Table G5.A2. Studies Reviewed for Evidence That Physical Activity Reduces Risk of Osteoporosis by Increasing, or Slowing the Decline in, Bone Mineral Density or Bone Mineral Content (n=15)

Reference	Type	Subjects	Primary Outcomes	Study Inclusion and Exclusion Criteria	Studies Included	Major Results [NOTE: bold=statistical significance]
Berard et al., 1997 (1)	MA	Postmenopausal women 50+ years Did not have osteoporosis	Forearm, lumbar spine (LS), hip, heel BMD or BMC Reported effect size (ES) and 95% CI	RCTs and CTs Any type of exercise, any duration, any intensity Only studies that did not include other treatments (calcium, estrogen)	5 RCTs 13 CTs	**Lumbar Spine (LS):** L2-L4 BMD 0.34 (−0.19-0.88) L1-L4 BMD 1.11 (−0.27-2.50) **Hip:** FN BMD 0.35 (−0.47-1.17) Troch BMD 0.85 (−0.10-1.80) **Forearm:** Radius BMD 0.38 (−0.41-1.17) Wrist BMD 0.28 (−0.03-0.60)
Kelley et al., 1998a (2)	MA	Postmenopausal women	LS BMD Reported OT as the difference between exercise and control groups (% change)	RCTs and CTs Endurance training (ET) as the only exercise intervention Calcium supplementation and estrogen were allowed	4 RCTs 6 CTs	**LS BMD: 2.83 (1.15-4.50)** No significant differences when partitioned by RCT vs. CT, calcium vs. no calcium, or higher- vs. lower-impact activities. Similar results were found when hormone therapy (HT), smoking, alcohol consumption were excluded.
Kelley et al., 1998b (3)	MA	Postmenopausal women	Hip BMD Reported outcomes as effect size (ES) and 95% bootstrap CI (BCI)	RCTs and CTs with ET as the only intervention Site specificity of exercise for loading the hip region	2 RCTs 4 CTs	**Overall: 0.43 (0.04-0.81)** The change in ES was equivalent to a between-group difference in BMD of 2.4% (2.1% in exercisers, −0.3% in controls). **Subgroup analyses** **Study design:** RCT 0.15 (−0.45-0.63) CT **0.76 (0.37-1.29)** **Calcium intake:** <1,000 mg/day −0.23 (−0.85-0.21) >1,000 mg/day **0.83 (0.49-1.23)**
Kelley et al., 1998c (4)	MA	Postmenopausal women	Regional BMD Reported outcomes as differences between exercisers and controls in the relative change in BMD (%)	RCTs with exercise as the primary intervention Calcium supplementation and use of estrogen were allowed	11 RCTs Subgroup analyses were conducted to assess training mode (endurance training vs. resistance training [ET vs. RT]) and the site measured (LS vs. femur vs. radius)	**Overall: 0.27 (0.16-0.37)** The overall treatment effect represented changes of −0.51% in exercisers and −0.86% in controls. **Subgroup analyses** **Training mode:** ET 0.02 (−0.11-0.15) RT **0.73 (0.56-0.91)** **Site measured:** LS **0.73 (0.52-0.93)** Femur 0.37 (0.20-0.55) Radius **−0.22 (−0.39- −0.05)**

Table G5.A2. Studies Reviewed for Evidence That Physical Activity Reduces Risk of Osteoporosis by Increasing, or Slowing the Decline in, Bone Mineral Density or Bone Mineral Content (n=15) (continued)

