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Lifetime Leisure Exercise and Osteoporosis

The Rancho Bernardo Study

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Between 1988 and 1991, the relation between leisure time physical activity, bone mineral density (BMD), and osteoporotic fracture was evaluated in a cohort of community-dwelling California adults (1,014 women and 689 men) with a mean age of 73 years. By means of a modified Paffenbarger questionnaire, participants were asked to report exercise from the past year and to recall their level of exercise during three other periods: the teenage years, age 30 years, and age 50 years. The survey asked the number of times strenuous (e.g., jogging), moderate (e.g., fast walking), or mild (e.g., golfing) exercise was undertaken in an average week. A summary score was constructed to represent lifetime exercise. Analyses of the exercise-fracture and exercise-BMD associations were performed using logistic and linear regression analyses, respectively. Linear regression models were controlled for age, body mass index, sex, diagnosis of arthritis, dietary calcium intake, and use of cigarettes, alcohol, thiazides, and estrogen (women only). No association between current or former exercise and BMD at the radius, wrist, or spine was found. A positive association between current exercise and BMD was found at the total hip (p = 0 001) and at each hip component—greater trochanter (p = 0.02), intertrochanter (p = 0.001), and femoral neck (p = 0.02). Mean hip bone densities of strenuous (p = 0.004) and moderate (p = 0.004) current exercisers were higher than those of mild or less than mild exercisers. Lifetime exercise was also positively associated with BMD of the total hip (p = 0.008) and hip components, and demonstrated a borderline-significant association (p = 0.06) with spine BMD. At the hip, each pairwise comparison between the highest and lowest tertiles of lifetime exercise showed a significant difference ($p \leq$ 0.007). Exercise was unassociated with minimal trauma fracture occurring at any site between 1972 and 1991. These data suggest a protective effect of current and lifelong exercise on hip BMD, but not on osteoporotic fracture, in older men and women. *Am J Epidemiol* 1995;141:951–9.

aged; bone density, exercise; fractures; osteoporosis

Theoretical, observational, and interventional studies suggest that exercise is effective in the maintenance of bone mass (1). Mathematical models that relate loading history to trabecular orientation and density have been formulated and substantiated in animal models (2, 3). Cross-sectional reports of higher bone density in self-selected athletic persons versus nonathletic persons support the exercise hypothesis in humans (4). More modest levels of exercise were not associated with higher appendicular bone density in a large cohort of postmenopausal women, however (5). Small nonrandomized and randomized intervention trials have reported modest gains in bone density as a result of diverse training programs (6–8).

Important issues related to the possible beneficial effects of exercise on the skeleton remain to be addressed. Primary among them is the potential self-selection bias inherent in observational studies and nonrandomized interventions. This well-recognized deficit can only be overcome by large, randomized clinical trials. Nonetheless, other salient questions can be approached using observational data. For example, in many reports, the required level of physical activity has been high (6, 9); whether lower levels of activity confer any skeletal benefit has received limited investigation (10). Additionally, almost all studies to date have examined the effect of physical activity at a single point in time; thus, the effect of exercise over the life span can only be deduced by comparing the results of different studies in different populations. Whether the observed higher bone densities in athletic older women are attributable to their current activity or

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Abbreviations: BMD, bone mineral density; OR, odds ratio.

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to former activity has not been studied (11). The effectiveness of physical activity in the preservation of bone density at the lumbar spine or hip has not been examined in community-dwelling adults; in fact, little information about exercise and bone mass in persons over 65 has been published (5). Finally, the relation between exercise and osteoporotic fracture has received limited investigation (12–15).

This study examined the effect of self-reported current and prior leisure time physical activity on axial and appendicular bone mineral density (BMD) and osteoporotic fracture in a population-based sample of older adults.

MATERIALS AND METHODS

The participants in this study were members of a geographically defined, Caucasian, upper middle-class cohort established in 1972 to study heart disease risk factors (Rancho Bernardo, California). Between 1988 and 1991, surviving community-dwelling residents aged 35 years or older were invited to participate in a study of osteoporosis; 80 percent of eligible participants agreed. The current analysis was restricted to persons aged 50 years or more (n = 1,703). All participants gave written informed consent. The study was approved by the Institutional Review Board of the University of California, San Diego.

