-house coefficient of variation for this measurement is 4%. Each subject received five to seven warm-up trials, followed by three to four maximal knee extensions from a position of 85° to 150° at a speed of $30°\cdot s^{-1}$, separated by a 1-min rest period.

Muscular power. Maximum muscular power of the lower extremities was assessed using the Wingate Anaerobic Power Test (WAPT) on a cycle ergometer (Monarch, Varberg, Sweden) and a computerized sensor (SMI Opti-Sensor, Model 1000, St. Cloud, MN). A 5-min warm-up was followed by 30 s of maximum speed pedaling against a resistance equal to 7.5% of body weight (7). Test-retest reliability for this measure in several studies of children and young adults is very high (r = 0.95–0.97) (1). In-house coefficient of variation is 4%.

Static balance. Static balance was measured using the Biodex Stabilometer (Shirley, NY). Subjects performed two 30-s trials using a stability level of 2 (range 1–8, 1 being least stable/most difficult and 8 being most stable/least difficult). The same foot position was used for pre- and posttests.

Exercise Training Protocol

Classes were held three times per week for approximately 30–45 min each session. The exercises were performed on a variety of surfaces, including wrestling mats, grass, concrete stairs, and wood gym floors. An appropriate progression of exercises was selected each day, with emphasis on muscular development at the beginning of the class, and increasingly more difficult and higher intensity activities toward the end of the class. Exercise classes were held three

TABLE 1. Weighted vest resistance training protocol.

Month	Sets	Repetitions	Intensity
1	2	8–10	5–7% of body weight
2	2	10–12	10–12% of body weight
3	3	12	15% of body weight

times per week during the 9-month school year, excluding school in-service days and holidays, when subjects were assigned workouts to perform at home.

Resistance exercises. Progressive resistance training was performed (in addition to plyometrics) for the first 3 months of the program, using a padded nylon vest loaded with 0.5-lb weights. Subjects loaded their vests based upon a percentage of body weight and performed exercises consisting of squats, forward and side lunges, toe raises and heel drops, bench stepping, and jumping onto and off of an 8-inch wooden box (Table 1).

Plyometric training. These exercises imposed a range of intensities from low intensity activities, such as simple two-footed, in-place jumps, to high intensity activities, such as stair jumping, bounding, and depth jumps onto and off of 12- to 24-inch wooden boxes. This program was designed to impose moderate to high intensity loads on the skeleton using exercises that increase muscular strength and power. Weighted vests were not worn during plyometrics, and most exercises were performed on wrestling mats and grass when possible.

Plyometrics are progressive in nature, and proper muscle conditioning was required before higher intensity exercises were added. Jumping exercises included simple jumps in place, squat jumps, box jump progressions, knee tucks, stride jumps, split jumps, and depth jump progressions (27). Bounding drills were performed for maximum height and distance using both or alternating feet, and included prancing, galloping, skip progressions, ankle flips, stair exercises, alternating leg bounds, and double leg butt kicks (27). Hopping exercises (one-footed landing) emphasized vertical height and quick leg movement, and consisted of hop progressions, hurdle hops, side cone hops, and single leg hops (27). Because of the considerably more difficult nature of depth jump activities which require proper body mechanics for safe execution, these were not added to the program until the third month, when subjects displayed adequate leg strength to correctly perform a two-footed landing from a 12-inch box.

Plyometric drills progressed from two sets, 10 repetitions of five to seven different exercises during the first 2 months (100–140 total jumps), to two to three sets, 2–20 repetitions of 12–20 different exercises the eighth and ninth months (360–1000 total jumps). The exercises were chosen based on intensity level, ranging from the simplest activities to the more difficult and higher intensity depth jumps as the months progressed. It should be noted that during the final months of training when the number of depth jumps was highest, the number of boxes (and therefore repetitions) used in one set was only two to four because of the high ground reaction forces being sustained during each repetition. As a result, the other plyometric exercises chosen included more low-intensity jumps. So while the total number of jumps was quite high in the final months, the number of high intensity jumps was between 40 and 100.

