Effects of Exercise Training on Bone Density in Older Men and Women

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Objectives: To determine the effects of up to 14 months of aerobic exercise on measures of bone density in older adults.
Design: Randomized controlled trial with subjects assigned to either an aerobic exercise condition, non-aerobic yoga, or a wait list non-exercise control group for 4 months. Aerobic fitness and bone density were evaluated in all subjects at baseline (Time 1) and after 4 months (Time 2). A semi-crossover design was utilized with all subjects completing 4 months of aerobic exercise, followed by another evaluation (Time 3). All subjects were then given the option of 6 additional months of aerobic exercise, after which they had a fourth evaluation (Time 4).
Setting: An outpatient exercise rehabilitation facility at a large, major medical center.
Subjects: One-hundred-one healthy men (n = 50) and women (n = 51) over age 60 (Mean age = 67.0), recruited from the community.
Intervention: The exercise program included stretching, cycle ergometry, and walking three times per week for 60 minutes throughout the course of the study.
Outcome Measures: Aerobic fitness ($\dot{V}O_2$max) as assessed by cycle ergometry, and bone density (bone mineral content) measured by single photon absorptiometry.
Results: Subjects achieved a 10%–15% increase in $\dot{V}O_2$max after 4 months of exercise training, and 1%–6% further improvement with additional training. Aerobic fitness was associated with significant increases in bone density in men, but not women, who maintained aerobic exercise for 14 months. **J Am Geriatr Soc 39:1065–1070, 1991**

Osteoporosis is a major health problem in the United States and is responsible for at least 1.2 million bone fractures annually. One-third of women over 65 will have vertebrae fractures, and one-sixth of men will have a hip fracture.[1] Three potentially modifiable risk factors include endogeneous sex hormone concentrations, intake of dietary calcium, and exercise or activity levels.

The use of physical exercise in the prevention of osteoporosis has received much attention recently.[2] A number of cross-sectional studies have examined the relationship of physical fitness and bone mass. It appears that highly trained individuals have greater bone density than non-exercising adults.[3–7] For example, Lane et al[5] demonstrated that 41 long distance runners had greater bone mineral content than a matched group of sedentary controls. Talmage[7] reported that highly active women had greater bone mass than sedentary women in a sample of over 1,200 subjects, and Jacobson et al[4] reported that older "athletic" women had significantly greater bone density than their sedentary counterparts. In a study of 18 older women (mean = 81 years), Smith et al[8] demonstrated greater bone mineral content in a group of women exercising regularly and receiving calcium supplements compared to sedentary controls. Other cross-sectional studies, however, have shown that exercise may not increase bone density when light or recreational exercise is considered,[2] suggesting that exercise intensity also may be an important variable. For example, Williams et al[9] showed that bone density for male marathoners was greater than for age-matched controls, whereas the bone density for less consistent runners was comparable to the control subjects. Cross-sectional studies also may be biased by self-selection; for example, exercise participants may be resistant to osteoporosis, and non-exercisers may choose not to exercise because of early osteoarthritis.

In addition to the issues of self-selection and exercise intensity, measurement of physical fitness has also been responsible for some of the inconsistencies in the results. For example, questionnaire methods,[10,11] movement sensors,[12] and estimates of aerobic capcity[13,14] show a relatively small correlation between exercise and bone density.

There also have been a number of longitudinal studies, with conflicting findings. Several studies have shown that exercise of relatively short duration does not appear to enhance radial bone mass,[15–19] although non-exercising comparison groups may show a decline in bone density.[18,19] On the other hand, other studies have been more encouraging.[9,19,20] However, there have been only two randomized clinical trials of aerobic exercise and bone density. One study[21] had mixed results, while the second study[22] found that both aerobic exercise and aerobic exercise combined with strength training increased bone mass. However, the subject sample in the second study consisted only of healthy women aged 50–62 years. The purpose of this report is to document changes in bone density among both men and women over age 60 who were participants in a longitudinal randomized clinical trial of exercise training.

