Received: 5 September 2022 | Revised: 9 October 2023 | Accepted: 11 October 2023
DOI: 10.1111/obr.13666

REVIEW

OBESITY Reviews WILEY

Effects of various exercise types on visceral adipose tissue in individuals with overweight and obesity: A systematic review and network meta-analysis of 84 randomized controlled trials

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Summary

The purpose of this systematic review and network meta-analysis (NMA) of randomized controlled trials (RCTs) was to investigate the effects of various exercise categories on visceral adipose tissue (VAT) and other anthropometric variables in individuals with overweight and obesity. A total of 84 RCTs (4836 patients) were included. Aerobic exercise (AE) of at least moderate intensity, resistance training (RT), AE combined with RT (AE + RT), and high-intensity interval training (HIIT) were beneficial for reducing VAT. A subgroup analysis showed that RT improves VAT in males and those with BF% < 40% but not in females and those with body fat percentage (BF%) ≥ 40%. AE, RT, AE + RT, and HIIT significantly improved weight (except RT), total body fat (TBF), body mass index (BMI), waist circumference (WC), and subcutaneous adipose tissue (SAT). Surface under the cumulative ranking curve (SUCRA) probability ranking showed that AE with vigorous intensity and HIIT have the highest probability of being the best exercise intervention for improving VAT, weight, TBF, BMI, WC, and SAT. These findings suggest that regular exercise can improve VAT in individuals with overweight and obesity. AE of vigorous intensity and HIIT may be the best exercise treatment, and RT is the least effective intervention.

KEYWORDS
body composition, exercise, obesity, visceral adipose tissue

1 | INTRODUCTION

Over the past 50 years, the global prevalence of obesity, which is closely linked to a range of diseases, such as cardiometabolic, digestive, respiratory and musculoskeletal diseases,[1,2] has become one of the major health problems threatening the world today.[3,4] A huge source of damage affecting the health of people with obesity is the accumulation of visceral adipose tissue (VAT).[5] VAT is mainly located inside the intraabdominal cavity close to major organs, including the liver and intestines.[6] Excessive VAT accumulation, which results in more detrimental obesity-

Abbreviations: AE(M), moderate-intensity aerobic exercise; AE(MV), moderate-vigorous intensity aerobic exercise; AE(V), vigorous-intensity aerobic exercise; AE + RT, aerobic exercise combined with resistance training; BF%, body fat percentage; BMI, body mass index; CON, control; HIIT, high-intensity interval training; HIIT + RT, high-intensity interval training combined with resistance training; HRR, heart rate reserve; MHR, maximum heart rate; NMA, network meta-analysis; RCTs, randomized controlled trials; RM, repetition maximum; ROB, risk of bias; RT, resistance training; SAT, subcutaneous adipose tissue; SIT, sprint interval training; TBF, total body fat; VAT, visceral adipose tissue; VO_2max, maximal oxygen uptake; WC, waist circumference.

related health effects than excess body weight,[7] is highly associated with an increased risk of type 2 diabetes,[8] hepatic steatosis,[9] cardiovascular disease,[10] and metabolic syndrome.[11] Furthermore, it is highly correlated with all-cause and cause-specific mortality[8–12] and has been associated with the severity of COVID-19.[13] Moreover, excessive accumulation of VAT leads to chronic low-grade inflammation, with infiltration of inflammatory factors in almost all body tissues, leading to a high incidence of cancer. Even some lean people who have excessive VAT accumulation unexpectedly have a risk of type 2 diabetes and cardiovascular disease, which is similar to the increased risk observed in most people with obesity.[5] Therefore, improving VAT to reduce the risk of health impairment is considered more important than other anthropometric variables in the management of obesity.[14]

Regular exercise training has been recommended as an effective therapeutic strategy for improving body composition in obesity and obesity-related chronic diseases.[15–17] Given that exercise training does not always aim to reduce body weight or total body fat (TBF) percentage, as subcutaneous adipose tissue (SAT) and VAT have different health effects,[5] more studies should focus on the potent effects of exercise on reducing VAT. Researchers have recently investigated the effects of exercise on VAT and have consistently concluded that exercise can reduce VAT. However, several questions require verification, including the controversial effect of some types of exercise, such as resistance training (RT), on VAT,[18–21] which type of exercise is the most suitable, and whether population differences occur in the effect of exercise on VAT improvement for individuals with obesity.

Several meta-analyses with VAT as an outcome compared dietary restriction with exercise training[14] and exercise training with pharmacological treatment.[22] Furthermore, the effects of different exercise modalities[23–26] have recently been reported. However, the conclusions of the above meta-analyses on the effects of exercise on VAT remain controversial. Two meta-analyses have reported that aerobic exercise (AE) is an efficient intervention for reducing VAT in people with overweight and obesity, whereas RT or AE combined with RT (AE + RT) has no significant benefits.[24,25] In contrast, Jung et al.[26] observed that AE + RT significantly positively impacted VAT reduction. The reason for these controversial conclusions is that the number of original studies included in most meta-analyses is insufficient, and most of them included all populations rather than just individuals with overweight and obesity. To the best of our knowledge, most of the analyses are pairwise meta-analyses. Only one network meta-analysis (NMA),[25] which included only 34 studies and had no restriction as to the type of chronic condition of the participants, summarized direct and indirect comparisons of the impact of exercise on VAT.

The purpose of the current systematic review and NMA of randomized controlled trials (RCTs) was to investigate the effect of various exercise categories on VAT in individuals with overweight and obesity and to explore the most effective exercise type. We also reported other anthropometric variables, including weight, TBF, body mass index (BMI), waist circumference (WC), and SAT, to explore whether the effects of different exercise categories on these variables were consistent with the effects on VAT. This study is the first NMA to assess the effects of different exercises on VAT in individuals with overweight and obesity.

2 | METHODS

2.1 | Registration

This systematic review and NMA were conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement guidelines.[27] The study protocol was registered in the International Prospective Register of Systematic Reviews ID: CRD42022340752.

2.2 | Literature search strategy

Articles were retrieved from PubMed, Embase, Cochrane, Web of Science, and EBSCO after a systematic electronic search. For searches in PubMed/Cochrane and Embase, terms from MeSH and Emtree were used, respectively. Details of the implemented search strategy for each database are presented in Appendix S2. The search strategy was based on key phrases relating to the PICOS tool: (P) Population: individuals with overweight and/or obesity; (I) Intervention: exercise; (C) Comparator: no exercise or slight stretching; (O) Outcomes: primary outcome: VAT; secondary outcomes: weight, TBF, BMI, WC, and SAT; (S) Study type: RCTs. In addition, we searched the reference lists of selected articles and reviews to identify any relevant studies that electronic searches might have missed. All RCTs published in English between January 2000 and June 2022 were included.

2.3 | Eligibility criteria

Studies were eligible if they (1) were RCTs; (2) included participants with overweight and/or obesity, with a BMI > 25 kg/m^2 (overweight) and/or BMI ≥ 30 kg/m^2 (obese) for European participants, BMI ≥ 24 kg/m^2 (overweight) and/or BMI ≥ 28 kg/m^2 (obese) for Asian participants (if BMI was not provided in a study, body fat percentage [BF%] was used as a criterion [BF% ≥ 30 for females and BF% ≥ 25 for males]), and no restriction on the age in the included studies was applied; (3) compared an experimental group receiving a structured program of exercise training for at least 8 weeks; (4) comparator: no exercise or slight stretching; and (5) assessed VAT before and after exercise intervention, with no restrictions on measurement methods.

Studies were excluded if they (1) were duplicate publications, were literature review papers, were letters to the editor, had abstracts published in conference proceedings, reported acute effects of a single exercise session, and were animal model studies; or (2) were exercise interventions mixed with other interventions (e.g., diet combined with an exercise intervention but including control and exercise groups with no caloric intervention).

Two investigators independently screened the articles according to the inclusion and exclusion criteria. Multiple publications for the same trial were collated, and the first or most complete report was used as the primary reference. Different genders were merged into one group when the study reported males and females separately.

2.4 | Exercise categories

Eight categories were used to classify the exercise interventions for the included RCTs:

1. AE, vigorous intensity (AE[V])
2. AE, moderate to vigorous intensity (AE[MV])
3. AE, moderate intensity (AE[M])
4. RT
5. AE combined with RT (AT + RT)
6. HIIT
7. HIIT combined with RT (HIIT + RT)
8. Control group: no exercise or slight stretching (CON)

Vigorous AE intensity was defined as >65% maximal oxygen uptake (VO_2max) or >65% heart rate reserve (HRR) or >75% maximum heart rate (MHR) and moderate as 45%–65% VO_2max or 50%–65% HRR or >65%–75% MHR.[28] Table 1 provides detailed definitions for each exercise category.

