Review

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Effects Of Moderate-Frequency Resistance Training On Cardiometabolic Risk Factors In Adults With Overweight And Obesity: A Systematic Review And Meta-Analysis

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Review

Effects of Moderate-Frequency Resistance Training on Cardiometabolic Risk Factors in Adults with Overweight and Obesity: A Systematic Review and Meta-Analysis

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Abstract: Background: Cardiometabolic risk factors (CRFs) are significant health concerns among adults with overweight and obesity. Resistance training (RT) is known to manage CRFs, but the impact of moderate-frequency RT (two to three times weekly) remains unclear. **Methods:** We conducted a systematic review and meta-analysis of randomized controlled trials (RCTs) comparing moderate-frequency RT with non-exercise control or usual care in overweight and obese adults. Searches were performed in PubMed, Web of Science, EMBASE, and Cochrane Library up to February 2024, following the PRISMA 2020 guidelines. Eligible studies included non-athletic adults (BMI ≥ 25) aged 18 years or older, with RT interventions lasting 7 weeks or longer. **Results:** Fifteen RCTs were included. Moderate-frequency RT significantly reduced systolic blood pressure by -4.66 mmHg (95% CI -9.34 to 0.02, p=0.01) and mean arterial pressure by -6.48 mmHg (95% CI -10.63 to -2.33, p=0.002) compared to controls. Additionally, RT significantly lowered fasting insulin levels by -12.52 mmol/L (95% CI -24.17 to -0.88, p=0.04) and HOMA-IR by -1.49 (95% CI -1.63 to -1.35, p< 0.00001). Improvements were more pronounced in participants with dietary control. **Conclusions:** Moderate-frequency RT effectively improves CRFs in overweight and obese adults, suggesting its potential as a beneficial intervention for this population.

Keywords: Resistance training; Overweight; Obesity; Cardiometabolic risk factors

PROSPERO registration number: CRD42022343167

1. Introduction

Over recent decades, significant environmental and lifestyle changes have contributed to the increasing prevalence of overweight and obesity [1,2]. Research strongly links these conditions to cardiometabolic health issues including, including hypertension, hyperglycemia, insulin resistance, high cholesterol, and elevated triglyceride levels [3]. These factors collectively heighten the risk of cardiovascular disease (CVD) and mortality, potentially shortening lifespan [4].

The term "cardiometabolic risk factors (CRFs)" encompasses all risk factors associated with diabetes and CVD, including being overweight and obese, elevated blood glucose and blood pressure, insulin resistance, and abnormal lipid metabolism [5]. Addressing all CRFs is essential due to their interplay, which exacerbates CVD vulnerability and contributes to its pathogenesis [5]. The American Heart Association has issued a statement advocating physical activity as a strategy to ameliorate CRFs [6].

Resistance training (RT) involves utilizing equipment such as resistance machines, weights, elastic bands, or one's own body weight to improve muscle strength and endurance. This form of exercise primarily enhances skeletal muscle strength, muscle cross-sectional area, muscle fiber number, and cardiac pumping capacity, while also facilitating adaptive vasodilation [7,8]. Conversely, a reduction in skeletal muscle mass coupled with an increase in body fat (e.g., sarcopenic obesity) is detrimental to the well-being of adults with obesity. This scenario can lead to decreased physical performance, increased cardiometabolic risk, and increased likelihood of adverse clinical outcomes [9,10]. Notably, RT is the only non-pharmacological intervention that consistently counteracts age-related declines in skeletal muscle mass, strength, and power [11,12].

Aerobic exercise is known to enhance CRFs in populations with obesity. However, it usually requires prolonged exercise duration and a conductive environment, which may reduce exercise compliance among individuals with overweight and obesity [13]. Additionally, previous meta-analyses have shown that the effect of aerobic exercise on blood glucose depends on the appropriateness of the training load, which may be compromised if individuals are unable or unwilling to complete the prescribed training [14]. Conversely, RT does not encounter the constraints of space, equipment, or time commitments, redenring it a convenient option for individuals with overweight and obesity, whether at home or another location [15]. Indeed, RT aligns with global physical activity guidelines that advocate for 2-3 RT sessions per week for adults [16,17].

It is worth noting that in recent years, concurrent training (a combination of both aerobic training and RT) has exhibited efficacy in improving CRFs in adults [18,19]. However, concurrent training is time-demanding, and the interference effects between aerobic training and RT warrant careful consideration due to the possible compromise of skeletal muscle mass and function [20]. Recent studies have reported the positive effects of high-intensity interval training(HIIT) on CRFs in the general population [21], but these effects have not been validated in populations with overweight and obesity. Considering that overweight and obesity are often associated with various metabolic and other diseases, performing HIIT without professional supervision may increase the risk of injury or impair the function of certain organs in this population [22,23]. On the contrary, RT can be adjusted to individual perceptions and, when performed with an optimal dose interval, can mitigate barriers to participation and positively influence the intervention outcome [24]. Based on the advantages of RT, it becomes imperative to elucidate the effects of moderate-frequency RT (two or three times weekly) on cardiometabolic health outcomes, to support further research endeavors and the practical application of RT.

Currently, although some studies have reported CRFs as a secondary outcome, there is limited research employing it as the primary outcome for RT, especially in populations with overweight and obesity. Moreover, interpreting the impact of RT on CRFs is limited by methodological diversity, such as RT frequency and dietary regulation. Previous meta-analyses have explored the effects of short-, medium- and long-term RT on CRFs in adults, while ignoring the assessment of improved cardiometabolic health at the prevailing and recommended frequency of RT endorsed by the global physical activity guidelines [25]. A high-quality systematic review and meta-analysis can help overcome these challenges by providing more precise effect sizes while accounting for bias and heterogeneity. Therefore, the objective of this systematic review is to comprehensively assess the effects of moderate-frequency RT on CRF outcomes in adults with overweight and obesity, with a subgroup analysis examining the role of dietary control.

2. Methods

2.1. Protocol

This systematic review and meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist [26] and was registered with PROSPERO(ID: CRD42022343167).

2.2. Eligibility Criteria

To determine the inclusion criteria for the literature, we followed the PICOS model (see Table 1).

Table 1. PICOS criteria for the inclusion of studies in the systematic review.

Parameter	Inclusion Criteria
Population	Adults with overweight and obesity
Intervention	Resistance training
Comparators	No additional physical exercise
Outcomes	Waist circumference, systolic blood pressure, diastolic blood pressure, mean arterial pressure, variables related to glucose metabolism and lipids, including glycated hemoglobin, fasting glucose, balance model assessment of insulin resistance (HOMA-IR), total cholesterol (TC), triglycerides (TG), HDL cholesterol, LDL cholesterol, fasting insulin
Study design	All randomized controlled trials

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2.3. Information Sources and Search Strategy

A systematic search was conducted on PubMed, Cochrane Library, and Web of Science databases from inception until April 2023. Medical subject heading (MeSH) terms and text words related to overweight, obesity, resistance training, glucose metabolism, lipid metabolism, and randomized controlled trials were used to identify studies that could be potentially relevant. We also checked the reference lists of all trials that met the screening criteria, although no additional eligible trials were found.

The search strategy employed a combination of subject headings and free text words, adjusted for each database's characteristics. The search was conducted using four main categories of terms: (ⅰ) population; (ⅱ) intervention; (ⅲ) study type; and (ⅳ) outcome. For example, the specific search strategy used in PubMed is shown in Table 2. The reference lists of the included studies were also searched to supplement the obtained information.

