Supplementary files

Effects of resistance training on bone mineral density and biomarkers of bone metabolism in postmenopausal women: Systematic review and meta-analysis

Rodrigues-Junior, Sinval, 2024, "Effects of resistance training on bone mineral density and biomarkers of bone metabolism in postmenopausal women: Systematic review and meta-analysis", https://doi.org/10.7910/DVN/KVH9O0, Harvard Dataverse, V1.

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Table S1. Search strategy built and applied in PubMed

Problem (#1)	Intervention (#2)	Outcome (#3)	Study type (#4)
((((("Osteoporosis"[Mesh] OR Osteoporoses OR Osteoporosis, Age-Related OR Osteoporosis, Age Related OR Bone Loss, Age-Related OR Age-Related Bone Loss OR Age-Related Bone Losses OR Bone Loss, Age Related OR Bone Losses, Age-Related OR Age-Related Osteoporosis OR Age-Related Osteoporosis OR Age-Related Osteoporoses OR Osteoporoses, Age-Related)	("Resistance Training"[Mesh] OR Training, Resistance OR Strength Training OR Training, Strength OR Weight-Lifting Strengthening Program OR Strengthening Program, Weight-Lifting OR Strengthening Programs, Weight-Lifting OR Weight Lifting Strengthening Program OR Weight-Lifting Strengthening Programs OR Weight-Lifting Exercise Program OR Exercise Program, Weight-Lifting OR Exercise Programs, Weight-Lifting OR Weight Lifting Exercise Program OR Weight-Lifting Exercise Programs OR Weight-Bearing Strengthening Program OR Strengthening Program, Weight-Bearing OR Strengthening Programs, Weight-Bearing OR Weight Bearing Strengthening Program OR Weight-Bearing	("Bone Density"[Mesh] OR Bone Densities OR Density, Bone OR Bone Mineral Density OR Bone Mineral Densities OR Density, Bone Mineral OR Bone Mineral Content OR Bone Mineral Contents OR Bone Diseases, Metabolic OR Metabolic Bone Diseases OR Bone Disease, Metabolic OR Metabolic Bone Disease OR Osteopenia OR Osteopenias OR Low Bone Density OR Bone Density, Low OR Low Bone Densities OR Low Bone Mineral Density))	((((Randomized Controlled Trial[ptyp])) OR ((Controlled Clinical Trial[ptyp])) OR ((Clinical Trial[ptyp])) OR ("Clinical Trials as Topic"[Mesh]) OR ("Clinical Trials, Phase III as Topic"[Mesh]) OR ("Clinical Trials, Phase IV as Topic"[Mesh]) OR ("Controlled Clinical Trials as Topic"[Mesh]) OR ("Clinical Trial"[Publication Type]) OR ("Controlled Clinical Trial"[Publication Type]) OR ("Clinical Trial, Phase III"[Publication Type]) OR ("Clinical Trial, Phase IV"[Publication Type]) OR ("Multicenter Study"[Publication Type]) OR ("Multicenter Studies as Topic"[Mesh]) OR ("Random Allocation"[Mesh]) OR ("Double-Blind Method"[Mesh]) OR ("Single-Blind Method"[Mesh]) OR ("Cross-Over Studies"[Mesh]) OR ("Placebos"[Mesh]) OR

	Strengthening Programs OR Weight-Bearing Exercise Program OR Exercise Program, Weight-Bearing OR Exercise Programs, Weight-Bearing OR Weight Bearing Exercise Program OR Weight-Bearing Exercise Programs))	(controlled[tiab] AND (trial[tiab] OR trials[tiab] OR study[tiab] OR studies[tiab])) OR (blind[tiab] OR blinding[tiab] OR blinded[tiab] OR mask[tiab] OR masking[tiab] OR masked[tiab] OR placebo[tiab] OR placebos[tiab] OR rct[tiab] OR random[tiab] OR randomised[tiab] OR randomized[tiab] OR randomly[tiab] OR randomisation[tiab] OR randomization[tiab]) OR (factorial[tiab]) OR (divided[tiab] AND (group[tiab] OR groups[tiab])) OR (crossover[tiab]) OR ("crossover"[tiab]) OR (multicentre[tiab] OR multicentred[tiab] OR multicentric[tiab]) OR (versus[ti] OR vs[ti]) OR ("treatment arm"[tiab]) OR ("phase III"[tiab] OR "phase three"[tiab] OR "phase 3"[tiab]) OR ("latin square"[tiab]) NOT (("Animals"[Mesh] OR mouse[ti] OR mice[ti] OR pig[ti] OR pigs[ti] OR rat[ti] OR rats[ti] OR rabbit*[ti]) NOT (("Animals"[Mesh] OR mouse[ti] OR

	mice[ti] OR pig[ti] OR pigs[ti] OR rat[ti] OR rats[ti] OR rabbit*[ti] OR cadaver[ti] OR cadavers[ti]) AND ("Humans"[Mesh]))))

Note: Final stratregy: #1 AND #2 AND #3 AND #4.