Reference	Type	Subjects	Primary Outcomes	Study Inclusion and Exclusion Criteria	Studies Included	Major Results [NOTE: bold=statistical significance]
Wolff et al., 1999 (5)	MA	Pre- and postmenopausal women	Changes in LS and femur neck (FN) BMD or BMC Reported published changes and annualized changes	RCTs and CTs of exercise training (endurance training [ET]; resistance training [RT]) Duration ≥16 weeks Adequate data to compute treatment effect Calcium supplementation and hormone therapy were allowed	16 RCTs, Women 12 postmenopausal 7 ET, 5 RT 4 premenopausal 3 ET, 1 RT 9 CTs, Women 6 postmenopausal 5 ET, 1 RT 3 premenopausal 3 RT Separate analyses for RCTs and CTs, pre- and postmenopausal women, LS and FN Insufficient studies for separate analyses of RT and ET Overall treatment effect (OT) expressed as difference between exercisers and controls in change in BMD or BMC (%/year)	**Annualized changes (%/year)** **RCTs, premenopausal:** LS ET+RT **0.91 (0.44-1.37)** FN ET+RT **0.90 (0.29-1.50)** **RCTs, postmenopausal:** LS ET+RT **0.79 (0.35-1.22)** ET **0.96 (0.43-1.49)** RT 0.44 (−0.32-1.21) FN ET+RT **0.89 (0.36-1.42)** ET **0.90 (0.29-1.51)** RT 0.86 (−0.18-1.91) **RCTs, all:** LS **0.84 (0.53-1.16)** FN **0.89 (0.50-1.29)** **CTs, premenopausal:** LS ET+RT 0.90 (−0.29-2.09) FN ET+RT inadequate data **CTs, postmenopausal:** LS ET+RT **2.40 (2.00-2.81)** ET **2.25 (1.83-2.67)** RT inadequate data FN ET+RT **1.68 (0.65-2.72)** ET **1.86 (0.80-2.91)** RT inadequate data **CTs, all:** LS **1.85 (1.59-2.11)** FN **1.39 (0.46-2.33)**

Table G5.A2. Studies Reviewed for Evidence That Physical Activity Reduces Risk of Osteoporosis by Increasing, or Slowing the Decline in, Bone Mineral Density or Bone Mineral Content (n=15) (continued)

Reference	Type	Subjects	Primary Outcomes	Study Inclusion and Exclusion Criteria	Studies Included	Major Results [NOTE: bold=statistical significance]
Kelley et al., 2000 (6)	MA	Men	BMD, any region Reported outcomes as ES and 95% BCI	RCTs and CTs in which exercise was the only intervention Training duration ≥16 weeks	2 RCTs Heart transplant patients Obese, for weight loss 6 CTs	**Overall:** 0.028 (-0.166-0.230) The nonsignificant change in ES was equivalent to a between-group difference in BMD of 2% (1.6% in exercisers, −0.4% in controls). **Subgroup analyses** **Age:** >31 years **0.605 (0.324-1.032)** <31 years 0.066 (−0.157-0.312) The change in ES for the older group was equivalent to 6.7% (4.2% in exercisers, −2.5% in controls). **Skeletal region:** Femur **0.482 (0.270-0.705)** Lumbar Spine **0.749 (0.099-1.327)** Os calcis **0.565 (0.260-1.048)** The changes in ES for the femur, lumbar spine, and os calcis were equivalent to 5.9% (4.0% in exercisers, −1.9% in controls), 10.7% (5.8% in exercisers, −4.9% in controls), and 1.6% (2.1% in exercisers, 0.5% in controls). **Study design:** RCT **1.082 (0.705-1.569)** CT **0.442 (0.204-0.799)** The changes in ES for the RCTs and CTs were equivalent to 13.5% (9.8% in exercisers, −3.7% in controls) and 4.2% (2.0% in exercisers, −2.2% in controls).

Table G5.A2. Studies Reviewed for Evidence That Physical Activity Reduces Risk of Osteoporosis by Increasing, or Slowing the Decline in, Bone Mineral Density or Bone Mineral Content (n=15) (continued)

