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Deterring Bone Loss by Exercise Intervention in Premenopausal and Postmenopausal Women

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Summary. This study investigated the efficacy of 4 years of exercise intervention in deterring bone loss in middle-aged women, and is a correction and extension of previously published data. Sixty-two control subjects (mean age 50.8) and 80 exercise subjects (mean age 50.1) completed a 4-year study. Subjects exercised three times a week, 45 minutes per session. Bilateral radius, ulna, and humerus bone mineral content (BMC) and width (W) were measured on each subject 11 times over the 4-year period. The two groups did not differ initially in age, height, or weight, but the control group had a greater maximum $\dot{V}O_2$ (ml/kg/min) than the exercise group. Slopes and intercepts of the bone variables vs. time were determined for each subject, and these values were used for between-group comparisons of loss. The control group BMC and BMC/W declined significantly in all three bones in both arms. The exercise group rate of decline was significantly less than that of the control group for 12 of the 18 bone variables. The greatest effect of the exercise intervention was on the ulna and radius. Exercise subjects lost significantly less than control subjects in left and right ulna and radius BMC and BMC/W, and left ulna and radius W. Lesser differences between groups were observed in the humerus. BMC and W loss rates of the left humerus were reduced in the exercise group, with no difference between exercise and control subjects in the other humerus variables. To determine if menopausal status influenced the response to exercise, we analyzed the difference between groups for premenopausal and postmenopausal subjects separately. Regardless of menopausal status, exercise subjects had lower bone loss rates than control subjects. In both premenopausal and postmenopausal subjects, exercise reduced bone loss significantly for 10 of the 18 bone variables. It can be concluded that physical activity significantly reduces bone loss in the arms of middle-aged women.

Key words: Bone — Exercise — Women — Osteoporosis.

Osteoporosis is a major public health problem for older women. Common interventions for prevention and treatment are calcium supplementation, estrogen replacement therapy, and exercise [1]. The role of mechanical stress in skeletal mineral homeostasis is evident in extreme states such as weightlessness or athletic training [2–4]. In athletes, bone hypertrophy is specific to the area stressed. Magnitude and frequency of the stress also affect the amount of bone hypertrophy [5, 6]. The particular exercise necessary to prevent bone involution in the weightbearing and nonweightbearing components of the skeleton in aging women has not been clearly delineated. Intervention studies, however, have provided some clarification as to the responsiveness of skeletal components to stress. Krolner et al. [7] studied 31 women (mean age 61) for 8 months. Lumbar spine bone mineral content (BMC) increased nonsignificantly in the exercise group and declined in the control group. Change in lumbar spine BMC, but not forearm BMC, differed significantly between groups. In 9 postmenopausal women (mean age 52), Aloia et al. [8] found that total body calcium, but not radius BMC, increased

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significantly relative to controls during a year of exercise. Smith et al. [9] measured radius BMC and width (W) in elderly women (mean age 82), 12 of whom exercised for 3 years, and 18 sedentary controls. Rate of change of BMC and BMC/W was significantly different in the exercise group than in the control group. The estimated changes in BMC and BMC/W were positive in the exercise group and negative in the control group.

While many cross-sectional studies have compared the BMC of sedentary and active groups, few researchers have addressed long-term exercise intervention in middle-aged women. Prevention of bone loss in this group could greatly reduce the number of fractures later in life. The purpose of this study was to determine bone changes in formerly sedentary women who participated in a 4-year exercise program.

The first 3 years of this study were reported in an earlier paper [10]. The interpretation of the data has been changed and corrected due to the discovery of errors introduced by equipment malfunction.

Methods

Subject Selection

Two hundred and twelve women between the ages of 35 and 65 (85 control subjects and 127 exercise subjects) were selected for this study. Because exercise intervention programs typically have 30–50% dropout rates within the first year [11], we recruited more exercise than control subjects. The subjects were recruited from the general population of Madison, WI, the University of Wisconsin, and Madison Public schools. Subjects applied separately for the exercise or control group, and were accepted into the study on the basis of equal allocation of 5-year age groups. Control subjects were recruited as part of a double-blind study on calcium supplementation, and received placebo tablets throughout the study. While desirable, it was not logistically possible to initiate all 212 subjects into the study concurrently, and the control group was started before the exercise group.

Subjects were excluded from the study if they had a history or current diagnosis of osteoporosis, malignancy, chronic hepatitis, renal disease, chronic digestive or eating disorders, rheumatoid arthritis, parathyroid dysfunction, adrenal or respiratory disease, hyperthyroidism, or diabetes mellitus that could not be controlled by diet, prolonged bedrest, or corticosteroid therapy. Women taking calcium supplements, calcitonin, diphosphonates, or fluoride were also excluded. These factors were used as exclusions because of their possible effect on bone loss or ability to exercise. Although we wished to examine the effects of exercise on both premenopausal and postmenopausal women, women taking estrogen or progesterone were excluded, as this would have introduced an additional source of variation and required a larger population. Any subject that required any of the above drugs during the study period was eliminated from the study. Applicants who exercised regularly were also excluded.

All subjects gave informed consent indicated by signing a consent form approved by the University of Wisconsin Human Subjects Committee.