Statistical Analyses

All statistical analyses were performed using the Statview statistical software package (Abacus Concepts, ver. 4.1, Berkeley, CA). Repeated measures analysis of variance (ANOVA) were performed on the bone variables to assess post-training differences between groups. Pre and post-test changes in the remaining dependent measures (body composition, strength, power, stability) were analyzed using a 2×2 MANOVA as an evaluative measure of the exercise program. Subsequent to these analyses, post-training group differences were evaluated using one-sample Student *t*-tests, comparing the percent change in bone and performance measures to zero for each group separately. Significance was established at the 0.05 level.

The number of subjects required for this study was determined by formal power calculations. It was hypothesized that BMC of the whole body, proximal femur, lumbar spine, and femoral shaft would increase significantly more in the exercisers versus nonexercisers. With an expected group difference of 1%, a power of 0.8 and an alpha level of 0.05, it was calculated that 17 subjects were needed per group.

TABLE 2. Pre- and post-test subject characteristics.

Characteristic	Exercise (N = 25) (Mean ± SD) Pretest	Exercise Post-test	Control (N = 28) (Mean ± SD) Pretest	Control Post-test
Age (yr)	14.6 ± 0.4	15.4 ± 0.4	14.5 ± 0.6	15.3 ± 0.6
Months past menarche	22.5 ± 14.2	31.5 ± 14.2	22.4 ± 13.7	31.4 ± 13.7
Height (cm)	164.3 ± 5.6	165.0 ± 5.0	165.1 ± 6.4	165.8 ± 6.4
Weight (kg)	61.0 ± 15.2	61.5 ± 13.1	61.0 ± 15.2	61.5 ± 9.0
Lean mass (kg)	42.6 ± 5.8	43.0 ± 5.2	43.1 ± 5.7	43.7 ± 5.8
Fat mass (kg)	15.7 ± 10.1	15.5 ± 8.9	14.6 ± 4.2	14.9 ± 3.9
% Body fat	24.3 ± 7.9	24.3 ± 7.0	24.1 ± 3.9	23.3 ± 5.7
Past 2-yr # sports/yr	1.0 ± 1.1*	N/A	2.0 ± 1.8*	N/A
Energy intake ($kcal \cdot d^{-1}$)	1340 ± 714#	1241 ± 517^	1475 ± 432#	1293 ± 447^
Calcium intake ($mg \cdot d^{-1}$)	1107 ± 639#	997 ± 659^	1244 ± 470#	1121 ± 584^
Ca/Pro	17.8 ± 5.9#	17.2 ± 5.7^	19.1 ± 4.7#	18.5 ± 5.6^
Ca/Phos	0.84 ± 0.15#	0.85 ± 0.15^	0.89 ± 0.12#	0.87 ± 0.14^

* Significantly different between groups at baseline ($P < 0.02$).
\# Based on N = 22 exercise subjects; N = 17 control subjects.
^ Based on N = 17 exercise subjects; N = 13 control subjects.

TABLE 3. Pre- and post-test BMC and performance measurements.

Bone Site/Performance Measure	Exercise (N = 25) (Mean ± SD)		Control (N = 28) (Mean ± SD)	
	Pretest	Post-test	Pretest	Post-test
WB BMC (g)	2059.07 ± 445.52	2122.73 ± 408.28	2111.97 ± 326.73	2185.42 ± 331.43
FN BMC (g)	4.08 ± 0.70	4.24 ± 0.64	4.35 ± 0.73	4.45 ± 0.75
GT BMC (g)	7.00 ± 1.15	7.23 ± 1.19	7.33 ± 1.38	7.59 ± 1.57
LS BMC (g)	42.23 ± 6.41	44.83 ± 5.81	41.60 ± 6.08	43.81 ± 6.60
FS BMC (g)	30.72 ± 4.10	31.71 ± 4.08	31.88 ± 3.62	32.59 ± 3.58
Leg strength (kg)	96.0 ± 19.9	107.7 ± 17.3	107.2 ± 23.5	112.3 ± 22.2
Leg power (W)	392 ± 82	445 ± 91	440 ± 102	484 ± 83
A/P stability (° dev)	4.1 ± 2.3	2.1 ± 1.5	4.9 ± 2.0	3.5 ± 2.0
M/L stability (° dev)	2.7 ± 1.5	1.7 ± 1.3	3.8 ± 1.9	3.2 ± 1.7

RESULTS

Baseline data for the two groups are presented in Tables 2 and 3. The groups did not differ at baseline on any anthropometric or bone variables, but the control group had participated in more sports than the exercise group during the 2 yr before the study. They also tended to have higher initial strength and leg power values than the exercisers ($P = 0.07$).