Reference	Type	Subjects	Primary Outcomes	Study Inclusion and Exclusion Criteria	Studies Included	Major Results [NOTE: bold=statistical significance]
Wallace et al., 2000 (7)	SR	Pre- and postmenopausal women	Changes in LS and FN BMD	Only RCTs of women ET was impact exercise (e.g., walking, running, dance) RT was non-impact exercise Excluded studies with combined ET and RT Calcium supplementation or hormone use was allowed	24 postmenopausal 9 ET only 6 RT only 7 ET and RT 8 premenopausal 3 ET only 5 RT only	**Published changes (%)** **Postmenopausal:** LS ET **1.6 (1.0-2.2)** RT **1.0 (0.4-1.6)** FN ET **0.9 (0.5-1.3)** RT **1.4 (0.2-2.6)** **Premenopausal:** LS ET **1.5 (0.6-2.4)** RT **1.2 (0.7-1.7)** FN ET 0.9 (−0.2-2.0) RT inadequate data **Annualized changes (%/years)** **Postmenopausal:** LS ET **1.3 (0.7-1.9**) RT **1.0 (0.4-1.6)** FN ET **0.5 (0.1-0.9)** RT **1.4 (0.2-2.6)** **Premenopausal:** LS ET **1.5 (0.6-2.4)** RT **1.3 (0.8-1.8)** FN ET 0.7 (−0.3-1.7) RT Inadequate data

Table G5.A2. Studies Reviewed for Evidence That Physical Activity Reduces Risk of Osteoporosis by Increasing, or Slowing the Decline in, Bone Mineral Density or Bone Mineral Content (n=15) (continued)

Reference	Type	Subjects	Primary Outcomes	Study Inclusion and Exclusion Criteria	Studies Included	Major Results [NOTE: bold=statistical significance]
Kelley et al., 2001(8)	MA	Pre- and postmenopausal women	LS, femur, radius BMD Reported outcomes as ES and 95% BCI	RCTs and CTs Studies of RT only in adult women BMD of the LS, femur, radius RT duration ≥16 weeks	18 RCTs of women 12 postmenopausal 1 perimenopausal 5 premenopausal 11 CTs of women 5 postmenopausal 6 premenopausal	**Outcomes by BMD site:** LS **0.24 (0.11-0.38)** Femur 0.07 (−0.20-0.15) Radius **0.30 (0.13-0.48)** Treatment effects were equivalent to 1.26% for the LS, 0.38% for the femur, and 2.17% for the radius **Subgroup analyses, femur:** **Study quality** 0-2 0.03 (−0.07-0.10) 3-5 **0.24 (0.03-0.44)** **Menopausal status** Pre −0.01 (−0.16-0.09) Post **0.15 (0.03-0.28)** **Subgroup analyses, radius:** **Study quality** 0-2 −0.01 (−0.09-0.05) 3-5 **0.56 (0.38-0.75)** **Menopausal status** Pre −0.02 (−0.13-0.05) Post **0.52 (0.33-0.71)** No significant between-group differences in subgroup analyses of ES changes at the LS
Kelley et al., 2002 (9)	MA of independent data	Postmenopausal women 355 exercisers 344 controls	LS BMD Changes in BMD in exercisers and controls evaluated by repeated measures ANOVA	RCTs and CTs Exercise duration ≥16 weeks	7 RCTs 6 CTs	**Change in LS BMD (g/cm²):** Exercisers 0.005±0.043 Controls −0.007±0.045 **Interaction effect, P <0.001** **Group effect, P=0.003** The treatment effect was equivalent to a 2% benefit in LS BMD (1% in exercisers, −1% in controls)

Table G5.A2. Studies Reviewed for Evidence That Physical Activity Reduces Risk of Osteoporosis by Increasing, or Slowing the Decline in, Bone Mineral Density or Bone Mineral Content (n=15) (continued)