Testing Procedures

Each participant had an initial physical examination by a project physician or by her family physician, and a 12-lead ECG. Yearly blood chemistries (SMA-20) were obtained to verify that subjects were within the reference range for blood values. No hormonal analysis was done on the serum. Maximal work capacity was tested by a progressive treadmill test which was conducted at 3 mph, starting at a 0% grade and increasing by 2.5% in grade every 2 minutes (modified Balke protocol) [12]. If a subject successfully completed 2 minutes at a 20% grade, 3 mph, the grade was held constant and the speed was increased by 0.2 mph every 2 minutes. During the test, the ECG (lead 5), blood pressure, breathing volume, and oxygen and carbon dioxide expiration were monitored. The endpoint of the test was determined by signs or symptoms of exertional intolerance as defined by ACSM [13] or volitional exhaustion. Exercise subjects performed the work capacity test yearly and control subjects on alternate years. In each 29-day period during the last 3 years of the study, subjects completed two NARS III diet records [14]. The initial 2 recording days were assigned randomly for each subject. Subsequent recording dates were 29 days after the previous one. A 29-day period was chosen to systematically vary the day of the week. NARS III analysis quantifies intake of kilocalories, protein, calcium, iron, vitamin A, thiamin, riboflavin, niacin, vitamin C, magnesium, zinc, vitamin B6, vitamin B12, and folacin.

Bilateral BMC and W of the radius, ulna, and humerus were determined by the same single photon absorptiometry (SPA) system (Instrumentation Systems Center, University of WI) on each subject 11 times, at 3-month intervals the first year and 6-month intervals for the next 3 years. The radius and ulna were measured at a site one-third the distance from the olecranon to the head of the ulna. The humerus was measured at a site one-half the distance between the olecranon and the greater tubercle of the humerus adjacent to the acromion. All subjects were measured within 3 months of the start of the scan period, which began within 7 days of receiving a new 200 millicurie I-125 source. The data used for each time point were the mean of six scans at the measurement site. To minimize positioning error between time points, the subjects' arms were repositioned after every two scans for all measurement sites. A specially designed, ruled arm holder was used (Fig. 1). The arm was locked into place by quarter-inch sections of plexiglas between the middle and ring fingers and along the outside of the forearm and elbow. The position settings of the ring finger, forearm, and elbow sections of the plexiglas, determined by using anatomical landmarks, were recorded during the initial bone scans, and these settings were used for all subsequent scans.

A three-chamber standard was measured 100 times prior to the beginning of the study to determine standard values. Each subject's final values were determined by applying a regression to the raw data. The regression was based on 10 measurements of the standard prior to the subject scan vs. the standard values. The standards were measured before the start of daily subject measurements, at noon, and at the end of the day. The coefficient of variation for our single photon absorptiometry system was 2.3–3.0% for the radius, 3.0–4.0% for the ulna, and 2.3–3.2% for the humerus.

Exercise Program

The control group did not participate in any organized physical

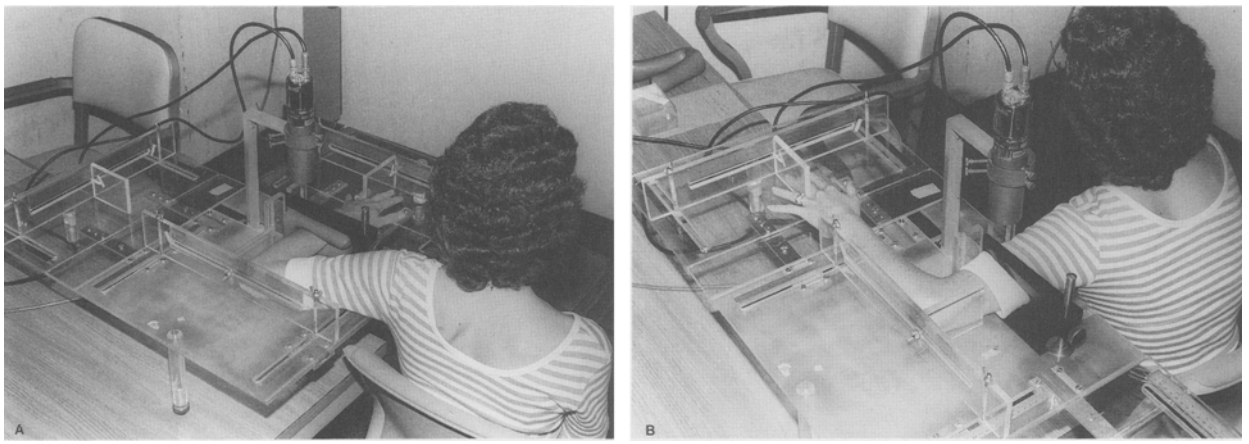

Fig. 1. Limb scanner table for single photon absorptiometry. **(A)** Forearm scan. **(B)** Humerus scan.

Table 1. Baseline anthropometric characteristics and fitness of dropouts and those who remained in study

	4-Year participants				Dropouts			
	Control		Exercise		Control		Exercise	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	50.8	6.8	50.1	8.2	48.4	9.1	49.0	8.4
Height (cm)	164.1	6.6	163.1	6.6	164.8	5.3	163.8	6.6
Weight (kg)	66.7	12.0	65.2	10.7	77.5[a]	14.4	69.0	14.1
Max $\dot{V}O_2$[b] (ml O_2/kg/min)	30.5	8.7	28.1[a]	4.7	28.3	8.5	26.4[c]	5.9
No. of subjects	62		80		21		47	

[a] Significantly differently from controls who remained in study. Exercise dropouts were not compared to control 4-year participants, nor were control dropouts compared to exercise participants

[b] All subjects who were tested are included. Some subjects did not meet criteria for physiological maximum