A total of 90 formal classes were conducted at each school, with an additional 15 d assigned as home workouts during school holidays. Attendance in the formal classes averaged 86% for all exercise subjects (range 71–97%), including days missed because of sickness and school required activities such as sports participation and a health/physical education (PE) class which occasionally overlapped with the sessions. Attendance averaged 90% (range 72–100%) when considering only unexcused absences from class. Offering this class as a regular physical education course for school credit was a key factor in maintaining high rates of attendance and participation.

A total of 25 girls completed the 9-month exercise program. One subject moved out of the area, and one subject contracted mononucleosis during the first part of the study and chose to withdraw. Only one control subject did not return for follow-up testing because of repeated scheduling conflicts.

On average, controls engaged in an average of 5.6 h of physical activity per week besides their mandatory PE class, while the exercisers performed only 2.6 $h \cdot wk^{-1}$ of activity outside of the plyometrics class. Nine of the exercise participants did not perform any activities in addition to plyometrics, whereas only four control subjects were inactive outside their mandatory PE class.

Initial observation of the data showed all variables to be normally distributed. The stability variables, however, tended to be positively skewed, with more girls displaying lower scores (better stability). There were no obvious outliers or missing values. Standard deviations for most variables were high, however, indicating a wide range of scores.

Repeated measures ANOVA, however, showed that the improvements in BMC for the exercise group were not statistically greater than the improvements in controls. Similarly, MANOVA treatment of the remaining dependent measures (body composition, strength, power, and stability) revealed no statistical differences between the exercise and control groups. Follow-up analysis using one-sample *t*-tests was performed separately for each group on the changes in anthropometric, performance, and bone variables. Both groups significantly increased BMC of the whole body, femoral neck, lumbar spine, and femoral shaft, but only the exercise group significantly increased BMC at the greater trochanter (Tables 3 and 4). In addition, the exercise group displayed significant improvement in both knee extensor strength and medial-lateral stability, which did not occur in the controls (Figs. 1-3).

DISCUSSION

We report that plyometric training improves trochanteric BMC, leg strength, and balance in adolescent girls. Although the improvements in these variables were not statistically different from the improvements in control subjects,

TABLE 4. Mean percent change compared to zero for each group (one-sample Student *t*-tests).

	Exercise (N = 25)		Control (N = 28)	
	% Change (Mean ± SD)	*P* value	% Change (Mean ± SD)	*P* value
WB BMC (g)	3.71 ± 4.40	0.0003	3.57 ± 2.41	<0.0001
FN BMC (g)	4.49 ± 7.06	0.004	2.37 ± 4.25	0.006
GT BMC (g)	3.13 ± 6.44	0.02	1.96 ± 6.69	0.13*
LS BMC (g)	6.57 ± 4.37	<0.0001	5.34 ± 3.82	<0.0001
FS BMC (g)	3.39 ± 2.39	<0.0001	2.30 ± 2.61	<0.0001
Height (cm)	0.39 ± 0.52	0.001	0.45 ± 0.52	0.0001
Fat mass (kg)	3.56 ± 13.80	0.21	2.60 ± 7.05	0.06
Lean mass (kg)	1.15 ± 4.15	0.18	1.43 ± 2.68	0.01
Leg strength (kg)	14.69 ± 19.36	0.001	7.31 ± 21.60	0.09*
Leg power (W)	14.61 ± 14.10	<0.0001	11.56 ± 10.43	<0.0001
A/P stability (° deviation)#	−46.04 ± 24.94	<0.0001	−29.03 ± 29.43	<0.0001
M/L stability (° deviation)#	−38.11 ± 31.78	<0.0001	−9.45 ± 44.55	0.27*

* Significant increases in exercise group but not control group.

