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Systematic Review of Randomized Trials of the Effect of Exercise on Bone Mass in Pre- and Postmenopausal Women

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Abstract. Studies of the effect of exercise programs on bone mass appear inconsistent. Our objective was to systematically review and meta-analyze randomized trials of the effect of exercise on bone mass in pre- and postmenopausal women. A computerized MEDLINE search was conducted for the years 1966–1997. Thirty-five randomized trials were identified. Meta-analytic methods were used to statistically pool results of studies of the effect of impact (e.g., aerobics) and non-impact (e.g., weight training) exercise on the lumbar spine and femoral neck. The most studied bone site was the lumbar spine in postmenopausal women (15 studies), where both impact [1.6% bone loss prevented, 95% confidence intervals (CI): 1.0%–2.2%] and non-impact (1.0%, 95% CI: 0.4%–1.6%) exercise programs had a positive effect. Results for the lumbar spine in premenopausal women (eight studies) were similar: 1.5% (95% CI: 0.6%–2.4%) less bone loss (or net gain) after impact exercise and 1.2% (95% CI: 0.7%–1.7%) after non-impact exercise. Impact exercise programs appeared to have a positive effect at the femoral neck in postmenopausal women (five studies), 1.0% (95% CI: 0.4%–1.6%) bone loss prevented, and possibly in premenopausal women, 0.9% (95% CI: −0.2%–2.0%) bone loss prevented. There were too few trials to draw conclusions from meta-analyses of the effect of non-impact exercise on the neck of femur. This systematic review of randomized trials shows that both impact and non-impact exercise have a positive effect at the lumbar spine in pre- and postmenopausal women. Impact exercise probably has a positive effect at the femoral neck. More studies are required to determine the optimal intensity and type of exercise.

Key words: Bone density — Exercise — Meta-analysis — Osteoporosis.

It is widely believed that exercise has an important role in maximizing peak bone mass and reducing subsequent rates of bone loss. Experiments using laboratory animals have shown that mechanical loading of the skeleton is necessary for maintaining bone mass [1–3]. Observational epidemiological studies have consistently found that athletes have higher bone mass than people leading more sedentary lifestyles and that people who are physically active in old age are at reduced risk of hip fracture [4, 5]. However, observational studies are prone to selection bias. For example, athletes may be self-selected to an active lifestyle because they inherited a stronger body (and stronger bones). Randomized trials of exercise interventions are the best design for preventing this type of bias.

Many intervention studies have failed to find that participating in an exercise program has a statistically significant effect on bone mass. However, most reviews of the effect of exercise on bone mass do not distinguish among cross-sectional studies, longitudinal observational studies, and intervention studies. Even reviews that focus on intervention studies ignore the much greater scientific validity of randomized trials compared with other experimental designs. The purpose of our review was to systematically review randomized trials of the effect of exercise on bone mass in pre- and postmenopausal women, using statistical methods to pool (or meta-analyze) results of studies that involved similar types of exercise programs. We hoped to be able to assess the relative efficacy of impact (e.g., aerobics) and non-impact (e.g., weight training) exercise programs at different bone sites.

Another systematic review and meta-analysis was done by Bérard et al. [6]. Our study differs from this review in several important ways: we excluded studies in which subjects were not allocated at random to exercise or control groups; we did not exclude studies in which all subjects (both intervention and control) also had treatments such as calcium supplements and/or estrogen; instead of excluding studies without the published standard deviations (SDs) needed to pool study findings, we made estimates of these SDs; and we included studies involving premenopausal women. Furthermore, several relevant randomized trials have been published since the time of Bérard et al's work. The net result is that our review includes many more randomized trials than Bérard et al's.

Methods

Identification of Eligible Studies

A computerized literature search of the MEDLINE database was conducted from 1966 to January 1998. The search was done using the MESH terms "exercise," "bone mineral density," and "osteoporosis." No language restrictions were used. The reference lists of all identified randomized trials and some review articles were carefully reviewed for any studies not found in the MEDLINE search. All abstracts were reviewed to identify articles that could possibly be randomized trials. Only articles that included a clear statement that subjects were randomly assigned to exercise and control

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groups proceeded to full critical appraisal and inclusion in this review. Only studies involving women were included.