[c] n = 37

Table 2. Anthropometric characteristics and fitness at start and end of study

	Control			Exercise		
	Start (mean, S.D.)	End (mean, S.D.)	Diff (mean, S.D.)	Start (mean, S.D.)	End (mean, S.D.)	Diff (mean, S.D.)
Height (cm)	164.1[a]	163.6[a]	−0.5	163.1[d]	162.8[d]	−0.3
	6.6	6.9	1.0	6.6	6.6	1.0
Weight (kg)	66.7[b]	68.2[b]	1.5[f]	65.2	64.6	−0.7[f]
	11.9	12.5	3.3	10.7	9.2	5.1
Max $\dot{V}O_2$*	30.7[cg]	28.2[ch]	−2.5[i]	28.1[eg]	32.5[eh]	4.4[i]
(ml O_2/kg/min)	7.7	6.0	6.2	4.7	5.5	3.7

Values with same superscript are significantly different ($P < 0.05$)

* N = 50 control, 74 exercise. Twelve control subjects and 6 exercise subjects, while completing 11 bone scans, were not available for the final work capacity test. Their initial measurements of fitness are not included in this table. These data include all subjects who took their final volitional maximum stress test, even those who did not meet the criteria for physiological maximum

activity, but continued their normal activity pattern. The exercise group participated in 45 minutes of physical activity per session, 3 days per week. Each session consisted of approximately 10 minutes of warmup, 30 minutes of aerobic (endurance) activities including dancing, walking, and jogging, and 5 minutes of cooldown. Each participant was instructed to reach and sustain her target heart rate (THR) throughout the aerobic segment of the class. THR was calculated as 70–85% heartrate reserve determined from the yearly work capacity test using the Karvonen method [15]. Exercise heart rates were taken randomly three times during each session of aerobic exercise and recorded by the participant in her exercise log.

The exercise program was designed around the principles of safety, exercise overload, and participant interest. In the first

Table 3. Usual dietary intake, years 2–4

	Control (N = 59) Mean, S.D.	Exercise (N = 69) Mean, S.D.	Difference between groups	T
Energy (Kcals)	1582.97	1628.38	−45.41	−0.79
	319.09	324.97		
Protein (g)	67.23	65.97	1.25	0.52
	14.10	12.99		
Calcium (mg)	718.66	857.83	−139.17	−3.02[a]
	269.88	251.05		
Phosphorus (mg)	1158.75	1233.35	−74.60	−1.60
	281.89	245.48		
Iron (mg)	15.03	18.97	−3.94	−1.78
	6.56	15.92		
Vitamin A (IU)	8528.89	8679.83	−150.94	−0.24
	3635.10	3529.87		
Thiamin (mg)	3.38	5.76	−2.38	−1.27
	5.85	13.29		
Riboflavin (mg)	3.87	6.06	−2.19	−1.19
	5.62	13.14		
Niacin (mg)	26.38	32.45	−6.07	−1.34
	20.99	28.74		
Ascorbic acid (mg)	199.74	272.15	−72.41	−1.59
	205.07	295.05		
Magnesium (mg)	240.47	270.76	−30.29	−2.62[b]
	63.82	66.15		
Zinc (mg)	10.20	12.23	−2.03	−1.88
	3.42	7.69		
Vitamin B6 (mg)	5.00	7.10	−2.10	−0.94
	9.76	14.53		
Vitamin B12 (mcg)	7.76	11.61	−3.84	−1.54
	7.11	18.03		
Folacin (mcg)	316.90	371.08	−54.18	−2.00[b]
	148.48	156.80		
No. of records	57.98	50.14	7.84	1.96
	18.54	25.52		

[a] $P < 0.01$; [b] $p < 0.05$

year of the study, the major emphasis was placed on increasing aerobic capacity, and little upper body work was performed. During successive years, additional emphasis was placed on upper body strength by the use of light weights, elastic tubing, push-ups, and various dance routines stressing the upper body. Some endurance dance routines were designed to increase muscular strength by including weights on the wrists and/or ankles. Many warmup and cooldown activities used wrist bands of 1.1 lbs plus 3.3 lb dumbbells to increase upper body work. No strength measurements were determined on the participants. Throughout the study, aerobic activities accounted for 30 minutes of each class.

Statistical Analysis

Each individual's bone values were regressed vs. time (years), producing individual slope and intercept values for 18 bone variables (six measurement sites; BMC, W, and BMC/W at each site). Detailed inspection of values vs. time revealed a gradual degradation of edge detection in our SPA system between July 1980 and June 1981. This edge detection malfunction resulted in lowered readings of BMC and W. Therefore, three data points for the control group and four for the exercise group taken during this period were dropped from the final analysis. The equipment was repaired in the summer of 1981. These points had been used for the analysis in our earlier study [10]. The slopes using all 11 data points were compared with the slopes with these data points removed. While the slopes using the differing sets of data were significantly different, the between-group trend was the same in both cases. With all data points used, there was a greater difference between the control and exercise groups.

The difference in rates of change between control and exercise groups was analyzed by linear regression using an indicator variable (Z_1). Z_1 is 1 for the exercise group and 0 for the control group. The regression model used was

$$Y = \beta_0 + \beta_1 Z_1 + \epsilon$$

where Y is the predicted rate of change, β_0 is the rate of change for the control group, β_1 is the difference between rates of change of the control group and exercise group, and ϵ is the error term. Two-tailed t tests on the coefficient/standard deviation were used to determine significance.

For anthropometric characteristics and fitness, a two-tailed independent t test was used to compare 4-year participants with dropouts of the same group and control vs. exercise participants. A paired t test was used to analyze changes within groups over the 4 years.