METHOD

The Duke Aging and Exercise Study was conducted between 1985–1987. Results from the first 4 months have been published,[23] and the cardiovascular, lipid,

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and psychological effects of up to 14 months of exercise training also have been reported.[24,25] Although the details of subject selection and experimental design have been described in the earlier report,[23] the study design will be briefly reviewed. One hundred and one healthy elderly (Mean = 67.0 yrs; range 60–83) men (n = 50; mean age 66.4 yrs) and women (n = 51; mean age 67.7 yrs) were randomly assigned to an Aerobic exercise (AE) group (n = 33), a Yoga and flexibility (YO) group (n = 34), or a Waiting list (WL) control group (n = 34) following the completion of an extensive psychological and physiological assessment battery. Twelve women (5 AE, 2 YO, 5 WL) received hormone replacement therapy, and two women (no men) reported taking calcium supplements. No subjects were taking cardiac or psychiatric medications, however. All subjects were relatively sedentary and did not engage in regular exercise prior to enrollment in the study. The men were an average 1.8 meters ± .07 tall and weighed 80.6 ± 9.6 kg. The women were 1.6 ± .07 meters tall and 63.8 ± 10.6 kg.

Subjects in the AE group attended three supervised exercise sessions per week for 16 consecutive weeks. Based on maximum heart rate achieved during the bicycle exercise test, subjects were assigned six-beat training ranges equivalent to 70% maximum heart rate reserve ((HR max − HR rest) .7 + HR rest). Each aerobic exercise session began with a 10-minute warm-up exercise period followed by 30 minutes of continuous bicycle ergometry at an intensity that would maintain HR within the assigned training range. The subjects then engaged in brisk walking/jogging and arm ergometry for 15 minutes. The exercise session was concluded with 5 minutes of cool-down exercises. Heart rates were monitored via radial pulses and were recorded, along with ratings of perceived exertion,[26] three times during each exercise session.

Subjects in the YO group participated in 60 minutes of non-aerobic yoga exercises at least two times per week for 16 weeks. The supervised yoga classes provided a control for the effects of social stimulation and attention from trainers without providing an aerobic training stimulus.

Subjects randomized to the WL control group did not receive any form of treatment between Time 1 and Time 2 evaluations. They were instructed not to change their physical activity habits and specifically not to engage in any aerobic exercise for the 4-month period. Subjects in all three groups were told to maintain their regular dietary habits until completion of the study. No suggestions for dietary modification were offered to any subjects. After 4 months, subjects participated in 4 months of aerobic exercise following the protocol described above and underwent a third (Time 3) assessment. Following this assessment, subjects were given the option of participating in 6 additional months of supervised aerobic exercise, and subjects (regardless of their exercise status) underwent an assessment at Time 4. Thus, participants underwent evaluations prior to the beginning of the exercise program (Time 1), after 4 months (Time 2), after 8 months (Time 3), and after 14 months (Time 4).

Aerobic Fitness In order to measure aerobic fitness, subjects underwent cycle ergometry testing. Each subject performed a maximum effort exercise test following an initial practice test on a Fitron cycle ergometer (#F1000750, Cybex Lumex Inc.). The graded exercise protocol consisted of 3-minute stages starting at 150 kpm and increasing by 150 kpm at each successive stage. Subjects maintained a pedalling rate of 60 rpm. Subjects exercised until exhaustion. A 12-lead EKG (Hewlett Packard, #1517A) was employed to provide continuous electrocardiographic monitoring. Heart rates were recorded every minute. Blood pressure was measured by cuff sphygmomanometry at 3-minute intervals. Respiratory and oxygen consumption measurements were obtained using a System 4400 metabolic system (Alpha Technologies, Inc., Laguna Hills, CA). Fitness was assessed by peak VO_2, total exercise time on the bicycle, and heart rate at a submaximal (300 kpm) workload.

Bone Density Bone density, measured by single photon absorptiometry with I-125, was performed using a Bone Densitometer (Norland Corporation, Fort Atkinson, WI). Each subject was seated in front of the scanner and positioned comfortably. A 1-inch roll of tape was placed under the fifth digit to position the arm in a slight pronation (1–10°). A tissue equivalent bag was placed over their distal radius and ulna. A limb holder bar was placed over the tissue equivalent bag just proximal to the styloid process of the ulna. A prescan was performed to determine the position at which the radius and ulna were separated by 5 mm. This positioning technique was repeated for each study. The examiner was unaware of subjects group assignments and exercise status. Bone density measures (mg/cm^2) were obtained from the distal radius of the nondominant arm.

