REVIEW

Combined versus independent effects of exercise training and intermittent fasting on body composition and cardiometabolic health in adults: a systematic review and meta-analysis

Mousa Khalafi[1*], Michael E. Symonds[2], Aref Habibi Maleki[3], Mohammad Hossein Sakhaei[4], Mahsa Ehsanifar[3] and Sara K. Rosenkranz[5]

Abstract

Introduction and aim Exercise training (Ex) and intermittent fasting (IF) are effective for improving body composition and cardiometabolic health overweight and obese adults, but whether combining Ex and IF induces additive or synergistic effects is less well established. We therefore, performed a systematic review and meta-analysis to compare the combined versus independent effects of Ex and IF on body composition and cardiometabolic health in adults.

Method An electronic search was conducted in three main online databases including PubMed, Web of Science, and Scopus, from inception to March 9, 2023 for studies involving Ex plus IF trials versus standalone Ex and/or IF interventions in adults. Interventions had a duration of ≥ 2 weeks. Standardized (SMD) or weighted mean differences (WMD) and 95% confidence intervals were calculated in order to compare effects on body weight, body mass index (BMI), body fat lean body mass (LBM), visceral fat, and waist circumference. For cardiometabolic health, outcomes included fasting glucose, insulin, total cholesterol (TC), low-density lipoprotein cholesterol (LDL), triglycerides (TG), high-density lipoprotein cholesterol (HDL), systolic (SBP) and diastolic (DBP) blood pressure, and VO_2max/peak.

Results Ex plus IF decreased body weight [WMD: -3.03 kg (95% CI: -3.44 to -2.61), $p = 0.001$], BMI [WMD: -1.12 kg.m^2 (95% CI: -1.28 to -0.95), $p = 0.001$], body fat [SMD: -0.72 (95% CI: -1.23 to -0.21), $p = 0.005$], visceral fat [SMD: -0.34 (95% CI: -0.63 to -0.05), $p = 0.01$], and waist circumference [WMD: -2.63 cm (95% CI: -4.16 to -1.11), $p = 0.001$] more than Ex alone. However, changes in body composition and cardiometabolic health markers were not significantly different for Ex plus IF when compared with IF alone, with the exception of VO_2max/peak [SMD: 0.55 (95% CI: 0.14 to 0.97), $p = 0.009$].

Conclusion We demonstrate that a combination of Ex and IF produces superior changes in body composition, but not in markers of cardiometabolic health when compared with Ex or IF alone. Ex plus IF could therefore be effective for weight and fat loss but has no additive or synergistic effects for other cardiometabolic health markers.

*Correspondence:
Mousa Khalafi
mousa.khalafi@kashanu.ac.ir
Full list of author information is available at the end of the article

Introduction

Overweight and obesity are primary risk factors for the development of non-communicable chronic diseases including cardiovascular and metabolic diseases such as type 2 diabetes mellitus [1–3]. Although the etiology of obesity is complex, an imbalance between caloric intake and expenditure is a primary cause of obesity and subsequent co-morbid chronic diseases [4]. Obesity is associated with numerous complications including insulin resistance, low-grade inflammation, hypertension, dyslipidemia, and endothelial dysfunction, which all contribute to the development of cardiometabolic disease [3, 5–10]. With the worldwide epidemic of obesity [11], both pharmacological and non-pharmacological interventions are widely used in preventing and managing obesity related disease.

Non-pharmacological interventions including exercise training (Ex) and dietary modifications are initial treatment strategies for obesity and the prevention of co-morbid conditions [12–15]. Ex is an effective intervention and is associated with substantial cardiometabolic health benefits such as improved insulin resistance, lipid profiles, and blood pressure [16, 17]. Regardless of exercise type, various meta-analyses have suggested that Ex improves cardiometabolic health in overweight and obese adults with co-morbid conditions, independent of sex and age. Dietary interventions, primarily caloric restriction, are also effective [18–21], but have the potential to negatively affect muscle mass. In recent years, intermittent fasting (IF) has become an alternative and popular dietary intervention, including different eating patterns such as alternate-day fasting (ADF), 5 plus 2 diets, and time-restricted eating (TRE). Regardless of type, IF is effective in reduce body weight and fat mass, and is also associated with improvements in cardiometabolic health. In this regard, several meta-analyses have confirmed that IF is effective for improving lipid profiles, glycemic markers, and blood pressure [22–25].

Despite the beneficial effects of Ex and IF dietary interventions on weight loss and obesity management, the combination of exercise and dietary interventions appears to elicit larger effects as compared to exercise or dietary interventions alone [15, 26–30].. Several meta-analyses have suggested that combined Ex and dietary interventions may be more effective than standalone exercise or dietary interventions for improving body composition, inflammation, glycemic markers, and lipid profiles, [15, 26–30]. However, to date, no comprehensive meta-analysis has investigated the combined versus independent effects of Ex and IF interventions. Therefore, we completed a systematic review and meta-analysis to determine whether Ex combined with IF, compared with standalone Ex or IF interventions, has further beneficial effects on body composition and cardiometabolic health markers in adults.

Method

The current systematic review and meta-analysis was conducted and written in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines, and followed the additional guidance provided by the Cochrane Handbook of Systematic Reviews of Interventions. The systematic review and meta-analysis was pre-registered in the International prospective register of systematic reviews (PROSPERO; ID: CRD42023459841).

Data sources and search strategy

A comprehensive electronic literature search was conducted in three main online databases including PubMed, Web of Science, and Scopus. The search was performed from inception to March 9, 2023 using the following key words: ("time-restricted feeding" OR "time restricted feeding" OR "time-restricted eating" OR "time restricted eating" OR "time-restricted diet" OR "time restricted diet" OR "time-restricted fasting" OR "time restricted fasting" OR "intermittent fasting" OR "intermittent energy restriction" OR "alternate fasting" OR "periodic fasting" OR "reduced meal frequency" OR "alternate-day fasting") and (exercise OR "exercise training" OR "physical activity" OR "aerobic training" OR "aerobic exercise" OR "resistance training" OR "resistance exercise" OR "combined training" OR "combined exercise" OR "concurrent training" OR "concurrent exercise" OR "interval training" OR "interval exercise"). Relevant key words were combined with the Boolean operators OR/AND. When available in databases, filters including human, English language, and journal were applied. In addition, manual searches of reference lists of all included studies and follow on searches in Google Scholar were performed to make sure that no eligible studies were missed. Complete search strategy details are summarized in Supplementary Table 1. The searches were conducted independently by two authors (M H S and A H M) and any disagreements were resolved by discussion with another author (M Kh).

Study selection and inclusion and exclusion criteria

The following inclusion criteria were applied based on the Population, Intervention, Comparison, Outcomes, and Study Design (PICOS). For the population, studies of participants with overweight and obesity or hidden obesity and ages ≥ 18 years, and healthy individuals regardless of biological sex, were included. There were no limitations for participant health status, and therefore

overweight and obese adults with and without co-morbid conditions were included. For intervention, studies that included combined Ex and IF trials with intervention durations ≥ 2 weeks were included. There were no limitations regarding mode, intensity, frequency, or time of exercise. For IF, interventions included ADF, TRE, and Ramadan diurnal intermittent fasting (RIF). For comparison, studies involving standalone Ex and/or IF interventions were included. For outcomes, studies were included when results were reported for body composition (body weight, BMI, bod fat including fat mass or body fat percentage, LBM, waist circumference and visceral fat); glycemic markers (fasting glucose, fasting insulin and insulin resistance); fasting lipid profiles (total cholesterol (TC), low-density lipoprotein cholesterol (LDL), triglycerides (TG), high-density lipoprotein cholesterol (HDL)); and blood pressure (systolic (SBP) and diastolic (DBP) and $VO_{2max/peck}$. For study design, randomized trials comparing combined Ex IF versus either standalone Ex and/or IF interventions were included. Further inclusion criteria were: articles written in the English language, and peer-reviewed articles. Exclusion criteria were: non-original studies such as reviews and non-randomized trials, and studies including participants without overweight and obesity, and studies involving trained or athletic populations. Study selection was performed by two independent authors (M H S and A H M) and any disagreements were resolved by discussion with another author (M Kh). All retrieved studies were exported into EndNote (version 20.2.1) and duplicates were recorded were removed. The remaining studies were screened against the inclusion and exclusion criteria in two steps; 1) based on title and abstract, and 2) based on full-text.