Results

Only the 62 control and 80 exercise subjects who completed the 4-year study were included in the final data analysis. Initially, these 4-year participants did not differ in age, weight, or height, but the exercise participants were significantly less fit than the controls (Table 1). Menopausal status of the two groups were also similar: 44% of the exercise subjects and 48% of the control subjects were postmenopausal and the average number of years since menopause was 6 in each group; 34% of the exercise and 23% of the control subjects were premenopausal; 7% of exercise and 13% of control subjects ceased menstruation during the study. Fifteen percent of exercise subjects and 16% of control subjects had had hysterectomies prior to the natural cessation of menstruation, but had one or both ovaries intact, and their hormonal status is unknown.

Twenty-three control and 47 exercise subjects dropped out of the study. Reasons given for not continuing participation were scheduling problems/moved (14 exercise, 4 control); personal and family reasons (8 exercise, 1 control); medical reasons (17 exercise, 10 control); and unknown (8 exercise, 8 control). No subjects from either group were eliminated from the study because of rapid bone loss. Ten exercise subjects dropped out of the study because of chronic foot, knee, hip, or back

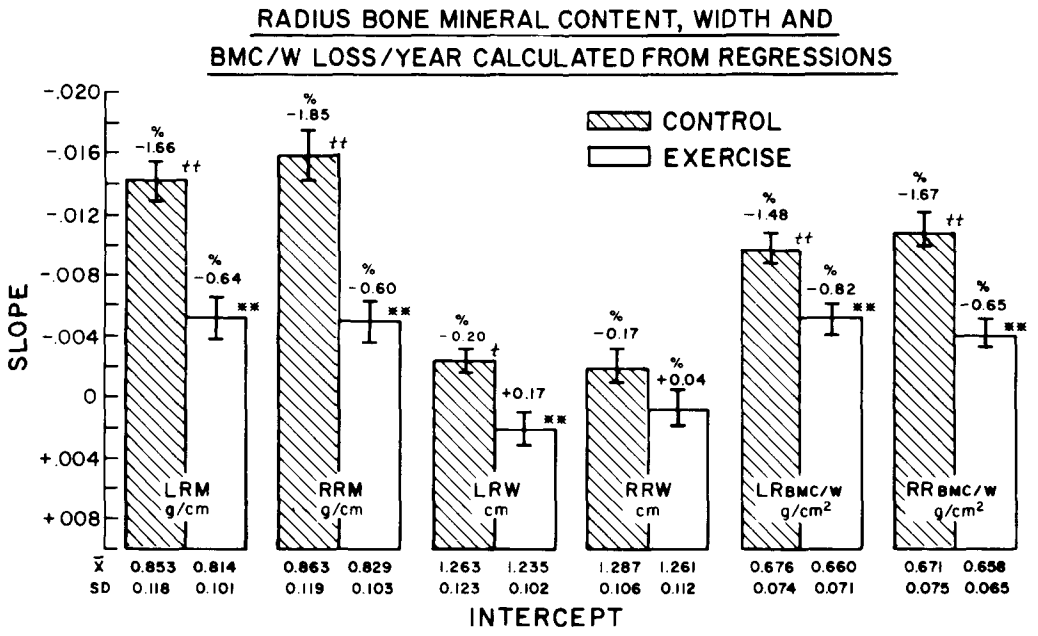

Fig. 2. Radius bone mineral content, width, and BMC/W loss/year calculated from regressions. LRM = left radius BMC (g/cm); RRM = right radius BMC; LRW = left radius W (cm); RRW = right radius W; LR BMC/W = left radius BMC/W (g/cm^2); RR BMC/W = right radius BMC/W. The data are expressed as mean slopes (±SEM). t ($P < 0.05$), tt ($P < 0.01$) control group slope significantly different from zero; * ($P < 0.05$), ** ($P < 0.01$) exercise group significantly different from control.

problems that were exacerbated by the exercise program or interfered with attendance. No subjects dropped out because of acute injury in the exercise program. The only significant difference between dropouts and those in the same group who remained in the study was that control dropouts were heavier than the controls who remained in the study (Table 1).

During the 4-year study, both groups decreased minimally in height, and the control group increased in weight. Fitness of the control group declined significantly whereas that of the exercise group increased significantly (Table 2). Usual dietary intakes of the two groups were not significantly different for 12 of the 15 nutrients measured. Exercise subjects consumed significantly more calcium, magnesium, and folacin than control subjects (Table 3). Exercise subjects were less compliant than control subjects in completing nutrition records, with 59 of the 62 control subjects returning records (averaging 58 of 72 requested) and 69 of 80 exercise subjects handing in records (averaging 50 of 72 requested). Exercise subjects attended an average of 74% of the exercise classes.

The slopes and intercepts for the radius, ulna, and humerus of each group are presented in Figs. 2–4. In the control group, BMC and BMC/W for all three bones declined significantly. Left radius and left humerus W also declined significantly in the control group. The exercise group lost significantly less BMC and BMC/W of the left and right radius and ulna, and W of the left radius and ulna ($P < 0.01$). Loss rates of left humerus BMC ($P < 0.05$) and W ($P < 0.01$) were also significantly decreased in the exercise group, with no significant differences from the control group in other humerus variables. Rates of change in the exercise group were positive only in ulna and radius W and left ulna BMC.