TABLE 1 The classifications of exercise training.

Type	Definition	
CON	No exercise or slight stretching	
AE(V)	Type: Any continuous traditional mode of aerobic training only (e.g., walking, running, cycling, rowing, aerobics, and elliptical exercise).[28]	Intensity: >65% VO_2max or >65% HRR or >75% MHR
AE(MV)		Intensity: Intensity ranges from vigorous to moderate
AE(M)		Intensity: 45%–65% VO_2max or >50%–65% HRR or 65%–75% MHR
RT	Intensity: ≥50% 1RM Type: Any mode of resistance training, including circuit-based programs (e.g., free weights, weights machines, and resistance bands).[28]	
AE + RT	AE combined with RT	
HIIT	Intensity: >65% VO_2max or >65% HRR or >75% MHR in the high-intensity periods Type. Exercise training involves repeated short-to-long bouts of rather high-intensity exercise interspersed with recovery periods, including interval sprint training.[29,30]	
HIIT + RT	HIIT combined with RT	

Abbreviations: AE(M), moderate-intensity aerobic exercise; AE(MV), moderate to vigorous-intensity aerobic exercise; AE(V), vigorous-intensity aerobic exercise; AT + RT, aerobic exercise combined with resistance training; CON, control; HIIT, high-intensity interval training; HIIT + RT, high-intensity interval training combined with resistance training; HRR, heart rate reserve; MHR, maximum heart rate; RM, repetition maximum; RT, resistance training; VO_2max, maximal oxygen uptake.

2.5 | Data extraction

Two investigators independently extracted all data, and disagreement was resolved by consensus or the opinion of a third author, if necessary. The following information was extracted: lead author, publication year, country, characteristics of the subject (number of people in the experimental group and control group, sex, age, BMI, BF% and concomitant diseases), intervention information (exercise type, intensity, duration, frequency, period, supervised or non-supervised), and the measurement method and unit of reported outcomes. In the case of insufficient information, the authors of the included studies were contacted via email for missing values, where required.

2.6 | Risk of bias and GRADE assessment

Two investigators independently assessed the risk of bias (ROB) of the included studies according to the Cochrane Risk of Bias Tool,[31] which includes seven different domains: (a) allocation generation, (b) concealment of allocation, (c) blinding of participants and personnel, (d) blinding of outcome assessment, (e) incomplete outcome data addressed, (f) freedom from selective reporting bias, and (g) other forms of bias. Given that blinding participants to an exercise intervention is difficult, this component was not included in the overall ROB score, and we considered the blinding of the operator to the outcome assessment as a quality criterion. Then, we summatively rated the overall ROB of each study as follows: studies were classified as having low ROB if none of the domains above was rated as high ROB and three or less were rated as unclear risk, and as moderate ROB if one was rated as high ROB or none was rated as high ROB, but four or more were rated as unclear risk, and all other cases were assumed to pertain to high ROB.[32]

We assessed the certainty of evidence contributing to network estimates of the primary and secondary outcomes with the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework.[33]

2.7 | Data synthesis and statistical analyses

The pre-to-post changes in the experimental and control groups were pooled to estimate the effects. The calculation method of the standard deviation (SD) of the change was based on the formula provided by the *Cochrane Handbook for Systematic Reviews of Interventions* (version 6.3)[34] (the formula is: $SD_{change} = \sqrt{SD_{baseline}^2 + SD_{final}^2 - (2 \times Corr \times SD_{baseline} \times SD_{final})}$).

Interventions are, by definition, heterogeneous, and pairwise meta-analytic estimates are also reported in addition to the network estimates to find heterogeneity among studies by using Review Manager 5.3 (Nordic Cochrane, Denmark),[35] and this heterogeneity can be analyzed by a sensitivity analysis. The random-effects model was used for pooled-effect estimates. Standardized mean difference (SMD) with 95% confidence intervals (CIs) was calculated for VAT, TBF, and SAT. The mean difference (MD) was calculated for weight, BMI, and

WC. The I^2 statistic and Cochran's Q test were used to quantify heterogeneity. An I^2 greater than 50% or a *p* value of 0.10 or less for the Q test was interpreted as indicating substantial heterogeneity.[36] We evaluated publication bias by inspecting funnel plots and statistically assessing the bias using the method of Begg's test.

STATA 16.0 software (StataCorp, College Station, TX, USA) was used to perform a random-effects multivariate NMA for pooled estimates and 95% CIs within a frequentist framework[37] following the current PRISMA NMA guidelines.[27] Because adipose tissue was measured using different tools and units in the included studies, the SMD was used to detect the effect size for VAT, fat, and SAT, and MD was used for weight, BMI, and WC.

The relationship between exercise interventions was presented by a network diagram, where the lines connecting nodes represented direct head-to-head comparisons between interventions, and the size of each node and the thickness of each line connecting the nodes were proportional to the number of studies. A network contribution graph was drawn to calculate the contribution of each direct comparison.

Transitivity assumptions were assessed by evaluating the inclusion criteria for individual studies, by determining whether all participants in the network could be randomly subjected to any intervention, and by using consistency models.[38] Transitivity is a key assumption of NMA and refers to the belief that indirect comparisons are valid estimates of unobserved direct comparisons[37] and that all studies have homogenously distributed effect modifiers.[39] Inconsistency factors (IFs) with 95% CI were calculated to evaluate the consistency of each closed loop, and consistency is indicated by the lower limit of 95% CI being equal to 0.[40] The inconsistency model was used to test inconsistency. The consistency model was used when the inconsistency was not significant ($p > 0.05$).[41] Node-splitting analysis was used to check local inconsistency, and the result was reliable, with $p > 0.05$.

The surface under the cumulative ranking curve (SUCRA) was used to rank and compare the effects of different types of exercise.[42] SUCRA values range from 0 to 100, where 100 indicates the best treatment with no uncertainty and 0 indicates the worst treatment with no uncertainty.[43] Thus, higher SUCRA values indicated the better effects of an exercise intervention. To check whether NMA publication bias caused by small-scale studies occurred, we generated a network funnel plot and conducted an intuitive check using the symmetry criterion.

3 | RESULTS

3.1 | Literature selection

The flow diagram reporting trial selection is shown in Figure 1. A total of 1525 potentially eligible articles were identified, 1520 of which were from database searches and five from reference lists. After 731 duplicates were removed, 794 articles remained for screening. By screening the titles and abstracts, 685 articles were deleted, and 25 articles were deleted after obtaining and reading the full text, leaving 84 articles for quantitative synthesis.

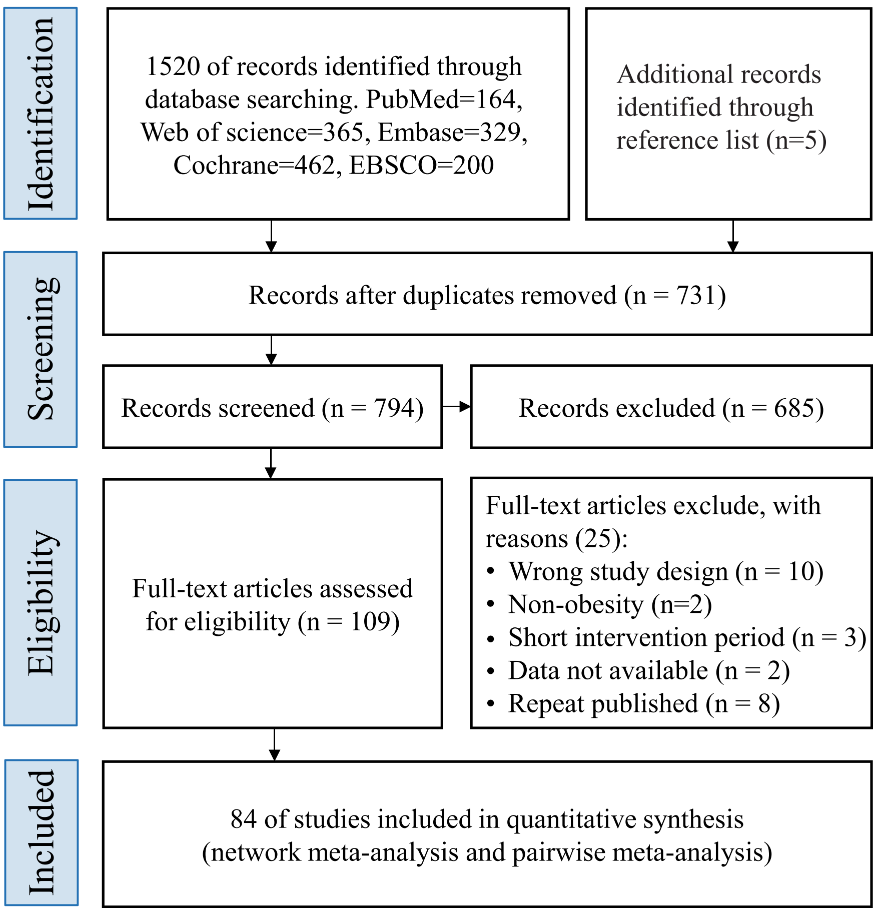

FIGURE 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram depicting the study selection process.