Data extraction and synthesis

For each eligible study, two authors independently extracted the following data, and any disagreements were resolved by discussion with another author (M Kh): (1) study characteristics including study design and sample size; (2) participant characteristics including age, biological sex, BMI, health status; (3) Ex characteristics including mode, intensity, frequency, and duration; (4) IF characteristics including type (ADF, TRE, or RIF) and duration; and (5) outcome variables including body weight, BMI, body fat (fat mass)or body fat percentage if fat mass was not available), visceral fat mass, lean body mass (LBM or fat-free mass (FFM) if LBM was not (available), waist circumference, fasting glucose, insulin and insulin resistance, fasting TC, LDL, TG, HDL, SBP and DBP, and VO_2max/peak. In addition, other relevant data required for calculating effect sizes, including means and standard deviations (SDs) or mean changes and their

SDs, and sample sizes for each outcome were extracted. When required, these data were extracted from figures using Getdata Graph Digitizer software. In addition, when required, relevant data were calculated from standard errors, medians, and interquartile ranges [31–33]. For lipid profiles, data were expressed in milligrams per deciliter (mg/dL), and when required mmol/L values were converted to mg/dL with the conversion factor 1 mg/dL = 0.0259 mmol/L (for TC, LDL, and HDL) and 1 mg/dL = 0.0113 mmol/L (for TG) [34]. For studies where data were not available or were not able to be extracted from figures, the corresponding authors were contacted [35], but no response was received. Meta-analyses were performed when there were three or more intervention studies for each variable.

Quality assessment

Quality assessments were conducted for all included studies according to the Physiotherapy Evidence Database (PEDro) Scale, a valid measure of the methodologic quality of clinical trials [36]. The items on this assessment include: (1) eligibility criteria specified, (2) random allocation of participants, (3) allocation concealment, (4) groups similar at baseline, (5) blinding of participants, (6) blinding of intervention groups, (7) blinding of assessors, (8) outcome measures assessed in more than 85% of participants, (9) intervention to treat analysis, (10) reporting of between-group statistical comparisons and point measures, and (11) measures of variability reported for mean effect. Each item is scored as either present () or absent (x). Two authors (M H S and A H M) independently assessed the quality of each study, and any disagreements were resolved by discussion with another author (M Kh).

Statistical analysis

Two separate analyses were conducted to calculate the effect sizes for determining the effects for the following on the main outcomes: (1) combined Ex and IF versus Ex only, and (2) combined Ex and IF versus IF only. The standardized mean differences (SMDs) or weighted mean differences (WMDs) and 95% confidence intervals were calculated using random effect models to determine measures of intervention effectiveness. Interpretation for SMDs was according to the Cochrane guidelines, with 0.20–0.49, 0.50–0.79, and ≥ 0.8 indicating small, medium, and large effect sizes, respectively. Heterogeneity was quantified using I^2 and decomposed Q-statistics, where I^2 was interpreted according to Cochrane guidelines, with 25%, 50%, and 75% indicating low, moderate, and high heterogeneity, respectively. Publication bias was assessed

using visual interpretation of funnel plots with Egger's tests as secondary determinants, where a p-value of < 0.10 indicated possible publication bias. In addition, the trim and fill method was used to correct the potential effects of publication bias when visual interpretation of funnel plots indicated publication bias. Sensitivity analyses were performed when 10 or more intervention arms were included in an analysis. All analyses and funnel and forest plots presented, were conducted using comprehensive meta-analysis (CMA) software version 3.

Results

Included studies

The search strategy yielded 267 records from PubMed, 409 records from Web of Science, and 474 records from Scopus. Following removal of duplicate records, a total of 739 records remained. After title and abstract screening,
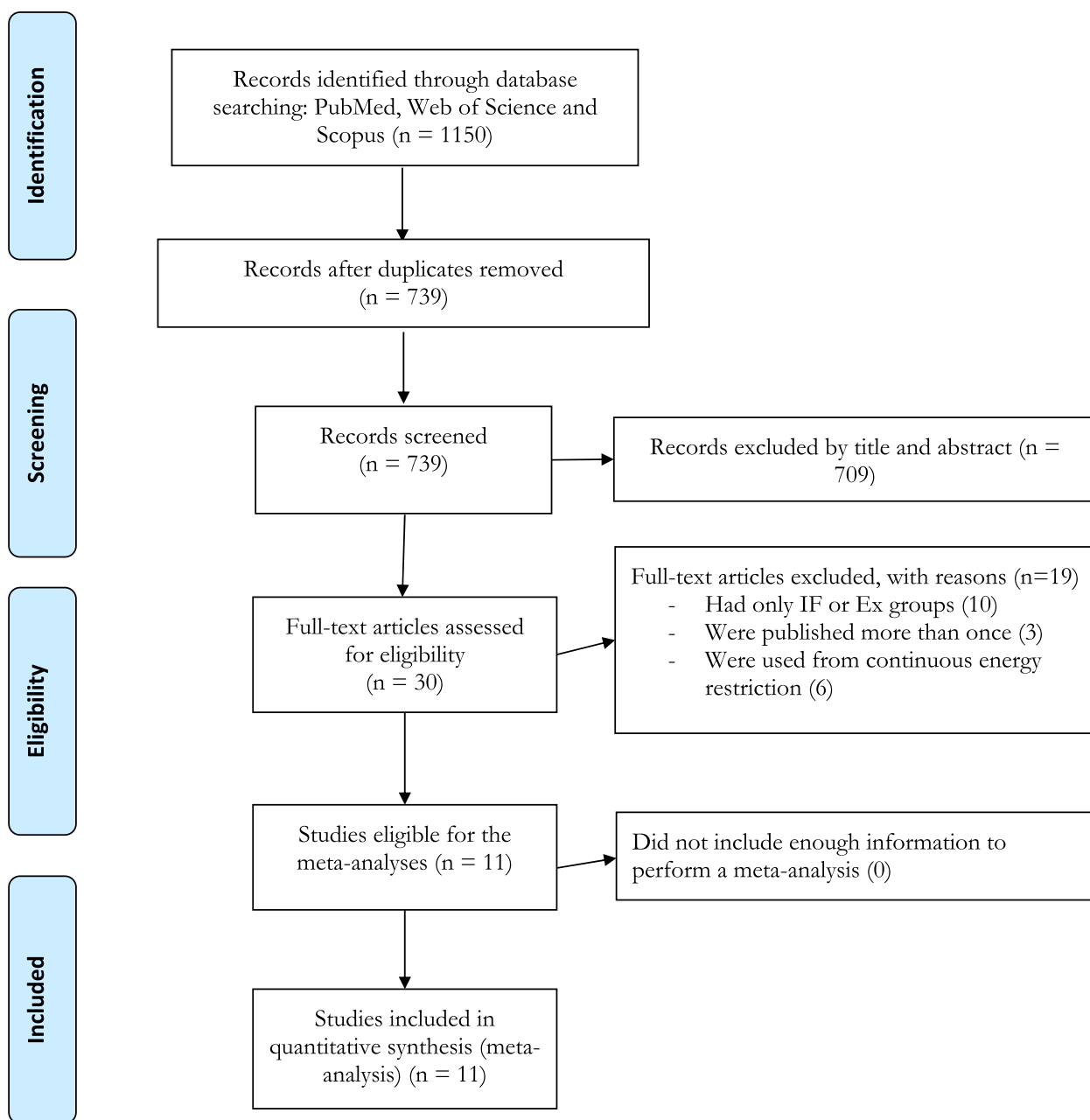

Fig. 1 Flow diagram of systematic literature search

709 additional studies were excluded. Of the remaining 30 studies, 19 studies were excluded due to the reasons presented in Fig. 1 Finally, 11 studies met all inclusion criteria, and were included in the meta-analysis. Among the 11 randomized clinical trials included, seven studies included combined EX and IF as well as Ex only, and IF only groups [37–43]; and four studies included combined EX and IF as well as Ex only groups [35, 44–46].

Participant characteristics

A total 606 participants who were overweight or obese or had hidden obesity with mean BMI ranges from 22 to 37 kg/m^2, and ages ranging from 21 to 45 years, were included in the meta-analysis. Sample sizes of individual studies ranged from 20 to 98. Among those studies, three included females only [37, 38, 43], one included males only [45], and seven studies included both males and females [35, 39–42, 44, 46]. One study included adults with obesity and non-alcoholic fatty liver disease [42] and one included adults with hidden obesity [37].

Exercise and intermittent fasting characteristics

The Ex and IF characteristics are summarized in Table 1. Briefly, all included studies used supervised exercise sessions with intervention durations ranging from 4 weeks [35, 45] to 16 weeks [41], and frequency of exercise sessions ranging from 3 to 5 sessions per week. For Ex modes, four studies used HIIT [35, 38, 41, 43], three studies used aerobic training [37, 39, 42], and four studies used combined training including resistance and aerobic or interval training [40, 44–46]. For IF, seven studies used 5:2 or 4:3 feeding and fasting days [35, 38–42, 46], three studies used TRE protocols [37, 43, 44], and one study used RIF [45].