Included studies were classified according to subjects' menopausal status, bone sites assessed, and type of exercise program (impact or non-impact). Impact exercises included walking, running, aerobics, dancing, using treadmills, and "heel drops." Non-impact exercises included resistance training, strength training, and weightlifting. This categorization did not take into consideration the intensity or duration of the exercise program.

Statistical Methods

The mean percentage changes in bone density over the duration of the study for the exercise and control group in each study were extracted or calculated from the published data. The mean difference in rate of bone loss (or gain) between the exercise and control groups was then calculated. Positive values for the mean percentage difference indicate that the control group lost more bone, on average, than the exercise group. If there was more than one impact or non-impact exercise group, only results for subjects in the more intensive exercise program were used. If a study included separate impact and non-impact exercise groups, each exercise group was included separately in the relevant meta-analysis. Data were estimated from graphs if not given in tables or text.

Statistical methods were used to pool (or meta-analyze) the results of studies that included measurements of bone density at the lumbar spine or femoral neck. These were the most frequently measured bone sites and they are probably also the most clinically important sites. Results were pooled separately for studies involving impact and non-impact exercise programs, and for pre- and postmenopausal women.

Measures of effect were combined across studies with a fixed effects model, as described in Petitti [7]. Each study was weighted by the inverse of its variance. Study variances were calculated using SDs of the mean percent bone loss (or gain) in the exercise and the control groups. Where SDs were not available for a particular study, a study SD was estimated from the SDs of the two studies of the same bone site with the closest sample sizes [8]. Methods described in Petitti were used to calculate 95% confidence intervals (CI) around pooled percentage differences in bone loss and to assess heterogeneity of study results [7].

We repeated all analyses with study results converted to differences in percentage change in bone density per year ('annualized' results). For example, if there was a 1% difference in bone density after a 6-month exercise program, we assumed that there would have been a 2% difference if the program had continued for 12 months.

A meta-regression analysis was done of the 15 studies of the lumbar spine in postmenopausal women to assess whether differences in study results could be explained by age of subjects, duration of exercise program, and type of exercise (impact or non-impact). Multiple linear regression was used, weighted by study-specific variances. There were too few studies to perform meta-regressions of studies of premenopausal women or of the femoral neck.

Results

A total of 253 articles was identified, with the vast majority being review articles. Fifty-one articles were reviewed in full and 35 papers reporting randomized trials of exercise programs with bone mass as the outcome were identified [9–43]. Two studies were excluded because they only gave results for men and women combined [41, 42], and another study was excluded because it gave no relevant bone mass results [43].

There were 24 studies of postmenopausal women and 8 of premenopausal women. Characteristics of studies involving postmenopausal women are shown in Table 1 and studies of premenopausal women are shown in Table 2. Most (88%) studies of postmenopausal women were published in the 1990s and most (75%) studies of premenopausal women were published after 1994. Studies tended to be small: the largest study in premenopausal women had 84 subjects with outcome data and only five of the studies in postmenopausal women had more than 100 subjects.

Pooled measures of effect for studies of postmenopausal women are shown in Table 3. There was a statistically significant positive effect of impact and non-impact exercise on bone mass at both the lumbar spine and the femoral neck. For the lumbar spine, the pooled percentage difference in bone density between exercise and control groups was 1.6% (95% confidence interval (CI): 1.0%–2.2%) for studies with impact exercise programs and 1.0% (95% CI: 0.4%–1.6%) for non-impact exercise programs. At the femoral neck, the meta-analysis showed a 0.9% (95% CI: 0.5%–1.3%) benefit for subjects involved in impact exercise programs and a 1.4% (95% CI: 0.2%–2.6%) benefit for subjects in non-impact exercise programs.

There was statistically significant heterogeneity ($P < 0.05$) of study findings in all four meta-analyses involving postmenopausal women. In three cases, this heterogeneity was due to the results of one particular study: Grove and Londeree [13] (impact exercise at the spine), Sinaki et al. [29], (non-impact exercise at the spine) and Lau et al. [17] (impact exercise at the femoral neck).