History of alcohol consumption, cigarette use, thiazide use, estrogen use (women only), physician-diagnosed arthritis, and occurrence of bone fracture was obtained by self-administered, standardized questionnaire. All pills and prescriptions were brought to the study center for confirmation of current medication use. Detailed information about the site(s) of bone fractures, the level of trauma associated with any fracture, and age at the time of each fracture was recorded. Fractures of the spine, hip, wrist, and clavicle were confirmed by medical record review. Height and weight were measured with the participant wearing light clothing without shoes. Body mass index was calculated as weight (kg)/height (m)^2.

Dietary intake was estimated using the Harvard food frequency questionnaire (16). A modified Paffenbarger questionnaire was used to obtain current and former exercise information (17). This survey asked participants whether they usually engaged in strenuous (e.g., jogging, squash), moderate (e.g., fast walking, easy swimming, dancing), or mild (e.g., easy walking, golfing) exercise for at least 15 minutes per session. These and other illustrative examples of each intensity were given in the questionnaire. For current exercise, subjects were asked to report their usual pattern during the last year. In addition to current exercise habits, participants were requested to recall usual exercise during their teenage years, at 30 years of age, and at 50 years of age.

BMD of the subject's nondominant arm was measured at the ultradistal radius and midshaft radius using single-photon absorptiometry (Lunar Corporation, Madison, Wisconsin; model SP2B). BMD of the spine (L1–L4) and hip was obtained using dual-energy x-ray absorptiometry (Hologic, Inc., Waltham, Massachusetts; model QDR 1,000). Hip BMD included the femoral neck, intertrochanter, greater trochanter, and total hip. BMD machines were calibrated daily. Manufacturers' quoted precisions for the BMD measurements are 7 percent for the ultradistal radius, 5 percent for the midshaft radius, 1 percent or less for the spine, and 1.5 percent or less for the total hip.

Incident osteoporotic fractures were those that occurred between 1972 and 1991 in the absence of significant trauma or local bone disease, at sites classified by the Study of Osteoporotic Fracture's definition as osteoporotic (18). Significant trauma included accidents, traumatic injuries, and falls from any height greater than four stairs. Minimal trauma fractures considered osteoporotic were those of the hip, leg, wrist, pelvis, spine, rib, humerus, clavicle, radius, and ulna (18). The age at which these minimal trauma fractures occurred was confirmed to be greater than 50 years in all cases. In cases of participants with more than one fracture, only the first fracture was considered in the summary of total fractures.

For each time period (the teenage years, 30 years of age, 50 years of age, and current age), participants were classified by the highest level of exercise they performed for at least 15 minutes per session at least three times per week. Categories of exercise were strenuous, moderate, and mild/less than mild (combined). For analyses related to age-specific exposures, categories of exercise were entered into statistical models as class variables. For analyses related to lifetime exercise exposure, less than mild exercise was scored 1, mild exercise was scored 2, moderate exercise was scored 3, and strenuous exercise was scored 4; the lifetime exercise score (range, 4–16) represented the sum of the scores for the teenage years, 30 years of age, 50 years of age, and current age. Population tertiles of lifetime activity were calculated and were entered into models as class variables.

Data were analyzed using the Statistical Analysis System (19) and STATA (20). All BMD variables were normally distributed. Potentially confounding factors, based on previously reported associations between each variable and BMD or osteoporotic fracture, included age, sex, body mass index, dietary calcium, arthritis, and use of estrogens, thiazides, cigarettes, and alcohol. The relation between each potential confounder and exercise was examined with odds ratios, using the lowest category of exercise as the referent. Mild, moderate, and strenuous exercise were compared with low (below the median) versus high values of body mass index and calcium intake, with ever/never use of cigarettes and estrogen, with the presence/absence of a diagnosis of arthritis, and with current use/no use of thiazides and alcohol. Because the goal of these analyses was to make a qualitative assessment of potential confounders, the odds ratios and apparent trends were not tested for significance.