Meta-analysis
Body composition

Combined Ex and IF vs. Ex Combined Ex and IF decreased body weight [WMD: -3.03 kg (95% CI: -3.44 to -2.61), $p=0.001$; 10 trials], BMI [WMD: -1.12 kg. m^2 (95% CI: -1.28 to -0.95), $p=0.001$; 7 trials], body fat [SMD: -0.72 (95% CI: -1.23 to -0.21), $p=0.005$; 10 trials], visceral fat [SMD: -0.34 (95% CI: -0.63 to -0.05), $p=0.01$; 6 trials], and waist circumference [WMD: -2.63 cm (95% CI: -4.16 to -1.11), $p=0.001$; 5 trials], but did not change LBM [SMD: -0.04 (95% CI: -0.35 to 0.25), $p=0.76$; 6 trials] significantly more than Ex alone (Supplementary Figs. 1–6). Heterogeneity was not significant for body weight (I$^2=0.00$, $p=0.69$), BMI (I$^2=0.00$, $p=0.56$), visceral fat mass (I$^2=0.00$, $p=0.65$), and LBM (I$^2=8.32$, $p=0.36$), but there was high heterogeneity for body fat (I$^2=78.64$, $p=0.001$) and waist circumference

(I$^2=78.25$, $p=0.001$). Visual interpretation of funnel plots suggested publication bias, but Egger's tests only confirmed bias for body fat ($p=0.009$), not for body weight ($p=0.46$), BMI ($p=0.15$), waist circumference ($p=0.64$), or LBM ($p=0.15$). In addition, neither visual interpretation of funnel plots or Egger's tests showed publication bias for visceral fat mass ($p=0.25$) (Supplementary Figs. 31–36). Sensitivity analyses for body weight and body fat showed that significance did not change by removing any individual study, but high heterogeneity for body fat may be explained by the study of Xu et al. 2022 [35] (see Supplementary Table 2). In addition, when the missing studies were accounted using the trim and fill method, the overall changes were as follow: body weight [WMD: -3.15 kg (95% CI: -3.66 to -2.63)], BMI [WMD: -1.16 kg.m^2 (95% CI: -1.37 to -0.96)], body fat [SMD: -1.05 (95% CI: -1.58 to -0.51)], waist circumference [WMD: -2.50 cm (95% CI: -4.10 to -0.89)] and LBM [SMD: -0.09 (95% CI: -0.37 to 0.18)].

Combined Ex and IF vs. IF Combined Ex and IF did not decrease body weight [WMD: -0.13 kg (95% CI: -1.46 to 1.18), $p=0.83$; 8 trials], BMI [WMD: -0.06 kg.m^2 (95% CI: -0.65 to 0.52), $p=0.83$; 5 trials], body fat [SMD: 0.02 (95% CI: -0.26 to 0.31), $p=0.86$; 8 trials], visceral fat mass [SMD: -0.16 (95% CI: -0.53 to 0.21), $p=0.39$; 4 trials], or waist circumference [WMD: -3.42 cm (95% CI: -6.90 to 0.04), $p=0.05$; 3 trials], or affect LBM [SMD: 0.08 (95% CI: -0.26 to 0.43), $p=0.62$; 4 trials], significantly more compared with IF alone (Supplementary Figs. 7–12). The heterogeneity was not significant among for body weight (I$^2=0.00$, $p=0.99$), BMI (I$^2=0.00$, $p=0.96$), body fat (I$^2=23.18$, $p=0.24$), visceral fat (I$^2=13.22$, $p=0.32$), LBM (I$^2=0.00$, $p=0.58$), or waist circumference (I$^2=0.00$, $p=0.83$). Visual interpretation of funnel plots suggested publication bias for all outcomes except waist circumference, and Egger's tests indicated bias for body weight ($p=0.06$) and waist circumference ($p=0.05$), but not for BMI ($p=0.39$), body fat ($p=0.89$), visceral fat mass ($p=0.43$), or LBM ($p=0.66$) (Supplementary Figs. 37–42). In addition, when the missing studies were accounted using the trim and fill method, the overall changes were as follow: body weight [WMD: 0.11 kg (95% CI: -1.08 to 1.31)], BMI [WMD: -0.00 kg.m^2 (95% CI: -0.57 to 0.55)], body fat [SMD: 0.13 (95% CI: -0.13 to 0.39)], visceral fat mass [SMD: -0.23 (95% CI: -0.58 to 0.10)] and LBM [SMD: 0.02 (95% CI: -0.29 to 0.34)].

Lipid profiles

Combined Ex and IF vs. Ex Combined Ex and IF did not decrease TG [WMD: 3.18 mg/dl (95% CI: -7.77 to

Khalafi *et al. Nutrition Journal*   (2024) 23:7

Page 6 of 15

Table 1 Participants and intervention characteristics

Source, year	Study characteristics				Participant characteristics				Exercise intervention characteristics			Dietary intervention characteristics
	Sample size (sex)	Intervention Groups	Intervention duration (~week)	Outcomes	Health status	Age (years)	BMI (kg/m^2)	Type	Protocol	Weekly sessions (weekly min)		
Batitucci, et al. 2022 [38]	60 (F)	EX DI EX+DI	8 weeks	Weight, BMI, WC, BF (%), FFM, VO_{2max}	Obesity	EX:33.0±3.0 DI:30.0±5.0 EX+DI:32.0±4.4	EX:31.8±2.02 DI:34.8±3.2 EX+DI:34.0±2.6	HIIT	Exercise execution 30-45 s at 70–85% HR_{max} with 15-30 s recovery, total 25 min duration	3 Supervised sessions (75)	IF protocol: 5:2 (5 days' ad libitum & 2 days fasting); 6:18 h (6 h eating period & 18 h of complete fasting); 25% of the total daily energy needs on IF days (approximate total of 600 kcal that were divided into two meals), while on the other days of the week food was allowed ad libitum
Bhutani et al. 2013c [39]	67 (M & F)	EX DI EX+DI	12 weeks	Weight, BMI, BF (kg), FFM, WC, Chol, TG, HDL, LDL, Glucose, Insulin, SBP, DBP	Obesity	EX:42.0±9.8 DI:42.0±10.0 EX+DI:45.0±21.1	EX:35.0±4.9 DI:35.0±5.0 EX+DI:35.0±4.2	Aerobic	25–40 min at 60–75% of HR_{max}	3 supervised sessions (75–120)	IF protocol: Week 1–4: Consumed 25% of their baseline energy needs on the fast day (24 h) and consumed food ad libitum on each feed day (24 h) Week 5–12: continued with the IF regimen but no fast day food was provided to them, fast day meals were consumed between 12.00 pm and 2.00 pm to ensure that each subject was undergoing the same duration of fasting, 30% kcal from fat, 15% kcal from protein, and 55% kcal from carbohydrate

Khalafi *et al. Nutrition Journal*   (2024) 23:7

Page 7 of 15

Table 1 (continued)