More negative stability scores indicate less deviation from the center of gravity.

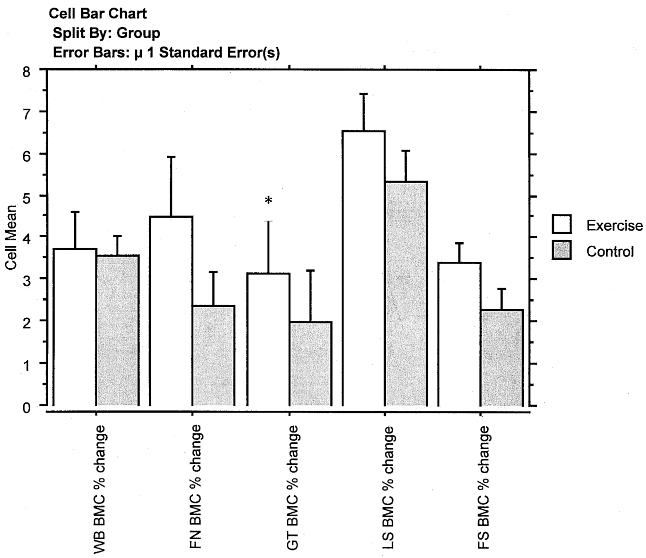

Figure 1—Percent change in BMC. *Exercise group significantly different from zero, while control group was not.

exercisers exhibited significant increases in these variables when compared to zero whereas control girls did not. Furthermore, a trend toward greater increases in BMC compared with controls was observed across all BMC sites.

This study has several strengths. It is the first to examine effects of moderate-to-high intensity jump training in young adolescent girls. In addition, the exercise was specific to jumping activities, thus reducing the confounding effects of aerobic exercise or resistance training. While it was necessary to include weighted vest resistance training before introducing the high intensity plyometric activities, inclusion of these exercises for only 3 of the 9 months helped prevent the confounding effects of resistance training on the results of the jumping program. Another strength was that most girls were less than 2 yr past menarche, and thus in their early postpubertal years. Further, the compliance was extremely high (90%) and attrition low (5%) for an exercise intervention. Other studies in young women report lower compliance and much higher attrition (32). We attribute the success in compliance and low attrition to the fact that these girls were provided the opportunity to participate during school hours for PE credit. Thus, a bone-building intervention could be included as a PE option in high schools.

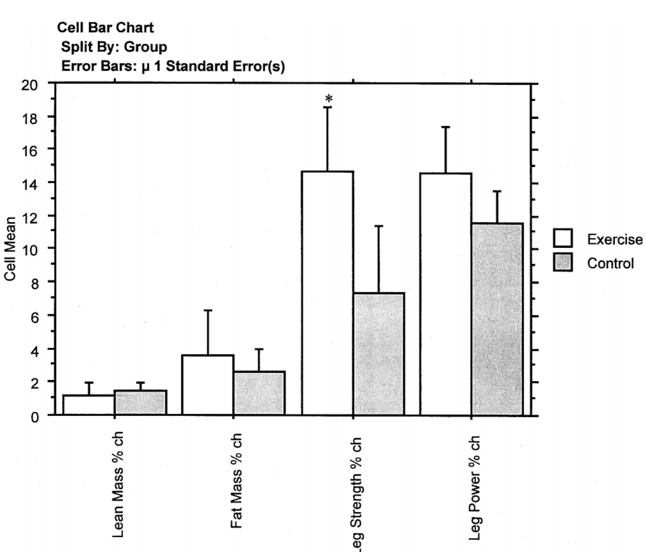

Figure 2—Percent change in body composition, leg strength, and leg power. *Exercise group significantly different from zero, while control group was not.