Statistical Analysis A 3 (Group) × 2 (Sex) × 2 (Time) repeated measures analysis of variance (ANOVA) was the initial method of data analysis. Between Times 1–2, and 2–3, Group and Sex served as between subject factors, and Time served as a within subject factor. Because there were significant differences between men and women in aerobic capacity and bone density, follow-up analyses were performed for men and women separately. We performed a series of analyses of covariance (ANCOVA), with initial baseline (Time 1) bone density values, age, and body mass index (BMI) serving as the covariates. For the comparison at Time 4 (the 6-month extension), subjects were grouped according to status (whether or not they participated in the extended 6-month supervised aerobic exercise program) rather than by their initial group assignment. In order to assess the effects of exercise in this clinical trial, we employed the "intention to treat" principle, ie, we performed serial assessments on all subjects regardless of the level of adherence. However, adherence was considered in comparisons of Times 1–4 and 3–4 when exercise status was used as a variable.

RESULTS

Compliance The results of the exercise intervention on cardiorespiratory function have been described

TABLE 1. ADHERENCE TO THE STUDY

	4 Months			8 Months			14 Months		
	Time 1–Time 2 Group			Time 2–Time 3 Group			Time 3–Time 4 Group		
	AE	YO	WL	AE	YO	WL	AE	YO	WL
Mean number of sessions attended (±SD)	46 (2)	32 (3)		44 (3)	45 (2)	44 (3)	52 (16)	56 (7)	53 (1)
% of time in training range	88			85	70	75	81	59	82
RPE (mean ± SD)	13.5 (1.8)			13.0 (2.2)	13.9 (1.8)	13.5 (2.3)	13.1 (1.9)	14.3 (2.5)	13.5 (3.1)
Change in body weight (kg)	.5 ± 1.7	.6 ± 2.7	.3 ± 1.7	−.1 ± 1.7	1.1 ± 2.0	.7 ± 2.0	.2 ± 1.7	−.8 ± 1.7	−.2 ± 1.6
Dropouts	2	0	2	3	3	1	0	0	1*
n	33	34	34	31	34	32	23	12	15

Note: AE = Aerobic, YO = Yoga, WL = Waiting list.
** 49 subjects (out of 50) completed the aerobic exercise program at Time 4, but 84 of the original cohort of 101 subjects returned for follow-up evaluation. Portions of this table have been reported elsewhere.[24]*
RPE = ratings of perceived exertion.

in detail elsewhere[24] and will be only briefly summarized for this report. Ninety-seven of the original 101 subjects completed their assessments at Time 2. Subjects in the aerobic group exercise for an average of 46 sessions (out of a possible 48) during which they were within their prescribed training ranges 88% of the time. All subjects participated in aerobic exercise between Times 2 and 3 and averaged 44 sessions maintaining their heart rates within the prescribed training range at least 70% of the time. Seven subjects dropped out before completing their Time 3 assessments for an overall 8-month dropout rate of 11%. Fifty subjects participated in an additional 6 months of aerobic exercise, of whom 49 (98%) completed the 6-month extended exercise program. Eighty-four subjects (50 of whom continued with the 6-month extension) returned for a Time 4 assessment, for an overall follow-up rate at 14 months of 84% (Table 1). Subjects reported that they maintained their usual diets and lost a minimal amount of weight during the study (< 1.5 kg).