Pooled measures of effect from studies of premenopausal women are shown in Table 4. Both impact and non-impact exercise had statistically significant positive effects on bone mass at the lumbar spine. The pooled percentage difference in bone density between exercise and control groups was 1.5% (95% CI: 0.6%–2.4%) for studies with impact exercise programs and 1.2% (95% CI: 0.7%–1.7%) for non-impact exercise programs. At the femoral neck, there was a 0.9% (95% CI: −0.2%–2.0%) improvement in bone density for subjects involved in impact exercise programs, but this was not statistically significant ($P > 0.05$). There were insufficient data (only one of four studies provided relevant SDs) to meta-analyse studies of the effect of non-impact exercise on the femoral neck in premenopausal women. There was no statistically significant heterogeneity in any of the three meta-analyses involving premenopausal women ($P > 0.25$).

In the linear regression equation involving the 15 studies of the lumbar spine in postmenopausal women, the only regression coefficient that even approached statistical significance was for non-impact versus impact exercise (beta $= -1.7$, $P = 0.06$). This suggests that non-impact exercise might be less effective than impact exercise for preventing bone loss at the lumbar spine. Duration of exercise program was not related to effectiveness (beta $= -0.07$, $P = 0.24$) in the regression analysis. Pooled measures of effect based on 'annualized' differences in bone mass were similar to results of the primary analyses (see Table 5).

Four studies in which the exercise program involved both impact and non-impact exercises were not included in any meta-analyses [18, 19, 31, 36]. Friedlander et al.'s [36] study involved premenopausal women and found a strong positive effect of exercise on bone mass. The only positive effect in the three studies in postmenopausal women was at the spine in the study by Lord et al. [18].

Three studies in postmenopausal women that did not give results for the spine or femoral neck were also excluded from meta-analyses [11, 24, 32]. All three studies found a positive effect of exercise on bone mass.

Two studies in postmenopausal women did not give re-

Table 1. Characteristics of randomized studies of the effectiveness of exercise for the prevention of bone loss in postmenopausal women

Author	Age (mean)	Intervention	Duration of exercise program (months)	No. with data	Dropout rate (%)	Compliance rate[a] (%)	Measurement sites	% difference in BMD[b]
Bassey [9]	55	'Heel drops'	12	44	30	84	Ultradistal forearm	1.6
							Spine	2.2
							Femoral neck	−0.8
							Ward's triangle	−1.0
							Trochanter	1.4
Bravo [10]	60	Walking, dancing, stepping up and down, flexibility exercises	12	124	18	?	Spine	1.8
							Femoral neck	0.8
Chow [11]	56	a) Aerobics b) Aerobics and light resistance training	12	58	17	70	Trunk/upper thighs	a) 5.3 b) 9.1
Ebrahim [12]	67	Brisk walking	24	97	41	100	Spine	−0.1
							Femoral neck	2.4
Grove [13]	56	Running in place, jumping	12	15	7	83	Spine	7.8
Hatori [14]	57	Walking	7	33	9	?	Spine	2.8
Heikkinen [15]	53	Resistance training	36	69	12	?	Spine	$P > 0.05$
							Femoral neck	$P < 0.05$
Kerr [16]	58	Resistance training a) Strength b) Endurance	12	46	18	82	Shaft radius	a) 1.2 b) 1.1
							Ultradistal radius	a) 3.6 b) 0.1
							Femoral neck	a) 0.4 b) 1.2
							Ward's triangle	a) 1.5 b) 1.0
							Trochanter	a) 2.3 b)−0.9
Lau [17]	76	Stepping block	10	50	17	?	Spine	0.6
							Femoral neck	−5.5
							Ward's triangle	−3.6
							Trochanter	−0.1
Lord [18]	72	Strengthening, coordination, balance, and weight-bearing exercise	10.5	138	23	73	Spine	0.7
							Femoral neck	−1.6
							Trochanter	0.0
Lynch [19]	69	Resistance exercise, brisk walking	15	26	?	?	Femoral neck	−1.3
							Trochanter	−1.2
Martin [20]	58	Treadmill	12	55	28	60	Proximal	1.1
							Distal forearm	1.6
							Spine	1.4
McMurdo [21]	65	Weight-bearing exercise	24	92	22	76	Ultradistal forearm	3.7
							Distal forearm	−0.8
							Spine	1.7
Nelson [22]	59	High intensity strength training	12	39	1	88	Total body	3.2
							Spine	2.8
							Femoral neck	3.4
Notelovitz [23]	45	Resistance weight training	12	20	40	>70	Total body	1.5
							Midshaft radius	4.4
							Spine	6.8
Preisinger [24]	60	Brisk walking and stretching exercises	12–60	146	0	48	Distal wrist	0.6/yr
							Proximal wrist	0.7/yr
Prince [25]	63	Weight-bearing exercise	24	84	?	39	Spine	1.7
							Femoral neck	0.5/yr
							Intertrochanter	0.1/yr
							Trochanter	0.3/yr
							Ultradistal ankle	0.6/yr

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Table 1. (continued).

