ORIGINAL ARTICLES

Resistance training and bone mineral density in adolescent females

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Objective: To examine the effects of 15 months of resistance training on bone mineral density (BMD) in female adolescents (aged 14 to 17 years).

Study design: Participants were randomly assigned to either a training (n = 46) or control group (n = 21). BMD and body composition were measured by using dual-energy x-ray absorptiometry. Strength was assessed by means of one-repetition maximums for the leg press and bench press. The exercise group trained 30 to 45 minutes a day, 3 days per week, using 15 different resistance exercises. Control participants remained sedentary (<2 hours of exercise per week).

Results: Leg strength increased significantly (40%) in the exercise group, but there were no changes in the control group. Femoral neck BMD increased significantly in the training group (1.035 to 1.073 g/cm^2, $P < .01$) but not in the control group (1.034 to 1.048 g/cm^2). No significant changes were seen in either group in lumbar spine BMD (1.113 to 1.142 g/cm^2 and 1.158 to 1.190 g/cm^2, respectively) or total body BMD (1.103 to 1.134 g/cm^2 and 1.111 to 1.129 g/cm^2, respectively).

Conclusion: Resistance training is a potential method for increasing bone density in adolescents, although such a program would be best done as part of the school curriculum. (J Pediatr 2001;139:494-500)

The major determinant of peak bone mass is the amount of bone mass gained during childhood and adolescence. Low peak bone mass is a major risk factor in the development of osteoporosis. During these early years, patterns of diet and physical activity begin forming and are carried into adulthood. If poor dietary or physical activity habits are established during this time, not only will peak bone mass be lower, but the decline in peak bone mass can be accelerated in later years.[1] Thus, the incorporation of good exercise habits during childhood and adolescence should provide one of the best stimuli for gaining and maintaining bone mass.[2-4]

See related articles, p 473, p 509, p 516, and p 522.

Although exercise should increase bone mineral density (BMD), conclusions from intervention studies in this area are equivocal. In adults, some studies have shown increases in BMD with exercise,[5,6] whereas others have shown decreases[7] or no change.[8] The reasons for the disparity are unclear, although the intensity of the training program, the type of activity used, or nutrition factors may have all played a role.[3,9] In younger children, studies in this area have generally shown positive results, with most studies showing gains in bone mass with exercise.[10-12] There are very few data regarding the effects of exercise or resistance training on bone mass in adolescent females. In one study that has used resistance training with adolescent females, no changes in BMD were found after 26 weeks.[13] However, that study may have been of insufficient duration to show changes in BMD in growing children.

BMAD	Bone mineral apparent density
BMC	Bone mineral content
BMD	Bone mineral density
RM	Repetition maximum
TWU	Texas Woman's University

Resistance exercise has the potential of being a relatively risk-free and low-cost method for increasing and maintaining BMD. It can provide a much more varied workout than can walking or other forms of exercise training, and thus, it has been suggested that resistance exercise may provide a more osteogenic effect than other forms of exercise.[14] Recent evidence suggests that bone loss may start earlier in life than once thought, perhaps as early as the second or third decade of life,[15,16]

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suggesting the need for studies of bone mass in younger women and adolescents. The purpose of this study was to determine the effects of 15 months of resistance training on BMD in female adolescents.

METHODS

Participants were between the ages of 14 and 17 years, with at least 2 years of regular menstrual cycles. Recruiting presentations were made at local high schools to all girls in the appropriate age groups. Girls participating in varsity sports were told they would not be eligible. Follow-up contact was initiated with 98 girls who indicated an interest in participating in the study. All participants were nonsmokers, were not pregnant, were engaged in <2 hours of physical activity per week, and had no history of major orthopedic problems or other disorders known to affect bone metabolism. Participants were randomly assigned to either the control or resistance training group. Participants were added to the study for approximately 1.5 years, but all were enrolled for 15 months of intervention. After the study had been ongoing for approximately 6 months, it became obvious that the dropout rate for resistance trainers would be much higher. Therefore, after that point, new participants were randomly assigned on a 2-for-1 basis to the resistance training group for an initial enrollment of 46 participants in the resistance training group and 21 control particpants. Baseline measurements were done for all participants at the time of enrollment, with follow-up measurements at 5, 10, and 15 months. The participants were all informed of the purpose and procedures of the investigation, and each provided written informed consent before any data collection was done. All participants were minors, so parental consent was also obtained. The study was approved by the Texas Woman's University's Human Subjects' Review Committee.

