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Effect of intermittent fasting on obesity and metabolic indices in patients with metabolic syndrome: a systematic review and meta analysis

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Abstract

Objective Dietary patterns play a vital role in the health management of individuals with metabolic syndrome. Many recent studies have shown that intermittent fasting (IF) has better effects, such as improving obesity. Nevertheless, it warrants further investigation to determine which approach is more effective in comparison to continuous energy restriction (CR), particularly when total calorie intake shows minimal variation. Consequently, it is crucial to evaluate the degree of enhancement of the two dietary patterns concerning different aspects of metabolic syndrome. This study presents a meta-analysis of randomized controlled trials (RCTs) aimed at comparing the impacts of IF and CR on obesity and glucolipid metabolism in individuals diagnosed with metabolic syndrome.

Methods In August 2024, a thorough examination of English-language literature was performed across the PubMed, Medline, Embase, and Cochrane Library databases. The meta-analyses was performed according to the established guidelines and reported the results. Weight change, Body Mass Index (BMI) change, and triglyceride (TG) level change were designated as key assessment indicators, while blood pressure, blood glucose, hip circumference, and waist circumference served as supplementary indicators for comparative analysis.

Result A total of nine studies involving 626 patients were analyzed, focusing on the influence of dietary patterns on obesity, cholesterol levels, and insulin resistance among individuals diagnosed with metabolic syndrome. Both dietary patterns were beneficial for patients with metabolic syndrome. However, IF was better than CRin terms of improvement in obesity over the trial period (mean -1.77, 95% CI [-3.06, -0.48]), and it was more conducive to a reduction in TG levels, which was beneficial in terms of improving insulin resistance (mean -10.16, 95% CI [-18.88, -1.45]).

Conclusion Given its notable advantages for obesity, lipids, and insulin resistance, along with improved patient adherence, IF may be regarded as a more effective dietary approach for individuals with metabolic syndrome. Nonetheless, the long-term effectiveness still necessitates additional validation.

Prospero registration CRD42024587335.

Keywords Intermittent Fasting, Continuous Energy Restriction, Obesity, Metabolic Syndrome, Meta analysis, Systematic Review

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Introduction

Global epidemiologic data indicates that around 25% to 30% of adults fulfill the diagnostic criteria for metabolic syndrome, with this figure being even more pronounced among the obese population. Studies have shown that the prevalence of metabolic syndrome was historically higher in North America and Europe but has recently increased in Asian countries due to lifestyle changes [1, 2]. It has been shown to be associated with a twofold increased risk of cardiovascular events and numerous endocrine disorders. Energy restriction has received significant attention as a dietary strategy to improve health by reducing daily caloric intake. A wide range of clinical and experimental investigations have demonstrated that energy restriction exerts beneficial effects on the amelioration of metabolic syndrome and its constituent elements, encompassing reductions in body weight, enhancements in glycemic regulation, and modulation of lipid levels [3, 4].

Metabolic syndrome is characterized by the presence of obesity, insulin resistance, hypertension, hyperglycemia, and dyslipidemia. Its pathogenesis involves multiple complex systems; however, its core lies in the disorders of glucose and lipid metabolism [5–7]. The current treatment strategies mostly involve lifestyle modifications, including dietary enhancements, increased physical activity, and weight reduction; in cases of significant index abnormalities, appropriate therapies such as cholesterol and blood sugar reduction are implemented. For severely obese patients, weight loss can also be achieved through surgical procedures [1, 8, 9]. One of the important lifestyle intervention strategies is both prevention and treatment. Research indicates that energy restriction may serve as an effective dietary intervention for metabolic syndrome, influencing various physiological mechanisms such as enhancing insulin sensitivity, lowering inflammation, modulating fat metabolism, and adjusting hormone levels [10]. Utilizing these strategies, the implementation of energy restriction can proficiently mitigate metabolic syndrome. The benefits of energy restriction have been demonstrated in numerous studies, leading to a preference for discovering more optimal patterns of energy restriction. Existing patterns include intermittent fasting (IF), continuous energy restriction (CR), cyclic energy restriction, and low-carbohydrate diets. Identifying the most beneficial model for metabolic syndrome continues to be an area of investigation.

CR is a dietary strategy that facilitates a negative energy balance by maintaining daily caloric consumption at a diminished level. It has been proven to be effective in reducing body weight and improving glycemic control and cholesterol levels, thereby facilitating the management of metabolic syndrome [11]. However, it has also been suggested that prolonged and sustained energy restriction may lead to a decrease in the basal metabolic rate, which could affect the feasibility of weight maintenance and increase the risk of rebound weight gain [12]. Consequently, it is essential to investigate more beneficial approaches to energy restriction. IF has gained considerable attention in recent years, with various studies indicating its efficacy in reducing body weight and potentially enhancing insulin sensitivity along with other metabolic indicators. For instance, it may facilitate fat mobilization and elevate metabolic rate [13]. However, it remains to be verified which of the two is more effective for weight loss and which is more favorable for metabolic syndrome control. A meta-analysis suggests that IF is more beneficial for weight loss [14]. Nevertheless, certain studies suggest that the origin of this benefit is attributed to the caloric deficit resulting from IF being more significant than that from CR. This may be due to the overall lower calorie intake rather than merely benefiting from different eating patterns [15]. When confronted with differing conclusions from multiple studies, it is essential to examine which of the two models exhibits greater effectiveness in relation to weight loss and metabolic syndrome, employing meta-analysis as a methodological strategy.

Previous meta-analyses have debated the advantages and disadvantages of IF and CR for weight loss, highlighting a lack of comparative studies that consider other factors related to metabolic syndrome. Nonetheless, a notable disparity in total calories was observed between the test and control groups, and there is a scarcity of research examining which method of energy restriction offers greater advantages to individuals with metabolic syndrome when there is no significant difference in overall caloric consumption. To fully assess the efficacy of these two modalities on different aspects of metabolic syndrome, pertinent clinical papers were selected using IF as the experimental group and CR as the control group for analysis, assessing their respective advantages and disadvantages through meta-analysis.

Materials and methods

Registration

The study protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) under the following registration number: CRD42024587335.

Search strategy and data extraction

This analysis is a meta-analysis that does not pertain to a clinical trial; thus, it does not necessitate approval from the Institutional Review Board. The research adhered meticulously to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [16]. A comprehensive search was conducted on

PubMed, EMBASE, and the Cochrane Central Register of Controlled Trials from their inception to August 2024. Furthermore, the references for the included studies were reviewed. The search strategy employed specific subject terms combined with free terms, including"Intermittent Fasting","Caloric Restriction","Obesity","Glucose Metabolism", "Lipid Metabolism","Insulin Resistance","Metabolic Syndrome", "Noncommunicable Diseases", and"Randomized Controlled Trials (RCTs)"to ensure the inclusion of all relevant literature. We placed the specific search strategy in Supplementary Material 1.