Author	Age (mean)	Intervention	Duration of exercise program (months)	No. with data	Dropout rate (%)	Compliance rate[a] (%)	Measurement sites	% difference in BMD[b]
Pruitt [26]	68	Resistance weight training	12	26	35	79	Spine	0.8
							Total hip	−0.1
							Femoral neck	−1.1
							Ward's triangle	2.4
Revel [27]	54	Training of psoas muscles	12	73	6	55	Spine	2.3
Sandler [28]	57	Walking	36	155	?	?	Shaft of forearm	'no effect'
Sinaki [29]	56	Back-strengthening exercises	24	65	4	66	Spine	−0.2/yr
Smidt [30]	56	Resistance exercise program for trunk muscles	12	49	11	?	Spine	0.8
							Trochanter	1.0
							Femoral neck	1.5
							Ward's triangle	−1.2
Svendsen [31]	54	Aerobics and weight training	3	118	2	97	Total body	0.0
							Forearm	−0.1
							Spine	−0.8
Taaffe [32]	68	Leg press with knee extension, knee flexion	12	25	30	79	Middle 3rd of femur	2.8

[a] Compliance rate is the percentage of prescribed exercise sessions that were actually completed
[b] Percentage change in bone density in exercise group minus percentage change in bone density in control group. A positive value indicates that subjects in the exercise group lost less bone, on average, than subjects in the control group

sults in sufficient detail to permit us to estimate the magnitude of the effect of exercise on bone mass [15, 28]. The study by Heikkinen et al. [15] reported a statistically significant exercise effect at the femoral neck but not the spine. The study by Sandler et al. [28] reported no effect of exercise at the shaft of the radius. The study by Kerr et al. [16] randomized one upper limb of each subject to exercise, with the other side serving as the control, and found that high intensity, low repetition resistance training was effective but that low intensity, high repetition training was not.

Discussion

Our systematic review of relevant randomized trials clearly shows that exercise slows the rate of bone loss at the spine in postmenopausal women. Randomized studies also provide strong evidence that exercise programs have a positive impact on bone mass at the lumbar spine in premenopausal women. There appeared to be no difference in the relative effectiveness of exercise at the lumbar spine in pre-compared to postmenopausal women.

Our results for the femoral neck are less clear cut. Although we found statistically significant pooled effects in postmenopausal women, these findings are less robust than those for the lumbar spine because there were fewer studies and there was more inconsistency between results of individual studies. For example, two out of five studies of impact exercise at the femoral neck in postmenopausal women did not find a positive effect of exercise compared with just one out of nine studies of impact exercise and the lumbar spine.

Observational studies of athletes suggest that sports involving jumping (such as volleyball and gymnastics) are highly osteogenic [44, 45]. However, it is unclear whether this osteogenesis is due to the impact (landing) or non-impact (muscle pull at take-off) component of these sports. There have been few randomized trials directly comparing impact and non-impact exercise programs. Snow-Harter et al. [40] found that running (impact exercise) and weight training (non-impact exercise) were equally effective for improving bone mass at the lumbar spine in female college students. Our analyses found no obvious differences in effectiveness between impact and non-impact exercise programs. This may simply reflect the fact that our classification of exercise programs is somewhat arbitrary.

We found a great deal of heterogeneity in study results, particularly among studies of postmenopausal women. This heterogeneity is not really surprising, as studies had very different exercise programs (separated here only crudely into impact and non-impact) of different durations. Compliance and dropout rates also differed between studies. Compliance, defined in the majority of studies as the percentage of completed exercise sessions out of the total prescribed sessions, ranged from 39% [25] to a reported 100% [12]. Many studies had high dropout rates, varying from a maximum of 47% [36] to a reported 0% [24]. Withdrawal was usually due to insufficient time, moving out of area, or injury. Block [46] has previously raised the problem of high dropout rates in studies investigating the role of exercise in the prevention of osteoporosis, suggesting that studies with more than a 20% dropout rate should be viewed with caution. Of those studies reporting dropout rates, 8 of 21 studies in postmenopausal women had dropout rates greater than 20%, as did five of seven studies in premenopausal women. Small sample sizes and high dropout rates mean that some studies may not be balanced for confounding factors despite the initial randomization [46].