To determine whether the exercise response could have been due to differences in hormonal status, we analyzed the difference between groups for premenopausal and postmenopausal subjects separately. For each menopausal status, exercise subjects had significantly lower rates of loss for 10 of the 18 bone variables (Figs. 5–7). The direction and magnitude of the exercise effect was similar in premenopausal and postmenopausal subjects. Multiple regressions using indicator variables for exercise, postmenopausal status, and exercise times postmenopausal status showed that premenopausal and postmenopausal subjects did not differ significantly in exercise response. Compared with premenopausal controls, premenopausal exercise subjects lost significantly less left and right radius BMC, W, and BMC/W; left humerus BMC and W; and right ulna BMC and W. Rates of change in the premenopausal exercise group were nonsignificantly positive for six of eight radius and ulna BMC and BMC/W variables and all widths. Postmenopausal

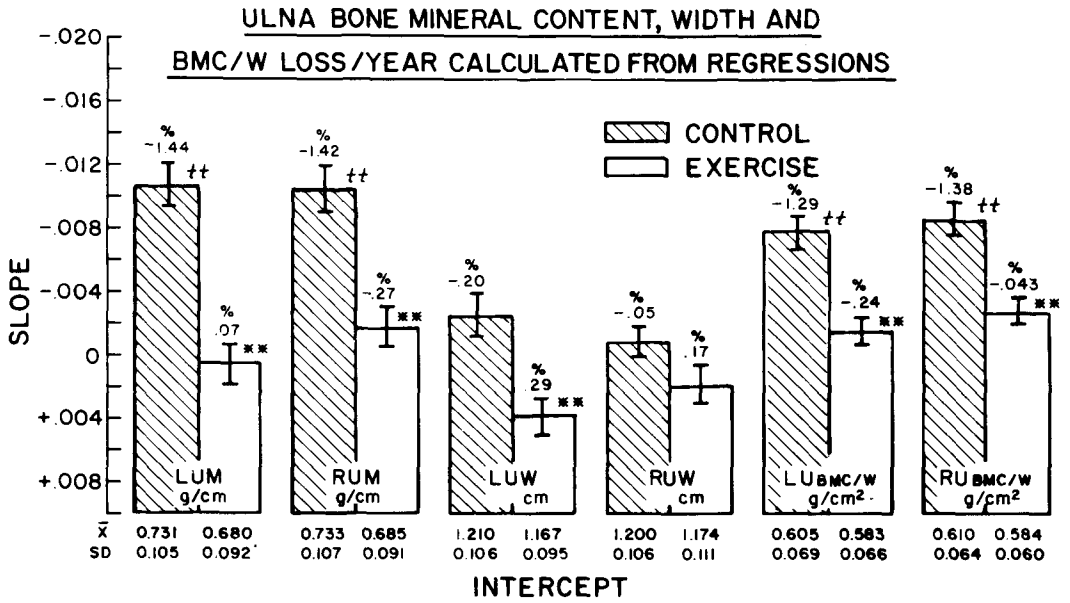

Fig. 3. Ulna bone mineral content, width, and BMC/W loss/year calculated from regressions. LUM = left ulna BMC (g/cm); RUM = right ulna BMC; LUW = left ulna W (cm); RUW = right ulna W; LU BMC/W = left ulna BMC/W (g/cm^2); RU BMC/W = right ulna BMC/W. The data are expressed as mean slopes (±SEM). t ($P < 0.05$), tt ($P < 0.01$) control group slope significantly different from zero; * ($P < 0.05$), ** ($P < 0.01$) exercise group significantly different from control.

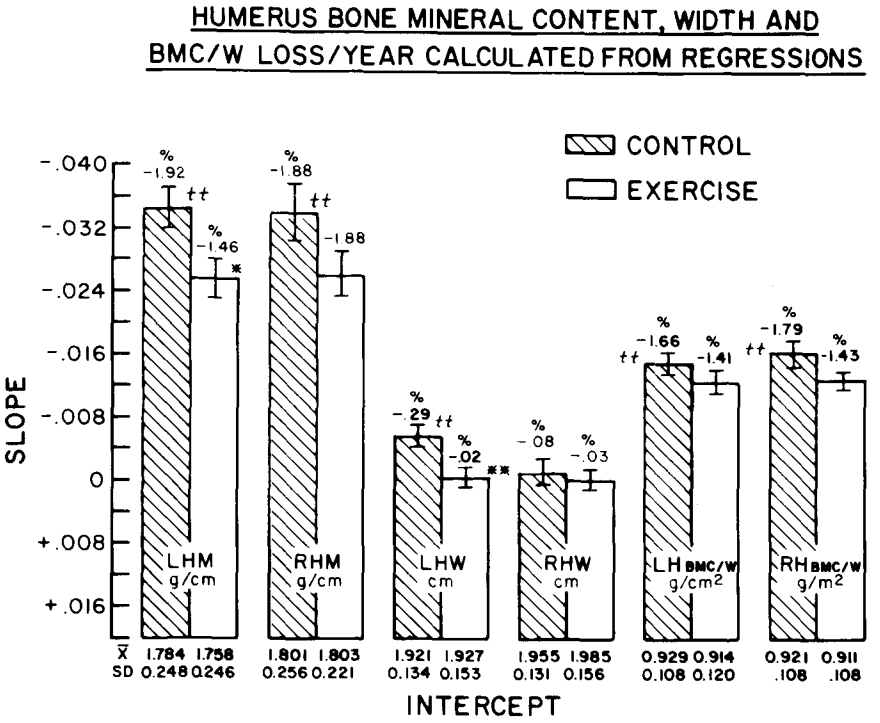

Fig. 4. Humerus bone mineral content, width, and BMC/W loss/year calculated from regressions. LHM = left humerus BMC (g/cm); RHM = right humerus BMC; LHW = left humerus W (cm); RHW = right humerus W; LH BMC/W = left humerus BMC/W (g/cm^2); RH BMC/W = right humerus BMC/W. The data are expressed as mean slopes (±SEM). t ($P < 0.05$), tt ($P < 0.01$) control group slope significantly different from zero; * ($P < 0.05$), ** ($P < 0.01$) exercise group significantly different from control.

exercise subjects lost significantly less left radius BMC and W; left ulna BMC, W, and BMC/W; left humerus BMC; right radius BMC and BMC/W; right ulna BMC/W; and right humerus BMC/W than postmenopausal controls.

