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Comparative effects of time-restricted feeding versus normal diet on physical performance and body composition in healthy adults with regular exercise habits: a systematic review and meta-analysis

Ke-wen Wan ,[1,2] Zi-han Dai,[1] Robin Sze-tak Ho ,[1] Huang Wendy Yajun,[2] Stephen Heung-Sang Wong [1]

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[1]Department of Sports Science and Physical Education, The Chinese University of Hong Kong, Hong Kong, People's Republic of China
[2]Dr. Stephen Hui Research Centre for Physical Recreation and Wellness, Hong Kong Baptist University, Hong Kong, People's Republic of China

Correspondence to
Dr Huang Wendy Yajun; wendyhuang@hkbu.edu.hk

ABSTRACT

Background Time-restricted feeding (TRF), a form of intermittent fasting, limits daily caloric intake to a 6–12 hour window and has been shown to effectively promote weight loss and improve overall health. This systematic review and meta-analysis aimed to compare the effects of TRF versus normal diet (ND) on physical performance and body composition in healthy adults with regular exercise habits.

Methods MEDLINE, PubMed, Embase, SPORTDiscus, Web of Science, CINAHL and the Cochrane Central Register of Controlled Trials (CENTRAL) electronic databases were searched for relevant records. Subgroup analyses were conducted based on the duration of intervention and type of exercise. Physical performance was analysed using standardised mean differences (SMDs) and 95% CIs, whereas body composition parameters were analysed using mean differences (MDs) and 95% CIs. The quality of the included studies was examined using the Cochrane risk-of-bias tool version 2.

Results 15 randomised controlled trials with 361 participants were included in the systematic review. In comparison with the ND group, TRF significantly decreased body weight (MD=−1.76 kg, 95% CI −3.40 to −0.13, p=0.03, I^2=11.0%) and fat mass (MD=−1.24 kg, 95% CI −1.87 to −0.61, p<0.001, I^2=0.0%). No between-group differences in physical performance-related variables and fat-free mass were found. According to the result of the risk-of-bias assessment, one study showed a low risk of bias, 13 showed some concerns, and one showed a high risk of bias.

Conclusion TRF may be a valuable nutritional strategy to optimise body composition and maintain physical performance in healthy adults engaged in regular exercise.

PROSPERO registration number CRD42022310140.

WHAT IS ALREADY KNOWN

⇒ Time-restricted feeding (TRF) is effective for weight loss, overall health improvement and optimal nutrient utilisation. It is a favourable approach for individuals with exercise habits to achieve desired body composition goals.

⇒ Previous randomised controlled trials evaluating the impact of TRF versus a normal diet (ND) in individuals with regular exercise habits have yielded inconsistent findings.

⇒ The effects of combining TRF with different exercise modalities show mixed results on physical fitness.

WHAT ARE THE NEW FINDINGS

⇒ TRF leads to significant weight and fat mass reduction without significant impact on fat-free mass compared with ND in healthy adults with regular exercise habits.

⇒ TRF with exercise does not lead to a significant impact on physical performance compared with an ND with the same exercise programme.

⇒ TRF combined with endurance or resistance training resulted in significant reductions in fat mass compared with ND combined with the same exercise modalities.

⇒ Practitioners should consider combining TRF with exercise as a viable fat loss strategy without negatively impacting physical performance.

INTRODUCTION

Intermittent fasting (IF) is a dietary approach that involves alternating periods of caloric consumption and caloric restriction.[1] Various versions of IF have been proposed, including the popular 16/8 method, alternate-day fasting and the 5:2 diet.[2] One specific version of IF, known as time-restricted feeding (TRF), involves dividing the day into a period of depletion and restriction.[3] TRF is a behavioural intervention that involves limiting daily caloric intake to a consistent 6–12 hour window and fasting for the remaining hours of the day, without the need for individuals to count calories or monitor food intake during the eating window.[4 5] It has demonstrated efficacy in promoting weight loss, enhancing overall health and optimising nutrient utilisation without explicitly restricting energy intake.[6 7] Study reports in both animals and humans have consistently demonstrated TRF's effectiveness in reducing obesity, inflammation and insulin resistance.[8 9]