Linear regression models were used to examine the associations between BMD and each age of self-reported exercise and lifetime exercise. Models were adjusted for age, sex, body mass index, dietary calcium intake (mg/day), current alcohol use (any/none), ever use of cigarettes (yes/no), current thiazide use (yes/no), diagnosis of arthritis (yes/no), ever use of estrogen (women only), and exercise intensity at the other time periods.

Logistic regression was used to analyze the associations between osteoporotic fractures and exercise during the teenage years, at 30 years of age, and at 50 years of age. Because exercise may decrease after a fracture occurs, current exercise was not included. As described above, models were controlled for age, body mass index, calcium intake, exercise during other time periods, and use of alcohol, cigarettes, thiazides, and estrogen. Age-adjusted and multiply adjusted logistic regression models were constructed for men and women separately with all osteoporotic fractures combined; site-specific models were estimated for hip, wrist, spine, and rib fractures in women and for rib fractures in men, since these sites had adequate numbers of fractures for analysis. The lifetime exercise score was recalculated omitting current exercise (lifetime-to-age 50). The association between all osteoporotic fractures and tertile of lifetime-to-age 50 exercise was also examined using logistic regression.

RESULTS

The mean age of both men and women at the bone density visit was 73 years. Average body mass index was 26 in men and 24 in women. Current consumption of any alcohol was reported by 78 percent of the population; 57 percent had ever smoked, and 16 percent were current smokers. Thiazide or thiazide-like diuretics were taken by 20 percent. Thirty-one percent of subjects reported having arthritis that was severe enough to require medication. Seventy-two percent of the women had ever used estrogen, and 37 percent were currently using it.

Compared with those who reported mild or less exercise, persons who were currently strenuous exercisers were more likely to report current alcohol use (odds ratio (OR) = 1.5), to be in the upper half of the population distribution of dietary calcium intake (OR = 1.7), and to have ever taken estrogen (OR = 2.2); they were less likely to use thiazides (OR = 0.45) or to have arthritis (OR = 0.7). Odds ratios were in the same direction but of smaller magnitude when moderate exercisers were compared with mild/less than mild exercisers.

The proportions of participants who engaged in less than mild, mild, moderate, or strenuous exercise at least three times per week during their teens, at 30 and 50 years of age, and at the time of the osteoporosis visit are summarized in table 1. For men and women combined, approximately 24 percent exercised moderately as teenagers; the overall proportion of moderate exercisers remained stable as age increased. In contrast, half of the cohort reported engaging in strenuous exercise as teenagers, but the proportion of heavy exercisers diminished with age: at age 30, 18.7 percent of all participants reported strenuous exercise; at age 50, 12.7 reported strenuous exercise; and only 3 percent reported having this level of activity in the weeks prior to the bone density evaluation. At all ages, men reported about 2–3 times more strenuous leisure activity than did women.

TABLE 1. Percentage of the study population* that reported having exercised at least three times per week at various ages, by age at exercise, level of exercise, and sex, Rancho Bernardo, California, 1988–1991

Exercise level and sex	Age (%)			
	Teenage years	30 years	50 years	Current age†
Less than mild‡				
Both sexes	27 8	44.4	38.4	56.4
Men	18.6	37.3	35.1	29.2
Women	34.1	49.1	40.4	36.1
Mild‡				
Both sexes	0.3	14.7	24.4	21.7
Men	0.2	12.2	22 9	32.5
Women	0.4	16.6	25 4	33.7
Moderate				
Both sexes	23.7	22 2	24.4	18.9
Men	12.6	20.0	23.7	31.6
Women	31.0	23.5	25.1	27.1
Strenuous				
Both sexes	48.2	18.7	12.7	3.0
Men	68.6	30.5	18.3	6.7
Women	34.5	10.8	9.1	3 1

* n = 1,703 (1,014 women and 689 men).