3.2 | Characteristics of the included studies

The characteristics of the included studies are presented in Appendix S3. A list of included studies is shown in Appendix S4. The studies were published from 2000 to 2022 and conducted in North America (24), South America (6), Australia (10), Asia (22), Europe (19), South Africa (1), and Oceania (2). A total of 3265 participants with overweight or obesity were included in the experimental group (AE[V]: 480; AE[MV]: 353; AE[M]: 859; RT: 484; AE combined with RT: 641; HIIT: 419; HIIT combined with RT: 29) and 1571 in the control group, with a mean age ranging from 10 to 70 years. Approximately 3420 (71%) participants were females; 36 studies involved females only, 14 were males only, 22 included both males and females, and the remaining 12 did not report sex ratios. Reported baseline demographics included BMI and fat%. A total of 19 studies involved participants with symptoms of diabetes, non-alcoholic fatty liver disease, metabolic syndrome, overactive bladder, and non-alcoholic steatohepatitis.

Exercise categories included AE with vigorous intensity (AE[V]), AE with moderate to vigorous intensity (AE[MV]), AE with moderate intensity (AE[M]), RT and AE combined with RT, and HIIT and HIIT combined with RT. The AE category was classified as vigorous intensity, moderate intensity, and moderate to vigorous intensity, according to Table 1. Many of the included articles did not report the intensity of the RT group, and some articles had a wide range of intensity (e.g., 55%–80% 1RM). Furthermore, some involved increasing load training, making it difficult to divide the intensity of the RT group and AE combined with the RT group. We excluded the low-intensity aerobic intervention group from two of the included studies.[44,45] Sprint interval training (SIT) was classified as a type of HIIT intervention. The exercise durations listed in Appendix S3 do not include warming up and cooling down (unless otherwise noted). The mean length of exercise interventions was 17 weeks (SD = 12.8), ranging from 8 to 52 weeks, with more than half (84.52%) of the studies reporting exercise interventions that lasted for 12 weeks. The average number of sessions per week was 3.5 (SD = 1). Only four studies were supervised, combined with home-based interventions, and the others were supervised interventions.

In relation to the outcome measures reported, the VAT measurement method included dual-energy X-ray absorptiometry (21), magnetic resonance imaging (24), computed tomography (26), electrical impedance tomography (6), ultrasound (3), calculated via fat index formula (3), and unreported measurement method (1). The unit of VAT was reported using kg (22), cm^2 (34), cm^3 (14), mm (1), cm (3), liters (3), fat index (3), percentages (2), and unreported unit (2). We also reported secondary outcomes, including body weight, BMI, TBF, WC, and SAT. We combined different genders into one group when the study reported males and females separately (3).[46–48]

3.3 | Results of ROB assessment

Details of the ROB assessment in each study are provided in Appendix S5. A total of 41 articles clearly stated the method of group allocation, 38 stated allocation concealment, and 42 reported blinding of outcome assessment. A total of 75 studies reported dropout rates. A dropout rate of more than 20% was considered high risk (unless an intention-to-treat analysis was performed). Furthermore, 75 studies showed a low risk of selective reporting. In other biases, the studies were evaluated as high risk because of the small sample size (any arm in the study is less than 10 participants), lack of supervision, and large measurement error of outcome assessment. In summary, 47 articles were judged to be of low ROB, 29 were of moderate ROB, and 8 were of high ROB.

3.4 | Direct pairwise meta-analyses

3.4.1 | Primary outcome

A pairwise meta-analysis was first conducted, and the forest plot of VAT based on the exercise category is provided with detailed individual trial-level information (Figure 2). Compared with the control group, AE(M) (SMD = −0.55, $p < 0.00001$, 95% CI [−0.69, −0.41], $I^2 = 23\%$) significantly decreased VAT with lower heterogeneity, while AE(V) (SMD = −0.70, $p < 0.0001$, 95% CI [−1.01, −0.39], $I^2 = 68\%$), AE(MV) (SMD = −0.76, $p = 0.009$, 95% CI [−1.33, −0.19], $I^2 = 81\%$), RT (SMD = −0.60, $p = 0.0005$, 95% CI [−0.93, −0.26], $I^2 = 71\%$), AR + RT (SMD = −0.65, $p = 0.0004$, 95% CI [−1.01, −0.29], $I^2 = 78\%$), and HIIT (SMD = −0.70, $p < 0.0001$, 95% CI [−1.03, −0.37], $I^2 = 69\%$) significantly decreased VAT with higher heterogeneity. Only HIIT + RT ($p = 0.1$) showed no significant effect on VAT compared with the control group. Funnel plots and Begg's test revealed publication bias in the HIIT subgroup ($p < 0.001$), whereas the other subgroups showed no publication bias (Appendix S6).

3.4.2 | Secondary outcomes

The forest plot of secondary outcomes (weight, TBF, BMI, WC, and SAT) based on exercise category is shown in Appendix S7 (1–5). The pairwise meta-analysis results demonstrated no significant effect of HIIT + RT compared with CON in all outcomes. The other exercise categories showed a significant reduction in all outcomes (except for RT in weight and BMI, which showed no significant effect). Funnel plots and Begg's test revealed publication bias only in the AE + RT subgroup of TBF ($p = 0.016$), whereas the others showed no publication bias (Appendix S6).

3.5 | Network meta-analysis

We conducted an NMA of VAT and secondary outcomes (including weight, TBF, BMI, WC, and SAT) to explore whether the effect of different exercise categories on secondary outcomes was consistent with that of VAT and to verify the effectiveness of exercise intervention. A subgroup analysis of VAT was conducted based on the sex,