Furthermore, a comprehensive review of numerous references from the collected publications was undertaken, alongside an active pursuit of additional pertinent materials, such as research reports and conference proceedings. This search was restricted to human randomized controlled trials. Duplicates were identified and eliminated based on title, author, year, and abstract through the utilization of EndNote X21. After reviewing the titles and abstracts, two authors (SX and BX) conducted an initial screening according to the inclusion and exclusion criteria of this article. The full texts of the selected literature were subsequently downloaded, followed by a second screening. The two researchers separately gathered data from the eligible randomized controlled trials based on the screening results, including the first author, year of publication, sample size, interventions for both the study and control groups, and outcome indicators. A third researcher (SJ) validated the extracted data at the conclusion of the data extraction process. Furthermore, SX and L assessed the risk of bias [17]. Any discord was addressed by a different investigator (QL).

Study selection

We utilized the PICOS (Population, Interventions, Comparisons, Outcomes, Study designs) framework to establish the criteria for eligibility. The studies included in the review met the following conditions: (1) Patients with metabolic syndrome between the ages of 18–75; (2) body mass index (BMI) > 25, with or without diabetes, hypertension, or dyslipidemia; (3) RCTs, where the intervention group follows IF and the control group undergoes CR; (4) Outcome indicators include evaluations of metabolic syndrome such as weight, BMI, waist circumference (WC), hip circumference(HC), blood lipids, blood pressure, fasting glucose, fasting insulin.

The exclusion criteria were as follows: (1) Patients with additional chronic conditions that could influence the measured indicators, such as heart failure; (2) Pregnant or breastfeeding women; (3) Patients with significant eating disorders or substantial weight changes in the last 3 months that may affect the study; (4) Lack of required outcome indicators or inability to provide data; (5) Exclusion of non-English studies.

Outcome measures

This meta-analysis integrated data from several randomized controlled trials. The key outcome indicators investigated were changes in body weight, BMI, and triglyceride (TG) levels in both cohorts before and after the intervention. Secondary outcome indicators included changes in fat mass, WC, blood pressure, fasting blood glucose, and fasting insulin levels before and after the intervention.

Statistical analysis

The retrieved continuous variables for the meta-analysis were analyzed using R version 4.4.1, which generated the standardized mean difference (SMD) with 95% confidence intervals (CI) or the odds ratio (OR) with 95% CI. We decided, as recommended by the Cochrane guidelines, and after considering factors such as sample size, weights, and study effects, it was decided that random effects models would be used for pooling when $I^2 > 50\%$, and fixed effects models would be used for pooling when $I^2 < 50\%$. Sensitivity analyses were performed to identify potential sources of heterogeneity. Studies leading to significant heterogeneity were removed, and the meta-analysis was repeated with the remaining studies to make necessary adjustments. The strength of our meta-analysis was validated when no significant discrepancies emerged between the adjusted outcomes and the primary outcomes. This study quantitatively analyzed the combined results of the Egger's test to evaluate the potential for publication bias.

Results

Literature search and included studies

A total of 5,240 citations were obtained from online databases as of August 17, 2024, following the previously established search strategy. After removing duplicates, 4,169 records remained. Subsequently, 4,139 records were excluded based on an evaluation of titles and abstracts. Of the 30 records that remained, 21 citations were eliminated for various reasons. Ultimately, nine full-text studies were deemed suitable for inclusion in this meta-analysis (Fig. 1). Table 1 presents the basic information for all included studies. A methodology for development and evaluation (GRADE) was utilized to assess the strength of the current evidence for each outcome and subgroup. In our review, evidence started at high quality and was downgraded on each of the following issues: (1) allocation of hidden bias (trials for this outcome were not disclosed as blinded); (2) $I^2 > 50\%$ heterogeneity; and (3) imprecision in meta-analyses when fewer than 200

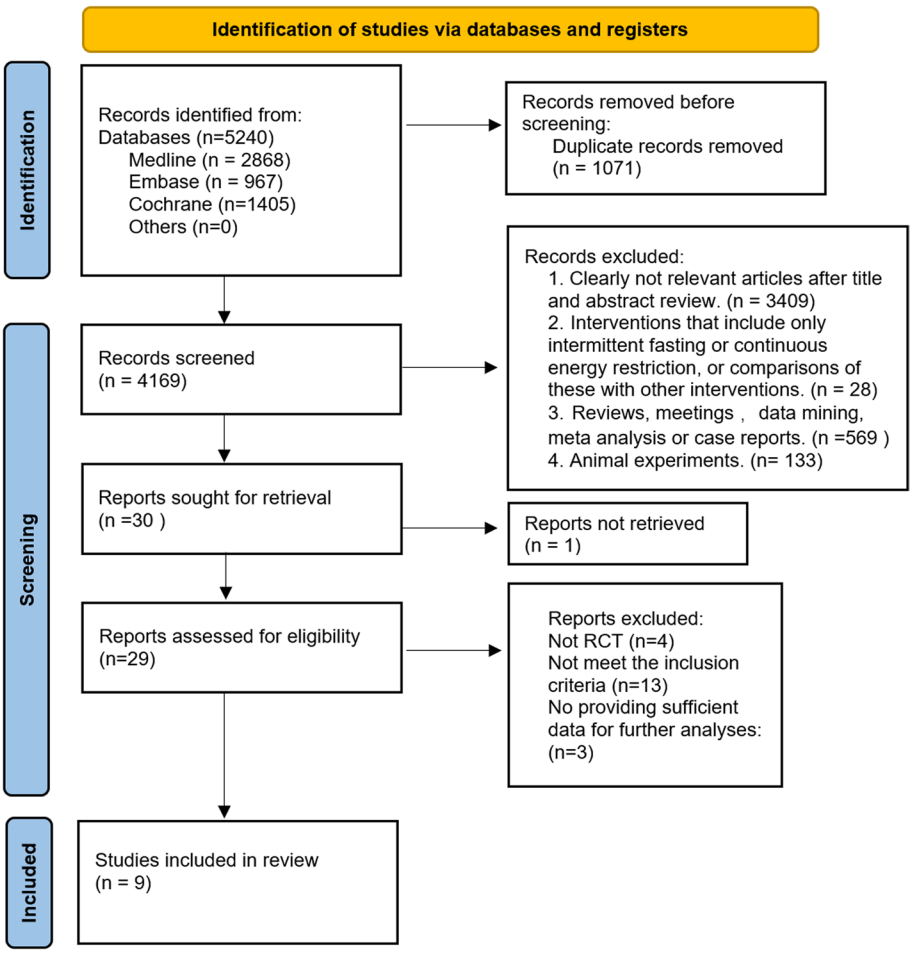

Fig. 1 PRISMA flow diagram for search and selection of eligible studies included in the meta-analysis

subjects were included. We chose to summarize cross-sectional judgments using the GRADE method at 4 confidence levels: very low, low, medium, or high (Supplementary Material 2). Furthermore, we conducted a thorough review of the full text in accordance with the PRISMA guidelines and made necessary adjustments to the PRISMA checklist (Supplementary Material 3).