Reference	Type	Subjects	Primary Outcomes	Study Inclusion and Exclusion Criteria	Studies Included	Major Results [NOTE: bold=statistical significance]
Kelley et al., 2004 (10)	MA of independent data	Premenopausal women, aged 18+ years, not competitive athletes 74 Exercisers 69 Controls	LS and FN BMD Changes in BMD in exercisers and controls evaluated by repeated measures ANCOVA	RCTs and CTs RT as the intervention Exercise duration ≥16 weeks	3 CTs	**Change in LS BMD (g/cm²):** Exercisers 0.006±0.035 Controls 0.008±0.091 There were no significant main effects of group or time or interaction effects of group * time **Change in FN BMD (g/cm²):** Exercisers 0.005±0.031 Controls 0.003±0.031 There were no significant main effects of group or time or interaction effects of group * time
Palombaro et al., 2005 (11)	MA	Peri- and postmenopausal women and men aged 50+ years	LS, FN, and calcaneal BMD Reported outcomes as effect sizes (ES)	RCTs and CTs Walking intervention, compared with either other types of exercise or no exercise Interventions that included walking plus stair-stepping were included	6 RCTs 4 CTs	There was a significant positive effect of walking exercise on LS BMD (0.32; P <0.03) but not FN BMD (0.00; *P*=1.00) or calcaneus BMD (0.32; *P*=0.56)
Kelley et al., 2006 (12)	MA of independent data	Postmenopausal women 295 Exercisers 300 Controls	FN BMD	RCTs and CTs Site-specific loading exercise program ≥16 weeks in duration	5 RCTs 5 CTs	**Change in FN BMD (g/cm²):** Exercisers 0.004±0.039 Controls 0.001±0.048 There were no significant main effects of group or time or interaction effects of group * time

Table G5.A2. Studies Reviewed for Evidence That Physical Activity Reduces Risk of Osteoporosis by Increasing, or Slowing the Decline in, Bone Mineral Density or Bone Mineral Content (n=15) (continued)

Reference	Type	Subjects	Primary Outcomes	Study Inclusion and Exclusion Criteria	Studies Included	Major Results [NOTE: bold=statistical significance]
Martyn-St James et al., 2006a (13)	MA	Postmenopausal women	Changes (g/cm^2) in LS, FN, and total hip BMD Reported treatment effects as weighted mean differences	Progressive RT, any number of sets of 8-12 repetitions at >60% of 1RM, 2-3 days/week Supplemental calcium and use of anti-osteoporosis drugs allowed	13 RCTs Subgroup analyses were conducted in RCTs that included subjects on HT, RCTs that excluded anti-osteoporosis therapy (no drug), and RCTs that increased calcium intake (Ca supp)	**LS:** All RCTs **0.006 (0.002-0.011)** On HT **0.011 (0.001-0.020)** No drug 0.003 (−0.003-0.009) Ca supp 0.006 (−0.002-0.014) **FN:** All RCTs 0.010 (−0.002-0.021) On HT 0.001 (−0.005-0.008) No drug 0.019 (−0.003-0.040) Ca supp 0.005 (−0.002-0.012) **Total hip:** All RCTs 0.002 (−0.001-0.005) On HT −0.004 (−0.009-0.002) No drug **0.005 (0.001-0.010)** Ca supp **0.008 (0.002-0.013)**
Martyn-St James et al., 2006b (14)	SR	Adult premenopausal women	Changes (g/cm^2) in LS and FN BMD Reported treatment effects as weighted mean differences	Progressive RT, any number of sets of 8-12 repetitions at >60% of 1 RM, 2-3 days/week; indication of progression Supplemental calcium allowed Excluded studies with combined RT and ET	7 studies: 6 RCTs 1 CT	LS BMD **0.014 (0.009-0.019)** Relative change in LS BMD was 0.98 %/year FN BMD 0.001 (0.006-0.008)
Lee et al., 2007c (15)	SR	Postmenopausal women; elderly women and men	Any bone parameter (BMD, bone turnover)	RCTs and CTs of tai chi Comparison groups were sedentary life style, other types of exercise, usual activity, or calcium and vitamin D supplementation	5 RCTs 3 postmenopausal 2 elderly 2 CTs 1 postmenopausal 1 elderly	No significant effects of tai chi

ANCOVA, analysis of covariances; ANOVA, analysis of variance; BCI, bootstrap confidence interval; BMC, bone mineral content; BMD, bone mineral density; Ca Supp, calcium supplement; CI, confidence interval; CT, controlled trial; ES, effect size; ET, endurance training; FN, femoral neck; HT, hormone therapy; LS, lumbar spine; MA, meta-analysis; OT, overall treatment effect; RCT, randomized controlled trial; RM, repetition maximum; RT, resistance training; SR, systematic review

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