Source, year	Study characteristics			Participant characteristics				Exercise intervention characteristics			Dietary intervention characteristics
	Sample size (sex)	Intervention Groups	Intervention duration (~week)	Outcomes	Health status	Age (years)	BMI (kg/m²)	Type	Protocol	Weekly sessions (weekly min)	
Cho et al. 2019 [40]	78 (M & F)	EX DI EX + DI	8 weeks	Weight, BMI, BF (kg), Visceral fat, Glucose, Insulin, Chol, TG, HDL, LDL, VO_{2max}	Overweight or obesity	EX:38.6 ± 8.2 DI:33.5 ± 5.0 EX + DI:34.5 ± 5.7	EX:26.9 ± 3.9 DI:27.8 ± 3.4 EX + DI:28.0 ± 2.6	Combined	40 min resistance exercise including weight training machines, barbells, and dumbbells; and 20 min aerobic exercise	3 supervised sessions (180)	IF protocol: 3:4 (3 days fasting & 4 days' ad libitum), 25% of their daily recommended energy intake (approximately 500 kcal) on each "fast day" (24 h), and consumed food ad libitum on each "feed day" (24 h)
Cooke et al. 2022 [41]	45 (M & F)	EX DI EX + DI	16 weeks	Weight, Visceral fat, BF (kg), FFM, WC, VO_{2max}, Glucose, TG, Chol, HDL, LDL, SBP, DBP	Overweight or obesity	EX:32.0 ± 8.3 DI:37.0 ± 5.9 EX + DI:39.0 ± 6.8	EX:32.0 ± 4.4 DI:30.0 ± 3.9 EX + DI:34.0 ± 2.1	HIIT	4–6 × 20 s cycling at 150% VO_{2peak} followed by 40 s of active recovery, total 10 min duration	3 supervised sessions (30)	IF protocols: 5:2 (2 days fasting & 5 days' ad libitum), fasting day intake was limited to a single 600 kilocalorie (kcal) foe men and 500 kcal meal for women
Ezpeleta et al. 2023 [42]	60 (M & F)	EX DI EX + DI	12 weeks	Weight, BMI, BF (kg), Visceral fat, FFM	Obesity and NAFLD	EX:44.0 ± 13.4 DI:44.0 ± 13.4 EX + DI:44.0 ± 13.4	EX:37.0 ± 26.8 DI:36.0 ± 35.8 EX + DI:37.0 ± 22.4	Aerobic	60 min at 65–80% of HR_{max}	5 supervised sessions (300)	IF protocol: 600 kcal/2,500 kJ "fast day" alternated with an ad libitum intake "feast day." The feast and fast days began at 12 am each day. Therefore, subjects fasted for approximately 17–20 h on the fast day
Haganes et al. 2022 [43]	98 (F)	EX DI EX + DI	7 weeks	Glucose, Insulin, Weight, BF (kg) Visceral fat, VO_{2max}, TG, Chol, HDL, LDL, SBP, DBP	Overweight or obesity	EX:34.9 ± 7.0 DI:36.2 ± 5.9 EX + DI:37.3 ± 5.7	EX:32.5 ± 4.5 DI:31.8 ± 3.3 EX + DI:31.4 ± 4.0	HIIT	4 × 4-min work bouts at 90–95% HR_{max} separated by 3 min moderate-intensity recovery, while the third session comprised 10 × 1-min work bouts at ≥ 90% of HR_{max} separated by 1 min low-intensity recovery	3 supervised sessions (108)	TRE protocol: ≤ 10-h daily eating window, with ad libitum energy intake

Table 1 (continued)

Source, year	Study characteristics				Participant characteristics				Exercise intervention characteristics			Dietary intervention characteristics
	Sample size (sex)	Intervention Groups	Intervention duration (~week)	Outcomes	Health status	Age (years)	BMI (kg/m²)		Type	Protocol	Weekly sessions (weekly min)	
Hottenrott et al. 2020 [46]	40 (M & F)	EX EX + DI	12 weeks	Weight, BF (kg), Visceral fat	Overweight	EX:45.5 ± 7.8 EX + DI:45.5 ± 7.8	25–30 kg/m²		Combined	30–60 min running and 20 min of strength training (training plans based on performance status and individual heart rate training zones)	3–4 supervised sessions (ND)	IF protocol: 4:3 (3 days fasting & 4 days' ad libitum) for the first 3 weeks, IF started with half-day fasting (800/1200 kcal per day, women/men). After 3 weeks: IF program: 5:2 (2 days fasting & 5 days' ad libitum) with a daily caloric intake of 400 kcal for female and 600 kcal for male
Kotarsky et al. 2021 [44]	23 (M & F)	EX EX + DI	8 weeks	Weight, BMI, WC, Visceral fat, BF (kg), FFM, Insulin, Chol, HDL, SBP, DBP	Overweight and obesity	EX:44.0 ± 6.3 EX + DI:45.0 ± 9.9	EX:29.4 ± 2.5 EX + DI:29.8 ± 2.7		Combined	75 min aerobic exercise at moderate-to-vigorous (≥55% HRR) intensity, and resistance exercises, 3 sets with 12 reps	3 supervised sessions (~150–300)	TRE protocol: consume all their calories between 12:00 p.m. and 8:00 p.m. each day, inducing a fasting window of 16 h
Maaloul et al. 2023 [45]	20 (M)	DI EX + DI	4 weeks	Weight, BF (kg), Glucose, Chol, TG, HDL, LDL	Obesity	DI:33.4 ± 7.9 EX + DI:30.2 ± 6.1	DI:32.06 ± 3.6 EX + DI:34.1 ± 4.9		Combined	8 intervals of 1 min at 90% of VO$_{2max}$ alternated with 2 min recovery at 45% of VO$_{2max}$, and resistance exercised; 3 sets with 10–12 reps at 60–75% of 1RM	4 supervised sessions (ND)	Ramadan diurnal intermittent fasting protocol: the daily fasting duration during this study was approximately 16 h

Table 1 (continued)

Source, year	Study characteristics				Participant characteristics			Exercise intervention characteristics			Dietary intervention characteristics
	Sample size (sex)	Intervention Groups	Intervention duration (~ week)	Outcomes	Health status	Age (years)	BMI (kg/m^2)	Type	Protocol	Weekly sessions (weekly min)	
Liu et al. 2023 [37]	58 (F)	EX, DI, EX+DI	8 weeks	Weight, BMI, BF, Chol, TG, HDL, LDL, SBP, DBP, LBM	Hidden obesity	EX:20.1±1.4, DI:20.3±1.8, EX+DI:19.9±0.6	EX:21.4±1.6, DI:21.6±1.2, EX+DI:21.6±1.5	Aerobic	11,000–12,499 steps per day	7 unsupervised sessions (ND)	Time-restricted feeding protocol: time-restricted feeding for 8 h, that is, eating at their discretion between 10:00 and 18:00 daily and fasting for the remainder of the day
Xu et al. 2022 [35]	57 (M & F)	EX, EX+DI	4 weeks	Weight, BMI, LBM, FM, WC, TG, Chol, HDL, LDL, VO$_{2max}$	Overweight or obesity	21.3±2.24	EX:26.1±2.0, EX+DI:26.9±1.5	HIIT	5 intervals of 3 min at 80% of VO$_{2max}$ separated by brief periods at 50% (Total time:30 min)	5 supervised sessions (150)	IF protocol: Intermittent energy restriction protocol: 2:5, 30% of their daily recommended energy intake (approximately 500–1,000 kcal)

14.14), *p*=0.56; 5 trials], TC [WMD: 3.77 mg/dl (95% CI: -4.43 to 11.98), *p*=0.36; 6 trials], or LDL [WMD: -2.18 mg/dl (95% CI: -10.78 to 6.42), *p*=0.61; 6 trials]; and did not increase HDL [WMD: 0.11 mg/dl (95% CI: -4.53 to 4.77), *p*=0.96; 6 trials] compared with Ex alone (Supplementary Figs. 13–16). Heterogeneity was not significant for TG (I^2=0.00, *p*=0.63), TC (I^2=0.00, *p*=0.85) or LDL (I^2=0.00, *p*=0.55), but there were moderate and non-significant heterogeneity for HDL (I^2=50.04, *p*=0.07). Visual interpretation of funnel plots suggested publication bias for TC, TG, and LDL, but Egger's tests indicated bias for TC (*p*=0.05), and not for TG (*p*=0.85), LDL (*p*=0.40), or HDL (*p*=0.74) (Supplementary Figs. 43–46). In addition, when the missing studies were accounted for using the trim and fill method, the overall changes were as follow: TG [WMD: 2.50 mg/dl (95% CI: -8.36 to 13.38)], TC [WMD: 5.87 mg/dl (95% CI: -1.68 to 13.44)] and LDL [WMD: 0.72 mg/dl (95% CI: -8.25 to 9.71].

Combined Ex and IF vs. IF　Combined Ex and IF did not decrease TG [WMD: -6.93 mg/dl (95% CI: -26.55 to 12.67), *p*=0.48; 6 trials], TC [WMD: -4.40 mg/dl (95% CI: -12.79 to 3.98), *p*=0.30; 6 trials], or LDL [WMD: -8.85 mg/dl (95% CI: -20.76 to 3.06), *p*=0.14; 6 trials]; and did not increase HDL [WMD: 1.34 mg/dl (95% CI: -2.26 to 4.95), *p*=0.46; 6 trials] significantly as compared with IF alone (Supplementary Figs. 17–20). Heterogeneity was not significant for TC (I^2=0.00, *p*=0.76), but there were small and non-significant heterogeneity for LDL (I^2=46.71, *p*=0.09) and HDL (I^2=26.00, *p*=0.23) and moderate and significant heterogeneity for TG (I^2=55.65, *p*=0.04). Visual interpretation of funnel plots suggested publication bias, but Egger's tests did not confirm for bias for TG (*p*=0.21), TC (*p*=0.61), LDL (*p*=0.65), or HDL (*p*=0.38) (Supplementary Figs. 47–50). In addition, when the missing studies were accounted using the trim and fill method, the overall changes were as follow: TG [WMD: 2.09 mg/dl (95% CI: -19.78 to 23.96)], TC [WMD: -3.36 mg/dl (95% CI: -11.43 to 4.69)], LDL [WMD: -14.37 mg/dl (95% CI: -27.00 to -1.74)] and HDL [WMD: 0.14 mg/dl (95% CI: -3.94 to 4.24)].