Table 2. Search strategies for PubMed.

#1 resistance training [Mesh]
#2 training, resistance OR strength training OR training, strength OR weight-lifting OR strengthening program OR strengthening program OR weight-lifting OR strengthening programs OR weight-lifting OR weight lifting strengthening program OR weight-lifting strengthening programs OR weight-lifting exercise program OR exercise program OR exercise programs OR weight lifting exercise program OR weight-lifting exercise programs OR weight-bearing strengthening program OR strengthening program OR weight-bearing OR strengthening programs OR weight-bearing OR weight bearing strengthening program OR weight-bearing strengthening programs OR weight-bearing exercise program OR exercise program OR weight-bearing OR exercise programs OR weight-bearing OR weight-bearing exercise program OR weight-bearing exercise programs
#3 #1 OR #2
#4 obesity [Mesh]
#5 appetite depressants OR body weight OR diet, reducing OR skinfold thickness OR lipectomy OR anti-obesity agents OR bariatrics
#6 #4 OR #5

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#7 overweight [Mesh]
#8 glucose metabolism disorders [Mesh]
#9 disorder, glucose metabolism OR disorders, glucose metabolism OR metabolism disorder, glucose OR metabolism disorders, glucose OR glucose metabolic disorders OR glucose metabolic disorders OR disorder, glucose metabolic OR disorders, glucose metabolic OR metabolic disorder, glucose OR metabolic disorders, glucose OR glucose metabolism disorder OR glucose metabolic disorder
#10 #8 OR #9
#11 Lipid metabolism [Mesh]
#12 Metabolism, lipid OR lipid metabolism disorder OR metabolism disorder, lipid OR metabolism disorders, lipid
#13 #11 OR #12
#14 Glycated hemoglobin OR Fasting plasma glucose OR Homeostatic model assessment-B cell function OR Homeostatic model assessment of insulin resistance OR Triglycerides OR Total-cholesterol OR HDL-cholesterol OR LDL-cholesterol OR insulin
#15 randomized controlled trial [Publication Type]
#16 randomized OR RCT
#17 #15 OR #16
#18 #3 AND #6 AND #10 AND #13 AND #17

2.4. Study Selection and Data Extraction

To identify relevant studies, we applied the following inclusion criteria: (i) reports that included clear participant information for body mass index (BMI) and age, adhering to the WHO definitions of overweight and obesity used (BMI ≥ 25 for overweight and BMI ≥ 30 for obesity); (ii) studies that included a control group, i.e., no additional physical exercise; and (iii) studies that employed a randomized controlled trial design. Exclusions were applied to studies that met the following criteria: (i) studies involving pregnant participants; (ii) studies involving exercise forms other than resistance training, such as a combination of aerobic exercise and resistance training; (iii) studies that used an acute resistance training intervention [25]; and (iv) studies that were published in a language other than English. After identifying studies that met the inclusion criteria, we first eliminated duplicate content. Subsequently, articles were subjected to title and abstract screening to eliminate those that did not meet the eligibility criteria. Finally, we carefully reviewed the full texts of these articles, excluding those that did not meet the inclusion criteria.

The data extraction process from the selected reference articles was performed using Microsoft Excel spreadsheets (Microsoft Corporation, Redmond, WA, USA). To ensure accuracy, another author scrutinized the data extraction, and any discrepancies were resolved through discussion. In situations where a consensus could not be reached between the two authors, a third person was consulted for resolution. The extracted data included information on study source (authors, publication year, country, and region), participant demographics (age, gender, and BMI), resistance training intervention details (total time, frequency, and intensity), and outcome measurements. If a study had multiple intervention arms (such as different resistance training doses, regimens, or participant populations), and at least one of these arms met the inclusion criteria, those individual arms were treated as distinct studies, termed trials. In addition, one author independently reviewed the titles and abstracts of all referenced articles, screening them against the inclusion criteria. Following the removal of duplicate articles, the other author further reviewed the full texts of the remaining articles. Any discrepancies between the two authors were resolved through discussion to reach a consensus.

2.5. Risk of Bias

We used the Cochrane Risk of Bias tool to assess the following aspects of bias risk: (1) random sequence generation (selection bias); (2) allocation concealment (selection bias); (3) blinding of participants and personnel (performance bias); (4) blinding of outcome assessment (detection bias); (5) incomplete outcome data (attrition bias); (6) selective reporting (reporting bias); and (7) other biases [27]. In parallel, we used funnel plots to assess potential publication bias [28].

2.6. Data Synthesis and Analysis

Meta-analysis was conducted using Review Manager (RevMan V.5.4) when more than two studies reported on the same outcome. Effect sizes were expressed as mean differences with 95% confidence intervals. To assess heterogeneity, both the I^2 statistic and p-value were used, with $I^2>50\%$ and $P<0.10$ indicating significant heterogeneity. In instances of significant heterogeneity, a random-effects model was employed for analysis. Conversely, if heterogeneity was not significant, a fixed-effects model was applied.

Sensitivity analysis was conducted to examine the impact of individual studies on the overall effect size by systematically excluding each study from the analysis. If significant heterogeneity was detected, but no clinical heterogeneity was absent, a random-effects model was used for analysis. If significant heterogeneity was observed but its source could not be identified, descriptive analysis was performed. Furthermore, funnel plots were utilized to assess publication bias, with a significance level of α=0.05. The Z-test was used to determine statistical significance, with $p<0.05$ indicating a significant result.

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3. Results

3.1. Search results

Initially, an extensive search across multiple databases yielded a total of 7011 references. After removing 573 duplicates and 2478 references using the Endnote automatic screening tool, 3925 references were excluded for other reasons such as animal experiments, systematic reviews, studies irrelevant to the research topics, and lack of full text availability. This left 35 references for a detailed screening of titles and abstracts. Subseqently, 12 articles were excluded due to the absence of resistance training or had non-pure resistance training interventions. One reference involved pregnant subjects, seven were written in languages other than English, and two lacked sufficient data for meaningful analysis. Ultimately, 13 articles, involving 651 adults with overweight and obesity, were included in the final analysis, with two trials featuring two resistance training groups (Refer to Figure 1 for a visual representation).

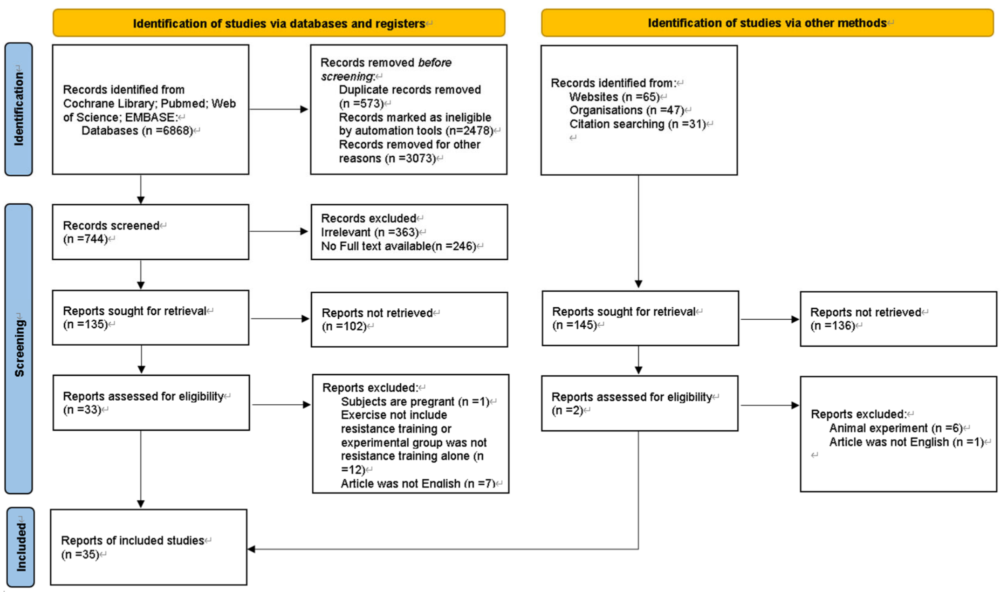

Figure 1. PRISMA Flow diagram of literature search.