† Age at the time of bone mineral density measurement.

‡ The referent group for age-specific analyses was the mild and less than mild levels combined.

Participants reporting a consistent level of exercise intensity were distributed as follows: always less than mild, 118 (7 percent); always mild, 0; always moderate, 52 (3 percent); and always strenuous, 30 (2 percent). Exercise patterns in the remainder (n = 1,503) varied over the ages queried. The minimum score for the lifetime exercise summary score was 4, and the maximum was 16. The lowest third of women scored between 4 and 6, the middle third scored between 7 and 10, and the highest third scored between 11 and 16. The tertile distributions in men were: 4–8 (low), 9–11 (medium), and 12–16 (high). Since exercise *level* (not specific activities) was reported, the types of exercise in which participants engaged could not be determined.

Between 1972 and 1991, there were 205 first osteoporotic fractures among the 1,703 women and men. By site, there were 72 wrist, 47 rib, 27 spine, 27 hip, 17 leg, 16 humerus, 11 pelvis, 9 clavicle, and 8 radius/ulna fractures. These sum to 234, since 21 women and one man had had more than one fracture. Women accounted for 78 percent of all fractures, 86 percent of wrist fractures, 85 percent of spine fractures, 93 percent of hip fractures, and 62 percent of rib fractures.

No effect of leisure exercise on the risk of any osteoporotic fracture (205 fractures) was found. As table 2 shows, age-adjusted logistic regression models for each exercise level during each time period (i.e., moderate or strenuous during the teenage years, at 30 years of age, or at 50 years of age) did not demonstrate any relation between exercise and the risk of any osteoporotic fracture in either men or women. Sex-specific, multiply adjusted models that controlled for age, body mass index, alcohol drinking, dietary calcium intake, thiazide use, smoking, estrogen use (women only), and exercise intensity during the other time periods also showed no significant association between all osteoporotic fractures and moderate or strenuous levels of exercise during the teenage years, at age 30 years, or at age 50 years. Lifetime exercise up to age 50 was similarly unrelated to the occurrence of all osteoporotic fractures.

The risks of selected fractures in moderately and strenuously exercising women compared with women who engaged in mild or less exercise, adjusted for age and estrogen use, are summarized in table 3. At the hip, wrist, spine, and rib, no pattern of effect of moderate or strenuous exercise on fractures was evident. Results of age-adjusted logistic models for rib fractures in men also revealed no effect or pattern of effect of exercise on fracture risk (data not shown).

Current exercise and bone density were significantly associated at the total hip (p = 0.001), where a gradient of increasing bone density was seen with increas-

TABLE 2. Relative odds of experiencing any osteoporotic fracture,* by exercise level at various ages and by sex, Rancho Bernardo, California, 1988–1991

Age and level of exercise	Age-adjusted relative odds						Multiply adjusted† relative odds‡,§			
	Both sexes		Women		Men		Women		Men	
	RO¶	95% CI¶	RO	95% CI	RO	95% CI	RO	95% CI	RO	95% CI
Teenage years										
Moderate	1.03	0.69–1.06	1.04	1.02–1.07	0.93	0 34–2.52	1.08	0.65–1.81	0.72	0 24–2 16
Strenuous	0.86	0.59–1.24	1.35	0.88–2.08	0.80	0.33–1.93	1 37	0 84–2.26	0.86	0.32–2.32
30 years										
Moderate	0.76	0.35–1.60	0.81	0.52–1 25	1.33	0.64–2 76	0 63	0 36–1.11	1.51	0.60–3.76
Strenuous	0.79	0.27–2.26	1.56	0.83–2.94	0.54	0.22–1.33	1.12	0 48–2 55	0.52	0 19–1.43
50 years										
Moderate	1.23	0.50–3.00	1.12	0.74–1.69	1.36	0.68–2.75	1.34	0 80–2.22	1 50	0.64–3.52
Strenuous	0.76	0.15–3.77	1.36	0.71–2.61	0.68	0 25–1.87	1.31	0.58–2.93	0.68	0 21–2 15
Lifetime to age 50‖										
Medium	0.97	0.69–1.36	1.30	0.89–1.91	0.72	0.33–1.56	1.38	0.91–2 09	0.58	0 25–1.31
High	0 87	0 59–1.29	1.39	0 85–2.28	0.91	0.41–1 99	1.43	0.84–2.43	0.86	0 38–1 94

* First fractures totalled 160 among women and 45 among men.