Discussion

Study Design and Implementation

Healthy, nonpatient volunteers for longitudinal research best represent the general population for in-

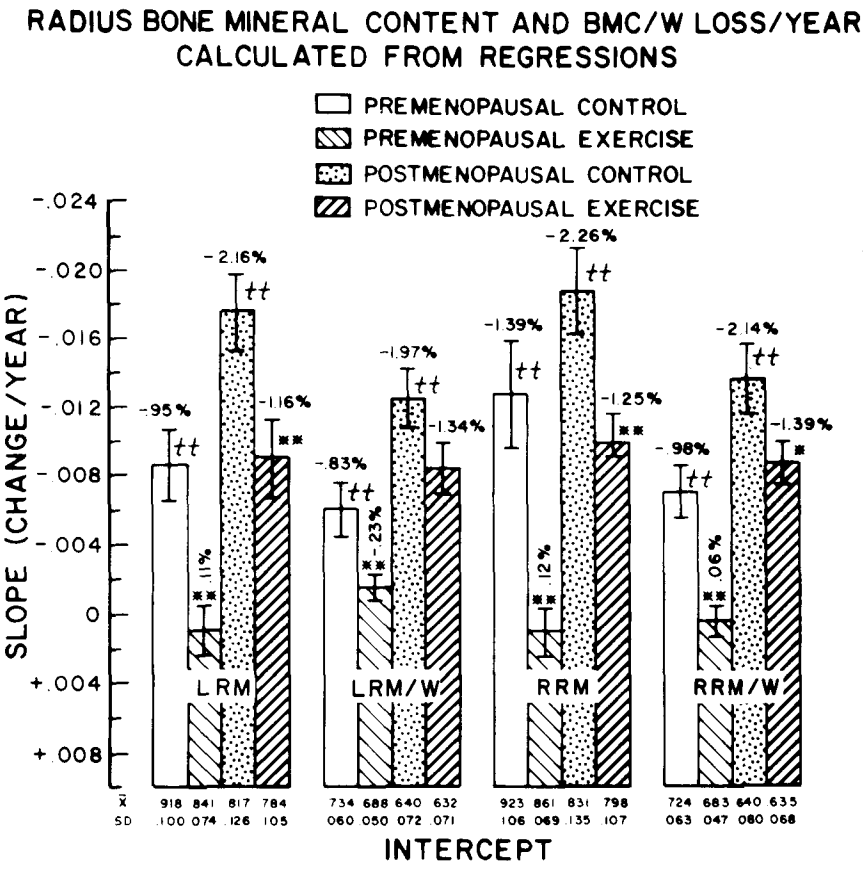

Fig. 5. Radius bone mineral content and BMC/W loss/year for premenopausal and postmenopausal subjects calculated from regressions. LRM = left radius BMC (g/cm); LRM/W = left radius BMC/W (g/cm^2); RRM = right radius BMC (g/cm); RRM/W = right radius BMC/W (g/cm^2). The data are expressed as mean slopes (±SEM). t ($P < 0.05$), tt ($P < 0.01$) control group slope significantly different from zero; * ($P < 0.05$), ** ($P < 0.01$) exercise group significantly different from control.

tervention studies, but some limits on research design are imposed by the nature of this subject population. In our experience, subjects who volunteer for a 4-year exercise program will not accept control group status. Therefore, it was not possible to randomly assign subjects to the two groups in this study. The lack of random design was partly countered by proportionally allocating each group into 5-year age intervals, and by the large study population. In anthropometric factors related to bone the two groups were very similar. At baseline, the two groups did not differ significantly in age, weight, or height, but the control group was slightly more fit than the exercise group (Table 1).

In 4 years, only 37% of the exercise subjects dropped out, compared with other exercise and bone research studies in which 28% of exercise subjects dropped out in 6 months [16] and 13% in 8 months [7]. Our high retention rate and class attendance of 74% was probably due to the quality of our exercise leaders, the convenience of class locations, and feedback given to subjects on results of yearly tests.

Another limitation of working with healthy, free-living volunteers is that subject diets cannot be controlled. Dietary records indicated that the exercise subjects consumed an average of 139 mg of calcium per day more than the control subjects (Table 3). To determine whether the higher calcium intake accounted for the difference in BMC, W, or BMC/W loss between groups, we regressed rate of change on calcium consumption in the control group. Calcium was a significant factor only for left radius BMC and right humerus BMC/W loss. Right humerus BMC/W change was not significantly different between groups. Based on the regression for left radius BMC, 139 mg/day greater calcium intake would account for 17% of the difference in bone loss between groups. The difference between exercise and control group loss was still significant if calcium intake was added as an independent variable in the regression. The 3-year average calcium intake for the exercise group was higher than previously reported for the first year [10]. Exercise subjects increased calcium intake over the course of the study, and some subjects with low intake did not report nutrition in years 3 and 4.