Blood pressure

Combined Ex and IF vs. Ex　Combined Ex and IF did not decrease SBP [WMD: -1.70 mmHg (95% CI: -4.57 to 1.16), *p*=0.24; 6 trials] or DBP [WMD: -0.21 mmHg (95% CI: -2.51 to 2.09), *p*=0.85; 6 trials] as compared with IF alone (Supplementary Figs. 21 and 22). The heterogeneity was not significant for SBP (I^2=0.00, *p*=0.68) or DBP (I^2=0.00, *p*=0.50). Visual interpretation of funnel plots

suggested publication bias for SBP, but Egger's tests did not confirm bias for SBP (*p*=0.57) or DBP (*p*=0.48) (Supplementary Figs. 51 and 52). In addition, when the missing studies were accounted using the trim and fill method, the overall changes were as follow: SBP [WMD: -1.35 mmHg (95% CI: -4.05 to 1.33)] and DBP [WMD: 0.65 mmHg (95% CI: -1.39 to 2.69)].

Combined Ex and IF vs. IF　Combined Ex and IF did not decrease SBP [WMD: -3.00 mmHg (95% CI: -6.06 to 0.05), *p*=0.05; 5 trials] or DBP [WMD: -0.11 mmHg (95% CI: -2.73 to 2.51), *p*=0.93; 5 trials] significantly as compared with IF alone (Supplementary Figs. 23 and 24). The heterogeneity was not significant for SBP (I^2=0.00, *p*=0.63) or DBP (I^2=0.00, *p*=0.86). Visual interpretation of funnel plots suggested publication bias for SBP, but Egger's tests did not indicate bias for SBP (*p*=0.12) or DBP (*p*=0.94) (Supplementary Figs. 53 and 54). In addition, when the missing studies were accounted using the trim and fill method, the overall changes were as follow: SBP [WMD: -3.85 mmHg (95% CI: -6.66 to 1.01)] or DBP [WMD: 0.58 mmHg (95% CI: -1.72 to 2.89)].

Glycemia

Combined Ex and IF vs. Ex　Combined Ex and IF did not significantly decrease glucose [WMD: -1.89 mg/dl (95% CI: -6.18 to 2.39), *p*=0.38; 4 trials] or insulin [SMD: -0.24 (95% CI: -0.58 to 0.10), *p*=0.16; 4 trials] compared with IF alone (Supplementary Figs. 25 and 26). Heterogeneity was not significant for insulin (I^2=0.00, *p*=0.65), but there was small and non-significant heterogeneity for glucose (I^2=37.86, *p*=0.18). Visual interpretation of funnel plots suggested publication bias for glucose, but Egger's tests did not confirm this bias for glucose (*p*=0.25) or insulin (*p*=0.85) (Supplementary Figs. 55 and 56). In addition, when the missing studies were accounted using the trim and fill method, the overall change was as follow: glucose [WMD: -2.42 mg/dl (95% CI: -6.16 to 1.31)].

Combined Ex and IF vs. IF　Combined Ex and IF did not significantly decrease glucose [WMD: -1.81 mg/dl (95% CI: -4.93 to 1.29), *p*=0.25; 5 trials] or insulin [SMD: -0.24 (95% CI: -0.62 to 0.13), *p*=0.20; 3 trials] compared with IF alone (Supplementary Figs. 27 and 28). The heterogeneity was not significant for glucose (I^2=0.00, *p*=0.55) or insulin (I^2=0.00, *p*=0.41). Visual interpretation of funnel plots and the Egger's test did not show publication bias for glucose (*p*=0.48). However, visual interpretation of funnel plots suggested publication bias for insulin, whereas the Egger's test did not (*p*=0.36) (Supplementary Figs. 57 and 58). In addition, when the missing

studies were accounted using the trim and fill method, the overall change was as follow**:** insulin [SMD: -0.14 (95% CI: -0.55 to 0.26)].

VO$_2$max/peak

Combined Ex and IF vs. Ex   Combined Ex and IF did not significantly increase VO$_{2max/peck}$ [SMD: 0.26 (95% CI: -0.10 to 0.63), $p = 0.15$; 4 trials] compared with Ex alone (Supplementary Fig. 29). The heterogeneity was no significant (I^2 = 0.00, $p = 0.95$). Both visual interpretation of funnel plots and the Egger's test did not show publication bias ($p = 0.21$) (Supplementary Fig. 59).

Combined Ex and IF vs. IF   Combined Ex and IF significantly increased VO$_{2max/peck}$ [SMD: 0.55 (95% CI: 0.14 to 0.97), $p = 0.009$; 3 trials] compared with IF alone (Supplementary Fig. 30). The heterogeneity was not significant (I^2 = 0.00, $p = 0.99$). Both visual interpretation of funnel plots and the Egger's test did not show publication bias ($p = 0.79$) (Supplementary Fig. 60).

Quality assessment
The overall qualities of included studies are summarized in Supplementary Table 3 which ranged from five to seven out of a maximum nine.

Discussion
The current systematic review and meta-analysis provides evidence that the combination of Ex and IF produces superior changes in body weight, BMI, body fat, and visceral fat when compared to Ex alone. However, combined Ex and IF was only more effective than IF alone for increasing VO$_2$max/peak. In contrast to our hypothesis, that combining Ex and IF did not improve lipid profiles, glycemic outcomes, or blood pressure compared to Ex or IF alone. Overall, these findings indicated that adopting both Ex and IF may be more effective for weight and fat loss, but not for other cardiovascular risk factors.

Previous reviews and meta-analyses have confirmed that combined Ex and IF interventions are effective for decreasing body fat and visceral fat mass in overweight and obese adults [47, 48]. Ex promotes weight loss mainly through enhanced energy expenditure [49]. However, without a dietary intervention combined with Ex, it is not as effective for weight loss [50]. Dietary energy restriction, that reduces energy intake by 15 to 60%, or IF, are more effective strategies for weight loss [47, 51], with a potential downside in a reduction of fat

free mass when not combined with Ex [51]. Our findings support the recommendation of combined protocols which is similar to an earlier study, despite the difference in the type of dietary interventions adopted [30, 52, 53].

Several meta-analyses have suggested that IF produces equivalent weight loss when compared to continuous energy restriction (CER) [54, 55], offering a potential option for those who struggle to consistently restrict caloric intake. Comparison between IF and CER during Ex was not possible due to the limited number of available studies, but IF may be a suitable substitute for CER. In this regard, Xu et al., showed that both IF and CER were effective for improving body composition when combined with Ex, with IF showing larger effects [35]. In the current meta-analysis, combined Ex and IF was more effective than Ex alone for reducing visceral fat and waist circumference, that also fell by -3.42 cm compared to IF alone, though the difference was not statistically significant. Visceral fat is known to be an important and independent risk factor for cardiometabolic diseases [56] and waist circumference is the best anthropometric predictor of visceral fat [57]. On other hand, our finding shows that the combination of EX and IF did not change LBM or fat-free mass versus Ex or IF alone demonstrating role of exercise in maintaining muscle mass. This is an important finding because it is well known that the loss of muscle mass during energy restriction is a negative effect of weight loss [58, 59]. In contrast, maintaining muscle mass may increase resting metabolic rate and energy production, thereby leading to better maintenance of weight loss and potentially greater fat loss [39].

Previous meta-analyses suggest that Ex and IF intervention positively alters lipid profiles, glycemic markers, and blood pressure [16, 60–64]. However, no published meta-analysis has investigated the combination of Ex and IF versus standalone Ex and IF interventions. In contrast to our hypothesis, combined Ex and IF was not associated with significantly greater improvements in cardiometabolic health markers which contrasts with earlier meta-analyses reporting that combining Ex and dietary interventions (DI) may be more effective for improving glycemic markers and lipid profiles [28, 30]. One possible explanation for similar cardiometabolic health benefits could be the effectiveness of either standalone interventions, and there are ceiling effects regarding the magnitude of improvement. In addition, most of the included participants, despite having overweight or obesity, did not have metabolic disorders and were within a healthy range at baseline, or reached a healthy range after intervention. Therefore, the combination of interventions may

be more effective in people with cardiometabolic disorders, such as those with type 2 diabetes mellitus, for improving glycemic markers; or with hypertension, for improving blood pressure, or people with dyslipidemia for improving lipid profiles.