3.2. Characteristics of the included studies

Table 2 presents the basic characteristics of the included studies. These 15 randomized controlled trials encompassed 691 participants, with 343 in the control group and 348 in the resistance training group. The trials were conducted in 9 countries at various settings, such as hospitals, specialized research centers, universities, and fitness centers. The number of participants in the resistance training group varied from 7 to 62 individuals per study, with 5 studies only including female participants and 1 study only including male participants. All participants in the studies were adults with overweight and obesity, ranging from 21 to 71 years old.

The duration of resistance training interventions exhibited a range from 7 weeks to 24 weeks, with resistance training sessions performed two to three times per week. All resistance training involved multiple muscle groups in different body regions. The majority of resistance training entailed a progressive intensity approach ranging from 40% 1RM to 85% 1RM. The regimen encompassed 1 to 8 sets per session, each comprising 8 to 20 repetitions per set, with a rest period between each set.

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Table 3. Summary of descriptive characteristics of included articles.

Author	Year	Samples(F/M)	Age(years)	Duration	Intervention	Primary outcomes
Dejan Reljic[29]	May-21	23/7	51.7 ± 11.7	12 weeks, twice a week	Weeks 1-4:50-60%1RM; Weeks 5-8:60-75%1RM; Weeks 9-12:70-80%1RM, one exercise per set	A, B, C, D, E, F, I, J, K
Dejan Reljic [29]	May-21	23/7	51.7 ± 11.7	12 weeks, three times a week	Weeks 1-4:50-60%1RM; Weeks 5-8:60-75%1RM; Weeks 9-12:70-80%1RM, three exercises per set	A, B, C, D, E, F, I, J, K
Javier Ibáñez [30]	Aug-09	12/0	51.4 ± 5.5	16 weeks, twice a week	During the first 8 weeks of the training period, subjects were loaded at 50 to 70% of the individual 1-RM, and during the last 8 weeks of the training period, the load was 70 to 80% of the maximum load. In addition, from week 8 to week 16, subjects performed a partial (20%)	A, F, G, H, I, J, K, L

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					calf extension and bench press set-up with loads ranging from 30% to 50% of the maximum load.	
Itamar Levinger [31]	Oct-07	5/9	51.9 ± 5.8	10 weeks, three times a week	With a 48-h recovery between sessions, the initial training intensity was two sets of 15-20 reps at 40-50% 1RM each. Starting in weeks 2-10, subjects performed three sets of each exercise at 50-85% 1RM for 8-20 repetitions.	A, B, C, F, I, J
Itamar Levinger [31]	Oct-07	6/4	48.9±7.4	10 weeks, three times a week	The total intervention duration was 10 weeks, with 48-h of recovery between sessions, and the initial training intensity was two sets of 15-20 reps at 40-50% 1RM. Starting in weeks 2-10, subjects	A, B, C, F, I, J

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					performed three sets of each exercise at 50-85% 1RM for 8-20 repetitions.	
Steven K [32]	Sep-13	7/0	20.9 ± 1.59	7 weeks, three times a week	At 60% 1-RM for 3 days/week and approximately 60 minutes/repetition, subjects performed three sets of 8-12 repetitions with 90-120 seconds of rest between sets.	A, F, L
Robert G. Memelink [33]	Dec-20	24/38	65.8 ± 6.4	13 weeks, three times a week	Total intervention length 13 weeks, three times a week, one hour each time	A, E, F, G, L
Ramin Shabani [34]	Apr-15	10/0	51.3 ± 6.63	12 weeks, three times a week	In the initial 1-3 weeks, the intensity is 40-50% 1-RM, 4-8 weeks, 50-65% 1-RM, with a total of 8 sets of movements, each set	F

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					repeated 8-12 times, with 3 minutes rest between sets	
D.W. Dunstan [35]	Feb-98	5/5	51.1 ± 2.2	8 weeks, three times a week	The total duration of the intervention was 8 weeks, three times a week, with a weight of 50-55% 1RM for each exercise.	B, C. F. L
Cíntia E. Botton [36]	Oct-18	8/14	68.6 ± 7.06	12 weeks, three times a week	The initial training load is determined during the familiarization training and increases with the load until a maximum of 15 repetitions is reached.	E, F, H, I, J, K
Sophie Drapeau [37]	Apr-11	22/0	58.5±4.6	24 weeks, three times a week	Phase 1: Start training (3 weeks, 15 repetitions, 2-3 sets each, 90-120 seconds between sets); Phase 2 (5 weeks, 12 repetitions, 2-3 sets each, 90 seconds between sets); Phase 3 (9 weeks, 8-10 repetitions, 2-4	F, G, H, I, J, K, L

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					sets each, 120-180 seconds between sets); Phase 4 (8 weeks, 10-12 repetitions, 3-4 sets each, 60-90 seconds between sets))	
RC Plotnikoff [38]	Jun-10	13/8	54±12	16 weeks, three times a week	Total intervention duration of 16 weeks, 3 training sessions per week	A, B, C, E, F, I, J, K, L
Mika Venojärvi [39]	Aug-12	0/40	54 ±7.2	12 weeks, three times a week	Increase exercise intensity and load every 4 weeks	A, B, C, E, F, G, H, I, J, K, L
Carmen Castaneda [40]	Sep-02	19/12	66 ± 5.57	16 weeks, three times a week	For 45 minutes each time, subjects performed three sets of eight repetitions on each machine at a time.	A, B, C, F, H, J, K
Marisol García-Unciti [41]	Dec-12	12/0	51.4±5.5	16 weeks, twice a week	During the first 8 weeks of the training period, subjects were loaded at 50-70% of the individual 1-RM, and	A, F, H, I, J, K, L

	during the last 8 weeks of the training period, the load was 70-80% of the maximum load.

Note: Values are presented as means ± SD. **F:** female; **M:** male; **A**: Waist circumference (cm); **B:** Systolic blood pressure(mmHg); **C:** Diastolic blood pressure(mmHg); **D:** Mean arterial pressure(mmHg); **E:** Glycated hemoglobin (%); **F**: Fasting glucose (mmol·L^{-1}); **G**: HOMA-IR(Homeostasis model assessment for insulin resistance); **H**: Serum total cholesterol (mmol·L^{-1}); **I**: Triglyceride (mmol·L^{-1}); **J**: High-density lipoprotein (mmol·L^{-1}); **K**: Low-density lipoprotein (mmol·L^{-1}); **L**: Fasting insulin (pmol·L^{-1}).