† Models were adjusted for age; body mass index; alcohol, cigarette, thiazide, and estrogen use (women only), and dietary calcium intake. *Age-specific models were also adjusted for exercise level during the other time periods.*

‡ n = 868 women and 624 men, because of the cumulative effect of missing data.

§ The referent category for the teenage years, age 30 years, and age 50 years was comprised of those who reported engaging in mild exercise or less during each of the time periods. The referent category for lifetime to age 50 was the lowest tertile.

¶ RO, relative odds; CI, confidence interval

‖ Lifetime to age 50 was lifetime exercise score up to age 50 years (excluding current age) Medium and high refer to population tertiles

TABLE 3. Adjusted* relative odds of osteoporotic fracture of selected bones in women, according to site and exercise level at various ages, Rancho Bernardo, California, 1988–1991†,‡

Age and level of exercise	Hip (n = 25)		Wrist (n = 62)		Spine (n = 23)		Rib (n = 29)	
	RO§	95% CI§	RO	95% CI	RO	95% CI	RO	95% CI
Teenage years								
Moderate	0.45	0.12–1.68	1.09	0.59–2.03	1 50	0.42–5 36	0.88	0.35–2 17
Strenuous	3.81	1.05–13.75	0.72	0.37–1.39	2.58	0.89–7 48	0.89	0.35–2 28
30 years								
Moderate	0.70	0.23–2.12	1.05	0.57–1.95	1 32	0.50–3 51	0 37	0.11–1 25
Strenuous	2.16	0.46–10.08	0.77	0.27–2.19	0.85	1.65–4.40	2 88	0.63–13.18
50 years								
Moderate	0.95	0.34–2.65	1.02	0.55–1.88	1.16	0.44–3.08	1 22	0.52–2.92
Strenuous	1.63	0.30–8 92	0.80	0.26–2.50	0 65	0.07–5.67	1.39	0.41–4.76

* Adjusted for age and estrogen use. Site-specific fractures include all osteoporotic fractures, not just first fractures.

† Sample size = 1,014; numbers of fractures (n) are shown in the headings.

‡ The referent category for the teenage years, age 30 years, and age 50 years was comprised of those who reported engaging in mild exercise or less during each time period

§ RO, relative odds, CI, confidence interval

ing intensity of current exercise (table 4). Results are shown for men and women combined, adjusted for sex. Pairwise comparisons between the adjusted mean total hip BMDs of mild/less than mild exercisers versus moderate exercisers and mild/less than mild exercisers versus strenuous exercisers showed significant differences ($p = 0.004$ for each comparison). The average total hip BMD of strenuous exercisers was greater than that of moderate exercisers, but this comparison did not reach statistical significance ($p = 0.09$). Those participants with the highest level of current exercise demonstrated a mean total hip bone density 6.5 percent greater than that of mild/less than mild exercisers and 3 percent higher than that of moderate exercisers.

The effect of current exercise on the bone density of each of the three regions that comprise the total hip is also presented in table 4. A statistically significant increase in BMD with increasing exercise level was evident at each of the three hip locations. At the intertrochanter, femoral neck, and greater trochanter, respectively, the bone densities of participants with the highest level of exercise were approximately 7.0 percent, 6.3 percent, and 4.5 percent greater that the BMD values of participants reporting the lowest level of exercise. Pairwise comparisons between mean bone densities of mild or less exercisers versus moderate exercisers and mild or less exercisers versus strenuous exercisers showed significant differences at each of the hip locations. Comparisons between moderate and strenuous exercisers were marginally significant at all sites except the greater trochanter, and were in the expected direction.