Three of the control group time points and four of the exercise time points were omitted in the final analysis, because these data were compromised by

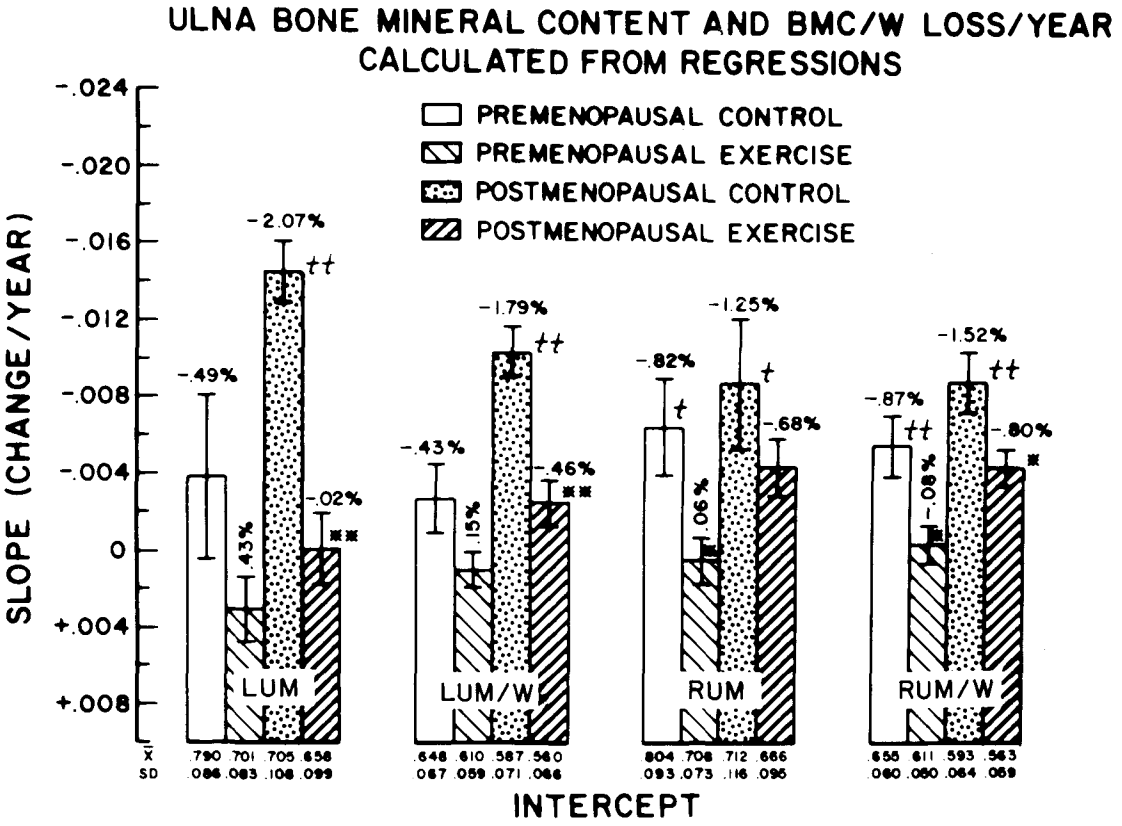

Fig. 6. Ulna bone mineral content and BMC/W loss/year for premenopausal and postmenopausal subjects calculated from regressions. LUM = left ulna BMC (g/cm); LUM/W = left ulna BMC/W (g/cm^2); RUM = right ulna BMC (g/cm); RUM/W = right ulna BMC/W (g/cm^2). The data are expressed as mean slopes (±SEM). t ($P < 0.05$), tt ($P < 0.01$) control group slope significantly different from zero; * ($P < 0.05$), ** ($P < 0.01$) exercise group significantly different from control.

equipment malfunction. Between July 1980 and June 1981, a progressive deterioration in edge detection lowered measured values of BMC and W. Slopes for this time period were approximately 0.01–0.05/year more negative than slopes on the remaining points ($P < 0.01$ for radius and ulna BMC and W). The edge detection decline was not immediately obvious as differences between contiguous scans were within the range of expected change plus system error. Measurements of the standards during this time period did not differ significantly from those in the remainder of the study, probably because the standards have a more distinct edge than do the human radius and ulna. Due to the large number of subjects and length of this project we do not feel that the overall study was compromised by the elimination of these points, and that loss rates of the groups determined by the remaining points were representative of actual loss rates.

In a previous paper [10] we reported on the first 3 years of this program. Because the points from July 1980 to June 1981 were included in the analysis, the exercise group appeared to lose significantly more than the control group in mineral and width during the first year. Overall, the control group loss rate with these points removed was less than that previously reported. Our previous conclusion that exercise reduces bone loss has not been changed. The proposal that bone might have been redistributed from the arms to weightbearing portions of the skeleton during the first year of the program is no longer supported by the reanalyzed data.

Comparison with Other Studies

Two other exercise intervention studies reported spine [7] and total body calcium [8] increases with exercise, but no significant differences between exercise and control groups in radius BMC. In both of these studies, performed on postmenopausal women, the exercise programs consisted primarily of weightbearing aerobic exercise and did not place much stress on the arms. On the other hand, White et al. [16] found that radius BMC responded in formerly sedentary postmenopausal women participat-