3.3. Risk of bias

3.3.1. Selection bias

All studies employed random allocation for group assignment, with 7 randomized controlled trials using a describable method for sequence generation, and the remaining 6 studies having unclear risk due to insufficient information on randomization methods. The majority of studies did not report allocation concealment and were considered to have unclear risk.

3.3.2. Performance and detection bias

All studies exhibited a notable susceptibility to performance bias (i.e., lack of blinding among intervention and outcome assessors). This absence of blinding among researchers could have introduced potential biases into the measurement of blood pressure and the extent of improvement in some indicators such as glucose and lipid metabolism among participants. Most studies were judged as unclear for detection bias (i.e., blinding of outcome assessors) due to insufficient information provided in the studies. Two studies stood out with a pronounced risk of detection bias.

3.3.3. Attrition bias

The majority of studies were categorized as having a low risk of attrition bias. However, three trials received a high-risk rating due to either high dropout rates or the exclusion of specific participants from the analysis.

3.3.4. Reporting bias

All studies were rated as low risk for selective reporting bias.

3.3.5. Publication bias

All measurements were plotted in funnel plots, which were asymmetrical, indicating potential publication bias.

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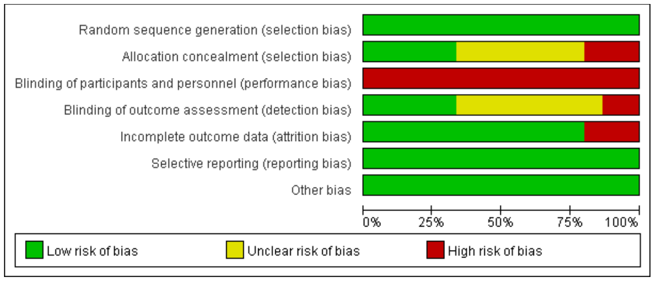

Figure 2. Results of the risk of bias assessment of the 15 studies included in this systematic review. **Green:** low risk of bias. **Yellow:** unclear risk of bias. **Red:** high risk of bias.

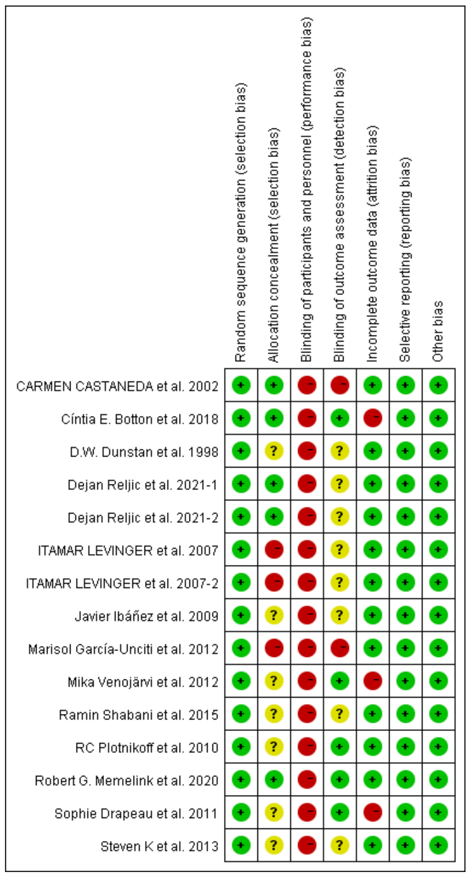

Figure 3. Results of the risk of bias assessment of the 15 studies included in this systematic review. **Green:** low risk of bias. **Yellow:** unclear risk of bias. **Red:** high risk of bias.

3.4. Study outcomes

Waist

Figure 4 illustrates the waist circumference data encompassing 550 participants from 11 trials. Evaluating the effect of resistance training on waist circumference in adults with overweight and obesity, no heterogeneity was observed among the studies (I^2=0%, p=0.5). Employing a fixed-effects model for analysis yielded a combined effect size of MD = 0.27, with 95% CI spanning from = 0.10 to 0.44 (p=0.002). Subgroup analyses showed no between-study heterogeneity in the dietary control group, with a total effect size of MD = 0.30, and 95%CI of = 0.13 to 0.47 ($p<0.001$); there was no heterogeneity in the no-dietary-control group, with a total effect size of MD = of -1.33, and 95%CI from = -2.62 to -0.03 (p=0.04). These findings suggest that resistance training does not manifest a favorable impact on the enhancement of waist circumference in adults with overweight and obesity.

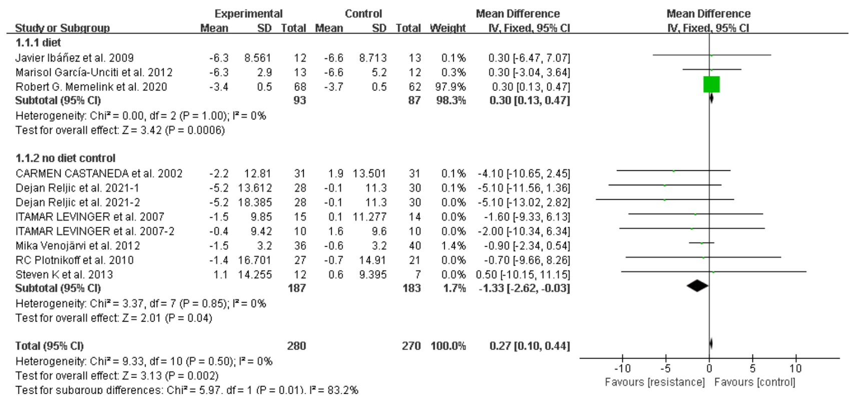

Figure 4. Forest plot: difference in waist circumference between resistance training group and control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Systolic blood pressure

Figure 5 presents the systolic blood pressure data encompassing 372 participants from 8 trials. Exploring the effect of resistance training on systolic blood pressure in adults with overweight and obesity, heterogeneity was observed among the studies (I^2=60%, p=0.01). Employing a random-effects model for the analysis, a combined effect size of MD = -4.66 is derived, accompanied by a 95% CI of = -9.34 to 0.02 (p=0.05). These findings suggest that resistance training has a positive effect on improving systolic blood pressure in adults with overweight and obesity.

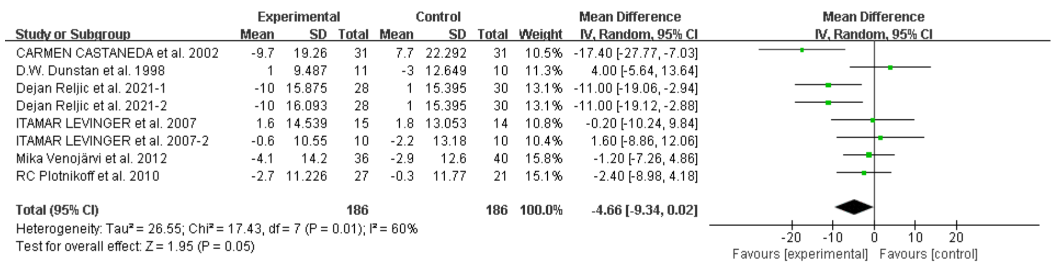

Figure 5. Forest plot: difference in systolic blood pressure between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Diastolic blood pressure

Figure 6 presents the diastolic blood pressure data encompassing 372 participants from 8 trials. Delving into the effect of resistance training on diastolic blood pressure in adults with overweight and obesity, no heterogeneity was observed among the studies (I^2=0%, p=0.8). The analysis adopted a fixed-effects model, yielding a combined effect size of MD = -1.32, with 95% CI of = -3.03 to 0.38 (p=0.13). These findings indicate that resistance training could potentially yield a favorable influence on improving diastolic blood pressure in adults with overweight and obesity.