The current meta-analysis also indicated that Ex is necessary for improving $VO_{2max/peak}$, where combining Ex and IF is more effective than IF alone, with a moderate effect size, but not compared with Ex alone. Ex is established to be a primary intervention for improving cardiorespiratory fitness, which has been confirmed in several meta-analyses of different populations and different types of Ex [60, 65–69], even during CER [70]. Cardiorespiratory fitness is an independent cardiometabolic health marker [71, 72] which decreases during CER [73]. Therefore, our results regarding promoting cardiorespiratory fitness during weight loss suggest that IF alone is not sufficient.

The current systematic review and meta-analysis had several limitations that should be considered when interpreting the results. There were only a small numbers of studies that met the inclusion criteria with blood markers and blood pressure outcomes available. Therefore, we were not able to compared the effects of Ex or IF type. Significant heterogeneity for some outcomes was found, which may be due to the variable types of Ex and IF, that we were unable to investigate further. In addition, a majority of included studies used a short intervention period (< 12 weeks) with further studies needed to detriment potential role of combined Ex plus IF. Finally, according to the available studies, the present meta-analysis was limited to young adults and further studies are needed to determine the importance of age.

In conclusion, the current systematic review and meta-analysis provides evidence that the combination of Ex and IF is effective for promoting weight and fat loss, as well as for maintaining muscle mass and increasing cardiorespiratory fitness. However, a combination of Ex and IF is not associated with greater improvements in lipid profiles, glycemic markers, or blood pressure. Further randomized trials are required to elucidate the types of Ex and IF that when combined, have the greatest benefit for cardiometabolic health.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12937-023-00909-x.

Additional file 1: Supplementary Table 1. Search strategy. **Supplementary Table 2.** Risk of bias assessment. **Supplementary Table 3.** Sensitivity analyses. **Supplementary Figure 1.** Forest plot of the effects of Combined Ex and IF versus Ex alone on Body weight. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 2.** Forest plot of the effects of Combined Ex and IF versus Ex alone on BMI. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 3.** Forest plot of the effects of Combined Ex and IF versus Ex alone on Body fat. Data are reported as SMD (95% confidence limits). SMD: standardized mean difference. **Supplementary Figure 4.** Forest plot of the effects of Combined Ex and IF versus Ex alone on Visceral fat. Data are reported as SMD (95% confidence limits). SMD: standardized mean difference. **Supplementary Figure 5.** Forest plot of the effects of Combined Ex and IF versus Ex alone on waist circumference. Data are reported as WMD (95% confidence limits). SMD: weighted mean difference. **Supplementary Figure 6.** Forest plot of the effects of Combined Ex and IF versus Ex alone on LBM. Data are reported as SMD (95% confidence limits). SMD: standardized mean difference. **Supplementary Figure 7.** Forest plot of the effects of Combined Ex and IF versus IF alone on Body weight. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 8.** Forest plot of the effects of Combined Ex and IF versus IF alone on BMI. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 9.** Forest plot of the effects of Combined Ex and IF versus IF alone on Body fat. Data are reported as SMD (95% confidence limits). SMD: standardized mean difference. **Supplementary Figure 10.** Forest plot of the effects of Combined Ex and IF versus IF alone on Visceral fat. Data are reported as SMD (95% confidence limits). SMD: standardized mean difference. **Supplementary Figure 11.** Forest plot of the effects of Combined Ex and IF versus IF alone on Waist circumference. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 12.** Forest plot of the effects of Combined Ex and IF versus IF alone on LBM. Data are reported as SMD (95% confidence limits). SMD: standardized mean difference. **Supplementary Figure 13.** Forest plot of the effects of Combined Ex and IF versus Ex alone on TG. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 14.** Forest plot of the effects of Combined Ex and IF versus Ex alone on TC. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 15.** Forest plot of the effects of Combined Ex and IF versus Ex alone on LDL. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 16.** Forest plot of the effects of Combined Ex and IF versus Ex alone on HDL. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 17.** Forest plot of the effects of Combined Ex and IF versus IF alone on TG. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 18.** Forest plot of the effects of Combined Ex and IF versus IF alone on TC. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 19.** Forest plot of the effects of Combined Ex and IF versus IF alone on LDL. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 20.** Forest plot of the effects of Combined Ex and IF versus IF alone on HDL. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 21.** Forest plot of the effects of Combined Ex and IF versus Ex alone on SBP. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 22.** Forest plot of the effects of Combined Ex and IF versus Ex alone on DBP. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 23.** Forest plot of the effects of Combined Ex and IF versus IF alone on SBP. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 24.** Forest plot of the effects of Combined Ex and IF versus IF alone on DBP. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 25.** Forest plot of the effects of Combined Ex and IF versus Ex alone on Glucose. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 26.** Forest plot of the effects of Combined Ex and IF versus Ex alone on Insulin. Data are reported as SMD (95% confidence limits). SMD: Standardized mean difference. **Supplementary Figure 27.** Forest plot of the effects of Combined Ex and IF versus IF alone on Glucose. Data are reported as WMD (95% confidence limits). WMD: weighted mean difference. **Supplementary Figure 28.** Forest plot of the effects of Combined Ex and IF versus IF alone on Insulin. Data are reported as SMD (95% confidence

---

limits). SMD: Standardized mean difference. **Supplementary Figure 29.** Forest plot of the effects of Combined Ex and IF versus Ex alone on VO2max/peck. Data are reported as SMD (95% confidence limits). SMD: Standardized mean difference. **Supplementary Figure 30.** Forest plot of the effects of Combined Ex and IF versus IF alone on VO2max/peck. Data are reported as SMD (95% confidence limits). SMD: Standardized mean difference. **Supplementary Figure 31.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on Body weight. **Supplementary Figure 32.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on BMI. **Supplementary Figure 33.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on Body fat. **Supplementary Figure 34.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on Visceral fat. **Supplementary Figure 35.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on waist circumference. **Supplementary Figure 36.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on LBM. **Supplementary Figure 37.** Funnel plot of the effects of Combined Ex and IF versus IF alone on Body weight. **Supplementary Figure 38.** Funnel plot of the effects of Combined Ex and IF versus IF alone on BMI. **Supplementary Figure 39.** Funnel plot of the effects of Combined Ex and IF versus IF alone on Body fat. **Supplementary Figure 40.** Funnel plot of the effects of Combined Ex and IF versus IF alone on Visceral fat. **Supplementary Figure 41.** Funnel plot of the effects of Combined Ex and IF versus IF alone on Waist circumference. **Supplementary Figure 42.** Funnel plot of the effects of Combined Ex and IF versus IF alone on LBM. **Supplementary Figure 43.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on TG. **Supplementary Figure 44.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on TC. **Supplementary Figure 45.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on LDL. **Supplementary Figure 46.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on HDL. **Supplementary Figure 47.** Funnel plot of the effects of Combined Ex and IF versus IF alone on TG. **Supplementary Figure 48.** Funnel plot of the effects of Combined Ex and IF versus IF alone on TC. **Supplementary Figure 49.** Funnel plot of the effects of Combined Ex and IF versus IF alone on LDL. **Supplementary Figure 50.** Funnel plot of the effects of Combined Ex and IF versus IF alone on HDL. **Supplementary Figure 51.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on SBP. **Supplementary Figure 52.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on DBP. **Supplementary Figure 53.** Funnel plot of the effects of Combined Ex and IF versus IF alone on SBP. **Supplementary Figure 54.** Funnel plot of the effects of Combined Ex and IF versus IF alone on DBP. **Supplementary Figure 55.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on Glucose. **Supplementary Figure 56.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on Insulin. **Supplementary Figure 57.** Funnel plot of the effects of Combined Ex and IF versus IF alone on Glucose. **Supplementary Figure 58.** Funnel plot of the effects of Combined Ex and IF versus IF alone on Insulin. **Supplementary Figure 59.** Funnel plot of the effects of Combined Ex and IF versus Ex alone on VO2max/peck. **Supplementary Figure 60.** Funnel plot of the effects of Combined Ex and IF versus IF alone on VO2max/peck.

Authors' contributions
Conceptualization, M.Kh., M.E.S., A HM; methodology, M.Kh., A.HM., MH.S., M.E.; software, M.Kh., A.HM., MH.S.; validation, M.E.S., M.Kh., S.K.R; formal analysis, M.Kh., A HM. and MH.S; investigation, M.Kh., A.HM., MH.S.; resources, M.Kh., A.HM., MH.S.; data curation, M.Kh., A.HM., MH.S., M.E.; writing—original draft preparation, M.Kh.; writing—review and editing,M.Kh., M.E. S and S.K.R.; supervision, M.Kh; project administration, M.Kh.; All authors have read and agreed to the published version of the manuscript.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author on request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Physical Education and Sport Sciences, Faculty of Humanities, University of Kashan, Kashan, Iran. [2]Centre for Perinatal Research, Academic Unit of Population and Lifespan Sciences, School of Medicine, University of Nottingham, Nottingham NG7 2UH, UK. [3]Department of Exercise Physiology and Corrective Exercises, Faculty of Sport Sciences, Urmia University, Urmia, Iran. [4]Department of Exercise Physiology, Faculty of Sport Sciences, University of Guilan, Guilan, Iran. [5]Department of Kinesiology and Nutrition Sciences, University of Nevada Las Vegas, Las Vegas, NV, USA.