Aerobic Fitness A series of repeated measures ANOVAs were performed for peak $\dot{V}O_2$ between Times 1–2, 2–3, and 3–4. For peak $\dot{V}O_2$ between Time 1–2 there were significant main effects for group ($P < 0.04$), sex ($P < 0.0001$), and time ($P < 0.0001$), and significant interactions of Group × Time ($P < 0.0001$) and Sex × Time ($P < 0.02$). The sex main effect was due to the men being relatively more fit (M = 22.2 ± 4.4 mL/kg/min) than the women (M = 16.0 ± 2.2 mL/kg/min). Examination of the Group × Time interactions indicated that the AE group achieved an average 11.6% improvement in peak $\dot{V}O_2$, ($P < 0.001$). There was no change in aerobic fitness for the YO and WL groups. Table 2 displays the peak $\dot{V}O_2$ data for men and women.

Because all subjects participated in aerobic exercise between Times 2 and 3, the repeated measures ANOVA for the Time 2–3 data assessed the effects of an additional 4 months of aerobic exercise for the AE group and of an initial 4 months of aerobic exercise for the YO and WL control groups. Significant Group × Time effects were observed for peak $\dot{V}O_2$ ($P < 0.003$). The YO and WL groups significantly increased their aerobic fitness, while the AE group merely maintained their previous improvements from Time 1–2. Examination of the mean change in peak $\dot{V}O_2$ from Time 2–

TABLE 2. MEAN VALUES (±SD) OF PEAK $\dot{V}O_2$ (ml/kg/min) FOR MEN AND WOMEN BY GROUP AND EXERCISE STATUS

	Males	Females	All
Time 1			
AE	22.8 (4.8) (n = 17)	15.7 (2.6) (n = 15)	19.5 (5.2) (n = 32)
YO	21.9 (3.9) (n = 17)	15.8 (2.7) (n = 17)	18.8 (4.5) (n = 34)
WL	20.5 (3.7) (n = 16)	16.7 (3.2) (n = 18)	18.4 (3.9) (n = 34)
Time 2			
AE	25.6 (4.8) (n = 16)	16.9 (2.4) (n = 15)	21.4 (5.8) (n = 31)
YO	21.9 (4.2) (n = 16)	15.6 (2.9) (n = 16)	18.7 (4.8) (n = 32)
WL	20.8 (3.7) (n = 15)	15.1 (2.4) (n = 15)	17.9 (4.2) (n = 30)
Time 3			
AE	26.2 (4.9) (n = 14)	16.9 (2.2) (n = 14)	21.6 (6.0) (n = 28)
YO	22.8 (5.1) (n = 15)	17.0 (2.6) (n = 16)	19.8 (4.9) (n = 31)
WL	24.1 (4.1) (n = 14)	17.3 (3.4) (n = 17)	20.4 (5.1) (n = 31)
Time 4			
Discontinued	22.1 (4.9) (n = 16)	17.7 (3.1) (n = 17)	19.9 (4.6) (n = 33)
Continued	26.4 (4.5) (n = 23)	17.4 (2.8) (n = 22)	22.0 (5.9) (n = 45)

Note: One subject was missing $\dot{V}O_2$ data at Time 1 (baseline); three subjects were missing $\dot{V}O_2$ data at Time 2 (4 months); and six subjects were missing $\dot{V}O_2$ data at Time 4 (14 months).

3 revealed that the YO group achieved a 10.5% improvement, and the WL group achieved an average improvement of 15.0%, relative to Time 2.

Because not all subjects elected to continue with 6 months of supervised aerobic exercise, the variable exercise status was substituted for group in the ANOVA as a between-subjects variable between Times 3 and 4, ie, the 50 subjects who elected to continue in the program for 6 additional months were compared to the 34 subjects who discontinued. There was a significant sex effect, ($P < 0.0001$), which reflects the consistent advantage in aerobic capacity for men throughout the duration of the study. Men achieved higher peak $\dot{V}O_2$ than women (25.0 ± 8.2 vs 17.3 ± 2.8 ml/kg/min). When men and women were considered separately in an ANOVA (with initial peak $\dot{V}O_2$ as the covariate), men who continued in the program had greater peak $\dot{V}O_2$ than men who discontinued ($P < 0.006$). However, the status effect for women was not significant at Time 4.