People with exercise habits and related practitioners often explore novel strategies regarding athletic training, nutritional supplementation and post-exercise recovery to improve physical performance.[10] Restricting energy intake can help them achieve a certain body mass category, aesthetic reasons or a better force-to-mass ratio.[11] Thus, many practitioners consider it an effective means of enhancing their physical performance.[12] TRF, identified as a highly adaptable form of IF, has been demonstrated in a systematic review to hold promise as a dietary approach for losing fat, improving metabolic health and maintaining physical fitness and muscular function, thereby warranting its inclusion as a component of a periodised nutrition plan for people with exercise habits.[13]

Additionally, recent randomised controlled trials (RCTs) have shown that TRF combined with exercise can significantly optimise the balance between fat mass (FM) and fat-free mass (FFM) by comparing with a normal diet (ND) combined with an equivalent amount of exercise.[14 15] Therefore, in recent years, more and more athletes and people with exercise habits tend to employ a combination of TRF and exercise training routines during the fat loss period to achieve better fat reduction results.

Existing RCTs examining the effects of TRF compared with ND on physical performance in healthy individuals with regular exercise habits present varying and inconsistent results. Specifically, different types of exercise training routines showed different effects on outcomes related to physical performance. Certain RCTs have shown that TRF compared with ND can enhance fat reduction effects in adults with resistance training habits.[8 16 17] Thus, the impact of TRF on physical fitness has exhibited substantial variability and inconsistency. Notably, M. Correia *et al* reported a significant increase in lower body jump performance and dynamic strength index in the TRF group compared with the ND group,[18] while other studies found no significant difference between the two groups on physical performance.[19] Regarding the synergistic effects of TRF with other types of exercise, a randomised crossover trial revealed that a 4 week TRF plus endurance training programme did not significantly improve submaximal or peak exercise capacity in well-trained males compared with an ND plus endurance training group.[20] Besides, after 8 weeks of high-intensity interval training (HIIT), the TRF group showed a significant increase in jumping performance compared with the ND group.[21] These discrepancies highlight the need for a systematic review to comprehensively evaluate the available evidence and provide a clearer understanding of the effects of TRF combined with various exercise modalities on physical fitness.

To the best of our knowledge, no systematic reviews have compared the effects of TRF and an ND on physical performance and body composition in healthy adults with regular exercise habits. Only one systematic review has examined the effects of IF on exercise performance outcomes.[1] However, that study analysed TRF as a subgroup, with limited included studies and mixed populations, showing that TRF might be effective in improving physical performance (aerobic capacity). The studies included in the systematic review mentioned used many types of IF strategies, and neither of them provided a systematic and detailed description of the strategy of combining TRF with exercise. Therefore, we conducted a systematic review with meta-analysis to examine the comparative effects of TRF versus ND on physical performance and body composition in healthy adults with regular exercise habits.

METHODS

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[22 23] recommendations and was registered at the International Prospective Register of Systematic Reviews (PROSPERO) (identification code: CRD42022310140; available at https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=310140).

Eligibility criteria

Studies that meet the following criteria were included in our systematic review: (i) included adults aged 18–64 years with regular exercise habits, (ii) the fasting protocol entailed a reduced eating window of time recurring daily (the usual length of fasting is 12–21 hours per day),[13] (iii) the studies performed comparisons with ND in participants' daily life, (iv) the outcomes included physical performance indicators (eg, one repetition maximums, maximal oxygen uptake (VO_2max), peak power output, jump height) and body composition indicators (eg, FM, FFM), (v) the study adopted a randomised controlled design and randomised crossover design and (vi) studies were peer-reviewed and written in English. Studies were excluded if they (i) were comments, editorials or reviews and (ii) included another type of fasting strategy (eg, Ramadan).

Information sources and search strategy

Seven electronic databases (MEDLINE, PubMed, Embase, SPORTDiscus, Web of Science, CINAHL and Cochrane Central Register of Controlled Trials (CENTRAL)) were searched for relevant studies on 30 October 2023. The search strategy is shown in online supplemental table S2. Endnote (Clarivate Analytics) was used to import all search results, and any duplicates were removed. Two researchers (KW, ZD) independently performed title, abstract screening and full-text screening of each article, and no automated or semi-automated approaches, including machine learning-based methods, were used for record screening. According to the PRISMA guidelines, duplicates were removed using the EndNote software. A third independent reviewer (RH) was consulted to settle any discrepancies in the results. Furthermore, we manually searched the reference lists of articles included in the final analysis.