Height and weight were measured in clothing without shoes. Standing height was measured with a stadiometer to the nearest 0.5 cm, and weight was measured on a beam scale to the nearest 0.1 kg. Precision errors for height and weight measurements were <1%. A questionnaire was administered at baseline and at the time of all follow-up measurements to determine menstrual history and the amount of physical activity performed both past and present.

Each participant was also asked to complete 3-day dietary records. Instructions on how to record the food intake were given to each participant by a registered dietitian. The 3-day records were computer-analyzed by using Nutritionist IV software (N-squared Computing, San Bruno, Calif).

BMD and body composition were measured by dual-energy x-ray absorptiometry (Lunar DPX, software version 3.61; Lunar Corp, Madison, Wis). Quality assurance measurements and precision measurements were performed as previously described.[5,15] The precision error was <1% for lumbar and total body BMD measurements and ≤2.3% for the proximal femur. Precision error was 1% for lean tissue mass and 2% for fat mass.

Measurements for determination of BMD of the lumbar spine (L2-L4), total body, and right proximal femur (femoral neck, Ward's area, and trochanter) were obtained. Lean tissue mass, fat mass, and percent body fat were determined from the total body measurements. To avoid possible problems with changes in the size or position of the regions of interest, the same certified technician performed all analyses using the same technique for all measurements. The default size for the region-of-interest box for the femoral neck was used for all measurements. Bone mineral apparent density (BMAD) was calculated according to the method of Kroger et al[17] to compensate for possible changes in bone size as a result of growth.

Strength was assessed at the time of each BMD assessment by measuring one-repetition maximums (RM) in the bench press and leg press. Universal weight machines were used to measure both RMs according to procedures outlined by American College of Sports Medicine.[18] Intra-class reliability coefficients for strength measurements were $r = 0.98$ or greater.

The resistance training program was conducted 3 times per week for 15 months. The program consisted of 15 different exercises designed to stress all major muscle groups with a combination of both free weights and machines and was designed based on methods described by Fleck and Kraemer.[19] Each exercise was performed to maximally load the spine and femur while loading the specific muscle group. For example, biceps curls were conducted in a standing position, as were triceps extensions, squats, lunges, and hip abduction/adduction. Other exercises performed were bench press, leg press, leg curls, leg extensions, shoulder press, lat pulldowns, seated cable rows, calf raises, and incline bench press. Initially, the amount of weight lifted was low, and one set of 12 to 14 repetitions was done to allow for adjustment to the training program. After 1 to 2 weeks, the number of repetitions were decreased to 9 to 10 per set, and two sets were done for each exercise. After an additional 4 to 8 weeks, the number of sets for major exercises (bench press, leg press, and squats) was increased to three. The amount of weight lifted was set so that the 10th repetition of the last set could not be completed. Weight was then increased when the 10th repetition of the second set could be completed. Specific exercises performed for each muscle group were changed approximately every 10 weeks, although the major exercises of bench press and leg press were always done. Logs were used to record the amount of weight lifted and the number of sets done for

Table I. Characteristics of female adolescents at baseline and 15 months (± SEM)