Table S2. Search strategy built and applied in the other databases

Database	**Search strategy**
EMBASE via Elsevier	#1. 'osteoporosis'/de #2. 'involutional osteoporosis'/exp #3. #1 OR #2 #4. 'resistance training'/de OR 'resistance exercise' OR 'resistance exercise training' OR 'resistance-type exercise' OR 'resistance-type training' OR 'strength training' OR 'strength-type exercise' OR 'strength-type training' #5. 'endurance training'/de #6. 'bone density'/de OR 'bone mineral density' OR 'density, bone' OR 'osseous density' #7. #3 AND #4 AND #5
Cochrane CENTRAL	**#1** Osteoporosis OR Osteoporoses OR Osteoporosis, Age-Related OR Osteoporosis, Age Related OR Bone Loss, Age-Related OR Age-Related Bone Loss OR Age-Related Bone Losses OR Bone Loss, Age Related OR Bone Losses, Age-Related OR Age-Related Osteoporosis OR Age-Related Osteoporosis OR Age-Related Osteoporoses OR Osteoporoses, Age-Related **#2** Resistance Training OR Training, Resistance OR Strength Training OR Training, Strength OR Weight-Lifting Strengthening Program OR Strengthening Program, Weight-Lifting OR Strengthening Programs, Weight-Lifting OR Weight Lifting Strengthening Program OR Weight-Lifting Strengthening Programs OR Weight-Lifting Exercise Program OR Exercise Program, Weight-Lifting OR Exercise Programs, Weight-Lifting OR Weight Lifting Exercise Program OR Weight-Lifting Exercise Programs OR Weight-Bearing Strengthening Program OR Strengthening Program, Weight-Bearing OR Strengthening Programs, Weight-Bearing OR Weight Bearing Strengthening Program OR Weight-Bearing Strengthening Programs OR Weight-Bearing Exercise Program OR Exercise Program, Weight-Bearing OR Exercise Programs, Weight-Bearing OR Weight Bearing Exercise Program OR Weight-Bearing Exercise Programs **#3** Endurance Training OR Training, Endurance OR Physical Endurance OR Endurance, Physical OR Exercise, Aerobic OR Aerobic Exercise OR Aerobic Exercises OR Exercises, Aerobic **#4** Bone Density OR Bone Densities OR Density, Bone OR Bone Mineral Density OR Bone Mineral Densities OR Density, Bone Mineral OR Bone Mineral Content OR Bone Mineral Contents OR Bone Diseases, Metabolic OR Metabolic Bone Diseases OR Bone Disease, Metabolic OR Metabolic Bone Disease OR Osteopenia OR Osteopenias OR Low Bone Density OR Bone Density, Low OR Low Bone Densities OR Low Bone Mineral Density **#1 AND #2 AND #3 AND #4**