The study finding the largest effect of exercise at the lumbar spine (7.8% bone loss prevented) was by Grove et

Table 2. Characteristics of randomized studies of the effectiveness of exercise for the prevention of bone loss in premenopausal women

Author	Age (mean)	Intervention	Duration of exercise program (months)	No. with data	Drop-out rate (%)	Compliance rate[a] (%)	Measurement sites	% difference in BMD[b]
Bassey [33]	31	Intermittent high impact exercise	6	27	?	76	Ultradistal forearm	1.1
							Distal radius	0.9
							Spine	−0.4
							Femoral neck	2.1
							Ward's triangle	2.0
							Trochanter	2.9
Blimkie [34]	16	Resistance training	6.5	32	11	?	Total body	0.3
							Spine	1.0
Dornemann [35]	44	High intensity weightlifting	6	26	26	78	Distal radius	−0.6
							Spine	1.4
							Femoral neck	−0.1
Friedlander [36]	29	Aerobics and weight training	24	63	47	61	Spine	1.1
							Femoral neck	2.4
							Trochanter	2.3
							Calcaneus	6.4
Heinonen [37]	39	Jump training and stretching	18	84	14	83	Distal radius	−0.7
							Spine	1.5
							Femoral neck	1.0
							Trochanter	0.6
							Distal femur	1.5
							Patella	0.8
							Proximal tibia	2.6
							Calcaneus	1.8
Lohman [38]	34	Resistance weight training	18	56	46	84	Total body	−0.3
							Radius shaft	0.0
							Spine	1.8
							Femoral neck	1.3
							Ward's triangle	2.6
Sinaki [39]	36	Weightlifting	36	67	30	56	Midshaft radius	−1.2
							Spine	0.4
							Femoral neck	0.2
							Ward's triangle	−0.4
							Trochanter	0.1
Snow-Harter [40]	20	a) Running b) Weight training	8	30	42	a) 97 b) 92	Spine	a) 2.1 b) 2.0
							Femoral neck	a) 0.0 b) 0.0
							Ward's triangle	a) 2.4 b) 0.2
							Trochanter	a) 0.0 b) 1.3

[a] Compliance rate is the percentage of prescribed exercise sessions that were actually completed
[b] Percentage change in bone density in exercise group minus percentage change in bone density in control group. A positive value indicates that subjects in the exercise group lost less bone, on average than subjects in the control group

al. [13]. This could be because this study obtained high compliance (83%) with a high intensity impact exercise program. The study finding the largest effect at the femoral neck (3.4% bone loss prevented) was by Nelson et al. [22] who also achieved high compliance (87%) to their exercise program, a high intensity strength training regime running for 12 months.

The study of postmenopausal Chinese women by Lau et al. [17] was least supportive of a beneficial effect of exercise on bone mass. Chinese women have tended to be more physically active than European and North American women. It is possible that an exercise program may be less effective in people who are habitually physically active. It is also possible that the effect of exercise on bone mass varies between races.

A systematic review of exercise studies in postmenopausal women by Bérard et al. [6] concluded that exercise was effective at the lumbar spine but not at the femoral neck or forearm. Most of the studies Bérard et al. included in their femoral neck meta-analysis were not randomized. This may explain our more positive finding for this bone site.

A limitation of our work is that we included only published results and so publication bias is a possibility: studies, especially small studies, that do not find a statistically significant effect are probably less likely to be published than studies finding a clearly positive effect. On the other hand, numerous small studies that did not find a statistically significant effect of exercise have been published, suggesting that publication bias may not be a large problem in research on exercise and bone mass. Another limitation of our review is that study weights often could not be estimated directly, but had to be estimated using data from other studies.