	Exercise group			Control group		
	Baseline		15 mo	Baseline		15 mo
	(n = 46)	(n = 5)	(n = 5)	(n = 21)	(n = 11)	(n = 11)
Age (y)	15.9 ± 0.1	16.01 ± 0.3	17.4 ± 0.4	15.7 ± 0.1	15.5 ± 0.2	16.8 ± 0.3
Age at menarche (y)	12.1 ± 0.2	12.8 ± 0.4	12.8 ± 0.4	12.4 ± 0.2	12.3 ± 0.3	12.3 ± 0.3
Height (cm)	157.0 ± 1.1	157.6 ± 2.1	158.3 ± 2.2	159.1 ± 1.7	158.2 ± 3.1	158.6 ± 2.9
Weight (kg)	63.5 ± 2.1	57.0 ± 3.9	56.3 ± 3.1	62.7 ± 3.6	63.8 ± 5.2	68.0 ± 5.6*
Body fat (%)	37.4 ± 2.3	33.8 ± 3.4	30.8 ± 3.5	36.4 ± 4.5	39.7 ± 4.4	40.4 ± 4.5
Total fat (kg)	23.8 ± 1.5	19.3 ± 3.2	17.3 ± 3.4	22.8 ± 2.8	25.3 ± 4.5	27.5 ± 4.5
Total lean (kg)	36.7 ± 0.7	35.5 ± 1.8	36.7 ± 1.4	36.3 ± 1.1	36.2 ± 4.0	38.1 ± 1.5
Leg 1 RM (kg)	76.4 ± 7.1	102.3 ± 4.1	143.2 ± 11.7*†	91.6 ± 5.9	100.5 ± 5.2	108.3 ± 8.1
Bench 1 RM (kg)	25.2 ± 2.2	33.6 ± 2.2	36.4 ± 7.9	31.5 ± 2.3	33.8 ± 2.2	32.8 ± 2.1

Baseline data are presented for the total number of subjects recruited into each group (n = 46 for exercise, n = 21 for control) and for those who completed the study (n = 5 for exercise, n = 11 for control). There were no significant differences between the groups in any baseline variable.
*Value is significantly increased from baseline.
†Value is significantly different from that for control participants.

each exercise. Training for the majority of the participants took place at the Wellness Center at Texas Woman's University (TWU). However, 10 participants trained as part of their physical education class at two local high schools. Because of the class schedule, their training time averaged 2.5 days per week (one week they trained 2 d/wk, the next, 3 d/wk), but otherwise, they followed the same basic program as the participants who trained at TWU. Training during the summer months was the same for all participants and was done at TWU. Research personnel supervised all resistance-training sessions, including those done at the high schools.

A 2 × 2 (group × time) repeated-measures multivariate analysis of variance was used to determine whether significant differences existed between and within the groups of participants over time in the bone density variables and in soft tissue mass. Because group sizes were unequal, Levene's test was used to ensure homogeneity of variance between the groups on each dependent variable. Variances were equal for all variables. Weight was used as a covariate when both between-group and within-group differences in bone parameters were analyzed. Level of significance was set at .05 for multivariate analysis and .01 for univariate analysis to adjust for multiple comparisons.

RESULTS

At baseline, 21 participants entered the study as control subjects and 46 entered in the resistance training group. After 5 months, 6 participants had dropped out of the control group and 25 had dropped out of the resistance training group. At the 10-month assessment, 4 more control participants and 12 more exercisers had dropped out. At the end of the 15 months, there were 11 participants in the control group and 5 in the resistance training group. Participants who left the study cited lack of time as the main reason. There were no significant differences in baseline BMD, weight, age, or other variables between participants who dropped out of the study and those who completed the study.

For adolescents completing 15 months of resistance training, compliance averaged 73% (number of sessions attended divided by total number possible to attend). The resistance training program was reasonably well tolerated by all individuals, and no overuse or other injuries occurred as a result of the program. However, there were alterations made in individual programs to accommodate chronic conditions not associated with resistance training. For example, one participant had chondromalacia that was aggravated when she used the hip machine to do standing leg abduction and adduction. Lying leg abduction and adduction were substituted. Control participants remained sedentary throughout the study.

Baseline physiologic characteristics of the participants including age, height, weight, age at menarche, and percentage of body fat (as determined with dual-energy x-ray absorptiometry) are presented in Table I. Height and weight were similar between the two groups and were within the normal range for this age group. Height did not change in either group over time, nor did weight in the resistance training group. However, there was a significant increase in weight in control participants (63.8 to 68.0 kg, $P < .01$), although weight of control participants was not different from that of

Table II. Mean daily dietary intakes (± SD)