Bone Density Changes in bone density were evaluated between Times 1–2, 2–3, and 3–4. Between Times 1 and 2, only a significant sex main effect was obtained, ($P < 0.0001$). Similarly, sex main effects were found between Times 2 and 3, ($P < 0.0002$) and between Times 3 and 4, ($P < 0.0002$). Men consistently had higher bone mineral content ($1.1 \pm .2$ mg/cm^2) than women ($.8 \pm .2$ mg/cm^2). Because of the sex differences in bone density, men and women were considered separately in subsequent analyses. Between Time 2 and 3, there also was a significant time main effect, with subjects in the three groups (all of whom were exercising) experiencing an increase in bone density ($.90 \pm .26$ to $.95 \pm .28$ mg/cm^2, $P < 0.0009$).

Because there may have been initial differences in bone density among participants, a series of 1-way ANCOVAs were performed with Time 1 bone density values and BMI as covariates. At Time 2 and Time 3, there were no group differences for either men or women. At Time 4, however, when exercise status was considered as an independent variable, there was a significant status effect for men ($P < 0.05$), but not for women. Men who continued in the program had greater bone density (1.4 ± 0.4 mg/cm^2) than men who discontinued the program (1.0 ± 0.3 mg/cm^2). However, there was no difference for the women who continued to exercise (0.7 ± 0.3 mg/cm^2) compared to the women who dropped out (0.9 ± 0.2 mg/cm^2) (P = ns). Table 3 displays the mean bone density values by exercise status over time.

A set of partial correlational analyses, partialling out BMI at Time 4, revealed similar findings. The correlation of the percent change in peak $\dot{V}O_2$ and percent change in bone density from Times 1–4 was significant for the entire cohort ($r = 0.24$, $P < 0.05$). In addition, separate correlations for men and women indicated the correlation was greater for men ($r = 0.35$, $P < 0.05$) than for women ($r = 0.12$, $P = 0.49$).

In order to examine the maximal effects of the exercise program, we contrasted subjects who were originally in the AE group and who continued in the program for the full 14 months with subjects who were initially in the WL group and elected not to continue in the program (Table 3). Once again, men and women were considered separately. Results of the ANCOVA (with bone density at Time 1 and BMI as covariates) revealed a significant effect for men ($P < 0.005$) but not for women. Male subjects in the AE group who continued to exercise for 14 months showed an increase in bone density from $1.1 \pm .2$ at Time 1 to 1.4 ± 0.2 mg/cm^2 at Time 4. In contrast, men who were initially in the WL group and did not continue with exercise from Time 3–4 actually decreased from 1.1 ± 0.1 to 0.7 ± 0.2 mg/cm^2.

DISCUSSION

The results of this study demonstrate that a 14-month program of regular aerobic exercise is associated with increased bone density for men, but not for women. Men who were randomly assigned to the

TABLE 3. MEAN VALUES (±SD) OF BONE DENSITY (mg/cm^2 × 10^{-3}) FOR MEN AND WOMEN BY EXERCISE STATUS

	Males		Females		All	
	Discontinued	Continued	Discontinued	Continued	Discontinued	Continued
Baseline						
Mean	1.10	1.14	0.77	0.66	0.93	0.90
Standard Deviation	(0.22)	(0.18)	(0.17)	(0.19)	(0.25)	(0.30)
n	25	25	26	25	51	50
Eight Months						
Mean	1.06	1.23	0.79	0.71	0.91	0.97
Standard Deviation	(0.18)	(0.21)	(0.14)	(0.19)	(0.21)	(0.33)
n	18	25	22	25	40	50
Fourteen Months						
Mean	1.04	1.35	0.89	0.73	0.96	1.03
Standard Deviation	(0.30)	(0.41)	(0.19)	(0.25)	(0.25)	(0.46)
n	17	23	18	24	35	47

Note: Two subjects were missing bone density data at Time 4 (14 months).

aerobic exercise condition and who continued to exercise for 14 months increased their bone density by 19%. In contrast, men who initially were assigned to the waiting list group for the first 4 months, who then exercised (between Times 2 and 3), but who then elected not to participate in the 6-month extended exercise program showed a decrease in bone density between Times 1 and 4. Our longitudinal data appear consistent with data from cross-sectional studies that have documented greater bone density among athletes or more active individuals relative to their more sedentary counterparts[3–7] as well as with several nonrandomized longitudinal studies.[8,9,19,27]