References
1. Popkin BM, Gordon-Larsen P. The nutrition transition: worldwide obesity dynamics and their determinants. Int J Obes. 2004;28(3):S2–9.
2. Wilson PW, et al. Overweight and obesity as determinants of cardiovascular risk: the Framingham experience. Arch Intern Med. 2002;162(16):1867–72.
3. Kahn SE, Hull RL, Utzschneider KM. Mechanisms linking obesity to insulin resistance and type 2 diabetes. Nature. 2006;444(7121):840–6.
4. Swinburn BA, et al. Diet, nutrition and the prevention of excess weight gain and obesity. Public Health Nutr. 2004;7(1a):123–46.
5. Sell H, Habich C, Eckel J. Adaptive immunity in obesity and insulin resistance. Nat Rev Endocrinol. 2012;8(12):709–16.
6. Mikhail N, Golub MS, Tuck ML. Obesity and hypertension. Prog Cardiovasc Dis. 1999;42(1):39–58.
7. Kotsis V, et al. Mechanisms of obesity-induced hypertension. Hypertens Res. 2010;33(5):386–93.
8. Jiang SZ, et al. Obesity and hypertension. Exp Ther Med. 2016;12(4):2395–9.
9. Heart N, et al. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: the evidence report. National Heart, Lung, and Blood Institute. 1998;(Suppl 2):51S–209S.
10. Tam C, et al. Obesity and low-grade inflammation: a paediatric perspective. Obes Rev. 2010;11(2):118–26.
11. Tchernof A, Després JP. Pathophysiology of human visceral obesity: an update. Physiol Rev. 2013;93(1):359–404.
12. Klein S, et al. Clinical implications of obesity with specific focus on cardiovascular disease: a statement for professionals from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism: endorsed by the American College of Cardiology Foundation. Circulation. 2004;110(18):2952–67.
13. Villareal DT, et al. Weight loss, exercise, or both and physical function in obese older adults. N Engl J Med. 2011;364(13):1218–29.
14. Van Gaal L, Scheen A. Weight management in type 2 diabetes: current and emerging approaches to treatment. Diabetes Care. 2015;38(6):1161–72.
15. Khalafi M, et al. The impact of exercise and dietary interventions on circulating leptin and adiponectin in individuals with overweight and obesity: a systematic review and meta-analysis. Adv Nutr. 2022;14(1):128–46.
16. Battista F, et al. Effect of exercise on cardiometabolic health of adults with overweight or obesity: Focus on blood pressure, insulin resistance, and intrahepatic fat—A systematic review and meta-analysis. Obes Rev. 2021;22:e13269.

17. Hayashino Y, et al. Effects of supervised exercise on lipid profiles and blood pressure control in people with type 2 diabetes mellitus: a meta-analysis of randomized controlled trials. Diabetes Res Clin Pract. 2012;98(3):349–60.
18. Ditschuneit HH, et al. Metabolic and weight-loss effects of a long-term dietary intervention in obese patients. Am J Clin Nutr. 1999;69(2):198–204.
19. Sackner-Bernstein J, Kanter D, Kaul S. Dietary intervention for overweight and obese adults: comparison of low-carbohydrate and low-fat diets. A meta-analysis PloS one. 2015;10(10):e0139817.
20. Astrup A, et al. The role of low-fat diets in body weight control: a meta-analysis of ad libitum dietary intervention studies. Int J Obes. 2000;24(12):1545–52.
21. Verheggen R, et al. A systematic review and meta-analysis on the effects of exercise training versus hypocaloric diet: distinct effects on body weight and visceral adipose tissue. Obes Rev. 2016;17(8):664–90.
22. Wang W, et al. Beneficial effect of time-restricted eating on blood pressure: a systematic meta-analysis and meta-regression analysis. Nutr Metab. 2022;19(1):77.
23. Gu L, et al. Effects of intermittent fasting in human compared to a non-intervention diet and caloric restriction: A meta-analysis of randomized controlled trials. Front Nutr. 2022;9:871682.
24. Pureza I.R.d.O.M, et al. Effect of early time-restricted feeding on the metabolic profile of adults with excess weight: A systematic review with meta-analysis. Clinical Nutrition. 2021;40(4):1788–99.
25. Cho Y, et al. The effectiveness of intermittent fasting to reduce body mass index and glucose metabolism: a systematic review and meta-analysis. J Clin Med. 2019;8(10):1645.
26. Cheng C-C, Hsu C-Y, Liu J-F. Effects of dietary and exercise intervention on weight loss and body composition in obese postmenopausal women: a systematic review and meta-analysis. Menopause. 2018;25(7):772–82.
27. Wu T, et al. Long-term effectiveness of diet-plus-exercise interventions vs. diet-only interventions for weight loss: a meta-analysis. Obes Rev. 2009;10(3):313–23.
28. Khalafi M, et al. Exercise training, dietary intervention, or combined interventions and their effects on lipid profiles in adults with overweight and obesity: a systematic review and meta-analysis of randomized clinical trials. Nutr Metab Cardiovasc Dis. 2023;33(9):1662–83.
29. Khalafi M, Symonds ME, Akbari A. The impact of exercise training versus caloric restriction on inflammation markers: a systematic review and meta-analysis. Crit Rev Food Sci Nutr. 2022;62(15):4226–41.
30. Khalafi M, et al. A comparison of the impact of exercise training with dietary intervention versus dietary intervention alone on insulin resistance and glucose regulation in individual with overweight or obesity: a systemic review and meta-analysis. Crit Rev Food Sci Nutr. 2022;63:1–15.
31. Wan X, et al. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol. 2014;14(1):135.
32. Hozo SP, Djulbegovic B, Hozo I. Estimating the mean and variance from the median, range, and the size of a sample. BMC Med Res Methodol. 2005;5(1):13.
33. Higgins JP, et al. Cochrane handbook for systematic reviews of interventions. 2019: John Wiley & Sons.
34. Guo Z, et al. Influence of consumption of probiotics on the plasma lipid profile: a meta-analysis of randomised controlled trials. Nutr Metab Cardiovasc Dis. 2011;21(11):844–50.
35. Xu R, et al. Differential effects of intermittent energy restriction vs. continuous energy restriction combined high-intensity interval training on overweight/obese adults: A randomized controlled trial. Front Nutr. 2022;9:979618.
36. De Morton NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. Aust J Physiother. 2009;55(2):129–33.
37. Liu H, et al. Effects of time-restricted feeding and walking exercise on the physical health of female college students with hidden obesity: a randomized trial. Front Public Health. 2023;11:1020887.
38. Batitucci G, et al. Impact of Intermittent Fasting Combined With High-Intensity Interval Training on Body Composition, Metabolic Biomarkers, and Physical Fitness in Women With Obesity. Front Nutr. 2022;9:884305.
39. Bhutani S, et al. Alternate day fasting and endurance exercise combine to reduce body weight and favorably alter plasma lipids in obese humans. Obesity (Silver Spring). 2013;21(7):1370–9.
40. Cho AR, et al. Effects of alternate day fasting and exercise on cholesterol metabolism in overweight or obese adults: A pilot randomized controlled trial. Metabolism. 2019;93:52–60.
41. Cooke MB, et al. Effects of Intermittent Energy Restriction Alone and in Combination with Sprint Interval Training on Body Composition and Cardiometabolic Biomarkers in Individuals with Overweight and Obesity. Int J Environ Res Public Health. 2022;19(13):7969.
42. Ezpeleta M, et al. Effect of alternate day fasting combined with aerobic exercise on non-alcoholic fatty liver disease: A randomized controlled trial. Cell Metab. 2023;35(1):56-70.e3.
43. Haganes KL, et al. Time-restricted eating and exercise training improve HbA1c and body composition in women with overweight/obesity: A randomized controlled trial. Cell Metab. 2022;34(10):1457-1471.e4.
44. Kotarsky CJ, et al. Time-restricted eating and concurrent exercise training reduces fat mass and increases lean mass in overweight and obese adults. Physiol Rep. 2021;9(10):e14868.
45. Maaloul R, et al. Effectiveness of Ramadan diurnal intermittent fasting and concurrent training in the management of obesity: is the combination worth the weight? Nutr Metab Cardiovasc Dis. 2023;33(3):659–66.
46. Hottenrott K, et al. Exercise Training, Intermittent Fasting and Alkaline Supplementation as an Effective Strategy for Body Weight Loss: A 12-Week Placebo-Controlled Double-Blind Intervention with Overweight Subjects. Life-Basel. 2020;10(5):74.
47. Pellegrini M, et al. Effects of time-restricted feeding on body weight and metabolism. A systematic review and meta-analysis. Rev Endocr Metab Disord. 2020;21:17–33.
48. Bellicha A, et al. Effect of exercise training on weight loss, body composition changes, and weight maintenance in adults with overweight or obesity: An overview of 12 systematic reviews and 149 studies. Obes Rev. 2021;22:e13256.
49. Cuthbertson DJ, Dobbie LJ. Role of Exercise and Physical Activity in Promoting Weight Loss and Weight Loss Maintenance. Clin Obes Adult Child. 2022;11:262–78.
50. Myers CA, et al. Examination of mechanisms (E-MECHANIC) of exercise-induced weight compensation: study protocol for a randomized controlled trial. Trials. 2014;15:1–12.
51. Varady K. Intermittent versus daily calorie restriction: which diet regimen is more effective for weight loss? Obes Rev. 2011;12(7):e593–601.
52. Khalafi M, et al. The impact of exercise and dietary interventions on circulating leptin and adiponectin in individuals who are overweight and those with obesity: A systematic review and meta-analysis. Adv Nutr. 2023;14(1):128.
53. Eglseer D, et al. Nutrition and exercise interventions to improve body composition for persons with overweight or obesity near retirement age: A systematic review and network meta-analysis of randomised controlled trials. Adv Nutr. 2023;14(3):516–38.
54. Rynders CA, et al. Effectiveness of intermittent fasting and time-restricted feeding compared to continuous energy restriction for weight loss. Nutrients. 2019;11(10):2442.
55. Enríquez Guerrero A, et al. Effectiveness of an intermittent fasting diet versus continuous energy restriction on anthropometric measurements, body composition and lipid profile in overweight and obese adults: a meta-analysis. Eur J Clin Nutr. 2021;75(7):1024–39.
56. Khalafi M, et al. Effect of resistance training with and without caloric restriction on visceral fat: A systemic review and meta-analysis. Obes Rev. 2021;22(9):e13275.
57. Han TS, et al. Waist circumference as a screening tool for cardiovascular risk factors: evaluation of receiver operating characteristics (ROC). Obes Res. 1996;4(6):533–47.
58. Weiss EP, et al. Lower extremity muscle size and strength and aerobic capacity decrease with caloric restriction but not with exercise-induced weight loss. J Appl Physiol. 2007;102(2):634–40.
59. Sparti A, et al. Relationship between resting metabolic rate and the composition of the fat-free mass. Metabolism. 1997;46(10):1225–30.
60. Ashton RE, et al. Effects of short-term, medium-term and long-term resistance exercise training on cardiometabolic health outcomes in adults: systematic review with meta-analysis. Br J Sports Med. 2020;54(6):341–8.
61. Wood G, et al. Determining the effect size of aerobic exercise training on the standard lipid profile in sedentary adults with three or more metabolic syndrome factors: a systematic review and meta-analysis of randomised controlled trials. Br J Sports Med. 2022;56(18):1032–41.