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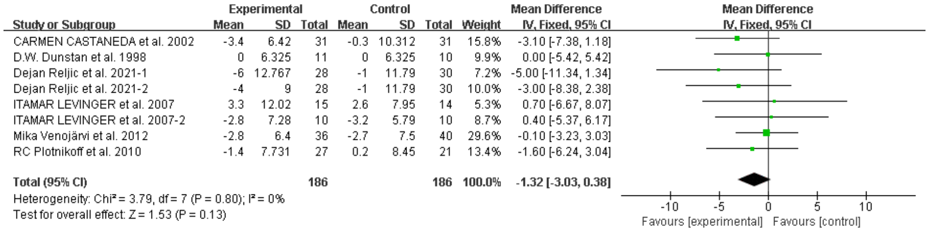

Figure 6. Forest plot: difference in diastolic blood pressure between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Mean arterial pressure

Figure 7 illustrates the mean arterial pressure data involving 116 participants from 2 trials. Exploring the potential effect of resistance training on mean arterial pressure in adults with overweight and obesity, no heterogeneity was observed among the studies (I^2=0%, p=0.81). Employing a fixed-effects model for analysis, a combined effect size of MD = -6.48 is derived, with 95% CI of = -10.63 to -2.33 (p=0.002). These findings indicate that resistance training exerts a significant positive effect on the enhancement of mean arterial pressure in adults with overweight and obesity.

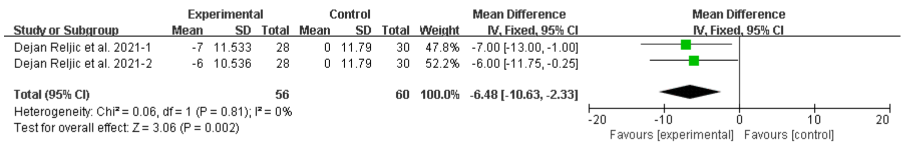

Figure 7. Forest plot: difference in mean arterial pressure between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Glycated hemoglobin (HbA_{1c} (%))

Figure 8 illustrates the glycated hemoglobin (HbA_{1c}) data derived from 418 participants across 6 trials. In examining the effect of resistance training on HbA_{1c} levels in adults with overweight and obesity, a substantial degree of heterogeneity was observed among the studies (I^2=89%, p<0.001). Employing a random-effects model, the resulting combined effect size is MD = 0.2, with a 95% CI spanning from = -0.33 to 0.73 (p=0.46). Subgroup analyses revealed a total effect size of MD = 1.30, with 95%CI from = -2.40 to 5.00 (p=0.49) in the dietary control group; notable heterogeneity (I^2=91%, p<0.001) is observed in the no-dietary-control group, with a total effect size of MD = 0.18,and 95%CI spanning from = -0.36 to 0.71 (p=0.52). These findings indicate that resistance training does not yield a favorable impact on the enhancement of HbA_{1c} levels in adults with overweight and obesity.

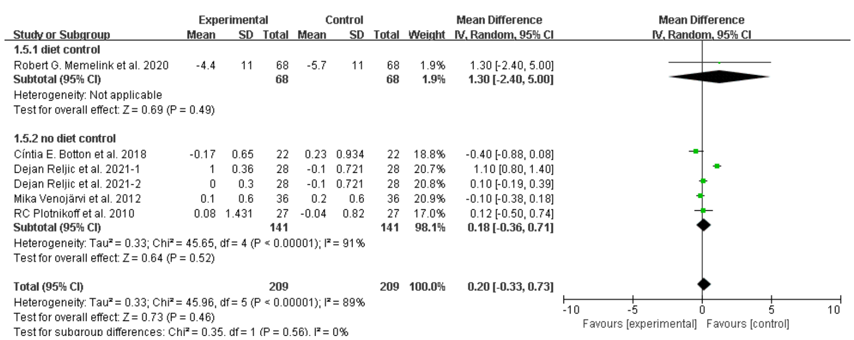

Figure 8. Forest plot: difference in glycated hemoglobin between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Fasting glucose

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Figure 9 illustrates the fasting glucose data from 681 participants across 15 trials. In examining the effect of resistance training on fasting glucose levels in adults with overweight and obesity, no heterogeneity was observed among the studies (I^2=0%, p=0.6). Utilizing a fixed-effects model for analysis, the resultant combined effect size stands at MD=-0.01, with a 95% CI spanning from = -0.08 to 0.05 (p=0.75). Subgroup analyses revealed a notable level of between-study heterogeneity (I^2=67%, p=0.05) in the dietary control group, with a total effect size of MD = -0.50, along with a 95%CI spanning from = -0.24 to 0.14 (p=0.6); there was no heterogeneity within the no-dietary-control group, with a total effect size of MD = -0.01, and a 95%CI ranging from = -0.07 to 0.06 (p=0.88). These findings indicate that resistance training does not yield a positive influence on the enhancement of fasting glucose levels in adults with overweight and obesity.

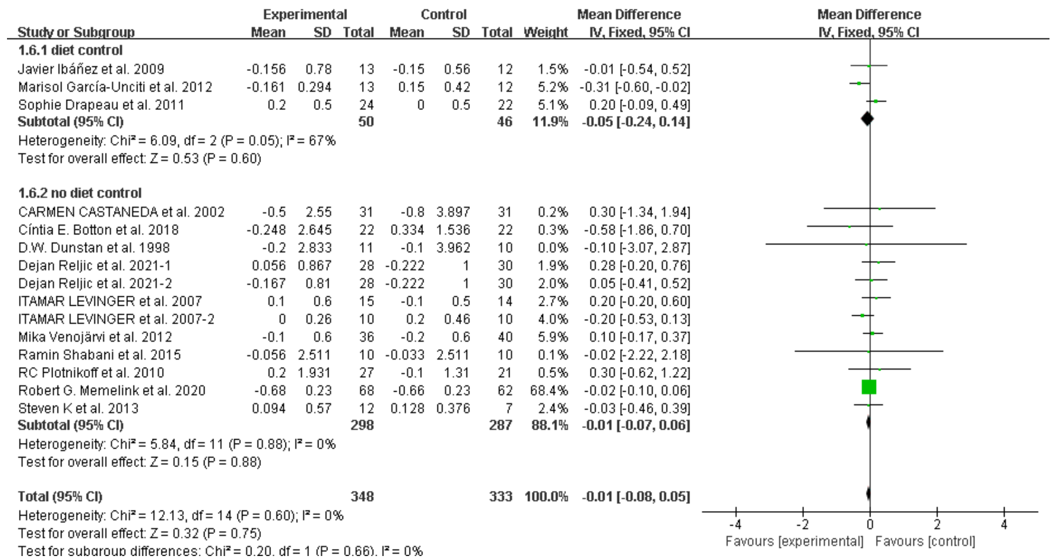

Figure 9. Forest plot: difference in fasting glucose between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Homeostasis model assessment for insulin resistance

Figure 10 illustrates the homeostasis model assessment for insulin resistance (HOMA-IR) data encompassing 277 participants from 4 trials. In examining the effect of resistance training on HOMA-IR in adults with overweight and obesity, a moderate level of heterogeneity was observed among the studies (I^2=48%, p=0.12). Employing a fixed-effects model for analysis, the resulting combined effect size is MD = -1.49, with a 95% CI spanning from = -1.63 to -1.35 ($p < 0.001$). Subgroup analyses revealed no between-study heterogeneity in the dietary control group, with a total effect size of MD = -1.52, accompanied by a 95%CI ranging from = -1.66 to -1.38 ($p < 0.001$); within the no-dietary group a total effect size of MD = -0.6 is observed, with a 95%CI spanning from = -1.41 to 0.21 (p=0.15). These findings indicate that resistance training exerts a significant and positive effect on the enhancement of HOMA-IR in adults with overweight and obesity.