Current or past exercise was not associated with bone density at the ultradistal radius, midradius, or lumbar spine. These results and those presented in table 4 were unaltered in analyses that excluded participants who reported osteoporotic fractures (data not shown).

Sex-specific models revealed the same associations or lack of associations as seen in the combined, sex-adjusted models. In both women and men, current exercise was related to hip bone density, with a similar gradient of increasing BMD with increasing exercise intensity in both sexes. The mean hip bone densities of strenuous, moderate, and mild/less than mild female exercisers were 0.8536 g/cm^2, 0.8347 g/cm^2, and 0.8065 g/cm^2, respectively (p for linear trend = 0.05). In men, mean hip bone densities of strenuous, moderate, and mild/less than mild exercisers were 0.9983 g/cm^2, 0.9644 g/cm^2, and 0.9382 g/cm^2, respectively (p for linear trend = 0.006). Current exercise was not associated with BMD at any other site in women or men examined separately. Past exercise was not associated with BMD at any site in either sex. Female-specific models were also stratified by current/noncurrent estrogen use and current/former/never use of estrogen. Patterns of effect in estrogen users and in non-estrogen users did not differ from those presented above (data not shown).

As table 5 shows, lifetime exercise was positively associated with BMD of the total hip and hip components in both sexes combined. Dose-response gradients by tertile of lifetime exercise score were found at the total hip, intertrochanter, femoral neck, and greater trochanter. Pairwise comparisons demonstrated statis-

TABLE 4. Adjusted* mean bone mineral density (BMD) values for various regions of the hip, by current level of exercise, Rancho Bernardo, California, 1988–1991

Site and current exercise level	BMD	p†
Total hip‡		
Mild or less	0 8284	
Moderate	0.8518	
Strenuous	0.8828	0 001
Interochanter§		
Mild or less	0.9665	
Moderate	0.9982	
Strenuous	1.0331	0 001
Femoral neck‖		
Mild or less	0.6657	
Moderate	0.6795	
Strenuous	0 7075	0.02
Greater trochanter¶		
Mild or less	0.6045	
Moderate	0 6217	
Strenuous	0.6316	0 02

* Models were adjusted for sex, body mass index; age; cigarette, alcohol, thiazide, and estrogen use (women only); dietary calcium intake, diagnosis of arthritis; and exercise level during the other time periods

† Significance test for analysis of variance.

‡ Pairwise adjusted comparisons. mild/less than mild vs. moderate, $p = 0.004$, mild/less than mild vs strenuous, $p = 0.004$, moderate vs. strenuous, $p = 0.09$.

§ Pairwise adjusted comparisons: mild/less than mild vs moderate, $p = 0.004$; mild/less than mild vs. strenuous, $p = 0.003$, moderate vs. strenuous, $p = 0\ 07$.

‖ Pairwise adjusted comparisons: mild/less than mild vs. moderate, $p = 0.05$; mild/less than mild vs. strenuous, $p = 0\ 01$; moderate vs. strenuous, $p = 0.08$.

¶ Pairwise adjusted comparisons. mild/less than mild vs moderate, $p = 0.02$; mild/less than mild vs. strenuous, $p = 0.05$, moderate vs strenuous, $p = 0\ 34$.

TABLE 5. Adjusted* mean bone mineral density (BMD) values for various regions of the hip, by site and by tertile of lifetime exercise score, Rancho Bernardo, California, 1988–1991

Site and tertile of lifetime exercise score†	BMD	p‡
Total hip§		
Low	0.8241	
Medium	0 8367	
High	0.8507	0.008
Interochanter§		
Low	0.9631	
Medium	0.9769	0.03
High	0.9908	
Femoral neck§		
Low	0.6597	
Medium	0 6716	
High	0.6819	0.01
Greater trochanter§		
Low	0.5969	
Medium	0 6093	
High	0.6248	0 0006
Lumbar spine§		
Low	0 9324	
Medium	0.9612	
High	0.9479	0.06

* Adjusted for sex; body mass index, age; cigarette, alcohol, thiazide, and estrogen use (women only), dietary calcium intake; and diagnosis of arthritis.