62. Meng H, et al. Effects of intermittent fasting and energy-restricted diets on lipid profile: A systematic review and meta-analysis. Nutrition. 2020;77:110801.
63. Yuan X, et al. Effect of intermittent fasting diet on glucose and lipid metabolism and insulin resistance in patients with impaired glucose and lipid metabolism: A Systematic Review and Meta-Analysis. Int J Endocrinol. 2022;2022:110801.
64. Yang F, et al. Effect of epidemic intermittent fasting on cardiometabolic risk factors: a systematic review and meta-analysis of randomized controlled trials. Front Nutr. 2021;8:669325.
65. Sultana RN, et al. The effect of low-volume high-intensity interval training on body composition and cardiorespiratory fitness: a systematic review and meta-analysis. Sports Med. 2019;49(11):1687–721.
66. Pito PG, et al. Effects of Concurrent Training on 1RM and VO2 in Adults: Systematic Review with Meta-analysis. Int J Sports Med. 2021;43(4):297–304.
67. Hurst C, et al. The effects of same-session combined exercise training on cardiorespiratory and functional fitness in older adults: a systematic review and meta-analysis. Aging Clin Exp Res. 2019;43:1–17.
68. Khalafi M, et al. Influence of exercise type and duration on cardiorespiratory fitness and muscular strength in post-menopausal women: a systematic review and meta-analysis. Front Cardiovasc Med. 2023;10:1190187.
69. Khalafi M, et al. Impact of concurrent training versus aerobic or resistance training on cardiorespiratory fitness and muscular strength in middle-aged to older adults: A systematic review and meta-analysis. Physiol Behav. 2022;254: 113888.
70. Khalafi M, Symonds M. Impact of exercise training plus caloric restriction on cardiometabolic health in menopausal women who are overweight or obese: A meta-analysis. Sci Sports. 2023;38(2):116–26.
71. Sui X, LaMonte MJ, Blair SN. Cardiorespiratory fitness as a predictor of nonfatal cardiovascular events in asymptomatic women and men. Am J Epidemiol. 2007;165(12):1413–23.
72. LaMonte MJ, et al. Cardiorespiratory fitness and coronary heart disease risk factors: the LDS Hospital Fitness Institute cohort. Circulation. 2000;102(14):1623–8.
73. Racette SB, et al. Effects of two years of calorie restriction on aerobic capacity and muscle strength. Med Sci Sports Exerc. 2017;49(11):2240.

Publisher's Note

Terms and Conditions

Springer Nature journal content, brought to you courtesy of Springer Nature Customer Service Center GmbH ("Springer Nature").

Springer Nature supports a reasonable amount of sharing of research papers by authors, subscribers and authorised users ("Users"), for small-scale personal, non-commercial use provided that all copyright, trade and service marks and other proprietary notices are maintained. By accessing, sharing, receiving or otherwise using the Springer Nature journal content you agree to these terms of use ("Terms"). For these purposes, Springer Nature considers academic use (by researchers and students) to be non-commercial.

These Terms are supplementary and will apply in addition to any applicable website terms and conditions, a relevant site licence or a personal subscription. These Terms will prevail over any conflict or ambiguity with regards to the relevant terms, a site licence or a personal subscription (to the extent of the conflict or ambiguity only). For Creative Commons-licensed articles, the terms of the Creative Commons license used will apply.

We collect and use personal data to provide access to the Springer Nature journal content. We may also use these personal data internally within ResearchGate and Springer Nature and as agreed share it, in an anonymised way, for purposes of tracking, analysis and reporting. We will not otherwise disclose your personal data outside the ResearchGate or the Springer Nature group of companies unless we have your permission as detailed in the Privacy Policy.

While Users may use the Springer Nature journal content for small scale, personal non-commercial use, it is important to note that Users may not:

1. use such content for the purpose of providing other users with access on a regular or large scale basis or as a means to circumvent access control;

2. use such content where to do so would be considered a criminal or statutory offence in any jurisdiction, or gives rise to civil liability, or is otherwise unlawful;

3. falsely or misleadingly imply or suggest endorsement, approval , sponsorship, or association unless explicitly agreed to by Springer Nature in writing;

4. use bots or other automated methods to access the content or redirect messages

5. override any security feature or exclusionary protocol; or

6. share the content in order to create substitute for Springer Nature products or services or a systematic database of Springer Nature journal content.

In line with the restriction against commercial use, Springer Nature does not permit the creation of a product or service that creates revenue, royalties, rent or income from our content or its inclusion as part of a paid for service or for other commercial gain. Springer Nature journal content cannot be used for inter-library loans and librarians may not upload Springer Nature journal content on a large scale into their, or any other, institutional repository.

These terms of use are reviewed regularly and may be amended at any time. Springer Nature is not obligated to publish any information or content on this website and may remove it or features or functionality at our sole discretion, at any time with or without notice. Springer Nature may revoke this licence to you at any time and remove access to any copies of the Springer Nature journal content which have been saved.

To the fullest extent permitted by law, Springer Nature makes no warranties, representations or guarantees to Users, either express or implied with respect to the Springer nature journal content and all parties disclaim and waive any implied warranties or warranties imposed by law, including merchantability or fitness for any particular purpose.

Please note that these rights do not automatically extend to content, data or other material published by Springer Nature that may be licensed from third parties.

If you would like to use or distribute our Springer Nature journal content to a wider audience or on a regular basis or in any other manner not expressly permitted by these Terms, please contact Springer Nature at

onlineservice@springernature.com