	Exercise group (n = 5)		Control group (n = 11)	
Nutrient	Baseline	15 mo	Baseline	15 mo
Kilocalories	1521 ± 552	1359 ± 221	1633 ± 323	1491 ± 325
Carbohydrates (g)	213 ± 90	186 ± 33	214 ± 66	207 ± 44.0
Protein (g)	54.1 ± 14.7	44.7 ± 13.7	54.7 ± 13.4	53.5 ± 18.6
Fat (g)	52.4 ± 20.3	51.4 ± 9.4	64.4 ± 17.7	52.3 ± 14.4
Calcium (mg)	545.4 ± 261.9	579.9 ± 235.5	743.2 ± 251.8	684.1 ± 310.4
Phosphorus (mg)	739.8 ± 370.2	596.8 ± 153.3	809.6 ± 266.9	859.5 ± 307.5
Vitamin D (μg)	2.58 ± 2.95	1.52 ± 0.96	3.57 ± 2.71	5.03 ± 6.16

Table III. Bone changes in female adolescents (mean ± SD)

	Exercise group (n = 5)			Control group (n = 11)		
Variable	Baseline	15 mo	Percent change	Baseline	15 mo	Percent change
Total BMD (g/cm^2)	1.103 ± 0.043	1.134 ± 0.031	2.81	1.111 ± 0.066	1.129 ± 0.065	1.62
Total BMC (g)	2187.96 ± 238.40	2258.05 ± 149.57	3.20	2284.21 ± 362.95	2357.92 ± 360.45	3.23
Lumbar BMD (g/cm^2)	1.113 ± 0.081	1.142 ± 0.069	2.61	1.158 ± 0.135	1.190 ± 0.125	2.76
Lumbar BMC (g)	40.83 ± 4.27	42.75 ± 4.66	4.70	44.95 ± 7.35	47.52 ± 7.27	5.72
Lumbar BMAD (g/cm^3)	0.377 ± 0.027	0.383 ± 0.021	1.45	0.384 ± 0.044	0.388 ± 0.040	0.90
Neck BMD (g/cm^2)	1.035 ± 0.157	1.073 ± 0.128*	3.67	1.034 ± 0.086	1.048 ± 0.075	1.35
Neck BMC (g)	4.55 ± 0.34	4.73 ± 0.59	3.96	4.83 ± 0.53	4.87 ± 0.47	0.83
Neck BMAD (g/cm^3)	0.070 ± 0.018	0.071 ± 0.012	1.58	0.068 ± 0.013	0.068 ± 0.009	0.00
Ward's area BMD (g/cm^2)	0.995 ± 0.122	1.023 ± 0.130	2.81	0.982 ± 0.113	0.999 ± 0.091	1.73
Ward's area BMC (g)	2.161 ± 0.246	2.224 ± 0.427	2.92	2.439 ± 0.614	2.432 ± 0.503	–0.29
Trochanteric BMD (g/cm^2)	0.862 ± 0.124	0.880 ± 0.135	2.09	0.820 ± 0.106	0.842 ± 0.099	2.68
Trochanter BMC (g)	9.02 ± 3.07	9.69 ± 3.23	7.43	8.54 ± 2.13	9.11 ± 1.87	6.67

*Significantly different from baseline value. Weight was used as a covariate when changes in all bone parameters were examined.

resistance trainers. Age at menarche was also similar between the two groups. Participants reported normal menstrual cycles (10-12 cycles per year) throughout the duration of the study.

Initial values for total lean and fat mass are presented in Table I and were similar between the groups. No significant changes occurred in fat or lean mass in either group. Initial values for strength, as measured by 1 RM in the leg press and bench press, are also presented in Table I. There were no initial differences in strength between the groups. There was a significant increase in leg strength as measured by 1 RM in resistance trainers after 15 months of training (102.3 to 143.2 kg; $P < .05$), and the final 1 RM for the leg press was significantly greater in resistance trainers as compared with control participants. Leg strength remained unchanged in control participants, as did 1 RM for the bench press in both groups.

Nutritional information is presented in Table II. Mean total caloric intake per day was similar between the two groups, as was carbohydrate, protein, and fat intake. Carbohydrates averaged 54% of total caloric intake; protein, 13%; and fat, 33% over the course of the study. Both groups had mean daily calcium intakes well below the 1300 mg/d recommended in the dietary reference intake.[20] The calcium/phosphorus ratio averaged 0.85 over the course of the study.

BMD values were similar between the groups in the initial measurements and are within the normal range provided by the manufacturer of the densitometer (Lunar Pediatric Reference Data). Individual changes in BMD over the 15 months for the lumbar spine and femoral neck are shown in the Figure and represent data from only those participants who completed the study. Individual increases in femoral neck BMD for the exercise group were varied, with 2 participants having increases of ≤1%, whereas 2 others had increases >6%.