Outcomes

Eight trials reported weight changes, encompassing a total of 528 samples. The I^2 statistic for between-study heterogeneity was 84%, with a p-value less than 0.01 for the χ^2 test. A sensitivity analysis was performed to discern potential sources of heterogeneity; nonetheless, no particular study emerged as having a significant impact on heterogeneity (Fig. 2). To better explore the sources of heterogeneity, we conducted subgroup analyses by determining whether there was a significant difference in total calories between the test and control groups, whether the included population had comorbid diabetes, and different patterns of intermittent fasting. An extensive examination of the complete texts showed that six trials demonstrated no notable difference in total caloric intake between the test and control groups, whereas the other two trials did not provide details on caloric intake. This distinction formed the basis for subgroup analyses. The 6 trials that specified total calories included 452 subjects, yielding an I^2 statistic of 52%, and their results were pooled using a random-effects model. The data indicated a significant advantage of IF over CR regarding weight loss (mean difference −1.77, 95% CI [−3.06, −0.48]) (Fig. 3). The 2 trials with unspecified caloric intake included 76 subjects, with an I^2 statistic of 0%, and their results were pooled using a fixed-effects model. The data demonstrated that IF was inferior to CR for weight loss (mean difference 0.87, 95% CI [0.23, 1.52]) (Fig. 3). The effect value for IF versus CR in the group where patients had definite comorbid diabetes was mean difference −0.4, 95% CI [−1.48, 0.68] (Fig. 4A). For the cohort of patients with confirmed exclusion of diabetes, the impact size

Table 1 Characteristics of studies used for analysis

Study	year	T	N	Age	Gender	Criteria	Duration
				Mean(SD)	(% female)		
Anglin et al	2013	IF	8			Weight	6 weeks
		CR	8			Weight	6 weeks
Schübe et al	2018	IF	49	49.4 ± 9.0	48.98	Glucose, Insulin, TC, TG, LDL-C	12 weeks
		CR	49	50.5 ± 8.0	48.98	Glucose, Insulin, TC, TG, LDL-C	12 weeks
Pinto et al	2019	IF	21	50 ± 12	71.43	Weight, BMI, Waist, Glucose, Insulin, TC, SBP, DBP	4 weeks
		CR	22	56 ± 8	72.73	Weight, BMI, Waist, Glucose, Insulin, TC, SBP, DBP	4 weeks
Beaulieu et al	2019	IF	12	34 ± 10		Weight, Fat mass, BMI, Waist, Hip circumference	12 weeks
		CR	18	35 ± 9		Weight, Fat mass, BMI, Waist, Hip circumference	12 weeks
Kundurac et al	2020	IF	32	47.44 ± 2.17	50	Weight, Fat mass, BMI, W, Glucose, Insulin, TC, TG, LDL-C, SBP, DBP	12 weeks
		CR	33	48.76 ± 2.13	54.55	Weight, Fat mass, BMI, W, Glucose, Insulin, TC, TG, LDL-C, SBP, DBP	12 weeks
Kang et al	2022	IF	42	34.7 ± 9.8	78.57	Weight, Fat mass	12 weeks
		CR	41	37.5 ± 11.7	87.80	Weight, Fat mass	12 weeks
Hooshiar et al	2023	IF	23	35.09 ± 8.38		Weight, BMI	8 weeks
		CR	24	36.08 ± 8.58		Weight, BMI	8 weeks
Lin et al	2023	IF	30	44 ± 12	83.33	Weight, Fat mass, BMI, W, Glucose, Insulin, TC, TG, LDL-C, SBP, DBP	12 months
		CR	30	44 ± 9	80	Weight, Fat mass, BMI, W, Glucose, Insulin, TC, TG, LDL-C, SBP, DBP	12 months
Xiao et al	2023	IF	85	57 ± 10	42.35	Weight, Fat mass, BMI, W, H, Glucose, Insulin, TC, TG, LDL-C, SBP, DBP	6 months
		CR	83	58 ± 10	40.96	Weight, Fat mass, BMI, W, H, Glucose, Insulin, TC, TG, LDL-C, SBP, DBP	6 months

N number of patients, *T* Treatment, *IF* Intermittent fasting, *CR* Continuous energy limitation, *SD* standard deviation, *BMI* Body mass index, *W* Waist, *H* Hip circumference, *TC* Total cholesterol, *TG* Triglyceride, *LDL-C* Low-density lipoprotein cholesterol, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure

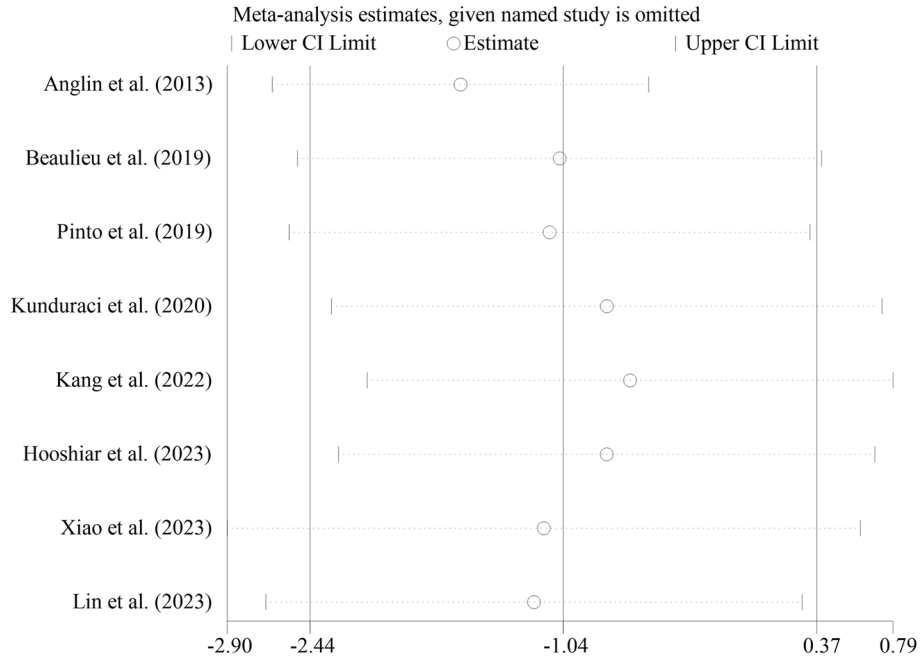

Fig. 2 Sensitivity Analysis Chart for Weight Evaluation

of IF versus CR was represented by the mean difference −0.9, 95% CI [−3.38, 1.58] (Fig. 4A). The effect value for IF and CR in the group adopting 5 + 2 fasting pattern was mean difference −2.37, 95% CI [−24.20, 19.46] (Fig. 4B). The effect value for IF and CR in the 16 + 8 fasting mode group was mean difference −1.25, 95% CI [−21.38, 18.88]