† Population tertiles of summed exercise scores from the teenage years, age 30 years, age 50 years, and current age

‡ Significance test for analysis of variance

§ Pairwise adjusted comparisons between low and high tertiles total hip, $p = 0.002$, intertrochanter, $p = 0.007$, femoral neck, $p = 0.003$, greater trochanter, $p = 0.0001$

tically significant differences ($p \leq 0.007$) between the highest and lowest tertile in each case. At the lumbar spine, a borderline-significant positive effect was found ($p = 0.06$). Lifetime exercise scores were unrelated to BMD at the ultradistal radius and midradius (data not shown). Sex-specific results mirrored those seen in the sex-adjusted models.

DISCUSSION

In this sample of older men and women, BMDs at all hip sites were greater in current and lifelong recreational exercisers than in those who engaged in mild or no exercise. A dose-response effect was evident in all regions of the hip, with higher levels of current exercise being associated with higher levels of BMD. A borderline-significant beneficial effect of lifelong exercise on the bone density of the lumbar spine was also found. In contrast, current exercise was unrelated to BMD of the ultradistal radius, midradius, and lumbar spine; no association between recalled past leisure exercise and BMD at any site was found. A relation between osteoporotic fracture and exercise was not supported by this study.

Many studies comparing younger self-selected athletes with non-exercisers have found higher bone densities among the athletes (21). However, few have examined the effect of current recreational physical activity on bone density in older adults. Nelson et al. (22) found that spinal and radial bone densities, but not proximal femur density, were higher in a small sample of 60-year-old female endurance runners than in sedentary controls. These results disagree with those of the present study; however, their analyses were not adjusted for potential confounders, and the absence of a femoral neck difference may be due to the small sample and the lower precision of dual-photon absorptiometry (23). Positive associations between fitness, muscle strength, and femoral neck BMD in postmenopausal women have been reported (24, 25). The Study of Osteoporotic Fractures found that current exercise was not independently predictive of appendicular BMD in older women (5). The absence of an effect of current exercise on the appendicular skeleton is in agreement with the present study; hip and spine BMD were not included in the Study of Osteoporotic Fractures report.

This study found an independent effect of exercise exclusively at the hip. Mechanical stimuli probably cause a beneficial structural adaptation in bone, primarily though local rather than systemic mechanisms (26). Therefore, it is biologically plausible that only bones loaded by a specific activity would be stimulated to remodel. Although the survey did not ascertain specific forms of recreational activity, we hypothesize that the common forms of strenuous exercise (e.g., jogging, squash) and moderate exercise (e.g., fast walking, folk dancing) preferentially load the hip. Although others have proposed a systemic bone-promoting effect of exercise (22), these findings are more consistent with a local mechanism.

Does benefit accrue from moderate levels of exercise, or is there a threshold of strenuous activity that must be reached to achieve bone remodeling? This is a critical question from the perspective of feasibility of exercise recommendations in older populations. The difference in BMD between the lowest and highest exercise categories ranged from approximately 4.5 percent (at the greater trochanter) to 7.0 percent (at the intertrochanter). Increases in hip BMD of this magnitude have been associated with a 50 percent decrement in future fracture risk (27). However, strenuous exercise is rare, and from a public health perspective, it may be more feasible to accomplish the goal of encouraging moderate exercise. The mean hip BMD of moderate exercisers was approximately 3 percent higher than that of mild/less than mild exercisers. Thus, the benefit to an individual of moderate exercise may be smaller than that associated with strenuous exercise, but the population benefit would be greater if many people exercised moderately. The presence of the observed dose-response relation also supports causal inference (28).

If subjects with fractures routinely reduced their physical activity as a result of the fracture, a spurious association between low activity and low bone density would result. Therefore, we repeated the analyses after excluding the 205 persons who had had an osteoporotic fracture. Results were unaltered, suggesting that the protective effect of exercise was not confounded by a postfracture decrease in exercise. Models were controlled for exercise at the other time periods; therefore, the effect of current exercise was isolated from the effect of previous exercise. In the fracture outcome analyses, we considered only the three time periods that preceded osteoporotic fracture.