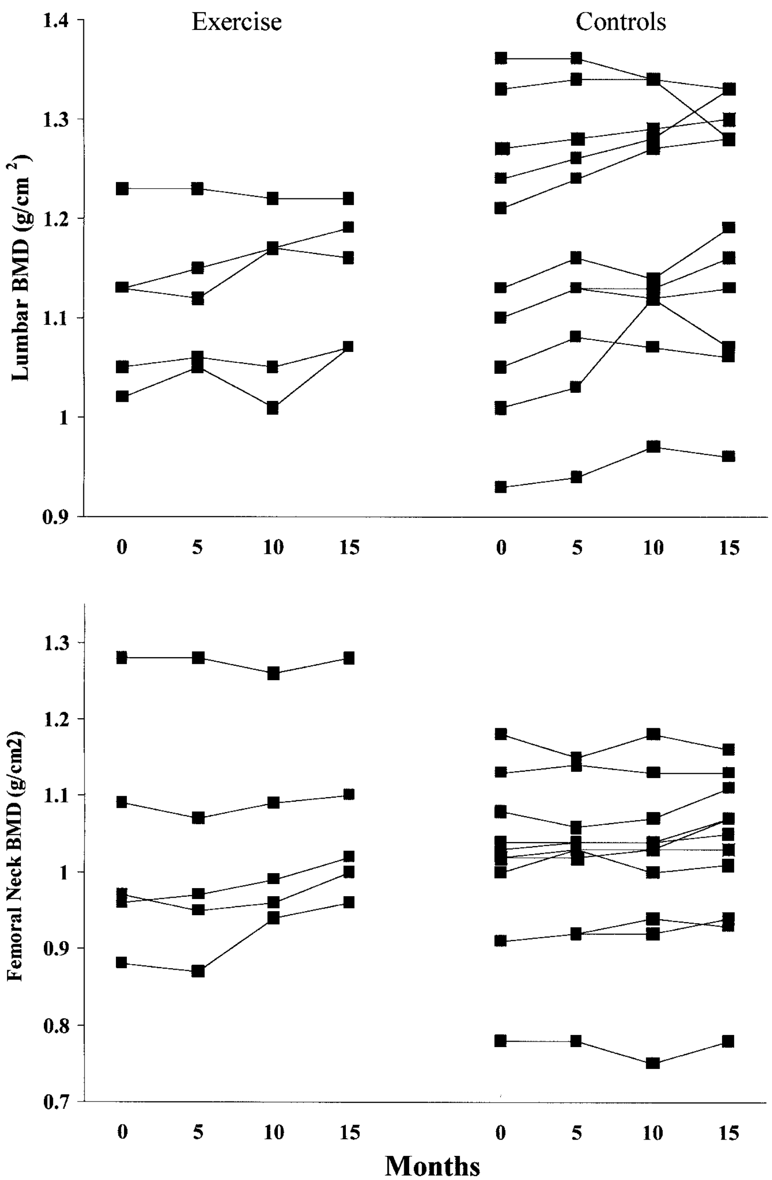

Figure. BMD changes in exercise and control groups over the 15-month period.

Mean changes in BMD for the groups are shown in Table III along with bone mineral content (BMC) and BMAD. Between- and within-group differences in bone measures were examined by using body weight as a covariate. Femoral neck BMD increased significantly in the exercise group but not in the control group. No significant changes were seen in either group in lumbar spine or total body BMD. There were no significant differences between the groups in BMD at baseline or in any follow-up measurements. There were also no differences in percent changes in BMD between the groups. However, the power to detect between-group differences was low (<0.3). There were no significant changes in BMAD, bone area, or BMC at any site, although it should be noted that the percent changes in BMC were of similar magnitude to the changes in BMD.

DISCUSSION

Adolescents represent a unique population in that, for the most part, they have not yet reached peak bone mass[21,22] and bone density is still increasing. Thus, it was unknown whether resistance training would provide a sufficient stimulus to increase BMD beyond what was naturally occurring, especially given the generally low calcium intake in this age group.[23] The major finding of the present study was that 15 months of resistance training significantly increased femoral neck BMD in adolescent females, although BMD values at other sites were unchanged.