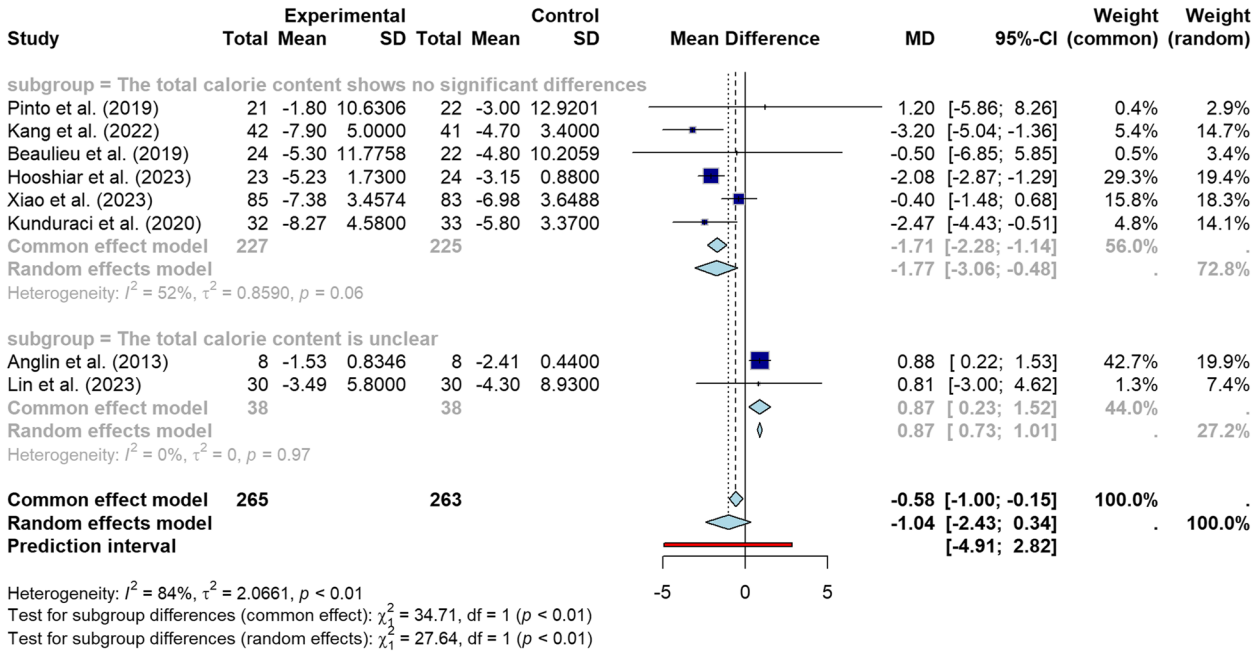

Fig. 3 Forest Plot for Subgroup Analysis Based on Whether There was a Difference in Total Calories

(Fig. 4B). The subgroup analyses examining the presence or absence of comorbid diabetes in patients, along with the specific fasting modalities reported in the included trials and the overall quantitative synthetic data, revealed no statistically significant difference in weight loss outcomes between the intermittent fasting and CR groups (mean difference −1.04, 95% CI [−2.43, 0.34]) (Fig. 4). The Egger test indicated a lack of statistical significance (P = 0.861), implying that no notable publication bias was detected (Supplementary Material 5).

We evaluated the outcome metrics utilizing the GRADE method. In the subgroups where total calories showed no significant difference, GRADE was rated as medium quality, indicating a moderate level of confidence in the results. The downgrading was primarily attributed to partial non-disclosure of the blinding method and heterogeneity among certain studies. Consequently, we conducted multifactorial subgroup analyses within the study. In the subgroup lacking heat description, GRADE evaluated the quality as low, primarily due to the absence of blinding disclosure in several studies and the limited sample size, resulting in two downgrades, awaiting future validation of the findings in larger sample studies. Detailed findings can be found in Supplementary Material 2.

Five trials documented alterations in BMI, involving a cumulative total of 261 samples. The I^2 statistic for between-study heterogeneity was 0%, indicating that a fixed-effects model was appropriate for the analysis. The data demonstrated that IF was more favorable for BMI reduction compared to CR (mean difference −0.81, 95% CI [−1.10, −0.52]) (Fig. 5). To evaluate the strength of the results, sensitivity analyses were performed, revealing no significant heterogeneity among the studies, thereby affirming the reliability of the findings (Fig. 6). Egger's test did not detect publication bias (P = 0.612) but given the small amount of literature included on this outcome metric (n = 5), its detection power was limited, and the risk of bias still could not be completely ruled out. The GRADE assessment indicated that the evidence quality for BMI was moderate, primarily due to the lack of blinding consideration in several of the included studies (Supplementary Material 2).

Changes in TG were documented across four trials, which included a cumulative total of 391 samples. The I^2 statistic for between-study heterogeneity was 8%, indicating the appropriateness of a fixed-effects model for analysis. The data demonstrated that IF conferred greater benefits for TG reduction compared to CR (mean difference −10.16, 95% CI [−18.88, −1.45]) (Fig. 7). Sensitivity analysis across studies indicated no substantial heterogeneity, implying that the conclusions are comparatively robust (Fig. 8). We conducted the Egger's test, yielding a P-value of 0.562, indicating the absence of significant publication bias (Supplementary Material 6). The evidence quality for the TG indicator was assessed as moderate due to the absence of clear