Scopus	(TITLE-ABS-KEY (***"osteoporosis"*** OR ***"osteoporoses"*** OR ***"osteoporosis, age-related"*** OR ***"osteoporosis, age related"*** OR ***"bone loss, age-related"*** OR ***"age-related bone loss"*** OR ***"age-related bone losses"*** OR ***"bone loss, age related"*** OR ***"bone losses, age-related"*** OR ***"age-related osteoporosis"*** OR ***"age-related osteoporosis"*** OR ***"age-related osteoporoses"*** OR ***"osteoporoses, age-related"***) AND TITLE-ABS-KEY (***"resistance training"*** OR ***"training, resistance"*** OR ***"strength training"*** OR ***"training, strength"*** OR ***"weight-lifting strengthening program"*** OR ***"weight-lifting exercise program"*** OR ***"weight-bearing strengthening program"*** OR ***"exercise program, weight-bearing"*** OR ***"exercise programs, weight-bearing"*** OR ***"weight bearing exercise program"*** OR ***"weight-bearing exercise programs"***) AND TITLE-ABS-KEY (***"endurance training"*** OR ***"training, endurance"*** OR ***"physical endurance"*** OR ***"endurance, physical"*** OR ***"exercise, aerobic"*** OR ***"aerobic exercise"*** OR ***"aerobic exercises"*** OR ***"exercises, aerobic"***))
Web of Science	“Osteoporosis” OR “osteoporosis” OR "Osteoporosis, Age-Related" OR "Osteoporosis, Age Related" OR "Bone Loss, Age-Related" OR "Age-Related Bone Loss" OR "Age-Related Bone Losses" OR "Bone Loss, Age Related" OR "Bone Losses, Age-Related" OR "Age-Related Osteoporosis" OR "Age-Related Osteoporosis" OR "Age-Related osteoporosis" OR "osteoporosis, Age-Related" (Todos os campos) and "Resistance Training" OR "Training, Resistance" OR "Strength Training" OR "Training, Strength" OR "Weight-Lifting Strengthening Program" OR "Weight-Lifting Exercise Program" OR "Weight-Bearing Strengthening Program" OR "Exercise Program, Weight-Bearing" OR "Exercise Programs, Weight-Bearing" OR "Weight Bearing Exercise Program" OR "Weight-Bearing Exercise Programs" (Todos os campos) and "Endurance Training" OR "Training, Endurance" OR "Physical Endurance" OR "Endurance, Physical" OR "Exercise, Aerobic" OR "Aerobic Exercise" OR "Aerobic Exercises" OR "Exercises, Aerobic" (Todos os campos)
LILACS via BVS	(osteoporosis) AND (resistance training OR strength training)
PEDro	Possibilidades: Therapy: Strength training Fitness training

	Subdiscipline: Gerontology Method: Clinical trial * Use of boolean operator AND between terms
Open Grey	‘osteoporosis’
Clinical Trials	Condition or disease: osteoporosis Other terms: resistance training AND endurance training
ReBEC	osteoporose AND exercicio
WHO - International Clinical Trials Registry Platform (ICTRP)	*Advanced search:* Title: osteoporosis Condition: osteoporosis Intervention: exercise Recruitment status: ALL

Table S3. Articles excluded from analysis after full reading

Article	Reason for Exclusion
Watson SL, Weeks BK, Wei LJ, Horan SA and Beck BR (2015). Heavy resistance training is safe and improves bone, function, and stature in postmenopausal women with low to very low bone mass: novel early findings from the LIFTMOR trial. Osteoporosis International 26(12), 2889–2894. DOI: https://doi.org/10.1007/s00198-015-3263-2	**Type of study (short communication):** This is a short communication that contains preliminary data from the LIFTMOR trial. These data were published in full in another study by the same group of authors. This second study was included in this review.
FilipoviĆ TN, LazoviĆ MP, BackoviĆ AN, FilipoviĆ AN, IgnjatoviĆ AM, DimitrijeviĆ SS, and GopČeviĆ KR (2021). A 12-week exercise program improves functional status in postmenopausal osteoporotic women: randomized controlled study. *European Journal Of Physical and Rehabilitation Medicine* 57(1), 120–130.	**Type of intervention:** The exercise protocol combined aerobic exercises and resistance exercises.
Tolomio S, Ermolao A, Travain G, and Zaccaria M (2008). Short-term adapted physical activity program improves bone quality in osteopenic/osteoporotic postmenopausal women. *Journal of Physical Activity & Health* 5(6), 844–853.	**Type of intervention:** Multicomponent exercise protocol, combining resistance exercises, balance, mobility and aerobic exercises.
Going S, Lohman T, Houtkooper L, Metcalfe L, Flint-Wagner H, Blew R, Stanford V, Cussler E, Martin J, Teixeira P, Harris M, Milliken L, Figueroa-Galvez, and Weber J (2003). Effects of exercise on bone mineral density in calcium-replete postmenopausal women with and without hormone replacement therapy. *Osteoporosis International* 14(8), 637–643.	**Type of intervention:** Multicomponent exercise protocol including stretching, balancing, and weight-bearing activities, an additional weight-lifting circuit, and moderate-impact activities (e.g., walking/running, skipping, skipping).
De Matos O, Lopes Da Silva DJ, Martinez de Oliveira J, and Castelo-Branco C (2009). Effect of specific exercise training on bone mineral density in women with postmenopausal osteopenia or osteoporosis. *Gynecological Endocrinology* 25(9), 616-620.	**Type of intervention:** Intervention protocol combining resistance and aerobic exercises.
Wen HJ, Huang TH, Li TL, Chong PN, nd Ang BS (2017). Effects of short-term step aerobics exercise on bone metabolism and functional fitness in postmenopausal women with low bone mass. *Osteoporosis International* 28(2), 539–547.	**Type of intervention:** Protocol based on aerobic step exercise.
Tolomio S, Ermolao A, Lalli A, and Zaccaria M (2010). The effect of a multicomponent dual-modality exercise program targeting osteoporosis on bone health status and physical function	**Type of intervention:** Protocol included exercises in an aquatic environment and used resistance exercises combined with aerobic exercises.