Other studies that have examined the effects of resistance training on BMD in adult women[6,24] have generally demonstrated increases in BMD, although there have been exceptions.[7] In the one published study found to date of resistance training in adolescent girls, Blimkie et al[13] found no significant increases in BMD or BMC in the lumbar spine or total body, although they did not measure BMD at the proximal femur site. One of the major differences between the two studies is that the present study was conducted for 15 months compared with only 26 weeks of training in the study by Blimkie et al.[13]

Studies in which other forms of exercise training were performed by adolescent and younger children have also demonstrated increases in bone mass.[10-12,25] McKay et al[11] examined the effects of an 8-month school-based jumping program on BMD changes in young girls and boys (aged 7 to 10 years) and found that the jumping group had a significantly greater increase in trochanteric BMD than did the control group. In a similar study in adolescent girls (mean age = 14.5 years), Witzke and Snow[25] examined the impact of exercise on BMC using plyometric jump training. After 9 months of training, they found a significant increase in BMC of the greater trochanter in their exercise group, which was not present in the control group. They also found significant increases in BMC at other sites (total body, lumbar spine, and femoral neck) in both the exercise and control groups. The reason that significant changes in BMD were not seen at other sites in the present study is unknown. It may have been the age of the participants or the fact that no impact activities were performed, as was done in other studies.[11,25] Changes in BMD at the femoral neck in the present study seem related to the initial values of BMD. Those participants in the exercise group who had the greatest increases in femoral neck BMD had the lowest initial values. Those participants with high initial BMD may have been unable to further increase their BMD.[26]

The use of BMC as the primary measure by Witzke and Snow[25] and the use of BMD as the primary measure by McKay et al[11] and the present study point out the controversy in the literature about the best measurement for assessment of bone changes in growing children. Both BMD and BMC, as well as BMAD, have been suggested to be the best measure for growing children.[17,27,28] However, no clear evidence exists to identify which is optimal.[28] In the present study, significant changes in the resistance training group were found in femoral neck BMD but not in BMC or BMAD. Changes in BMC were of similar magnitude to the changes in BMD; and the lack of significance in BMC, and possibly BMAD, was probably a result of the greater precision error associated with BMC and BMAD.

Participants in the exercise group in the present study had an average daily calcium intake of ~560 mg over the course of the study, well below the suggested dietary reference intake of 1300 mg/d,[20] although it is possible that the participants were underreporting their dietary intake.[23] Increased calcium intake without exercise has been shown to significantly increase bone density in adolescent girls when compared with control participants.[29] One potential confounder regarding calcium and its effects on BMD in the present study is vitamin D status. Not all participants were tested at the same time during the year, and seasonal variations in vitamin D status are known to exist,[30] although such variations have generally not been seen in less extreme latitudes such as in Texas.[31]

Some exercise-training studies have demonstrated significant increases in both BMD and lean tissue mass.[5,12] In the present study, there were no changes in lean tissue mass, but there were significant increases of 40% in leg press strength in the resistance training group. It is possible that the strength changes in the present study are simply a result of neuromuscular adaptations, independent of changes in lean tissue mass.[32] However, the reason significant increases in strength were seen in the leg press, but not the bench press, is unknown. One possibility is that different modes of exercise were used for testing and training, and perhaps training caused the most adaptations in the supporting muscles used to do the bench press with free weights and not in the muscles that were used in RM testing.

A major point that must be addressed regarding the present study is the difficulty involved in completing the training portion of the study. Monetary and other incentives were offered throughout the study in an effort to reduce attrition. Nevertheless, for the 15 months, attrition from the exercise group was 85%, which is far greater than that observed in other studies.[12,13,25] Blimkie et al[13] and Witzke and Snow[25] reported only one and two dropouts, respectively, in their exercise studies with adolescents, but their training programs were done at the high school and did not try to retain the participants over a summer break, as was done in the present study. On the basis of experience from the present study and other studies,[12,13,25] it would seem that if exercise or nutritional programs designed to increase BMD or other health measures in adolescents or younger-age children are to succeed, they should be incorporated into the school curriculum.

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