The magnitude of the effect of exercise on bone mass appears to be similar to that of calcium supplementation and

Table 3. Effect of exercise on bone mass at the lumbar spine and femoral neck in postmenopausal women: results of individual randomized studies and pooled measures of effect

Study	Exercise group			Control group			% difference in BMD[a]
	M[b]	SD	N	M[b]	SD	N	
Spine, impact exercise							
Bassey [9]	−0.8	8.9	20	−3.0	9.8	24	2.2
Bravo [10]	0.6	5.1[c]	61	−1.2	3.3[c]	63	1.8
Ebrahim [12]	1.7	5.1[c]	49	1.8	3.3[c]	48	−0.1
Grove [13]	1.7	2.7[c]	5	−6.1	2.4[c]	5	7.8
Hatori [14]	1.1	2.9	12	−1.7	2.8	12	2.8
Lau [17]	−1.9	2.4	11	−2.5	2.0	12	0.6
Martin [20]	0.8	4.5	16	−0.6	3.4	19	1.4
McMurdo [21]	−0.9	3.0	44	−2.6	1.6	48	1.7
Prince [25]	1.5	3.2	52	−0.2	2.6	42	1.7
Pooled measure of effect: 1.6% (95% CI: 1.0%–2.2%)							
Spine, non-impact exercise							
Nelson [22]	1.0	3.6	20	−1.8	3.5	19	2.8
Notelovitz [23]	8.3	5.3	9	1.5	12.4	11	6.8
Pruitt [26]	0.7	1.9	8	−0.1	2.3	11	0.8
Revel [27]	−1.3	2.6[c]	36	−3.6	2.8[c]	37	2.3
Sinaki [29]	−1.4	1.8	34	−1.2	2.2	31	−0.2
Smidt [30]	−1.6	2.6[c]	22	−2.3	2.8[c]	27	0.8
Pooled measure of effect: 1.0% (95% CI: 0.4%–1.6%)							
Femoral neck, impact exercise							
Bassey [9]	−0.8	3.1	20	0.0	2.4	24	−0.8
Bravo [10]	0.3	2.5[c]	61	−0.5	1.7[c]	63	0.8
Ebrahim [12]	−0.3	2.5[c]	49	−2.7	1.7[c]	48	2.4
Lau [17]	−6.6	3.8	11	−1.1	3.3	12	−5.5
Prince [25]	0.3	2.2	42	−0.2	1.3	42	0.5
Pooled measure of effect: 0.9% (95% CI: 0.5%–1.3%)							
Femoral neck, non-impact exercise							
Nelson [22]	0.9	4.5	20	−2.5	3.8	19	3.4
Pruitt [26]	−0.2	2.7	8	0.9	3.3	11	−1.1
Smidt [30]	1.2	1.7[c]	22	−0.3	3.6[c]	27	1.5
Pooled measure of effect: 1.4% (95% CI: 0.2%–2.6%)							

M = mean, SD = standard deviation, N = number
[a] Percentage change in bone density in exercise group minus percentage change in bone density in control group. A positive value indicates that subjects in the exercise group lost less bone, on average, than subjects in the control group
[b] Mean percentage change in bone density from baseline to completion of study
[c] When standard deviation (SD) data not available, SD was estimated from the two studies with the nearest sample size

somewhat less than that of pharmacological interventions such as estrogen replacement therapy and bisphosphonates. However, it is worth noting that exercise has the potential to be the cheapest of these interventions and it has health benefits that extend far beyond the skeleton.

The ultimate test of any medical intervention is a randomized trial with patient-centered outcomes. In studies aimed at osteoporosis, the relevant patient-centered outcome is fracture. It is unlikely that a trial of an exercise program with clinically important fractures as the outcome will ever be conducted, because it is probably impossible to achieve high compliance with any exercise program for long enough periods to detect a statistically significant effect. Hence, clinical and public health decisions about exercise for prevention of osteoporotic fractures may need to be based on randomized studies with intermediate endpoints (such as bone mass and falls), observational epidemiological studies with fracture endpoints, and animal studies. It should also be possible to conduct randomized trials of exercise with radiographically identified vertebral fractures as the outcome.