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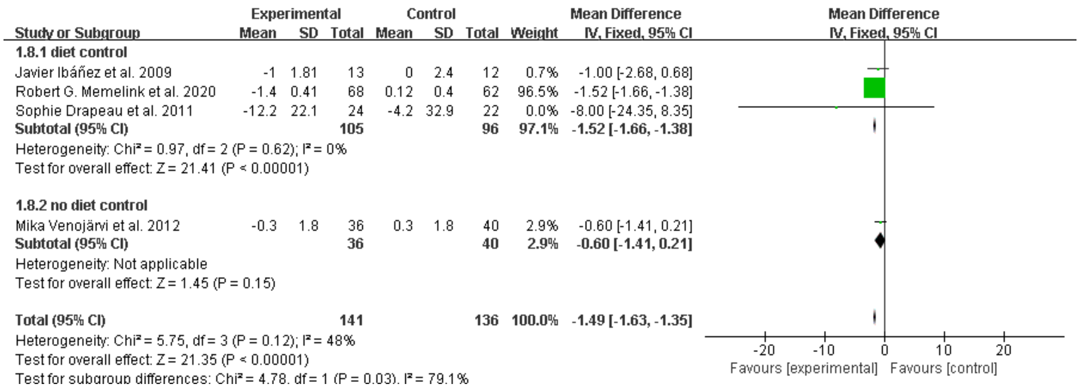

Figure 10. Forest plot: difference in homeostasis model assessment for insulin resistance between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Total cholesterol

Figure 11 illustrates the total cholesterol data derived from 278 participants spanning 6 trials. In examining the effect of resistance training on total cholesterol in adults with overweight and obesity, a substantial degree of heterogeneity was observed among the studies (I^2=63%, p=0.02). Utilizing a random-effects model for analysis, the resulting combined effect size is MD=-0.53, with a 95% CI ranging from = -1.14 to 0.08 (p=0.09). Subgroup analyses revealed no between-study heterogeneity in the dietary control group, with a total effect size of MD = -1.94, alongside a 95%CI ranging from = -3.07 to -0.82 (p＜0.001); within the no-dietary-control group low level of heterogeneity (I^2=10%, p=0.33) is observed, with a total effect size of MD = 0.00, alongside a 95%CI ranging from = -0.26 to 0.27 (p=0.98). These findings indicate that resistance training could potentially yield a favorable impact on the enhancement of total cholesterol in adults with overweight and obesity.

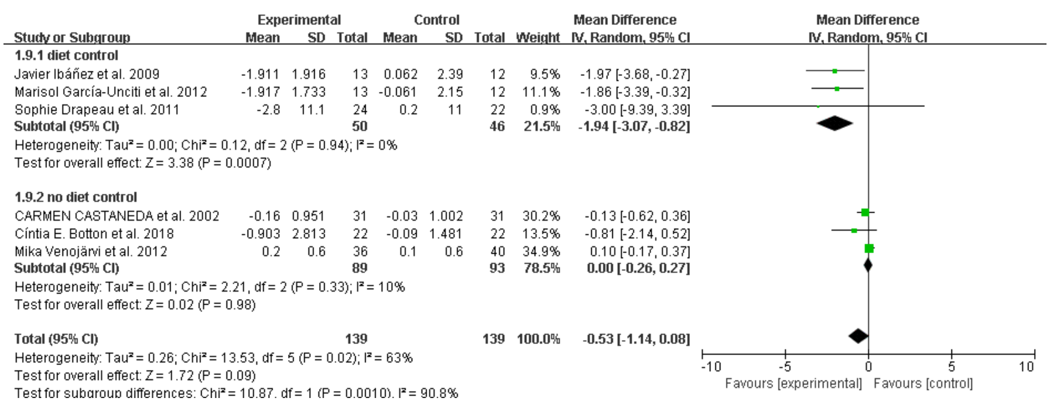

Figure 11. Forest plot: difference in total cholesterol between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Total triglycerides

Figure 12 illustrates total triglyceride data from 419 participants across 10 trials. In examining the effect of resistance training on total triglyceride levels in adults with overweight and obesity, no heterogeneity was observed among the studies (I^2=0%, p=0.83). Utilizing a fixed-effects model for analysis, a combined effect size of MD = -0.03 is observed, with a 95% CI ranging from = -0.20 to 0.14 (p=0.72). Subgroup analyses revealed no between-study heterogeneity in the dietary control group, with a total effect size of MD = 0.30, alongside a 95%CI ranging from = -0.96 to 1.56 (p=0.64); no heterogeneity is observed within the no-dietary-control group, with a total effect size of MD = -0.04, alongside a 95%CI ranging from = -0.21 to 0.13 (p=0.67). These findings indicate that resistance training does not yield a favorable impact on the enhancement of total triglyceride levels in adults with overweight and obesity.

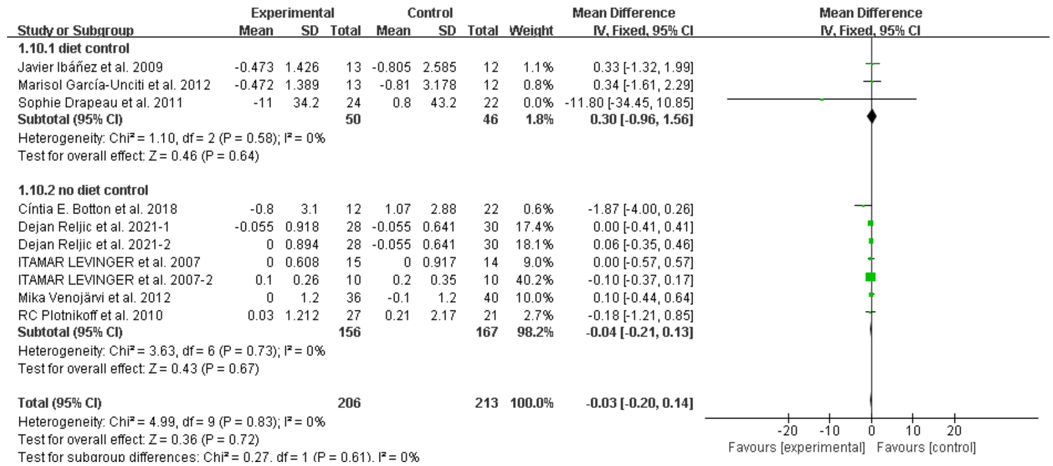

Figure 12. Forest plot: difference in total triglycerides between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

High-density lipoprotein

Figure 13 illustrates high-density lipoprotein data from 491 participants across 11 trials. In examining the effect of resistance training on high-density lipoprotein levels in adults with overweight and obesity, a low degree of heterogeneity was observed among the studies (I^2=27%, p=0.19). Subgroup analyses yielded no between-study heterogeneity in the dietary control group, with a total effect size of MD = -0.49, alongside a 95%CI ranging from = -0.82 to -0.17 (p=0.002); no heterogeneity was observed within the no-dietary-control group, with a total effect size of MD = 0.05, alongside a 95%CI ranging from = -0.04 to 0.15 (p=0.25). Utilizing a fixed-effects model for analysis, a combined effect size of MD = 0.01 was observed, with a 95% CI ranging from = -0.08 to 0.10 (p=0.79). These findings indicate that resistance training does not yield a favorable impact on the enhancement of high-density lipoprotein levels in adults with overweight and obesity.

