Calcif Tissue Int (1987) 40:59–63

Calcified Tissue International

Clinical Investigation

Increased Trabecular Bone Density Due to Bone-Loading Exercises in Postmenopausal Osteoporotic Women

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Summary. A program of diverse and dynamic loading exercises of the distal forearm, a common site of osteoporotic fractures, was applied three times a week for 5 months to 14 postmenopausal osteoporotic women. Two parameters were used to assess the effect of the exercises on bone mass. The mass density of bone (g/cm^3) was measured by the Compton scattering technique. The bone mineral content (g/cm^2) was measured by single photon absorptiometry. Both measurements were taken at the same location in the distal radius 1 year prior to the exercise period, at its beginning, and at its end, in both the exercised group and a matched control group of 26 osteoporotic women. During the exercise period the mean bone density decreased by 1.9% in the control group whereas it increased by 3.8% in the exercise group. The bone mineral content results did not demonstrate any significant trend over the whole period of the study. It is concluded that the trabecular bone tissue in the distal radius of postmenopausal osteoporotic women responds favorably to dynamic and diverse bone stressing exercises even in the seventh decade of life.

Key words: Bone density — Bone mineral content — Loading exercises — Osteoporosis.

The diminution of bone tissue in postmenopausal osteoporosis results in many of the fractures sustained by the elderly population. Fractures associated with osteoporosis are considered among the main causes of morbidity and disability in old age. Among these, fractures of the distal forearm are the most common [1].

Various medication regimes have been attempted to prevent or cure osteoporosis; their efficacy, however, has so far been inconclusive [2]. One approach to treating osteoporosis, which has received growing attention in the last decade, is through physical activity [3, 4]. It has long been known that bone atrophy is caused by bedrest and may be reversed when activity is resumed [5, 6]. On the other hand, bone hypertrophy has developed in individuals who were engaged in a high level of physical activity [7, 8]. The higher bone mass developed by such individuals persisted also in advanced age [9, 10].

These observations led to several controlled animal studies in which the dependence of bone remodeling on the mechanical loading of bones was demonstrated [11, 12]. According to these studies bone production is best affected by dynamic and repetitive mechanical loading. Loads causing high strain rates, within physiological limits, and a diverse strain regime were found most beneficial.

In this study, a set of physical exercises was planned specifically according to these principles to load the distal forearm. This site was chosen because of its high susceptibility to osteoporotic fractures. The distal radius consists mostly of trabecular bone with a rapid metabolic turnover. Therefore this tissue is expected to respond relatively early to changes in the load level exerted on the bone.

The purpose of the present study was twofold. First, to test the applicability of this exercise re-

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Table 1. Mean and standard deviation of age, height, weight, and years since menopause for the exercise group and the matched control group

	Exercise group n = 14	Control group n = 26	P^a
Age (years)	63.1 ± 7.0	62.5 ± 5.5	0.866
Height (cm)	153.3 ± 7.4	152.3 ± 4.8	0.640
Weight (kg)	60.5 ± 7.7	61.4 ± 9.8	0.747
Years since menopause	13.7 ± 6.7	15.5 ± 7.8	0.544

[a] Significance of difference, *t* test

gime in postmenopausal osteoporotic women, and secondly, to examine the effect of the bone-loading exercises on the bone mass of these women.

Material and Methods

Forty women who were under an epidemiological observation in the Jerusalem Osteoporosis Center took part in this study. All of them showed some morphological changes in the lumbar vertebrae, classifying them as osteoporotic according to the criteria of Smith and Rizek [13].

A group of 14 women aged 53–74 years participated in the specifically planned exercise program for 5 months. Twenty-six women, group-matched for age, weight, and height (Table 1) served as a control group. Cardiac, orthopedic, neurological, and cancer patients were excluded from the study. The women in both groups had been physically nonactive prior to the study.