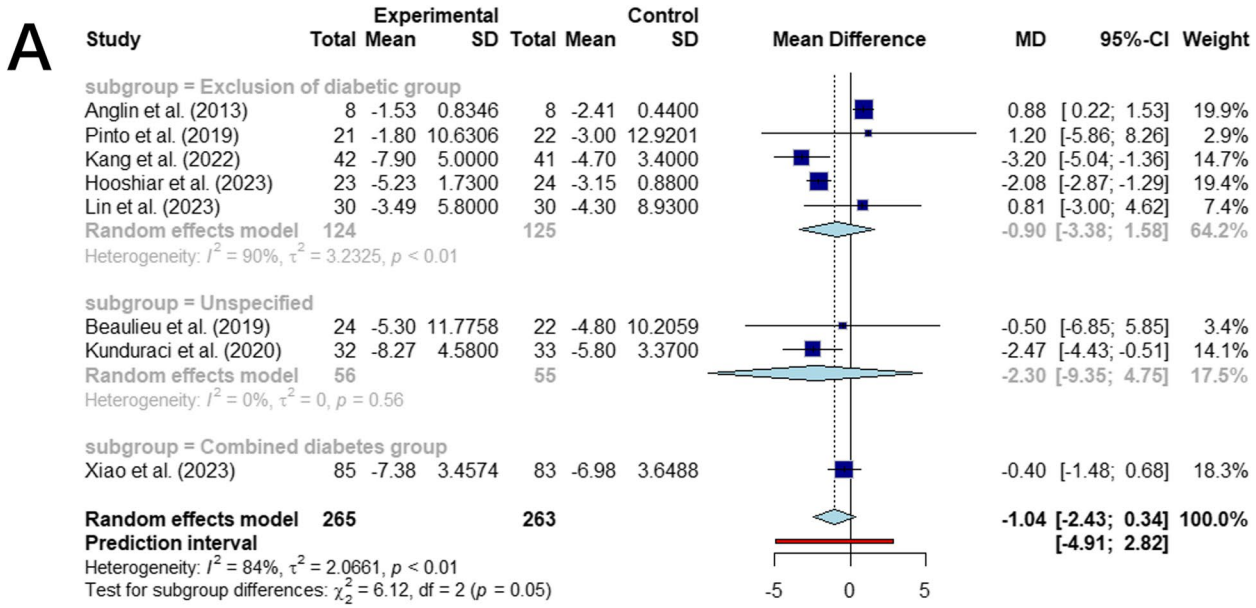

Fig. 4 Effects of IF and CR on Body Weight in Patients with Metabolic Syndrome. **A** Subgroup Analysis of Patients with or without Comorbid Diabetes, **B**. Subgroup Analysis of Types of Fasting Patterns

randomization in the methodology of several studies (Supplementary Material 2).

Nine studies encompassing 626 cases were selected to assess alterations in fat mass, WC, HC, fasting glucose, fasting insulin, blood pressure, total cholesterol (TC), and low-density lipoprotein cholesterol (LDL-C). Random-effects or fixed-effects models were employed for analysis based on heterogeneity. The results indicated no statistically significant differences between IF

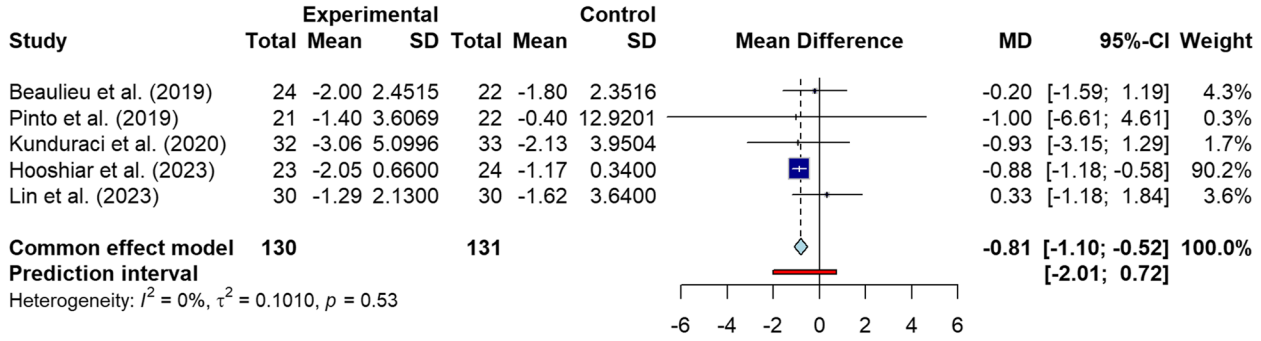

Fig. 5 Effects of IF and CR on BMI in Patients with Metabolic Syndrome

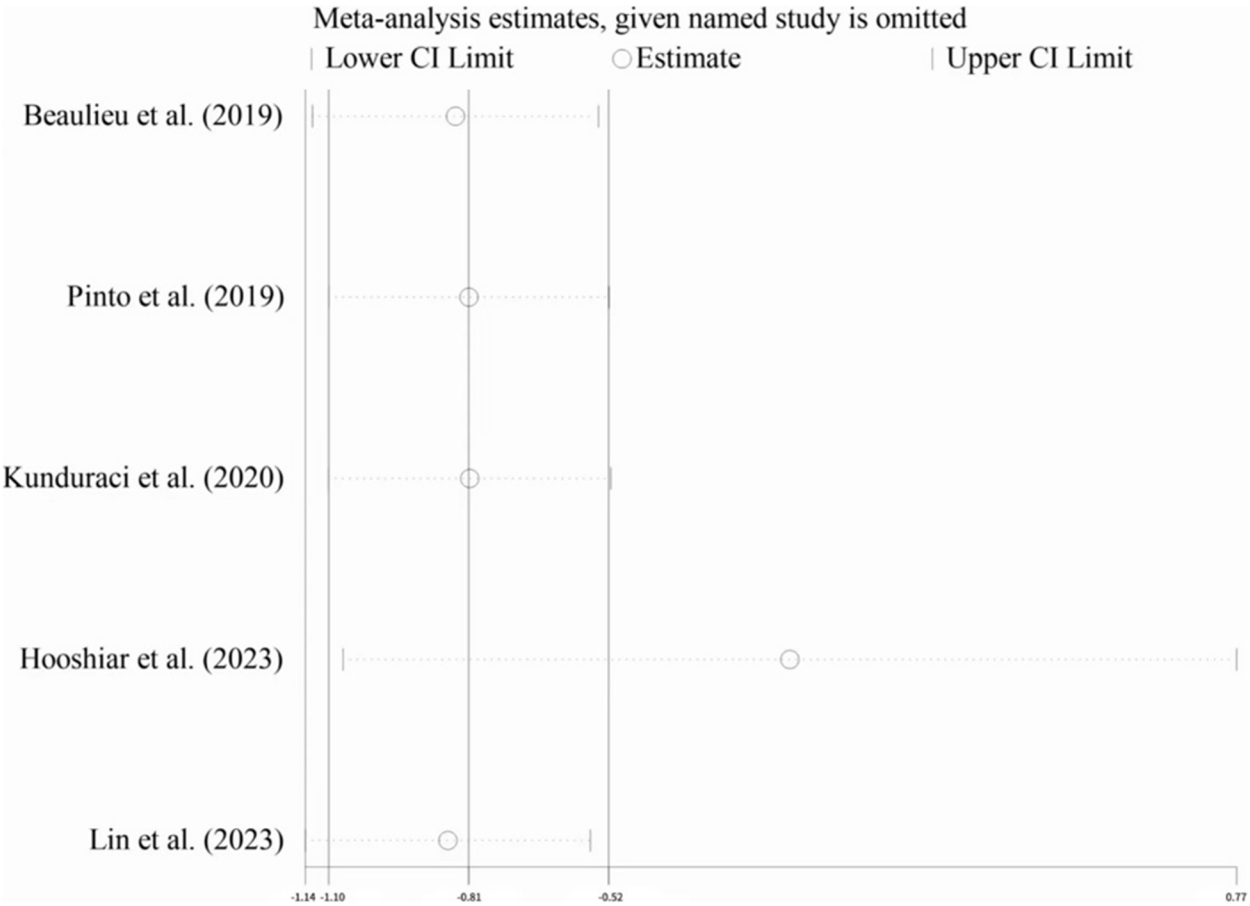

Fig. 6 Sensitivity Analysis Chart for BMI Evaluation

and CR concerning changes in these indices (Table 2). The results of the sensitivity analysis indicate that the results for these outcome indicators are robust and reliable (Fig. 9). The quality of evidence for the secondary outcome indicators in this investigation was evaluated using the GRADE method, revealing a moderate quality of evidence for all indicators, as detailed in Supplementary Material 2.