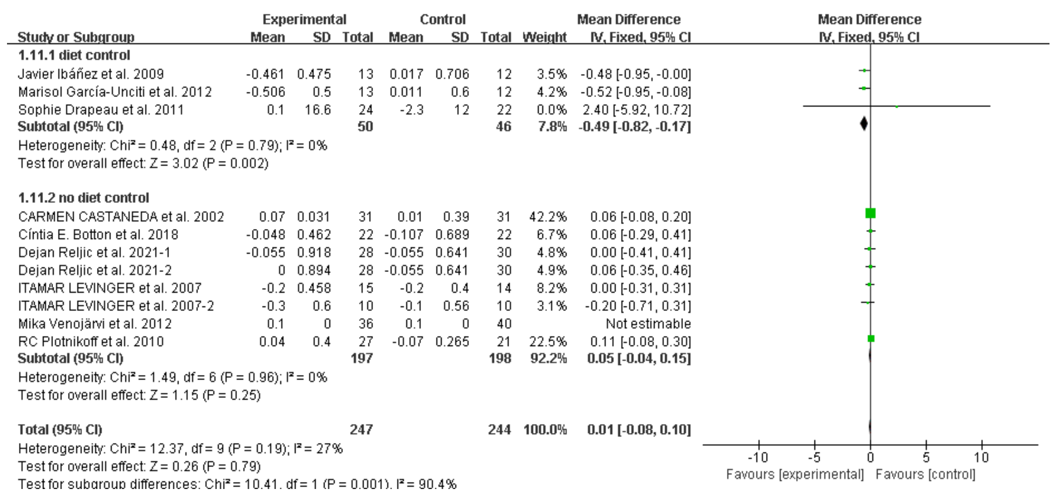

Figure 13. Forest plot: difference in high-density lipoprotein between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Low-density lipoprotein

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Figure 14 illustrates low-density lipoprotein data from 442 participants across 9 trials. In examining the effect of resistance training on low-density lipoprotein levels in adults with overweight and obesity, a substantial degree of heterogeneity was observed among the studies (I^2=69%, p=0.001). Utilizing a random-effects model for analysis, a combined effect size of MD = -0.06 was observed, with a 95% CI ranging from = -0.49 to 0.37 (p=0.79). Subgroup analyses yielded high between-study heterogeneity (I^2=88%, p<0.001) in the dietary control group, with a total effect size of MD = -0.29, alongside a 95%CI ranging from = -3.07 to 2.48 (p=0.84); low degree of heterogeneity (I^2=42%, p=0.12) was observed within the no-dietary-control group, with a total effect size of MD = -0.09, alongside a 95%CI ranging from = -0.39 to 0.21 (p=0.57). These findings indicate that resistance training does not yield a favorable impact on the enhancement of low-density lipoprotein in adults with overweight and obesity.

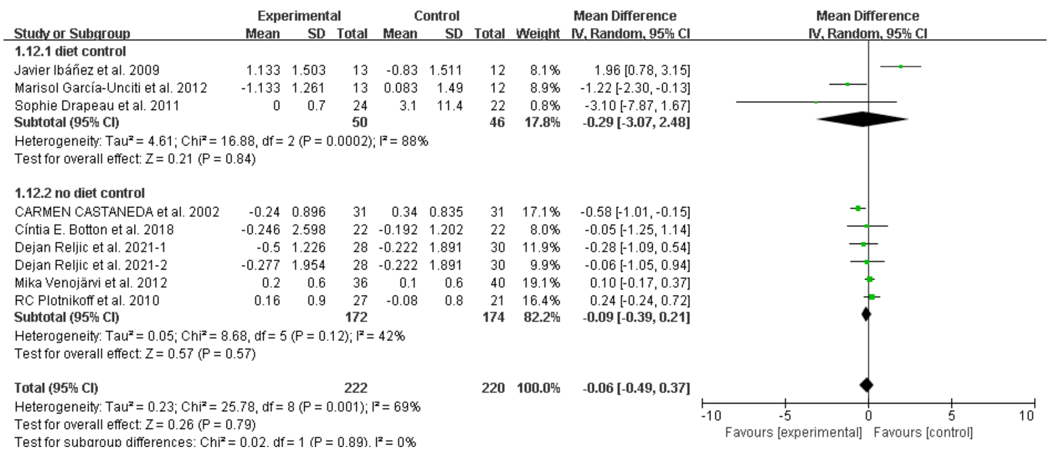

Figure 14. Forest plot: difference in low-density lipoprotein between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Fasting insulin

Figure 15 illustrates the fasting insulin data from 390 participants across 8 trials. In examining the effect of resistance training on fasting insulin levels in adults with overweight and obesity, a substantial degree heterogeneity was observed among the studies (I^2=98%, p<0.001). Utilizing a random-effects model for analysis, a combined effect size of MD = -12.52 was observed, with a 95% CI ranging from = -24.17 to -0.88 (p=0.04). Subgroup analyses yielded high between-study heterogeneity (I^2=99%, p<0.001) in the dietary control group, with a total effect size of MD = -8.56, alongside a 95%CI ranging from = -26.37 to 9.25 (p=0.35); a moderate degree of heterogeneity (I^2=51%, p=0.11) was observed within the no-dietary-control group, with a total effect size of MD = -20.51, alongside a 95%CI ranging from = -40.86 to -0.17 (p=0.05). These findings indicate that resistance training has a significant and positive effect on the enhancement of fasting insulin levels in adults with overweight and obesity.

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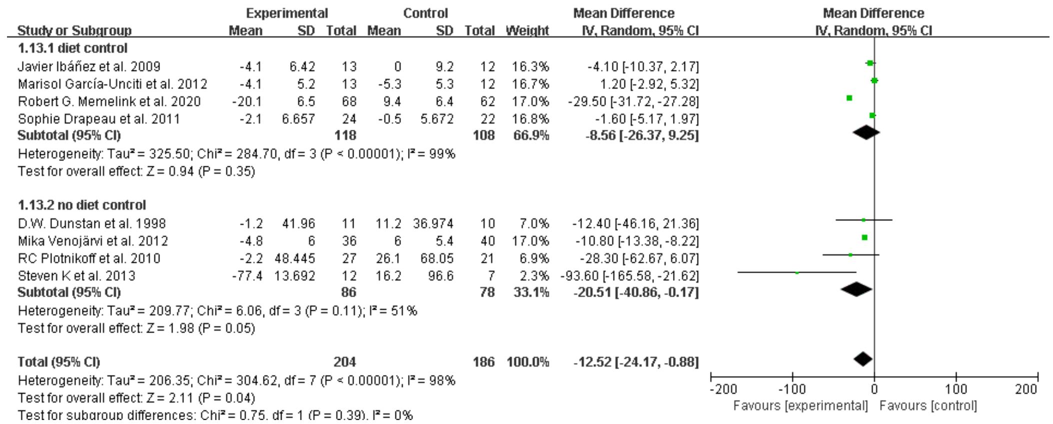

Figure 15. Forest plot: difference in fasting insulin between the resistance training group and the control group. CI confidence interval, IV inverse variance method, SD standard deviation.