The physical exercise program consisted of three weekly sessions of 45–50 minutes. The exercise attendance was registered for all participants and was found to be 73%. In each session bone-loading exercises were performed for 15 minutes. These exercises have been designed for the distal radius and ulna, taking into account that the diversity of strain is as important for bone remodeling as the strain rate and level. The diversity was achieved by loading the forearm in several modes: tension, compression, torsion, and bending in various planes. Loads were applied only by muscle activity and body weight in exercises such as hanging from a ladder (tension), pulling and twisting hands against a partner (tension and torsion), pushing against a wall (compression), and arm wrestling (bending). The subjects were asked to exert these loads quite rapidly so that the load rates would be high, but within physiological limits, considering the age of the subjects. The rest of the session included activities involving the whole body: warming-up, stretching, flexibility and strength exercises, and relaxation.

The bone mineral content (BMC) at the distal radius was measured by single photon absorptiometry in the nondominant arm, 3 cms proximal to the styloid process. This method of measuring BMC consists of passing a collimated beam of photons (27 KeV from I-125) through the bone and monitoring the resulting attenuation by means of a scintillation counter. A commercial bone mineral analyzer (Norland Instruments, Model 178) was used to measure the total mineral content per unit length of bone being scanned. Dividing the result by the width of the bone at the scanned level, given by the apparatus as well, yielded the BMC per unit area of bone (g/cm^2). The precision of our BMC results at the distal radius was 3.3% without repositioning of the forearm and 10.2% with its repositioning.

Photon absorptiometry examines the entire cross-section of the bone at the level being scanned, and does not discriminate between trabecular and cortical layers. The early bone loss in osteoporosis occurs mainly in the trabecular bone due to its rapid metabolic turnover [14]. Therefore, methods capable of measuring trabecular bone exclusively may be advantageous for detecting small changes in bone status. One such method, based upon the measurement of scattered radiation from a small volume of bone, was developed in our laboratory [15]. The device consists of a radiation source (Cs-137) which emits a collimated beam of photons (662 KeV), and a scintillation counter which measures the intensity of the radiation scattered by the Compton effect at a 90° angle. This device measures the overall mass density (g/cm^3) of bone, accounting for the minerals, collagen, water, and fat included in the volume (of about 0.25 cm^3) being examined. This mass density should not be confused with the "optical density" of X-ray film nor with the occasionally misused term "density" for the mineral content (mass per area) of bone in g/cm^2 [10, 17]. The measured volume can be confined to bone regions composed of trabecular tissue. The trabecular bone density was determined in the distal radius at the same level that the BMC was measured. The accuracy and precision of the Compton scattering method at this site are both better than 2% [15, 16].

All subjects were examined a year prior to the exercise period, at its beginning, and at its end.

Results

Table 2 shows the results of the bone density at the distal radius in the exercise and control groups. The mean values for each group are presented 1 year prior to the exercise period (PAST), at its beginning (PRE), and at the end (POST). During the year preceding the exercise program, the mean bone density decreased significantly (paired *t* test, $P < 0.02$) in both groups. The decrease was 2.8% in the control group and 2.0% in the exercise group. During the exercise period the mean density of the control group continued to decrease by 1.9% ($P < 0.02$) whereas that of the exercise group increased by 3.8% ($P < 0.01$). Although the exercise group started off with a lower mean bone density, at the end of the exercise program its density was slightly higher than that of the control group. The percentage changes of the mean bone density values in both groups and the standard errors are presented in Figure 1.

Table 3 shows the mean values of the BMC in both groups. The results did not demonstrate any significant trend over the whole period of the study in either group. The percentage changes of the mean BMC values and the standard errors are presented in Figure 2.