Most observational epidemiological studies have been concerned with hip fracture and these studies have consistently found that physically active people are at lower risk of hip fracture than more sedentary people [5]. The few epidemiological studies to date of physical activity and vertebral fractures have not been consistent [47–49]; only one of these studies involved new (incident) vertebral fractures [49]. It found that women who reported moderate-to-vigorous levels of physical activity at baseline were less likely to suffer a new vertebral fracture during follow-up than less active women [49]. Exercise might be expected to

Table 4. Effect of exercise on bone mass at the lumbar spine and femoral neck in premenopausal women: results of individual randomized studies and pooled measures of effect

Study	Exercise group M[b]	SD	N	Control group M[b]	SD	N	% difference in BMD[a]
Spine, impact exercise							
Bassey [33]	0.4	1.5	14	0.8	5.1	13	−0.4
Heinonen [37]	2.2	2.9	49	0.7	3.2	49	1.5
Snow-Harter [40]	1.3	1.8	10	−0.8	1.8	8	2.1
Pooled measure of effect: 1.5% (95% CI: 0.6%–2.4%)							
Spine, non-impact exercise							
Blimke [34]	1.0	1.8	16	0.0	1.9	16	1.0
Dornemann [35]	1.0	1.4	12	−0.4	2.0	14	1.4
Lohman [38]	1.3	1.8[c]	22	−0.5	1.9[c]	34	1.8
Sinaki [39]	0.6	1.8[c]	33	0.2	1.9[c]	36	0.4
Snow-Harter [40]	1.2	2.1	12	−0.8	1.8	8	2.0
Pooled measure of effect: 1.2% (95% CI: 0.7%–1.7%)							
Femoral neck, impact exercise							
Bassey [33]	1.2	7.5	14	−0.9	6.5	13	2.1
Heinonen [37]	1.6	2.9	49	0.6	2.9	49	1.0
Snow-Harter [40]	0.0	3.5	10	0.0	2.9	8	0.0
Pooled measure of effect: 0.9% (95% CI: −0.2%–2.0%)							
Femoral neck, non-impact exercise							
Insufficient data to calculate a pooled measure of effect							

M = mean, SD = standard deviation, N = number
[a] Percentage change in bone density in exercise group minus percentage change in bone density in control group. A positive value indicates that subjects in the exercise group lost less bone, on average, than subjects in the control group
[b] Mean percentage change in bone density from baseline to completion of study
[c] When SD data not available, SD was estimated from the two studies with the nearest sample size

Table 5. Pooled measures of effect of exercise on bone mass based on estimated percentage changes in bone density per year (annualized data) and on published data

	Pooled measures of effect (95% CI)[a]: Annualized data	Published data
Postmenopausal women		
Spine, impact exercise	1.3% (0.7%–19%)	1.6% (1.0%–2.2%)
Spine, non-impact exercise	1.0% (0.4%–1.6%)	1.0% (0.4%–1.6%)
Femoral neck, impact exercise	0.5% (0.1%–0.9%)	0.9% (0.5%–1.3%)
Femoral neck, non-impact exercise	1.4% (0.2%–2.6%)	1.4% (0.2%–2.6%)
Premenopausal women		
Spine, impact exercise	1.5% (0.6%–2.4%)	1.5% (0.6%–2.4%)
Spine, non-impact exercise	1.3% (0.8%–1.8%)	1.2% (0.7%–1.7%)
Femoral neck, impact exercise	0.7% (−0.3%–1.7%)	0.9% (−0.2%–2.0%)
Femoral neck, non-impact exercise	Insufficient data	Insufficient data

[a] Percentage difference in change in bone density in exercise groups and control groups. A positive value indicates that subjects in the exercise group lost less bone, on average, than subjects in the control groups
CI = confidence interval

reduce the risk of hip fracture more than the risk of vertebral fracture because exercise probably reduces the risk of falling [50], which is a risk factor for hip, but not vertebral fractures.

In conclusion, the results of randomized trials of exercise for prevention of bone loss in postmenopausal women show that exercise slows bone loss from the lumbar spine and probably the neck of the femur. Exercise probably has a similar effect in premenopausal women but more studies are needed to reach a firm conclusion. Although the effect of exercise is not great in the short term, it could be substantial if accumulated over a number of years through ongoing exercise programs. A greater effect would also be expected with greater compliance with exercise programs. Important unanswered questions remain about the optimal intensity and type of exercise. Randomized trials comparing the effects of different exercise programs on both bone- and fall-related outcomes are needed.

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