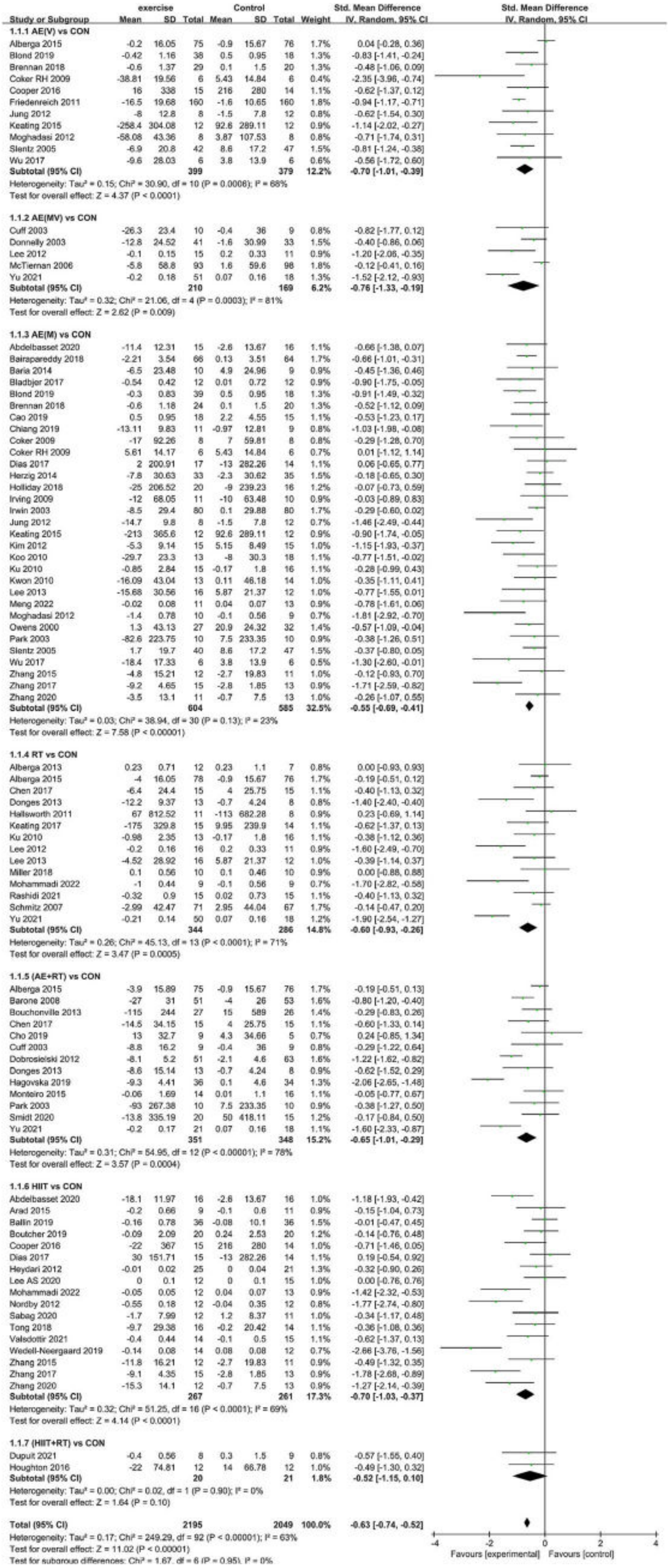

FIGURE 2 Forest plot of the effects of exercise versus control on visceral adipose tissue.

age, and BF% of participants to explore whether sex, age, and degree of obesity would affect the results.

The supporting materials for VAT and secondary outcomes are shown below.

Figure 3 shows NMA plots of eligible studies investigating the effectiveness of exercise category on VAT and secondary outcomes (weight, TBF, BMI, WC, and SAT). The size of the nodes relates to the sample size for that exercise category, and the thickness of the lines between exercise modes relates to the number of studies referring to that comparison. The most common type of intervention was AE (most of which were moderate intensity), and the least frequent was HIIT + RT.

Appendix S8 shows the contributions of direct and indirect comparisons to NMA and the number of studies of each direct comparison.

Inconsistency of VAT and secondary outcomes were tested by loop-specific heterogeneity estimates, inconsistency model, and node-splitting analysis (Appendix S9). Loop-specific heterogeneity estimates indicated good consistency for each closed loop in VAT, TBF, WC, and SAT, with only four loops found inconsistent in weight and one loop in BMI. The inconsistency model showed that the p values were >0.05 in VAT, weight, BMI, WC, and SAT, indicating no inconsistency. However, the inconsistency model showed significant inconsistency in TBF ($p < 0.05$), which resulted in one level of lower evidence grade in the ranking result of TBF. Therefore, the results of the paired meta-analysis should mainly be considered for this index. Node-splitting analysis shows no inconsistency between the direct and indirect evidence on the whole (only two comparisons were inconsistent in weight), suggesting a reliable result.

Forest plots of eligible comparisons of VAT and secondary outcomes, including 95% CI and 95% prediction intervals (95% PrI), are shown in Appendix S10.

The funnel plot graphics of VAT and secondary outcomes to check the existence of NMA publication bias are shown in Appendix S11. The funnel plots of all outcomes are symmetric, indicating a low possibility of publication bias or a small sample effect in the NMA.

The SUCRA probability of each intervention on VAT and secondary outcomes in the network is shown in Appendix S12. The SUCRA value is the probability that each intervention is among the best of those in the network, with larger values representing higher-ranking probabilities.

3.5.1 | Pooled estimates of primary outcomes

The pooled estimates of the NMA of VAT are shown in Table 2. AE(V) (SMD = −0.70, 95% CI [−0.92, −0.48], $p < 0.0001$), AE(MV) (SMD = −0.57, 95% CI [−0.86, −0.29], $p < 0.001$), AE(M) (SMD = −0.53, 95% CI [−0.68, −0.38], $p < 0.0001$), RT (SMD = −0.46, 95% CI [−0.67, −0.26], $p < 0.001$), AE + RT (SMD = −0.61, 95% CI [−0.81, −0.42], $p < 0.0001$), and HIIT (SMD = −0.64, 95% CI [−0.84, −0.44], $p < 0.0001$) demonstrated improvements in VAT compared with control. The SUCRA probability sorting result showed that AE(V) (SUCRA = 81.2) had the highest probability of being the best exercise intervention for VAT, whereas RT (SUCRA = 30.2) is most likely the least effective exercise intervention (Table 3, Appendix S12).

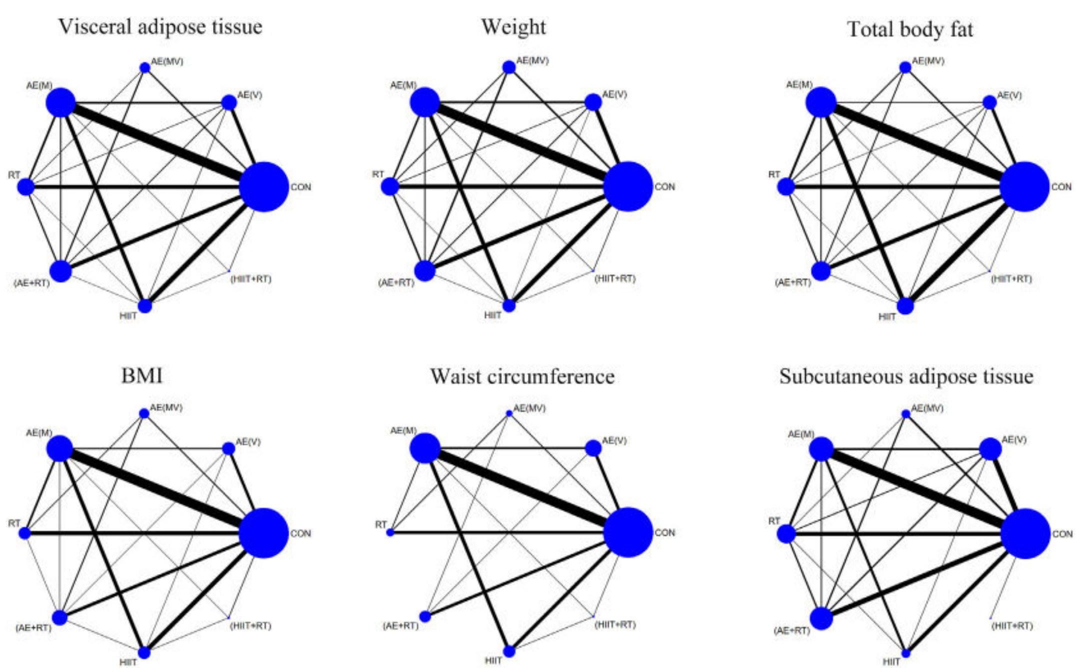

FIGURE 3 Network plot presenting the effects of different exercise type on visceral adipose tissue and secondary outcomes in individuals with overweight and obesity.

TABLE 2 Network meta-analysis matrix of VAT and secondary outcomes.