Table 2. Mean bone density (B.D.) and standard deviation for the two groups 1 year prior to the study (Past), at the beginning of the exercise program (Pre), and at its end (Post)

	Exercise group n = 14		Control group n = 26	
	B.D. (g/cm³)	Difference (%)[a]	B.D. (g/cm³)	Difference (%)[a]
Past	1.109 ± 0.037		1.162 ± 0.072	
		−2.0% ($P < 0.02$)		−2.8% ($P < 0.02$)
Pre	1.087 ± 0.048		1.129 ± 0.048	
		+3.8% ($P < 0.01$)		−1.9% ($P < 0.02$)
Post	1.128 ± 0.049		1.108 ± 0.043	

[a] The P value is the significance level of the difference (paired t test)

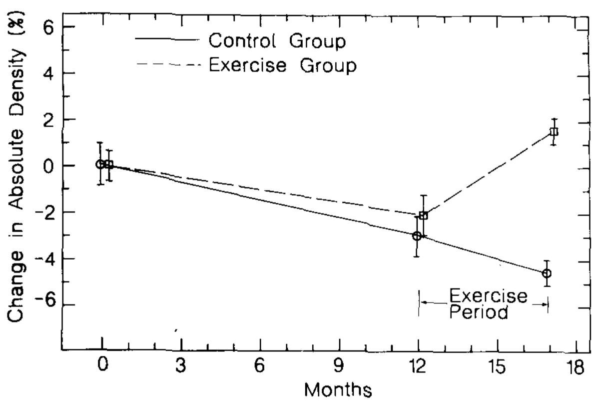

Fig. 1. Percentage changes of the mean bone density in the exercise and control groups 1 year prior to the exercise period, at its beginning, and at its end.

Discussion

In this study, a group of postmenopausal osteoporotic women participated in a program of controlled physical activity planned specifically to load the bones of the forearm. Following 5 months of three weekly sessions, a significant increase in the bone density of the distal radius was observed. No significant changes were found in the mineral content at the same site.

Several studies have been carried out in an attempt to increase, by physical activity, the bone mass of aging women. It is difficult to properly compare the results of these studies because they relate to different age groups, exercise regimes, and sites of bone measurement. Aloia et al. [18] found no changes in the BMC values of the radial diaphysis following exercise, and Krolner et al. [19] concluded that the BMC in the distal radius was independent of the exercise program. However, neither Aloia, who used mild exercises for general physical fitness nor Krolner, who used a somewhat more vigorous activity, focused on training the forearm specifically. Smith et al. [20, 21] observed diverse results for the BMC at the radial diaphysis, depending on the type of exercise. In a group of elderly women (69–95 years) who participated in a program of light physical activity for 3 years, they found a slight increase of BMC. In a group of relatively young women (35–36 years), a slight increase of BMC was found after 2 years of exercises designed to stress the upper body. The increase of BMC observed in these studies was significant only in comparison to the control group whose BMC decreased during the same period. In the younger group, 1 year of general aerobic activity caused a significant reduction of BMC even to a greater extent than in the control group. The approach of the present study was to load specifically the distal forearm and to measure the bone mass at the same region, i.e., the distal radius. At this site the radius consists of a thin layer of compact bone filled with a trabecular bone structure. At 3 cms proximal to the radial styloid tip, Schlenker and Von Seggen [22] found that the fraction of trabecular bone is only 10%. This figure refers to the mineral mass which was measured by ashing and weighing.

By volume, however, the trabecular tissue occupies most of the cross-section in the distal radius at this site, as demonstrated by computerized tomography. Because of the high concentration of minerals in the thin cortex, it contains most of the bone mass. The Compton scattering device examines a fixed volume which is defined by the apparatus. When this volume is located within the trabecular structure of the bone, the density of this tissue exclusively is measured. Photon absorptiometry, on the other hand, measures the mineral mass in the entire scanned cross-section of the bone, hence the contribution of trabecular bone is masked by the large mass of cortical bone surrounding it.