capacity of postmenopausal women. *Journal of Women & Aging* 22(4), 241–254.	
Marín-Cascales E, Rubio-Arias JA, and Alcaraz PE (2019). Effects of two different neuromuscular training protocols on regional bone mass in postmenopausal women: A randomized controlled trial. Frontiers in physiology, 10, 452676.	**Type of intervention:** The intervention protocols included multicomponent training and the use of exercises on a vibrating platform (whole body vibration).
Gianoudis J, Bailey CA, Sanders KM, Nowson CA, Hill K, Ebeling PR, and Daly RM (2012). Osteo-cise: strong bones for life: protocol for a community-based randomised controlled trial of a multi-modal exercise and osteoporosis education program for older adults at risk of falls and fractures. *BMC Musculoskeletal Disorders* 13, 78.	**Type of intervention:** The intervention protocols included multicomponent training.
Anupama DS, Norohna JA, Acharya KK, Ravishankar S, and George A (2020). Effect of exercise on bone mineral density and quality of life among postmenopausal women with osteoporosis without fracture: A systematic review. International journal of orthopaedic and trauma nursing, 39, 100796.	**Type of study (Study design):** Systematic review study.
Zhao R, Zhao M, and Xu Z (2015). The effects of differing resistance training modes on the preservation of bone mineral density in postmenopausal women: a meta-analysis. *Osteoporosis International* 26(5), 1605–1618.	**Type of study (Study design):** Systematic review study.
Yu PA, Hsu WH, Hsu WB, Kuo LT, Lin ZR, Shen WJ, and Hsu RW (2019). The effects of high impact exercise intervention on bone mineral density, physical fitness, and quality of life in postmenopausal women with osteopenia: A retrospective cohort study. *Medicine* 98(11), e14898.	**Type of study:** Retrospective study.
Behrens M, Müller K, Kilb JI, Schleese L, Herlyn PK, Bruhn S, Mittlmeier T, Schober HC, and Fischer DC (2017). Modified step aerobics training and neuromuscular function in osteoporotic patients: a randomized controlled pilot study. *Archives of Orthopaedic and Trauma Surgery* 137(2), 195–207.	**Type of intervention:** Protocol based on aerobic exercise. **Type of study (Study design):** Pilot study. **Type of outcome:** Did not evaluate BMD outcomes and/or markers of bone metabolism.
Burke N.,França, FJR, De Meneses SRF, Cardoso VI, and Marques AP (2010). Postural control in elderly persons with osteoporosis: efficacy of an intervention program to improve balance and muscle strength: a randomized	**Type of outcome:** Did not include BMD outcomes and/or bone metabolism biomarkers.

controlled trial. *American Journal of Physical Medicine & Rehabilitation* 89(7), 549-556.	
Nicholson VP, McKean M, Slater, GJ, Kerr A, and Burkett BJ (2015). Low-load very high-repetition resistance training attenuates bone loss at the lumbar spine in active post-menopausal women. *Calcified Tissue International* 96(6), 490–499.	**Participants:** Participants did not have a clinical diagnosis of osteoporosis or osteopenia.
Holubiac IȘ, Leuciuc FV, Crăciun DM, and Dobrescu T (2022). Effect of Strength Training Protocol on Bone Mineral Density for Postmenopausal Women with Osteopenia/Osteoporosis Assessed by Dual-Energy X-ray Absorptiometry (DEXA). *Sensors (Basel, Switzerland)* 22(5), 1904.	**Randomization:** Non-randomized study.

Table S4. PRISMA checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	2
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	3
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	5
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	4
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	4
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	7
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	7
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	7
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	7
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	10
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	9
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	12
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	8
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	16-17

Section and Topic	Item #	Checklist item	Location where item is reported
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	9-10
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	10
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	22
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	28
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	25
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	12
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	12
Study characteristics	17	Cite each included study and present its characteristics.	15-17
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	24
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	23
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	25-26
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	23
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	14
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	25-26
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	14
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	25-26
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	27-28
	23b	Discuss any limitations of the evidence included in the review.	27-28
	23c	Discuss any limitations of the review processes used.	28
	23d	Discuss implications of the results for practice, policy, and future research.	29

Section and Topic	Item #	Checklist item	Location where item is reported
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	4
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	5
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	29
Competing interests	26	Declare any competing interests of review authors.	29
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	29