Discussion

IF exhibits a distinct advantage over CR in terms of weight reduction, decreased BMI, and diminished TG levels. This dietary approach may also offer prospective

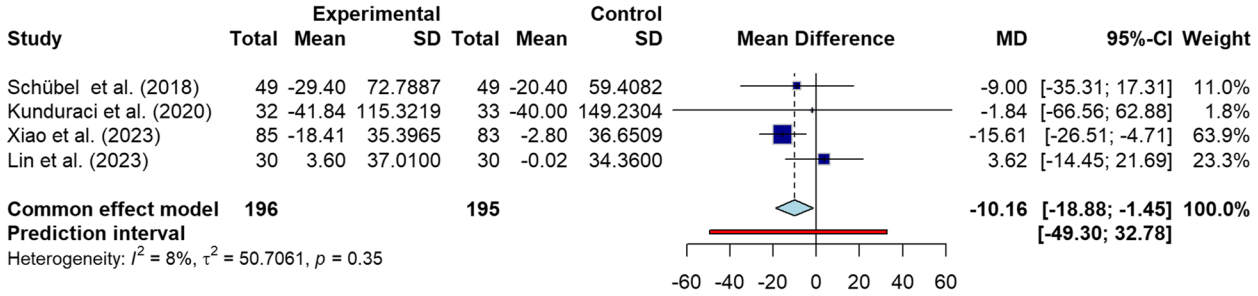

Fig. 7 Effects of IF and CR on Triglyceride in Patients with Metabolic Syndrome

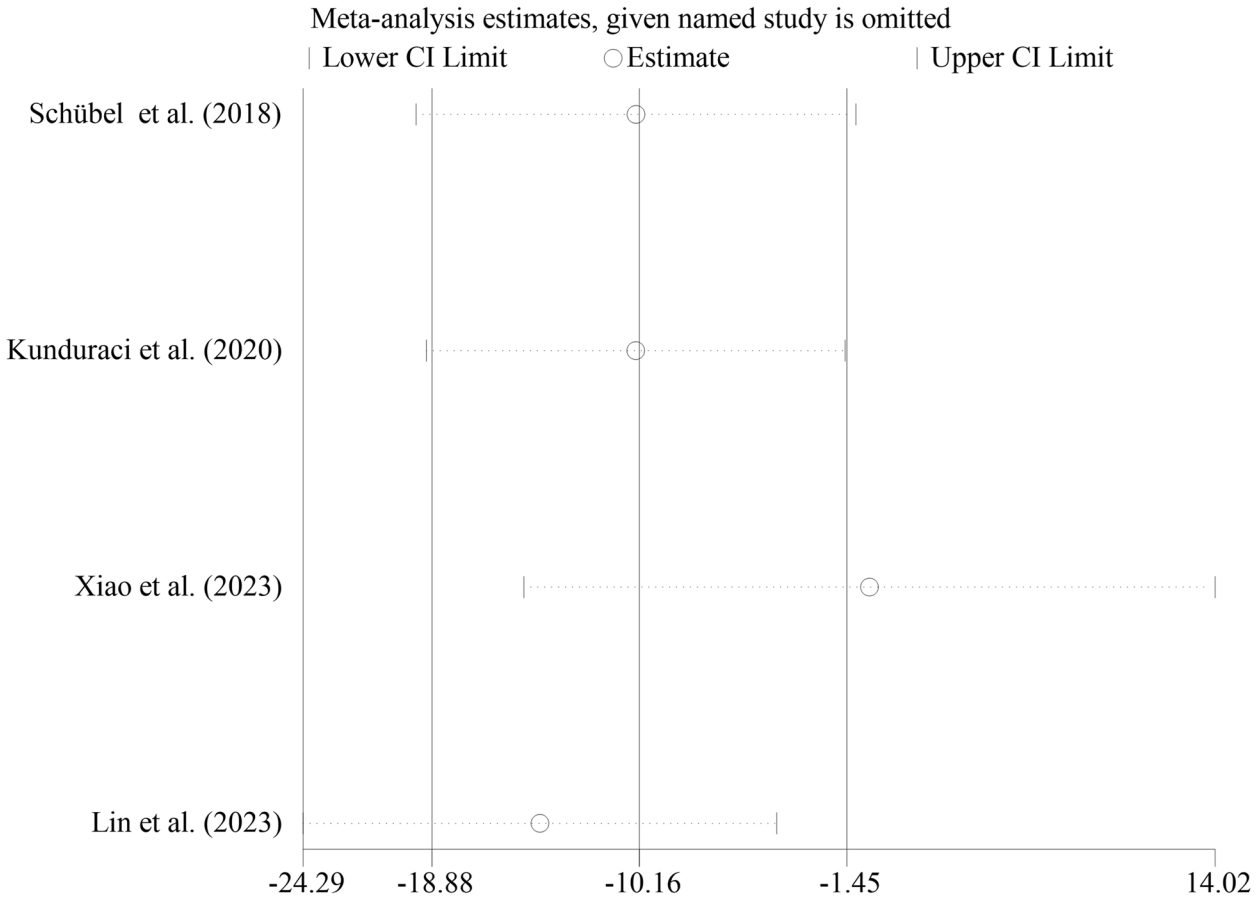

Fig. 8 Sensitivity Analysis Diagram for Triglyceride Evaluation

advantages for individuals experiencing metabolic syndrome.