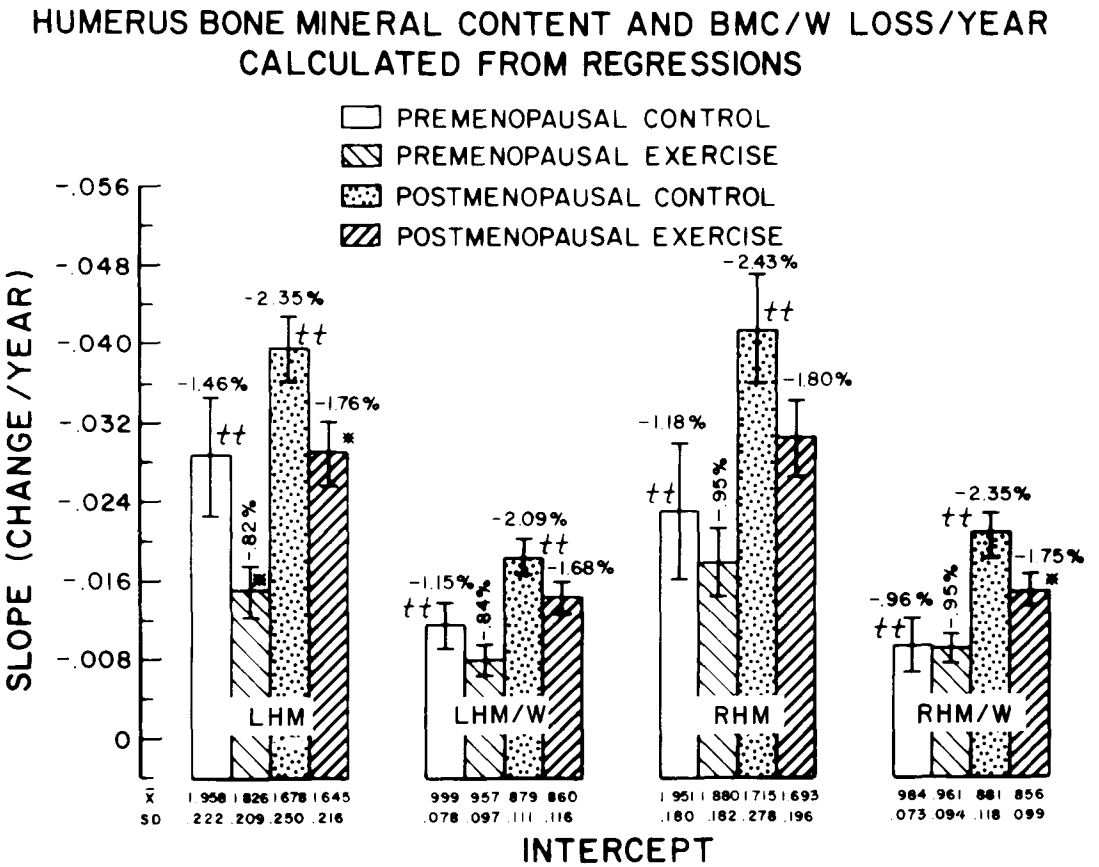

Fig. 7. Humerus bone mineral content and BMC/W loss/year for premenopausal and postmenopausal subjects calculated from regressions. LHM = left humerus BMC (g/cm); LHM/W = left humerus BMC/W (g/cm^2); RHM = right humerus BMC (g/cm); RHM/W = right humerus BMC/W (g/cm^2). The data are expressed as mean slopes (±SEM). t ($P < 0.05$), tt ($P < 0.01$) control group slope significantly different from zero; * ($P < 0.05$), ** ($P < 0.01$) exercise group significantly different from control.

ing in a 6-month aerobic dance program. Their subjects were divided into three groups: sedentary controls, walkers, and dancers. Initial BMC (0.81–0.83) and W (1.17–1.20) were similar but slightly lower than in our study (0.81–0.85 BMC, 1.24–1.26 W). Radius BMC declined in all three groups, but less in the dancers than controls. Projected loss per year in both their control subjects and dancers was greater than in our study (3.2 vs. 1.7% in controls, 1.6 vs. 0.6% in dancers/exercisers), but shows the same trend. Radius W increased in all three groups (1.8%/year in controls, 2.6%/year in dancers, 3.2%/year in walkers), whereas W changes in our study were minimal (−0.2%/year in controls and +0.2% in exercisers). White et al. also measured arm strength, which increased approximately 6% in the dancers and 3.5% (nonsignificant) in walkers. They stated that the increase in dancer's arm strength implies substantial loading of forearm bones during this form of exercise. Differences between White et al. and our results could be due to differences in population characteristics, and the shorter length and fewer measurements in White's study.

The evidence from our study and from the work of Krolner [7], Aloia [8], and White [16] indicates that exercise programs must be designed to stress the arm specifically if bone loss is to be reduced in the radius, ulna, and humerus. These studies indicate that the form of exercise may determine whether the weightbearing and/or nonweightbearing segments of the skeleton are stimulated.

Differences Between Left and Right Arms

Rate of change in W was significantly different between exercise and control groups in the left radius, ulna, and humerus but not in the right. Similarly, there was a significant difference between groups in the left humerus BMC but not in the right. These apparent differences between arms are due to minor differences in loss rates within groups, and are probably of little practical significance.

Summary and Conclusion

The greatest influence of the exercise program was on the ulna and radius. Lesser differences between exercise and control groups were seen in left humerus BMC and W, and differences between groups were not significant for other humerus loss rate variables. This may be due to the exercise program providing insufficient stress to the humerus. Width changed minimally in both the control and exercise groups.

Although the absolute difference between loss rates in exercise and control groups may seem small, projected over 20 years this may protect significantly against fractures. For example, based on the slopes we obtained, in 20 years left ulna BMC/W would decline 0.16 (about 25%) in the control group and only 0.03 (5%) in the exercise group. Physical activity is valuable in reducing arm bone loss in middle-aged women. The reduction of bone loss was evident in both estrogen-replete and estrogen-deplete women. In both premenopausal and postmenopausal women, bone loss was significantly reduced for 10 of 18 bone variables. The amount of reduction in loss was similar for exercising premenopausal and postmenopausal women. While some women are unwilling to exercise or have low compliance, physical activity offers a valuable alternative to hormonal replacement for the prevention of bone loss. Further research is necessary to investigate the effects of exercise on bone loss in the spine and hip, and on the specifics of exercise programming to reduce bone loss. Alternative programs for individuals with joint and mobility problems that inhibit participation in general aerobic exercise should be investigated.

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