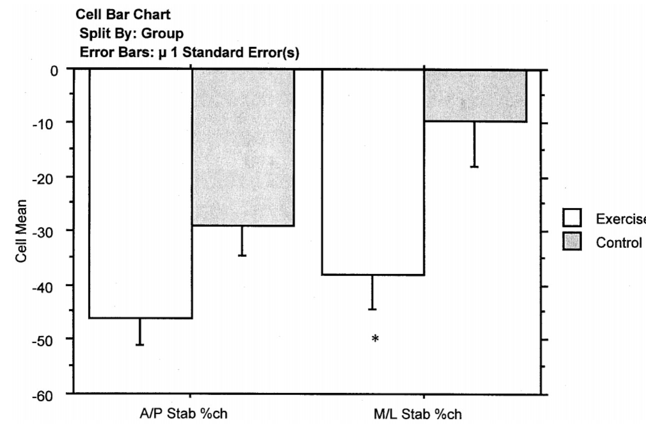

Figure 3—Percent change in anterior/posterior and medial/lateral balance. *Exercise group significantly different from zero, while control group was not.

It is also important to note study limitations. First, this study was not randomized. However, given that our intent was to offer this as a PE class, we sacrificed randomization in favor of high compliance and low attrition. Second, the control group contained more athletes than the exercise group, and the controls were more physically active than the exercisers, even before the study. We attempted to recruit only sedentary subjects, but discovered that a high percentage of freshmen girls are physically active and have higher sports participation than do older high school girls. Although control subjects also tended to have higher pretest BMC values at most sites (although not significantly different from exercisers), data from our laboratory indicate that high initial values do not necessarily attenuate further increases in bone (33). Third, given that a seated leg extension at a rate of $30°\cdot s^{-1}$ represents a constant angular, low-velocity, open kinetic chain exercise, the use of a 1-RM leg press or machine squat would have probably been a more appropriate strength measure. Similarly, a training-specific test such as a simple vertical jump test may have been a better choice for the assessment of leg power. We initially considered using this test but believed that since it was so similar to the training exercises, it may have produced a learning-induced improvement in performance. Fourth, since we obtained a smaller effect size than calculated for change in BMC between groups, subject numbers were not high enough to provide necessary statistical power. Observed power values ranged from 0.09 for changes in whole body BMC to 0.29 for femoral shaft BMC. Lastly, the length of the high intensity jump training was 6 months. We expect that given another 3 months at this intensity, significant differences would have been observed.

While there was a clear trend for greater improvements in bone mass at all sites among exercisers, the only significant increase (compared to zero) in the exercisers not accompanied by an increase in the control group was at the greater trochanter. This finding is similar to results of Bassey and Ramsdale (2), who reported gains of 3.6% at the greater trochanter in adult premenopausal women from jumping an average of 33 times per day. These improvements, which have not been produced by running or machine-based weight training, may be attributed to the high forces at the hip during jumping (15,33). While the femur experiences compressive forces during the jump landing phase, muscles that attach to the trochanter produce tensile forces during takeoffs and also during standing free weight training. It is plausible that the high forces produced during plyometric jumping in the present study, which incorporates squat-type preparation before takeoff, were of sufficient intensity to cause an increase in bone mass at this region of the hip. A unique feature of the exercise program in the current study is the variety of acceleration/deceleration patterns imposed on the lower extremities during plyometric training. These movement patterns may allow unusual or unaccustomed strains to be imposed on the skeleton. In addition, we speculate that the greater trochanter, given its higher percentage of trabecular bone than the femoral neck (24), is more responsive to loading.

Only one other study has evaluated the effects of exercise on bone mass during adolescence. Blimkie et al. (3) reported no significant changes in bone mass from 6 months of weight training in girls from 14–18 yr of age, despite large increases in muscle strength. However, they did observe a trend toward a transient increase in bone mass from training. The study differed from the current study in that it included girls with a wide postpubertal age range (12–18 yr), did not target hip bone mass, and was of shorter duration than the current study.