Weight and BMI are essential indicators of obesity. IF has proven to be more effective than CR in combating obesity, especially when total caloric intake remains comparable. This disparity may be attributed to metabolic adaptations, as CR can lead to a decrease in metabolic rate due to the body's adjustment to a chronic energy deficit. Consequently, while initial weight loss may occur, the rate of weight loss may diminish over time. In contrast, gap fasting offers a structured energy intake that helps maintain a relatively stable metabolic rate and is less susceptible to significant metabolic adaptation [18, 19]. Some studies suggest that IF may enhance the basal metabolic rate, as the body requires additional energy to adapt to irregular eating patterns, thereby increasing calorie consumption [20, 21]. IF has been proposed to enhance insulin sensitivity, improve fat oxidation, and

Table 2 Mean, Confidence Interval and Heterogeneity for Secondary Outcome Measures

Secondary outcome measures	No publication	Sample size		Mean	95%CI	Heterogeneity text	
		IF	CR			I^2 (%)	P
Fat mass	5	213	209	−0.46	(−1.16,0.25)	0	0.95
Waist	5	192	190	−0.94	(−2.03,0.15)	21	0.28
Hip circumference	2	109	105	−0.82	(−2.32,0.69)	0	0.95
Glucose	5	217	217	−0.95	(−5.03,3.12)	71	< 0.01
Insulin	5	217	217	−0.28	(−1.01,0.44)	46	0.12
Systolic blood pressure	4	168	168	1.58	(−0.61,3.77)	0	0.56
Diastolic blood pressure	4	168	168	−0.31	(−1.62,1.01)	35	0.20
Total cholesterol	5	217	217	−1.27	(−6.99,4.44)	0	0.73
Low-density lipoprotein cholesterol	4	196	195	−2.07	(−7.37,3.24)	0	0.92

IF intermittent fasting, *CR* continuous energy limitation, *CI* confidence interval, I^2 percentage of heterogeneity due to true differences within studies, *P* *p*-value for heterogeneity

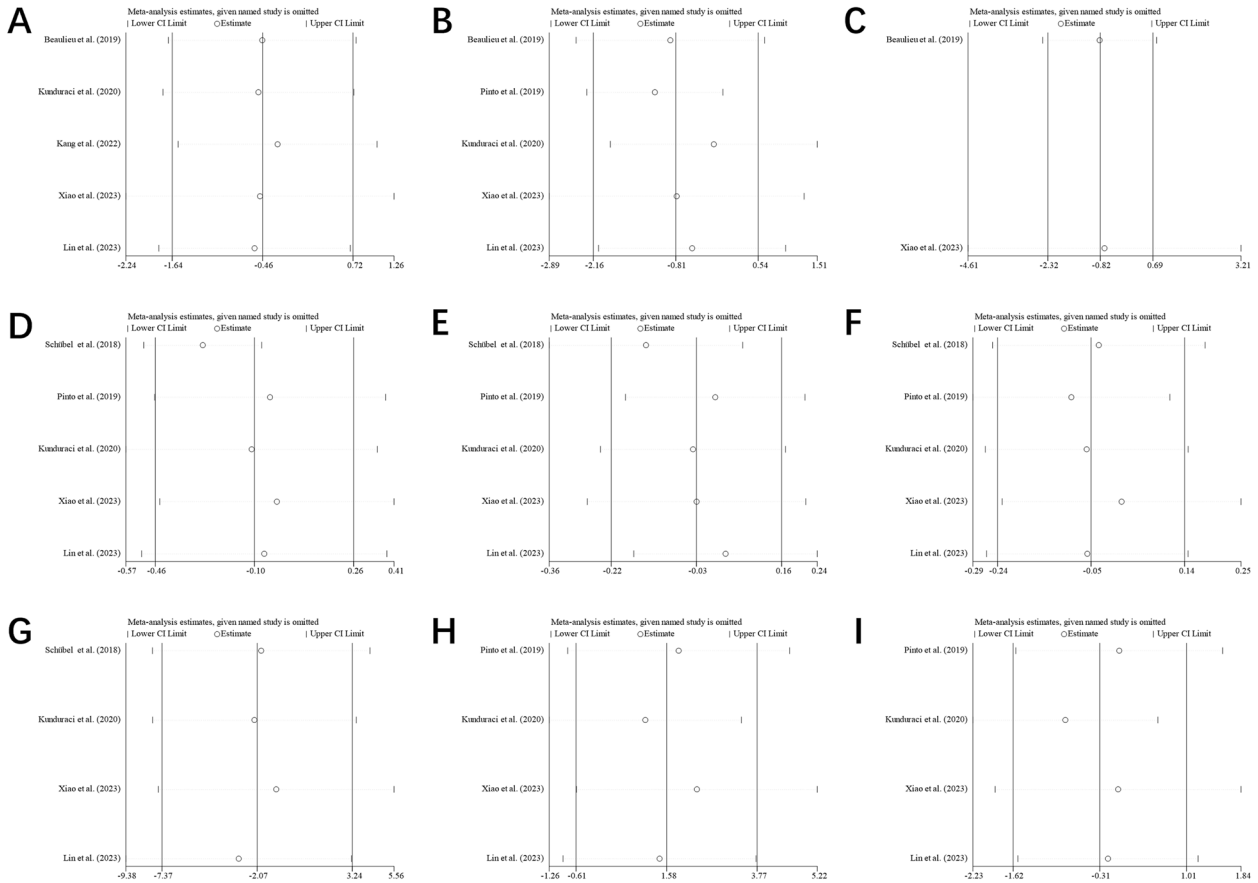

Fig. 9 Sensitivity Analysis Diagram for Secondary Outcome Measures. **A**. fat mass, **B**. waist circumference, **C**. hip circumference, **D**. fasting glucose, **E**. fasting insulin, **F**. total cholesterol, **G**. low-density lipoprotein cholesterol, **H**. systolic blood pressure, **I**. diastolic blood pressure

reduce insulin levels. These changes facilitate a more efficient utilization of fat reserves as an energy source [20, 22]. From an inflammatory perspective, numerous studies indicate that IF possesses anti-inflammatory effects, enhances intracellular signaling pathways, and diminishes chronic inflammation. The condition of diminished inflammation plays a significant role in enhancing overall metabolic well-being, thus facilitating effective

weight management [19, 22]. Furthermore, IF induces autophagy, an intracellular process crucial for removing damage and waste products, which is vital for maintaining cellular health and function [23, 24]. Enhanced cellular health may further promote metabolic efficiency and aid in weight management. Prior research indicates that IF leads to an enhancement in the oxidative mobilization of fat during comparable exercise conditions [25]. From the perspective of the patient, intermittent fasting generally provides the liberty to consume food within a specified timeframe, which may alleviate psychological stress and enhance adherence to dietary guidelines. In contrast, CR may exert greater pressure on individuals to eat, leading to rebound or binge eating behaviors [26]. It has been demonstrated that in terms of psychological factors, IF participants can reduce fatigue in dietary decision-making and report less mental stress and hunger compared to the CR group, thus contributing to improved adherence and facilitating long-term adherence [27, 28]. For the subgroup without caloric restriction, it is possible that total caloric intake accounted for the lack of statistically significant differences between the two groups. In conclusion, IF affects metabolism, hormonal levels, and dietary choices through multiple pathways and may provide superior advantages compared to CR for weight control in individuals with metabolic syndrome.