	AE(V)	-0.11 (-1.58,1.35)	-0.47 (-1.67,0.73)	**-1.57 (-2.80, -0.34)**	-0.61 (-1.80,0.58)	-0.11 (-1.58,1.35)	-1.99 (-5.23,1.24)	**-2.25 (-3.32, -1.18)**	Weight
VAT	-0.13 (-0.47,0.22)	AE(MV)	-0.35 (-1.67,0.96)	**-1.46 (-2.57, -0.34)**	-0.50 (-1.67,0.67)	-0.00 (-1.53,1.53)	-1.88 (-5.14,1.37)	**-2.14 (-3.26, -1.02)**	
	-0.17 (-0.41,0.07)	-0.04 (-0.35,0.27)	AE(M)	**-1.10 (-2.16, -0.05)**	-0.14 (-1.15,0.86)	0.35 (-0.82,1.53)	-1.53 (-4.65,1.60)	**-1.79 (-2.57, -1.01)**	
	-0.24 (-0.51,0.04)	-0.11 (-0.42,0.20)	-0.07 (-0.29,0.16)	RT	0.96 (-0.01,1.93)	1.46 (0.13,2.78)	-0.42 (-3.60,2.76)	-0.68 (-1.58,0.22)	
	-0.09 (-0.36,0.18)	0.04 (-0.25,0.32)	0.08 (-0.14,0.30)	0.15 (-0.09,0.39)	AE+RT	0.50 (-0.72,1.71)	-1.38 (-4.53,1.76)	**-1.64 (-2.41, -0.88)**	
	-0.06 (-0.34,0.21)	0.06 (-0.28,0.40)	0.10 (-0.11,0.31)	0.17 (-0.10,0.44)	0.03 (-0.24,0.29)	HIIT	-1.88 (-5.11,1.34)	**-2.14 (-3.26, -1.02)**	
	-0.10 (-0.75,0.55)	0.03 (-0.65,0.70)	0.07 (-0.55,0.69)	0.13 (-0.51,0.78)	-0.01 (-0.65,0.63)	-0.04 (-0.67,0.59)	HIIT+RT	-0.26 (-3.32,2.80)	
	-0.70 (-0.92, -0.48)	**-0.57 (-0.86, -0.29)**	**-0.53 (-0.68, -0.38)**	**-0.46 (-0.67, -0.26)**	**-0.61 (-0.81, -0.42)**	**-0.64 (-0.84, -0.44)**	-0.60 (-1.21, 0.01)	CON	
	AE(V)	0.01 (-0.93,0.95)	0.09 (-0.53,0.72)	-0.27 (-1.07,0.53)	0.20 (-0.60,0.99)	0.26 (-0.44,0.96)	-0.32 (-2.48,1.83)	**-0.94 (-1.52, -0.35)**	BMI
TBF	0.03 (-0.30,0.37)	AE(MV)	0.08 (-0.71,0.88)	-0.28 (-1.04,0.47)	0.19 (-0.63,1.01)	0.25 (-0.60,1.11)	-0.33 (-2.54,1.87)	**-0.95 (-1.70, -0.19)**	
	0.08 (-0.17,0.32)	0.04 (-0.24,0.32)	AE(M)	-0.37 (-0.94,0.21)	0.10 (-0.53,0.74)	0.17 (-0.32,0.66)	-0.42 (-2.50,1.67)	**-1.03 (-1.37, -0.69)**	
	-0.07 (-0.36,0.22)	-0.10 (-0.37,0.17)	-0.14 (-0.36,0.07)	RT	0.47 (-0.28,1.22)	0.54 (-0.16,1.24)	-0.05 (-2.20,2.10)	**-0.66 (-1.24, -0.09)**	
	-0.01 (-0.29,0.27)	-0.05 (-0.31,0.21)	-0.09 (-0.31,0.13)	0.05 (-0.18,0.29)	AE+RT	0.07 (-0.60,0.74)	-0.52 (-2.67,1.63)	**-1.13 (-1.70, -0.57)**	
	0.09 (-0.18,0.36)	0.05 (-0.25,0.35)	0.01 (-0.18,0.19)	0.15 (-0.09,0.40)	0.10 (-0.14,0.34)	HIIT	-0.59 (-2.69,1.52)	**-1.20 (-1.65, -0.75)**	
	-0.03 (-0.74,0.68)	-0.07 (-0.79,0.66)	-0.11 (-0.79,0.57)	0.04 (-0.67,0.74)	-0.02 (-0.72,0.68)	-0.12 (-0.80,0.56)	HIIT+RT	-0.61 (-2.69,1.47)	
	-0.46 (-0.69, -0.23)	**-0.49 (-0.74, -0.24)**	**-0.53 (-0.68, -0.39)**	**-0.39 (-0.59, -0.19)**	**-0.45 (-0.63, -0.26)**	**-0.54 (-0.72, -0.37)**	-0.43 (-1.10,0.25)	CON	
	AE(V)	-0.05 (-0.37,0.27)	-0.04 (-0.26,0.19)	-0.07 (-0.33,0.18)	-0.15 (-0.39,0.09)	-0.05 (-0.35,0.26)	-0.60 (-1.50,0.30)	**-0.40 (-0.59, -0.21)**	SAT
WC	-0.19 (-1.81,1.44)	AE(MV)	0.01 (-0.29,0.32)	-0.02 (-0.34,0.29)	-0.10 (-0.37,0.17)	0.01 (-0.36,0.37)	-0.55 (-1.47,0.37)	**-0.35 (-0.62, -0.07)**	
	-0.51 (-1.62,0.60)	-0.32 (-1.77,1.12)	AE(M)	-0.04 (-0.26,0.19)	-0.12 (-0.34,0.11)	-0.01 (-0.28,0.26)	-0.57 (-1.46,0.33)	**-0.36 (-0.52, -0.20)**	
	-0.42 (-1.98,1.14)	-0.23 (-1.28,0.82)	0.09 (-1.27,1.45)	RT	-0.08 (-0.32,0.16)	0.03 (-0.27,0.33)	-0.53 (-1.43,0.37)	**-0.33 (-0.53, -0.13)**	
	0.74 (-1.20,2.69)	0.93 (-1.20,3.06)	1.25 (-0.60,3.10)	1.16 (-0.94,3.26)	AE+RT	0.11 (-0.20,0.41)	-0.45 (-1.35,0.45)	**-0.25 (-0.43, -0.07)**	
	1.41 (-0.31,3.12)	1.60 (-0.35,3.54)	1.92 (0.47,3.36)	1.83 (-0.06,3.71)	0.67 (-1.59,2.92)	HIIT	-0.56 (-1.47,0.36)	**-0.35 (-0.60, -0.10)**	
	-0.13 (-6.34,6.09)	0.06 (-6.22,6.34)	0.38 (-5.76,6.53)	0.29 (-5.97,6.56)	-0.87 (-7.25,5.52)	-1.53 (-7.76,4.69)	HIIT+RT	0.20 (-0.67,1.08)	
	-2.54 (-3.49, -1.58)	**-2.35 (-3.67, -1.03)**	**-2.03 (-2.68, -1.38)**	**-2.12 (-3.36, -0.88)**	**-3.28 (-5.02, -1.55)**	**-3.95 (-5.39, -2.51)**	-2.41 (-8.56,3.73)	CON	

Note: Effects are expressed as the effect size (95% CI) between interventions. Bold indicates that the longitudinal intervention has a more significant reduction impact than the horizontal intervention (blue area)/the horizontal intervention has a more significant reduction impact than the longitudinal intervention (green area). For example, "−0.70 (−0.92, −0.48)" (last row of the first column of VAT) shows that AE(V) (the longitudinal intervention) significantly improves VAT compared with CON (the horizontal intervention). "−2.25 (−3.32, −1.18)" (first row of the last column of weight) shows that AE(V) (the horizontal intervention) significantly improves weight compared with CON (the longitudinal intervention).

Abbreviations: AE, aerobic exercise; CON, control; HIIT, high-intensity interval training; M, moderate intensity; MV, moderate to vigorous intensity; RT, resistance exercise; SAT, subcutaneous adipose tissue; TBF, total body fat; V, vigorous intensity; VAT, visceral adipose tissue; WC, waist circumference.

TABLE 3 Ranking of exercise interventions in order of effectiveness.

Visceral adipose tissue (84 studies, N = 4836)		Weight (72 studies, N = 4123)		Total body fat (68 studies, N = 3690)		BMI (60 studies, N = 3009)		Waist circumference (42 studies, N = 2393)		Subcutaneous adipose tissue (46 studies, N = 2858)	
Treatment	SUCRA	Treatment	SUCRA	Treatment	SUCRA	Treatment	SUCRA	Treatment	SUCRA	Treatment	SUCRA
AE(V)	81.2	AE(V)	80.6	HIIT	74.4	HIIT	78.4	HIIT	89.4	AE(V)	76.4
HIIT	68.4	AE(MV)	75.6	AE(M)	73.3	(AE + RT)	70.9	(AE + RT)	74.8	AE(M)	68.4
(AE + RT)	63.5	HIIT	75.5	AE(MV)	61.3	AE(M)	62.1	AE(V)	55.9	HIIT	65.4
(HIIT + RT)	58.7	AE(M)	60	AE(V)	52.7	AE(MV)	55.7	(HIIT + RT)	50.6	AE(MV)	64.3
AE(MV)	54.7	(AE + RT)	53.5	(HIIT + RT)	50.8	AE(V)	54.3	AE (MV)	49.8	RT	59.6
AE(M)	43	(HIIT + RT)	24.9	(AE + RT)	49.4	(HIIT + RT)	41.9	RT	40.4	(AE + RT)	40.5
RT	30.2	RT	22.9	RT	36.6	RT	32.4	AE(M)	35.9	(HIIT + RT)	15.6
CON	0.4	CON	7	CON	1.5	CON	4.3	CON	3.2	CON	9.7
Subgroup analysis of visceral adipose tissue											
Female (37 studies, N = 1730)		Male (15 studies, N = 667)		Adult (72 studies, N = 3826)		Teenager (12 studies, N = 1005)		BF% ≥ 40% (42 studies, N = 2926)		BF% < 40% (42 studies, N = 2096)	
Treatment	SUCRA	Treatment	SUCRA	Treatment	SUCRA	Treatment	SUCRA	Treatment	SUCRA	Treatment	SUCRA
HIIT	81.8	HIIT	76.4	AE(V)	88.4	AE(V)	76	HIIT	84.7	(AE + RT)	84.1
(HIIT + RT)	65.1	AE(M)	71.8	HIIT	70.2	AE(MV)	71.8	AE(MV)	67.1	AE(V)	82.9
AE(MV)	63.6	RT	68.9	(AE + RT)	64.1	(AE + RT)	58.3	(HIIT + RT)	64.2	AE(M)	59.8
AE(V)	57.6	AE(V)	56.7	(HIIT + RT)	59.9	HIIT	53.1	AE(V)	61.2	(HIIT + RT)	52.8
(AE + RT)	55.5	(AE + RT)	47	AE(M)	48.7	AE(M)	49.2	(AE + RT)	57.5	HIIT	46.9
AE(M)	53.8	AE(MV)	26.4	AE(MV)	40.6	RT	39.9	AE(M)	43.9	RT	46.8
RT	20	CON	2.7	RT	27.8	CON	1.8	RT	20.1	AE(MV)	21.4
CON	2.7			CON	0.5			CON	1.4	CON	5.3