The present study improved on several methodological limitations of previous research.[28] This was a randomized, longitudinal design in which a relatively large number of both men and women participated in up to 14 months of aerobic exercise under medical supervision. Bone density determinations were obtained at baseline and at regular intervals in a blinded fashion using a valid and reliable measure of bone density at a site (the distal radius of the non-dominant arm) that has been demonstrated to contain 50% trabecular bone.[29] However, it should be noted that our study is also limited by the relatively small number of subjects who continued to exercise for the full 14 months and by the potential bias of selective attrition; ie, although 84 subjects were assessed at Time 4, only 49 subjects continued to exercise for the extra 6 months, and only 23 exercised for the full 14 months (AE group and status continued). In addition, it has been argued that the neutron activation procedure is more reliable than bone density measures,[22] and indeed while single photon absorptiometry is widely considered a valid measure of bone density, newer techniques may be preferable.[30] Moreover, measurements at the appendicular skeleton cannot substitute for direct vertebral measurements.[1] Nevertheless, single-photon absorptiometry for measurements of the radius and dual-photon absorptiometry for measurements of the lumbar spine have been shown to be significantly correlated in asymptomatic subjects, and the single-photon technique also is predictive of risk for hip fracture.[31]

There have been only two other randomized prospective studies of exercise and bone density, and only one of these[22] yielded clear benefits of exercise. Chow et al[22] compared the effects of two structured exercise programs on the bone mass of 48 healthy postmenopausal women. Women were randomized to aerobic exercise, aerobic exercise and weight training, or a nonexercise control group. Forty-eight subjects (out of 68) completed the 1-year program. Subjects who participated in both exercise groups increased their aerobic capacity by 20%–30%, and achieved a 3%–7% increase in bone density determined by neutron activation analysis. In the present study, subjects who participated in the aerobic exercise group for the full 14 months achieved an 18% improvement in aerobic power, and the men increased their bone density by 15%. Differences in bone density values among studies may be a function of different techniques for measuring bone density. In addition, we observed greater effects for men than for women; Chow et al studied only women.

It has been suggested that exercise provides an osteogenic stimulus to bone, resulting in an increase in bone density. Although the mechanisms for this effect are not known, bone density may be affected by weight-bearing aerobic exercises and by forces generated by muscle contraction. Subjects in our study combined cycle ergometry, walking, and arm ergometry for 60 minutes, three times per week. We observed a significant correlation between the magnitude of improved aerobic power and increased bone density. Increases in bone density may have been greater if exercise intensity was further increased (our subjects maintained their heart rates at 70% of their maximum heart rate reserve; Chow et al,[22] for example, had subjects exercise to 80%). In addition, an exercise program involving greater use of arm ergometry or both weight training and aerobic exercise may also have proven more effective. Although data from Chow et al found that supplemental muscle strengthening exercises had no significant impact on bone mass, the exercise program was not sufficiently intensive, and the limited number of subjects (15–17 per group) may not have provided sufficient statistical power to detect group differences.

In summary, the present data demonstrate that a program of aerobic exercise for up to 14 months resulted in significant improvements in aerobic capacity and, for men, increased bone density. In terms of peak $\dot{V}O_2$, it would appear that most of the improvements in aerobic capacity occur within the first 4 months. Continued exercise training, however, was associated with further, albeit modest, improvements. The subgroup of male aerobic group subjects who exercised for 14 months achieved a 13% increase in peak $\dot{V}O_2$ at 4 months and an 18% increase at 14 months. Moreover, the men who maintained the exercise for 14 months achieved a 19% increase in bone density. These results are from a large randomized clinical trial of exercise training in older men and women with a follow up of 14 months. Unlike previous studies that reported data on only a select athletically inclined group of individuals, the present data appear to be representative of the changes that can be expected in relatively sedentary older adults. Although the clinical significance of these results awaits further study, it appears that regular exercise may not only reduce risk for future cardiovascular events but, for men, may also reduce risk for musculoskeletal complications associated with advancing age.

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