The Triglyceride-Glucose Index (TyG) serves as a crucial indicator of insulin resistance, exhibiting a positive correlation with TG and glucose levels. This investigation revealed no statistically significant difference between IF and CR in terms of improvement in fasting glucose levels. However, IF showed a more significant decrease in TG levels, indicating its potential advantage in improving insulin resistance in individuals with metabolic syndrome. It has been proposed that IF may lower TG levels by enhancing fatty acid oxidation through decreased energy consumption, while simultaneously regulating circadian genes and anti-inflammatory substances. This interplay influences the relationships between human hormones and lipid molecules, leading to improved metabolic efficiency, diminished fat accumulation, and reduced inflammatory responses, ultimately contributing to lower TG levels and offering advantages for metabolic syndrome [29, 30]. Additionally, IF is associated with increased secretion of growth hormone, which not only facilitates lipolysis but also positively influences muscle protection [31]. The elevation of growth hormone levels contributes to decreased triglyceride levels, reduces insulin secretion, and promotes fat mobilization and oxidation, thereby reducing blood triglyceride concentrations [21]. Furthermore, it improves the leptin-to-ghrelin ratio, which is critical for appetite control and energy balance [32]. A balanced state of these hunger hormones can mitigate binge-eating behaviors, consequently decreasing the propensity for triglyceride production. While CR may offer certain benefits, its effects are likely moderated by adherence and psychological factors, resulting in comparatively diminished advantages when contrasted with IF.

Additional elements of metabolic syndrome, such as LDL-C, WC, HC, blood glucose, insulin, and blood pressure, were examined; however, no statistically significant differences were found. Prior research has indicated that LDL-C is affected by various factors, including hepatic cholesterol synthesis, while triglycerides are more significantly impacted by dietary intake. This may elucidate why TG levels were markedly lower in the intermittent fasting group, whereas LDL-C, as a key indicator, did not exhibit a notable difference between the two groups [33]. In contrast, changes in WC and HC usually take longer because fat loss in these two areas is not only dependent on a chronic negative energy intake state but also related to hormones such as cortisol [34]. In addition, IF and CR, as dietary strategies, will reduce visceral fat mainly in the prenegative energy balance period, and the reduction of subcutaneous fat will take longer to achieve. Blood pressure is influenced by sympathetic nerve activity, sodium intake, vasodilatory function, and fluid regulation, and IF and CR do not differ significantly in their effects on these factors, resulting in no significant difference in blood pressure changes [35]. Indicators like fasting insulin and fasting glucose are shaped by personal sensitivities, as certain patients exhibit greater responsiveness to IF while others show improved outcomes with CR, resulting in mean values for group changes that lack statistical significance [36]. These outcome metrics that did not show statistical differences can be explored in the future with more refined studies and longer validation of their relationships.

Both dietary patterns—IF and CR—offer benefits for patients with metabolic syndrome. When making clinical decisions, it is essential to consider the effects of both approaches, as well as patient compliance and long-term sustainability. Our study suggests that IF is more effective in improving obesity and reducing TG levels. And IF increases fat oxidation, which makes weight loss even more effective when there is exercise to go along with it. From the standpoint of patient compliance, CR demands long-term dietary monitoring, which may lead to feelings of depression or dietary anxiety for some individuals. In contrast, IF is more flexible, easier to adhere to, and can help improve psychological resilience and dietary relationships.

Considering various elements, it is asserted that IF could provide significant advantages for individuals with metabolic syndrome who exhibit elevated TG levels and

demonstrate a readiness to engage in exercise therapy. Certain research indicate that IF may have anti-inflammatory advantages, suggesting that patients with metabolic syndrome and concurrent chronic inflammation could also derive benefits and enhance their metabolic regulation. In addition, it is also suitable for obese people who need long-term dietary management, due to other better compliance and the fact that it brings less dietary anxiety and is suitable for long-term adherence. There are fewer long-term studies related to IF, while CR has been validated over time as an earlier emerging mode of energy restriction. Therefore, if the patients themselves have good dietary management ability and favor a conservative and stable dietary strategy that has been validated, then they can also choose CR.

Strengths and limitations

This study offers significant benefits in comparison to previous investigations. Prior research typically compares the IF group with a standard healthy diet group; however, this study was conducted with IF as the intervention group and CR as the control group. This approach addresses the deficiency of studies examining the effects of varying energy restriction patterns on patients with metabolic syndrome, particularly when both groups experience substantial energy deficits. Furthermore, in contrast to certain unilateral trials, our study boasts a comparatively large sample size, which facilitates the acquisition of a more accurate representation of the situation.

It is important to acknowledge the inherent limitations present in this study. First, we excluded non-English-language studies, which may be subject to publication bias. Second, most of the included studies had a duration of 12 weeks or 6 months and lacked results and data on long-term effects. Third, 2 of the articles did not indicate whether there was a significant difference in calories between the two groups, and the calorie measurements relied mainly on calorie reporting without taking into account the effects of nutrients, which may have led to reporting bias. Fourth, limited data on some indicators and the possible existence of literature in some unused databases that could be included may have affected the results.

Conclusion and foresight

This meta-analysis reviewed nine studies involving 626 patients who participated in either IF or CR. The findings of the study indicate that IF is more effective in improving obesity and TG levels in patients with metabolic syndrome; however, its long-term efficacy requires further validation.

In the future, we can undertake longer-lasting study to investigate its long-term impacts, execute multicenter, large-sample studies to enhance the precision of study findings. Further investigation can be conducted, such as focusing exclusively on diabetes or hypertension patients within the metabolic syndrome. The research cohort can be divided into subgroups to enhance the reliability and specificity of the findings, thereby offering more tailored recommendations for clinical application.

Abbreviations

BMI	Body mass index
CI	Confidence intervals
CR	Continuous energy restriction
HC	Hip circumference
HDL-C	High-density lipoprotein cholesterol
IF	Intermittent fasting
LDL-C	Low-density lipoprotein cholesterol
OR	Odds ratio
PICOS	Population, Interventions, Comparisons, Outcomes, Study designs
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
RCTs	Randomized controlled trials
SMD	Standardized mean difference
TC	Total cholesterol
TG	Triglycerides
TyG	Triglyceride-Glucose Index
WC	Waist circumference

Supplementary Information

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Supplementary Material 1
Supplementary Material 2
Supplementary Material 3
Supplementary Material 4
Supplementary Material 5
Supplementary Material 6

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Clinical trial number

Not applicable.

Authors' contributions

All authors read and approved of the final manuscript. QL and L designed the study and developed the retrieve strategy. SX and BX executed the systematic evaluation as the first and second reviewers, searching and screening the summaries and titles, assessing the inclusion and exclusion criteria, generating data collection forms and extracting data, and evaluating the quality of the study. SX and BX performed a meta-analysis. SX drafted the article, which was reviewed and revised by SJ.

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Data availability

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

Declarations

Ethics approval and consent to participate
This is a systematic review and meta-analysis, ethics approval and consent to participate are not applicable.

Consent for publication
Not applicable. This study does not involve human participants.

Competing interests
The authors declare no competing interests.

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