Abbreviations: AE, aerobic exercise; CON, control; HIIT, high-intensity interval training; M, moderate intensity; MV, moderate to vigorous intensity; RT, resistance exercise; SUCRA, surface under the cumulative ranking curve; V, vigorous intensity.

3.5.2 | Pooled estimates of the secondary outcome

We also conducted an NMA for secondary outcomes (weight, TBF, BMI, WC, and SAT) to explore whether the effects of different exercise categories on secondary outcomes were consistent with the effects on VAT.

Weight was assessed in 72 studies ($N = 4123$). AE(V), AE(MV), AE(M), AE + RT, and HIIT resulted in a greater reduction in weight (with $p < 0.0001$) than the control (Table 2). However, no significant difference was observed in the RT ($p = 0.138$) and HIIT + RT ($p = 0.868$) groups compared with the control group (Table 2). AE(V) was the most effective exercise category in reducing weight (SUCRA = 80.6), considering both direct and indirect comparisons (Table 3, Appendix S12). TBF, BMI, WC, and SAT were assessed in 68 ($N = 3690$), 60 ($N = 3009$), 42 ($N = 2393$), and 46 ($N = 2858$) studies, respectively. AE(V), AE(MV), AE(M), RT, AE + RT, and HIIT significantly decreased TBF, BMI, WC, and SAT compared with the control group, and only HIIT + RT showed no significant effect on all outcomes. The SUCRA probability sorting results showed that HIIT has the highest probability of being the best exercise intervention for TBF (SUCRA = 74.4), BMI (SUCRA = 78.4), and WC (SUCRA = 89.4), whereas AE(V) (SUCRA = 76.4) is the most effective exercise category in reducing SAT (Table 3, Appendix S12).

3.5.3 | Subgroup NMA of primary outcome

We conducted a subgroup analysis of VAT based on sex, age, and BF% of participants to explore whether the above covariates would affect the results (Table 4). The network plot of the subgroup is shown in Appendix S13. Loop-specific heterogeneity estimates and node-splitting analysis showed good consistency between the direct and indirect comparisons of all subgroups. In sex subgroups, a mixed-sex group would be classified as the gender that made up more than 80% of the participants. Subgroup NMA showed that RT had no significant effect on the female ($p = 0.233$) and BF% ≥ 40% ($p = 0.097$) subgroups compared with the control group, but had a significant effect on the male group (SMD = −0.89, 95% CI [−1.34, −0.44], $p < 0.0001$). The reason why AE(MV) has no significant effect on the BF% < 40% subgroup may be because of the small number of included data (refer to Appendix S13). HIIT + RT showed a significant effect only on the adult group (SMD = −0.61, 95% CI [−1.20, −0.00], $p = 0.049$). The SUCRA probability sorting results showed that HIIT has the highest probability of being the best exercise intervention for females (SUCRA = 81.8), males (SUCRA = 76.4), and BF% ≥ 40% (SUCRA = 84.7), AE(V) for adults (SUCRA = 88.4), teenagers (SUCRA = 76.0), and AE + RT (SUCRA = 84.1) for BF% < 40%.

3.5.4 | GRADE assessment

Appendix S14 shows the GRADE assessment of each comparison and the SUCRA ranking of treatments for the primary and secondary outcomes. Overall, it was moderate to low for most of the comparisons in VAT, weight, and TBF and low to very low for most of the comparisons in WC and SAT. The GRADE of the SUCRA ranking was high in VAT and moderate in secondary outcomes.

4 | DISCUSSION

The current systematic review and NMA included 84 RCTs involving 4836 participants to investigate the effect of several different exercise categories on VAT, weight, TBF, BMI, WC, and SAT in individuals with overweight and obesity. A subgroup analysis of VAT was conducted based on sex, age, and BF% of participants to explore whether these covariates would affect the results. The results of the NMA suggested that AE of at least moderate intensity, RT, AE + RT, and HIIT can improve VAT in individuals with overweight and obesity. AE of at least moderate intensity, RT, AE + RT, and HIIT all significantly improved weight, TBF, BMI, WC, and SAT (except that RT showed no significant effect on weight). Probably because of the lack of studies with the HIIT + RT arm, we found that HIIT+RT had no significant effect on all outcomes. Subgroup analysis showed that RT significantly reduced VAT in males and those with BF% < 40% but not in females and those with BF% ≥ 40%. The SUCRA probability sorting result showed that AE(V) and HIIT have the highest probability of being the best exercise interventions for improving VAT, weight, TBF, BMI, WC, and SAT in individuals with overweight and obesity.

4.1 | Effect of exercise on primary outcomes

Previous systematic reviews and meta-analytical studies have suggested that AE training is an efficient clinical strategy for reducing VAT.[23–25] However, by summarizing a large number of studies in this study, we found that the effect size of AE is affected by the intensity of exercise, as the effect size of AE(V) (−0.70 in pairwise meta-analysis and −0.70 in NMA, a moderate effect[34]) was larger than that of AE(M) (−0.55 in pairwise meta-analysis and −0.53 in NMA, a moderate effect[29]) in both pairwise meta-analysis and NMA. When describing the effect of AE, we need to note the difference in intensity. The results of the SUCRA probability ranking showed that AE(V) seemed to be the most effective in reducing VAT in individuals with overweight and obesity, whereas AE(M) did not have a superior improvement effect compared with other exercise types.

RT can significantly improve VAT, which is consistent with the findings of previous meta-analyses.[17,26] The ability of RT to significantly decrease VAT may be partly explained by improvements in insulin sensitivity.[49] However, contrary to the results of this study, no significant improvement effect of RT on VAT was found in the meta-analysis by Chang et al.[25] or Ismail et al.,[24] which we speculated may be because of the small sample size of studies (7 and 14, respectively) and the differences in exercise intensity, number of sets, and repetition. The exercise prescription of RT protocols, such as volume, intensity, and work-to-rest ratios, between the sets, which could not be grouped for evaluation,

TABLE 4 Subgroup analysis of VAT based on sex, age, and body fat percentage of participants.