Discussion

This Meta-Analysis demonstrates that moderate-frequency resistance training exerts a beneficial influence on cardiometabolic risk factors (CRFs) in adults with overweight and obesity. The positive effects are evident in the enhancement of blood biomarkers, blood pressure, and HOMA-IR levels. Notably, individuals in the dietary control combined with resistance training cohort exhibited greater improvements in fasting glucose, HOMA-IR, total cholesterol, and LDL cholesterol levels compared to those without dietary control. These finding have significant clinical implications for populations dealing with overweight and obesity.

Waist circumference is a critical indicator of CRFs, with higher measurement signifying increased visceral adipose tissue [42,43]. Studies exploring the effects of weight loss strategies, including diet, physical activity/exercise, pharmacologically induced weight loss, consistently show that the greater initial amounts of visceral adipose tissue result in greater loss of visceral relative to subcutaneous adipose tissue following weight reduction [44,45]. There is ongoing debate on whether a similar caloric deficit, induced by diet or exercise, will generate the same loss of visceral adipose tissue. Unfortunately, the results of this analysis suggest that resistance training does not significantly impact waist circumference in adults with overweight and obesity. This observation aligns with the findings of Kordi et al. and is consistent with studies conducted on individuals with normal weight [46,47]. Interestingly, the improvement in waist circumference was greater in the group without diet control than in the group combing diet control and resistance training [30,33,41,48]. The underlying reasons for this phenomenon remain unclear. Given that diet control primarily revolves around creating an energy deficit, Marisol García-Unciti et al. propose that incorporating resistance training might influence the interaction between subcutaneous fat and glucose metabolism [41]. Further investigation into this aspect is warranted.

Resistance training positively impacts systolic blood pressure, diastolic blood pressure, and mean arterial pressure, with reductions comparable to those observed following aerobic exercise interventions [49,50]. Given the global prominence of hypertension as a significant cause of mortality [25], it is evident that moderate-frequency resistance training holds potential as an effective non-pharmacological strategy for preventing and managing blood pressure concerns. The blood pressure-lowering effects of moderate-frequency resistance training arise through mechanisms, such as enhanced vascular function, increased muscle mass and metabolic rate, and reduced sympathetic nervous activity. This multifaceted impact fosters improvements in cardiovascular metabolic health, thereby mitigating the risk of cardiovascular disease [51,52]. Mean arterial pressure is particularly important for specific patient groups, such as those with diabetes or the elderly, who often exhibit pronounced blood pressure fluctuations [53–55]. In this context, mean arterial pressure serves as a valuable metric for assessing the severity of blood pressure changes. The results of this meta-analysis

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indicate that the imprevements in mean arterial pressure are more pronounced than those observed in systolic and diastolic blood pressure.

Glycated hemoglobin, produced by the binding of blood glucose to hemoglobin in red blood cells, is a clinically significant marker for adjusting blood glucose levels and evaluating glycaemic control [56,57].Unfortunately, although some studies suggest that resistance training may improve glucose metabolism by enhancing glucose utilization and storage and increasing insulin sensitivity [58,59], the result of this meta-analysis do not support a significant modulatory effect of moderate-frenqency resistance training on glycaemic control. Glycated hemoglobin levels are influenced by many factors, with elevated blood glucose concentrations having the greatest impact [60,61]. Elevated blood glucose levels lead to an increase in glycation end products, promoting the production of glycated hemoglobin. Notably, this meta-analysis was conducted in adults with overweight and obesity, who may exhibit elevated fasting blood glucose levels, providing additional context for the outcomes presented. Furthermore, the role of erythrocytes in influencing glycated hemoglobin concentration should not be overlooked [62]. Several studies have shown that the stability of erythrocyte membranes improves during the recovery period after exercise, potentially prolonging erythrocyte lifespan and influencing glycated hemoglobin levels [63–65].

The effects of resistance training on various lipid markers, including total cholesterol, triglycerides, HDL cholesterol, and LDL cholesterol, have exhibited positive trends. Our finding indicate that total cholesterol and LDL cholesterol showed more favorable improvements among patients with overweight and obesity in the diet-controlled group compared to those in the diet-uncontrolled group. This observation suggests that lifestyle interventions tailored for this population can yield substantial benefits through a combination of dietary restriction and resistance training. This holistic approach holds clinical significance, potentially contributing to the prevention and management of conditions such as cardiovascular disease, diabetes mellitus, and metabolic syndrome [66–68]. However, a decrease in HDL cholesterol was noted in the dietary control group. Although studies have shown that HDL cholesterol can decrease in specific disease states, such as acute infections, chronic inflammation, and autoimmune diseases [69], the decrease in HDL observed in the dietary control group compared to the no-dietary control group remains unexplained. Interestingly, a decline in HDL cholesterol has also been observed in patients receiving statin therapy [70].

Beyond influencing glucose levels, HDL, LDL, and triglycerides, resistance training demonstrated varying degrees of improvement across other biomarkers. The most pronounced improvements were observed in fasting insulin and HOMA-IR. The decrease in fasting insulin and HOMA-IR levels may be attributed to the multifaceted influence of resistance training on body composition, including increased skeletal muscle mass and a decreased fat mass. These shifts further affect adipokine secretion, insulin sensitivity, and glucose transport mechanisms [71–74].

Future studies on resistance training should monitor and control for potential confounding factors beyond the scope of the intervention, such as the influence of aerobic exercise. The rationale behind the observed greater improvement in waist circumference within the no-diet-control group compared to the diet-control group remains unclear and may be associate with the limited sample size. The relative importance and potential of maximizing central, systemic, and peripheral adaptations by varying the training factors of resistance training (e.g., number of sets, intensity, repetitions) warrant further investigation. Additionally, more high-quality studies are required to develop optimal exercise intervention designs for resistance training, considering gender differences and catering to diverse populations. This evolution is crucial for promoting precise cardiovascular health management within various demographic groups.

Conclusions

This systematic review and meta-analysis highlights that moderate-frequency resistance training (RT) is a safe and effective intervention for improving cardiometabolic risk factors (CRFs) in adults with overweight and obesity. Specifically, RT significantly enhances resting blood pressure, insulin resistance, and key blood biomarkers linked to cardiometabolic health. The subgroup analysis

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reveals that the presence or absence of dietary control does not substantially alter the effects of moderate-frequency RT on most CRFs, except for total cholesterol. This indicates that RT alone can be a robust non-pharmacological strategy for managing cardiometabolic health in this population. These findings emphasize the potential of moderate-frequency RT as a practical and accessible intervention for adults with overweight and obesity, aligning with global physical activity guidelines. Future research should further explore the interaction between dietary control and RT to optimize intervention strategies, considering factors such as gender differences and specific population needs. This will enhance the precision and effectiveness of cardiovascular health management across diverse demographic groups.

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Conflict of Interest: All authors disclosed no relevant relationships.

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