We speculate that the improvements in bone mass and performance variables of the controls were partially a result of growth but may have been enhanced by a high level of physical activity. The controls participated in significantly more hours of physical activity per week in addition to their mandatory PE class than the exercisers (5.6 vs 2.6 $h \cdot wk^{-1}$). In both groups, most of the additional activity involved sports performance (basketball, volleyball, softball, and track). On average, controls experienced a larger increase in lean body mass, not accompanied by a larger increase in leg strength and power, than the exercise group. This is probably a reflection of the specific nature of the intervention training and may also imply that the training program enhanced physiological systems involved in muscle recruitment.

While we believe that the primary reason we did not observe significant differences between exercisers and controls was a result of the active control group, it is also plausible that following puberty, the skeleton is not as responsive to exercise training as it is before puberty. Results from several investigators support this theory since they have demonstrated that adults who began high load activity before or around puberty (6–14 yr) have higher bone mass than adults who were not active before puberty or began exercise after puberty (19,20). Further, the recent report by Morris et al. (25) who showed significantly higher bone mass in prepubertal girls who participated in 10 months of moderate to high load activity compared with controls corroborates this theory. However, until a randomized, high intensity jump training intervention is conducted in early postpubertal girls, it is not possible to make definitive conclusions.

The subjects in the current study were not supplemented with calcium to control for the confounding effects of additional calcium intake on bone mass accrual. Although we did not expect calcium intake to change during the study period, the limited dietary data obtained pre- and post-test for 17 exercisers and 13 controls revealed that calcium intake decreased slightly in the exercise group (13%) while increasing slightly in the control group (8%). While these data are incomplete for all subjects and may only reflect the intake of subjects motivated to complete the post-test questionnaire, it would be worthwhile to explore the attitudes about calcium intake in girls who are participating in activities they assume will be “good” for their bones. Perhaps some of the exercise participants believed calcium intake from dietary sources to be less important while they were in the exercise class and decreased their intake accordingly. Average calcium intake for both groups at the beginning of the study, however, approximated the RDA of 1200 mg, which may imply that a small reduction in intake should not compromise bone health based on this factor alone. However, since reported caloric intake was low (e.g., 1241–1475 $kcal \cdot d^{-1}$), these data may be unreliable.

Although static balance improved in both groups, the percent change from zero was significantly greater in exercisers than controls. Specifically, medial/lateral balance was 29% higher and anterior/posterior balance was 17% higher in exercisers than controls. We were surprised by the striking improvements in balance in such young subjects, which leaves us to speculate that stability requires specific training. Many of the selected plyometric drills contained lateral movement patterns, which activated muscles and neural pathways involved in hip ab- and adduction and knee and ankle stabilization. These exercises challenge the neuromuscular system that controls coordination and balance. The improvements in postural stability, particularly in the medial/lateral direction, suggest that any type of osteoporosis training program should include exercises that require movements to the side. Maintenance of medial/lateral stability throughout life could reduce side falls and, thus, the incidence of hip fractures.

Offering this form of physical activity as a regular PE class during the school day was an extremely successful method for maintaining high rates of compliance. While effort levels among the exercise subjects did vary among individuals, most considered it an enjoyable alternative to a traditional physical education class. Thus, physical education class represents an avenue for the incorporation of plyometric activities into the lives of growing adolescents. The plyometric exercises used in this investigation varied in intensity from relatively low intensity jumps and hops to very high intensity depth jumps onto and off of 24-inch boxes. It is probable that additional improvement in BMC could have been produced by including more high intensity jumps into the program. Given that only one injury was sustained during the entire 9 months of the study, it may be safe to increase the intensity and number of the loads imposed without an increased risk to safety in this population.

The trends in BMC improvements across sites and the increase in trochanteric BMC reported in this study are meaningful. Plyometric training affords skeletal benefit during adolescence without compromising the health or safety of the young participant. Furthermore, it may also improve other parameters of motor development such as strength, power, and balance, all of which are important to build and maintain during growth and throughout adulthood. A program such as this may also serve an important role in promoting lifetime activity in girls who would otherwise choose to be sedentary. With an increased understanding of the benefits of this type of activity on the femur, high school PE programs, could include plyometric training and potentially reduce future risk of hip fracture.

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