	AE(V)	-0.38 (-1.11,0.36)	0.16 (-0.58,0.89)	0.12 (-0.52,0.76)	-0.12 (-1.21,0.98)	-0.14 (-1.11,0.82)	-	**-0.77 (-1.33, -0.20)**	Male
Female	0.06 (-0.72,0.84)	AE(MV)	0.53 (-0.18,1.25)	0.49 (-0.07,1.06)	0.21 (-0.97,1.38)	0.23 (-0.81,1.27)	-	-0.39 (-0.91,0.12)	
	-0.02 (-0.66,0.61)	-0.08 (-0.62,0.46)	AE(M)	-0.04 (-0.63,0.56)	-0.29 (-1.48,0.89)	-0.30 (-1.36,0.75)	-	**-0.93 (-1.48, -0.37)**	
	-0.38 (-1.11,0.34)	-0.44 (-1.04,0.15)	-0.36 (-0.81,0.09)	RT	-0.28 (-1.35,0.79)	-0.26 (-1.22,0.69)	-	**-0.89 (-1.34, -0.44)**	
	-0.01 (-0.71,0.68)	-0.07 (-0.61,0.47)	0.01 (-0.39,0.41)	0.37 (-0.14,0.88)	AE + RT	-0.14 (-1.11,0.82)	-	-0.62 (-1.57,0.32)	
	0.21 (-0.48,0.91)	0.15 (-0.45,0.75)	0.23 (-0.15,0.61)	**0.60 (0.06,1.13)**	0.23 (-0.25,0.70)	HIIT	-	**-0.96 (-1.42, -0.50)**	
	0.11 (-0.92,1.14)	0.05 (-0.92,1.02)	0.13 (-0.72,0.99)	0.49 (-0.44,1.42)	0.12 (-0.78,1.03)	-0.10 (-0.97,0.76)	HIIT + RT	-	
	-0.63 (-1.24, -0.03)	**-0.69 (-1.19, -0.20)**	**-0.61 (-0.88, -0.35)**	-0.25 (-0.66,0.16)	**-0.62 (-0.98, -0.25)**	**-0.84 (-1.21, -0.48)**	-0.74 (-1.59,0.10)	CON	
	AE(V)	-0.15 (-1.22,0.92)	-0.36 (-1.43,0.70)	-0.44 (-1.48,0.60)	-0.28 (-1.26,0.70)	-0.33 (-1.55,0.89)	-	-0.94 (-1.92,0.04)	Teenager
Adult	-0.30 (-0.72,0.13)	AE(MV)	-0.22 (-0.88,0.45)	-0.29 (-0.84,0.25)	-0.13 (-0.67,0.40)	-0.18 (-1.09,0.72)	-	**-0.79 (-1.35, -0.23)**	
	-0.23 (-0.48,0.03)	0.07 (-0.32,0.46)	AE(M)	-0.08 (-0.63,0.47)	0.08 (-0.50,0.67)	0.03 (-0.71,0.77)	-	**-0.58 (-1.05, -0.10)**	
	-0.37 (-0.69, -0.05)	-0.07 (-0.50,0.36)	-0.14 (-0.41,0.13)	RT	0.16 (-0.34,0.66)	0.11 (-0.73,0.95)	-	**-0.50 (-0.96, -0.04)**	
	-0.15 (-0.46,0.15)	0.14 (-0.22,0.51)	0.07 (-0.18,0.32)	0.22 (-0.09,0.52)	AE + RT	-0.05 (-0.90,0.80)	-	**-0.66 (-1.14, -0.18)**	
	-0.12 (-0.41,0.17)	0.18 (-0.23,0.58)	0.11 (-0.11,0.32)	0.25 (-0.06,0.55)	0.03 (-0.25,0.32)	HIIT	-	-0.61 (-1.36,0.14)	
	-0.16 (-0.80,0.48)	0.14 (-0.56,0.83)	0.07 (-0.54,0.67)	0.21 (-0.44,0.85)	-0.01 (-0.64,0.63)	-0.04 (-0.65,0.57)	HIIT + RT	-	
	-0.76 (-1.00, -0.52)	**-0.46 (-0.83, -0.10)**	**-0.53 (-0.69, -0.38)**	**-0.39 (-0.64, -0.14)**	**-0.61 (-0.83, -0.39)**	**-0.64 (-0.84, -0.44)**	**-0.60 (-1.20, -0.00)**	CON	
	AE(V)	-0.58 (-1.18,0.01)	-0.17 (-0.47,0.13)	-0.25 (-0.61,0.10)	0.02 (-0.36,0.40)	-0.26 (-0.61,0.10)	-0.23 (-1.43,0.97)	**-0.80 (-1.09, -0.52)**	BF% < 40%
BF% ≥ 40%	0.04 (-0.43,0.51)	AE(MV)	0.41 (-0.15,0.98)	0.33 (-0.27,0.93)	0.60 (-0.01,1.22)	0.33 (-0.26,0.92)	0.35 (-0.93,1.63)	-0.22 (-0.75,0.30)	
	-0.11 (-0.52,0.30)	-0.15 (-0.54,0.24)	AE(M)	-0.08 (-0.38,0.22)	0.19 (-0.15,0.53)	-0.09 (-0.38,0.21)	-0.06 (-1.25,1.12)	**-0.64 (-0.84, -0.43)**	
	-0.32 (-0.76,0.12)	-0.36 (-0.73,0.01)	-0.21 (-0.57,0.15)	RT	0.27 (-0.09,0.63)	-0.00 (-0.37,0.36)	0.02 (-1.18,1.22)	**-0.55 (-0.85, -0.26)**	
	-0.03 (-0.44,0.39)	-0.06 (-0.38,0.26)	0.09 (-0.23,0.40)	0.30 (-0.05,0.64)	AE + RT	-0.28 (-0.68,0.13)	-0.25 (-1.47,0.96)	**-0.83 (-1.15, -0.50)**	
	0.17 (-0.29,0.64)	0.14 (-0.30,0.57)	0.29 (-0.02,0.59)	0.50 (0.08,0.91)	0.20 (-0.17,0.57)	HIIT	0.02 (-1.18,1.22)	**-0.55 (-0.82, -0.28)**	
	0.05 (-0.77,0.88)	0.02 (-0.79,0.82)	0.16 (-0.59,0.91)	0.37 (-0.42,1.17)	0.08 (-0.70,0.86)	-0.12 (-0.88,0.64)	HIIT + RT	-0.57 (-1.74,0.60)	
	-0.57 (-0.94, -0.20)	**-0.61 (-0.94, -0.28)**	**-0.46 (-0.70, -0.22)**	-0.25 (-0.55,0.05)	**-0.55 (-0.80, -0.29)**	**-0.75 (-1.05, -0.44)**	-0.62 (-1.37,0.12)	CON	

Note: Effects are expressed as the effect size (95% CI) between interventions. Bold indicates that the longitudinal intervention has a more significant reduction impact than the horizontal intervention (blue area)/the horizontal intervention has a more significant impact than the longitudinal intervention (green area/yellow area).

Abbreviations: AE, aerobic exercise; CON, control; HIIT, high-intensity interval training; M, moderate intensity; MV, moderate to vigorous intensity; RT, resistance exercise; V, vigorous intensity; VAT, visceral adipose tissue.

would be more varied widely than AE, and these various factors may have affected the results of VAT changes. Although our study showed that RT significantly reduced VAT in individuals with overweight and obesity, the overall effect size was relatively small (SMD = −0.46), and the SUCRA probability ranking showed that RT is most likely the least effective intervention. In addition, RT showed no significant effect in the female and BF% ≥ 40% subgroups. In conclusion, we do not recommend RT alone as a good treatment for improving VAT.

Combined exercise programs (AE + RT) have recently emerged as one of the most efficient strategies not only to improve body composition[28,50] but also as the most effective training mode for improving metabolic inflammatory markers.[30,51,52] The current NMA showed that AE + RT could significantly reduce VAT in individuals with overweight and obesity (SMD = 0.61, $p < 0.0001$) and is probably the third best treatment in the SUCRA probability ranking analysis. As RT is considered an effective training method for maintaining and increasing muscular strength and muscle mass, it could be achieved to improve body composition and muscle and bone mass when combined with AE. A previous study reported that AE reduced VAT and other body adipose tissues but did not increase muscle and bone mass. Increased muscle and bone mass and decreased VAT were observed only with the AE + RT regimen.[53] In addition, several meta-analyses have found that AE + RT is the best exercise mode for improving inflammation in obesity.[30,53,54] Therefore, AE + RT is recommended as the most appropriate treatment for the simultaneous improvement of VAT, inflammation, and muscle mass and strength.

HIIT could significantly improve VAT with a moderate effect (SMD = −0.64) in individuals with overweight and obesity compared with controls. The SUCRA probability ranking showed that HIIT ranks only second to AE(V), suggesting that HIIT is a time-efficient strategy for decreasing VAT mass. We found that AE(V) and HIIT were the most effective types of exercise to reduce VAT, and the common feature of both exercises was high-intensity stimulation. Recent studies have shown that high-intensity exercise can mobilize the secretion of interleukin-6, myokines and irisin, whereas AE(M) does not, which may be the underlying reason for the most effective reduction in VAT by AE(V) and HIIT.[55,56] HIIT appears to increase the resting metabolic rate in individuals with obesity, and excess metabolism after exercise may also be responsible for HIIT-induced VAT loss.[57,58] A recent study demonstrated that the augmenting effect of acute exercise on post-exercise oxygen consumption and fat utilization showed an intensity-dependent manner, with a greater impact with HIIT than with moderate-intensity endurance training.[59] In addition, HIIT was more effective in reducing postprandial insulin and triglycerides and increasing fat oxidation in the following morning than moderate-intensity endurance training.[60]

Individuals with overweight and obesity who underwent HIIT + RT did not show a significant difference in VAT reduction compared with the control group, but the result should be interpreted with caution because only a limited number of studies ($n = 3$)[61–63] involving HIIT + RT treatment were included. The SUCRA probability ranking showed that HIIT + RT ranks relatively high in VAT and WC, suggesting that this type of exercise may be a potential intervention with a better effect size than other interventions in reducing VAT and even other body composition indicators. More relevant RCTs are needed to examine whether HIIT + RT can be an efficient protocol for improving VAT in individuals with obesity and overweight.