In this study, the BMC did not show any significant trend in the exercise group. The standard error

Table 3. Mean bone mineral content (B.M.C.) and standard deviation for the two groups 1 year prior to the study (Past) at the beginning of the exercise program (Pre), and at its end (Post)

	Exercise group n = 14		Control group n = 26	
	B.M.C. (g/cm²)	Difference (%)[a]	B.M.C. (g/cm²)	Difference (%)[a]
Past	0.373 ± 0.093		0.384 ± 0.099	
		+5.6% (N.S.)		+1.0% (N.S.)
Pre	0.394 ± 0.080		0.388 ± 0.093	
		−3.3% (N.S.)		+3.1% (N.S.)
Post	0.381 ± 0.102		0.400 ± 0.071	

[a] N.S.—The difference is not significant statistically, i.e., $P > 0.05$ (paired t test)

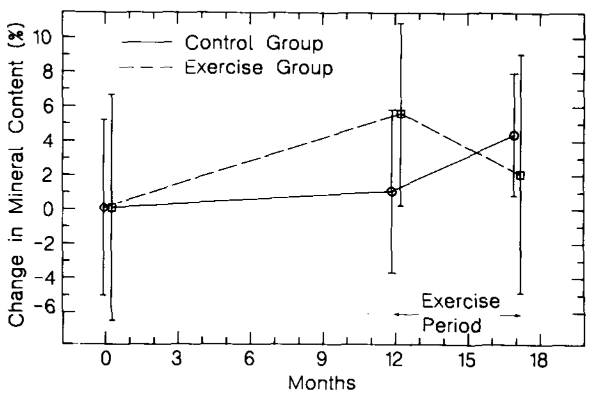

Fig. 2. Percentage changes of the mean bone mineral content in the exercise and control groups 1 year prior to the exercise period, at its beginning, and at its end.

of the mean BMC values was markedly greater than the longitudinal changes observed in both groups, as demonstrated in Figure 2. The irregular shape of the bone at the distal radius was reported to reduce the precision of this measurement [23–25] and was probably the cause of the high standard deviation of the results. The Compton scattering technique, which yields the density, does not depend on the shape of the bone cross-section, hence its better precision [15]. As a result, the standard error of the mean density values is small, as demonstrated in Figure 1.

The significant increase of bone density found in this study after 5 months of physical activity is higher than the increase of BMC observed by Smith et al. [20, 21]. This may be the effect of the more vigorous and diverse bone-loading exercises specifically planned for the distal forearm. Rubin and Lanyon [26] also demonstrated the effectiveness of dynamic and diverse loading of bone. They applied loads of such nature to the ulnae of mature roosters and achieved a marked increase (33–43%) in BMC with relatively few repetitions (36 cycles per day) over 6 weeks. Nonspecific or aerobic physical activity is probably less effective; in fact Smith et al. [20] found that aerobics caused a decline in the bone mineral mass, at least temporarily. In addition, the sensitivity of the density measurements is higher because the density changes in trabecular bone, unlike those of the BMC, are not masked by the cortical layer which changes much slower.

The changes in the bone density that we have observed are not necessarily attributed only to a change in the substance of the trabeculae (i.e., collagen, minerals). It may be due also to an interchange of marrow adipose tissue by red marrow, reversing the process observed in osteoporosis—an increase in the volume of marrow adipose tissue [27, 28]. However, if we examine variations of these components in trabecular bone, it emerges that only an extreme decrease of adipose tissue and its replacement by red marrow can account by itself for the changes we have observed.

No adverse side effects, fractures, or other injuries in the musculo-skeletal system were observed among the exercising women during the program period. Moreover, low back pain complaints were significantly reduced in this group both in number and severity of complaints.

It may thus be concluded that dynamic and diverse bone-stressing exercises in the forearm are feasible for postmenopausal osteoporotic women even in the seventh decade of life. Moreover, trabecular bone density increases in response to such exercises within a few months. These results are encouraging since it is obvious that controlled physical activity is more advantageous and favorable than drug therapy. Controlled physical activity has no adverse side effects, it is less costly, and more enjoyable.

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Received November 21, 1985, and in revised form July 15, 1986.