We found a positive association only between current leisure exercise and hip bone density. The interpretation of this finding depends, in part, on the validity of the instrument used to measure exercise. The survey was derived to measure the cardioprotective effect of physical activity (17). Although its validity with respect to cardiovascular outcomes has been well-documented (29, 30), it estimates fitness more than the potential bone-loading character of certain activities. This may limit its sensitivity to detect bone density effects. Recently, regular vigorous leisure exercise during each of three recalled age ranges was reported to protect against stroke (31); nonetheless, recalled information on physical activity in the distant past must be viewed with caution, as its accuracy may be questionable.

It is also possible that the association between BMD and exercise was confounded by other exposures. Moderate to strong evidence supports possible relations between estrogen use, body mass index, age, dietary calcium, smoking, thiazide use, alcohol consumption, and cigarette smoking and bone density (5, 32–36), and the fracture and BMD analyses were controlled for these potential confounders. Arthritis may be an important confounder, because persons with arthritis may exercise less and have lower bone densities. Osteoarthritis may also be associated with higher BMD of the spine or hip, which may be real or due to the presence of spinal osteophytes (37, 38), while rheumatoid arthritis is associated with reduced bone density (39, 40). Our bone density models were controlled for arthritis.

An effect of exercise earlier in life may be sustained only if the exercise is continued. Davis et al. (41) have noted that persons with higher bone mass lose bone at a greater rate than do those with a lower initial BMD. Thus, persons who discontinue exercise may suffer greater subsequent rates of bone loss. In the present study, few people exercised at the same level over time, precluding a direct analysis of persons with consistent exercise patterns. The finding that the lifetime score was associated with hip BMD supports the concept that sustained exercise is important. On average, persons in higher tertiles of lifetime activity would have had relatively higher consistent lifetime patterns of exercise.

The risk of osteoporotic fracture was unaltered by exercise in this study. To maximize power, we evaluated the effect of exercise on all osteoporotic fractures (18). However, if the effect of exercise differs by bone site (e.g., perhaps increasing wrist fractures due to increasing forward falls but decreasing hip fractures due to higher walking speed), the true effect might be obscured by combining sites (42). Although the numbers of fractures were few, models for fractures of the hip, wrist, spine, and rib in women revealed no pattern of effect. Spine, hip, wrist, and clavicle fractures were confirmed by medical record review; these comprised 70 percent of all fractures. However, the potential for inaccurate reporting of the remaining fractures may also explain the absence of an association between exercise and all fractures combined (43).

Others have described a weak association between current regular exercise and all (not uniquely osteoporotic) fractures in a large cohort of seniors (12). A protective effect of exercise and outdoor activity against hip fracture has been noted in case-control studies (13–15). However, one study considered exercise only in the 6 weeks prior to fracture (13), and another did not control for estrogen use (14). Multiple interrelated causes are postulated to predicate a fracture, including low bone mass, muscle weakness, cognitive impairment, decreased neuromuscular reflexes, and environmental hazards (44). Thus, the beneficial effect of exercise on the more proximal outcome of bone density should be easier to perceive than its role in the complex etiology of fractures.

In summary, we found a substantial protective effect of current and lifelong exercise on hip BMD but not on osteoporotic fracture in older men and women. These bone density findings are consistent with prior evidence of a beneficial effect of exercise on the skeleton. They cannot be directly compared with other results, however, since previous investigations have not assessed the effect of exercise at the hip in community-dwelling older persons. The observation that moderate exercise conferred an intermediate degree of benefit is a novel and promising outcome. Although we controlled for confounding factors that might influence these results, an observational design cannot overcome the potential selection bias inherent in studies of exercise. While we await the results of the ongoing randomized trials in this area, we believe that current evidence supports the encouragement of exercise as a probable osteoporosis prevention strategy.

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