Because of the differences in methods used to quantify VAT and the variability in the units of VAT reported, it is difficult to interpret whether the reductions in VAT observed with exercise are clinically meaningful. We found that the effect size on VAT exceeded 0.5 for all types of exercise except RT. According to Cohen's thresholds, an effect size of at least 0.5 may have some clinical relevance, contributing to improving the risk of related diseases and promoting overall health. VAT mass and area have been shown to be significant predictors of mortality.[64] Moreover, VAT quantified as WC has been identified as an independent risk factor for cardiovascular disease, hypertension, and stroke.[65] A systematic search indicated that each 10 cm (3.94 in.) increment in WC was associated with an 11% higher risk of all-cause mortality, with a hazard ratio of 1.11 (95% CI: 1.08–1.13).[66] While the magnitude of VAT reduction observed with exercise in this review may be clinically meaningful, it is crucial to comprehensively assess the specific clinical implications within the framework of other factors, including sample size, study design, and intervention duration.

In order to provide insight into the actual magnitude of change, we attempted to pool the effect sizes of the included studies that used the same measurements. We found that Cohen's d = −0.92 in the AE(V) subgroup corresponds to an MD of approximately -14.22 cm^2 (the results can be found in Appendix S16). The clinical significance of this value varied according to the baseline level of VAT. For example, for an individual with a basal value of 100 cm^2 of VAT, a 14% reduction in this individual would be clinically meaningful. In most of the included original studies, Cohen's d = −0.5 corresponds to an MD value of approximately -10 cm^2. It is important to note that different original studies will affect the MD corresponding to Cohen's d because of the influence of differences in values for the control group.

4.2 | Secondary outcomes

We found that AE of at least moderate intensity, RT, AE + RT, and HIIT, except HIIT + RT, had significant improvement effects on TBF, BMI, WC, and SAT. As for weight, all the above exercise categories, except RT, showed a significant effect on weight compared with the control group. A previous NMA also found no significant effect of RT on weight,[30] indicating that the beneficial effect of RT on VAT reduction may be independent of clinically significant weight loss. Several international guidelines recommend lifestyle interventions aimed at reducing weight by at least 5% as a treatment for obesity.[67–69] However, previous studies have demonstrated that a reduction in weight is a poor marker of VAT change.[7,14] The effects of exercise on VAT changes may occur irrespective of weight changes. Body weight is mainly influenced by BF% and muscle mass, and RT reduces fat tissue but increases muscle mass. Total body weight loss does not necessarily reflect changes in VAT and may represent a poor marker when evaluating the benefits of lifestyle interventions.

A large number of meta-analyses have confirmed that various kinds of exercise significantly improve body composition.[28,50,70–72] In contrast to previous studies, we included more studies to clarify the influence of exercise to make the results more credible and to explore whether the influence of exercise on secondary outcomes is consistent with that of exercise on VAT. We found a certain difference between the influence of exercise on secondary outcomes and VAT, indicating that the type of exercise treatment we choose should vary according to the body composition we are trying to improve. SUCRA probability ranking analysis showed that AE(V) and HIIT were most likely the best exercise methods to improve weight, TBF, BMI, WC, and SAT, which was basically consistent with the phenomenon observed in VAT.

4.3 | Subgroup NMA of primary outcome

Subgroup analysis showed that the effect of RT on VAT was influenced by the covariates of gender and BF%. In the gender subgroup, the effect of RT on VAT showed a significant reduction in males but not in females, with a greater effect size in males (SMD $= -0.89$) than in females (SMD $= -0.25$). A result similar to that was also found in previous studies.[26] Sex-specific hormones and different phenotypes of VAT may be associated with reduced VAT responses to exercise interventions.[73,74] Staiano et al.[75] pointed out that a significant amount of VAT volume in boys would be more sensitive to exercise intervention than in girls.

Regarding the BF% subgroup, we have set the subgroup to 40% based on the population characteristics of the included studies, which included a large number of people with a BF% ≥ 40% (considered to be severely obese[76]). RT had a significant reduction effect in people with BF% < 40% but no significant effect in people with BF% ≥ 40%, which may suggest that RT is not an effective way to reduce VAT for people with a higher BF%. In addition, the effect of HIIT was more significant than that of AE(M) in people with BF% ≥ 40%, suggesting that HIIT should be suitable as an effective way to reduce VAT for people with higher BF%.

We conducted a subgroup analysis for those using only imaging methods (computed tomography and magnetic resonance imaging) to check whether the results hold when the gold standard method is employed. The results indicated that all intervention groups, except for HIIT + RT (possibly because of the limited number of included articles), demonstrated significant improvements in VAT when compared with the control group. The SUCRA probability sorting result showed that HIIT (SUCRA = 81) had the highest probability of being the best exercise intervention for VAT, whereas RT (SUCRA = 29.1) is most likely the least effective exercise intervention (Appendix S15).

4.4 | Limitations

Limitations are inevitable in the current study. First, we classified SIT as a type of HIIT and did not separate the two exercise modes. In the NMA conducted by Chang et al.,[25] it was determined that SIT had no significant impact on VAT. However, it is important to note that these findings were based on the inclusion of only two articles with SIT in the analysis. The original studies by Meng et al.[58] and Heydari et al.[77] found that SIT can significantly reduce VAT, but no significant effect was found by Boutcher et al.[78] and Cooper et al.[79] Therefore, more high-quality studies need to be conducted to confirm the effect of SIT on VAT. Second, we included only the exercise intervention without considering the effect of diet. Future meta-analysis studies are recommended to examine the effects of exercise combined with dietary strategies. Third, RT protocols varied widely in intensity, frequency, and training exercises. Components such as exercise intensity could not be grouped for evaluation. Fourth, we did not separate elderly participants for further exploration because only 15 studies included elderly participants. More studies may be needed to explore the effects of different exercise methods on visceral fat in old participants in the future. Finally, the time-dose effect of various exercise types was not explored because of the limited number of original studies. If each exercise was divided into subgroups according to training duration and period to explore the time-dose effect, each subgroup may include fewer studies, and the conclusion will not be reliable.

5 | CONCLUSION

The current systematic review and NMA provide evidence that regular exercise, including AE of at least moderate intensity, RT, AE + RT, and HIIT, can reduce VAT in individuals with overweight and obesity. AE of at least moderate intensity, RT, AE + RT, and HIIT all significantly improved weight (except RT), TBF, BMI, WC, and SAT. Weight loss does not necessarily reflect changes in VAT and may represent a poor marker when evaluating the benefits of lifestyle interventions. A key finding of this review is that the effect of RT on VAT was influenced by the covariates of gender and BF%, with RT having a significant effect on men and those with BF% < 40% but no significant effect on women and those with BF% ≥ 40, suggesting that women and people with higher BF% should not use RT as a way to reduce VAT. High-intensity AE and HIIT may be the best exercise approaches for improving VAT, body weight, TBF, BMI, EC, and SAT; RT appears to be less effective as an exercise intervention for these specific outcomes.

AUTHOR CONTRIBUTIONS

All authors carried out the screenings and reviews, and the analysis of the articles. Xiaoke Chen drafted the manuscript, and Kejia Xie and Chunmei Cao revised the manuscript. All authors read and approved the final manuscript.

ACKNOWLEDGMENTS

This research did not receive any specific grant from any funding agency in the public, commercial, or not-for-profit sector.

CONFLICT OF INTEREST STATEMENT

No conflict of interest.

DATA AVAILABILITY STATEMENT

All data generated or analysed during this study are included in this published article.

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SUPPORTING INFORMATION

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How to cite this article: Chen X, He H, Xie K, Zhang L, Cao C. Effects of various exercise types on visceral adipose tissue in individuals with overweight and obesity: A systematic review and network meta-analysis of 84 randomized controlled trials. *Obesity Reviews*. 2023;e13666. doi:10.1111/obr.13666