Selection and data collection process

The data extraction was completed independently by two reviewers (KW, ZD). The characteristics of the included studies are summarised in online supplemental table S1. The following information was extracted: (i) first author name and year of publication, (ii) characteristics of participants (health status, number of participants, age, sex, body mass index), (iii) study design, (iv) characteristics of TRF (fasting duration, TRF strategy), (v) training protocol, (vi) physical performance test and (vii) sports-related results and findings of each study.

Physical performance and body composition indicators in the TRF and control groups are described as means and SD, which were screened and extracted by two reviewers (KW, ZD). A third independent reviewer (RH) was consulted to settle any discrepancies during the data extraction process. To convert SE to SD, we used the formula SD=SE * sqrt(n). If the missing data are still not available, the graph data were extracted using WebPlotDigitizer.[24]

Study risk-of-bias assessment

Two reviewers used the revised Cochrane risk-of-bias tool for randomised trials (RoB 2) and the RoB 2 additional considerations for crossover trials[25 26] to evaluate the risk of bias in each included study. The assessment encompassed six domains, including randomisation, deviation from the intended intervention, missing outcome data, measurement, selection of reported results, as well as period and carryover effects, which specifically applied to the RoB 2 additional considerations for crossover trials. The two reviewers judged each included study as 'high risk', 'some concerns' or 'low risk' by the signalling questions in each domain.[25] Any disputes between the two reviewers (KW, ZD) were resolved by a third researcher (RH).

Synthesis methods

Meta-analysis was performed with the aid of the metan package of the Software Stata v 15.0 (StataCorp, College Station, TX, USA) when data were available from two or more trials. In the meta-analysis, means and SD were extracted from the included studies where the outcome was continuous. Physical performance was analysed using standardised mean differences (SMDs) and 95% CIs, whereas body composition parameters were analysed using weighted mean differences (MDs) and 95% CIs. The results of the meta-analysis were based on the post-intervention data extracted from the included studies. If a trial was included more than once in the meta-analysis for comparison with other trials, the sample size for that trial was split by the number of times it was used.[27] For data synthesis, random effect models (DerSimonian and Laird) were used. Statistical significance was indicated by a p value less than 0.05.

Funnel plots visually explained publication bias if at least ten studies were included in the meta-analysis. Egger's linear regression test for funnel plot asymmetry was used to investigate publication bias. Egger's weighted regression tests for publication bias were also performed using the metan package of the Software Stata v 15.0 (StataCorp, College Station, TX, USA).

A series of sensitivity analyses were performed to examine the impact of each study, including those with a high risk of bias, on the overall conclusions to improve the robustness of the findings. We conducted sensitivity analyses using a leave-one-out approach. I^2 values were used to represent statistical heterogeneity, and I^2 values were classified as low (0% to 25%), moderate (26% to 50%), substantial (50% to 75%) and high (more than 75%).[27]

To further explore the effects of TRF intervention on body composition outcomes, we conducted a subgroup analysis based on the duration of the intervention (less than 8 weeks and 8 weeks or more) and the type of exercise employed (endurance training, resistance training, concurrent training and HIIT).[28 29] The subgroup analysis for the physical performance was only based on the duration of the intervention.

Certainty assessment

The Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach was employed to assess the certainty of evidence. The certainty of evidence was categorised as high, moderate, low or very low, reflecting the level of confidence in the estimated effect. To determine the potential downgrading of certainty and strength of recommendations, criteria such as risk of bias, consistency, directness, precision and publication bias were considered.[30]

RESULTS

Study selection

In the initial phase, 2893 records were identified through database searching in seven electronic databases. After removing 990 duplicate records, 1851 records remained. 1799 records that did not meet the inclusion criteria and were excluded by title and abstract screening. Full-text article assessment was performed for the remaining 52 records for eligibility and 38 records were excluded for the following reasons: (i) subjects did not meet the inclusion criteria (n=8), (ii) studies employed other types of fasting programmes (n=6), (iii) abstract only available (n=14), (iv) studies did not meet outcome criteria (n=5), (v) review paper (n=3) and (vi) the control group did not meet the inclusion criteria (n=2). The details are reported in the flow diagram (refer to PRISMA) based on the results of the literature search (figure 1).

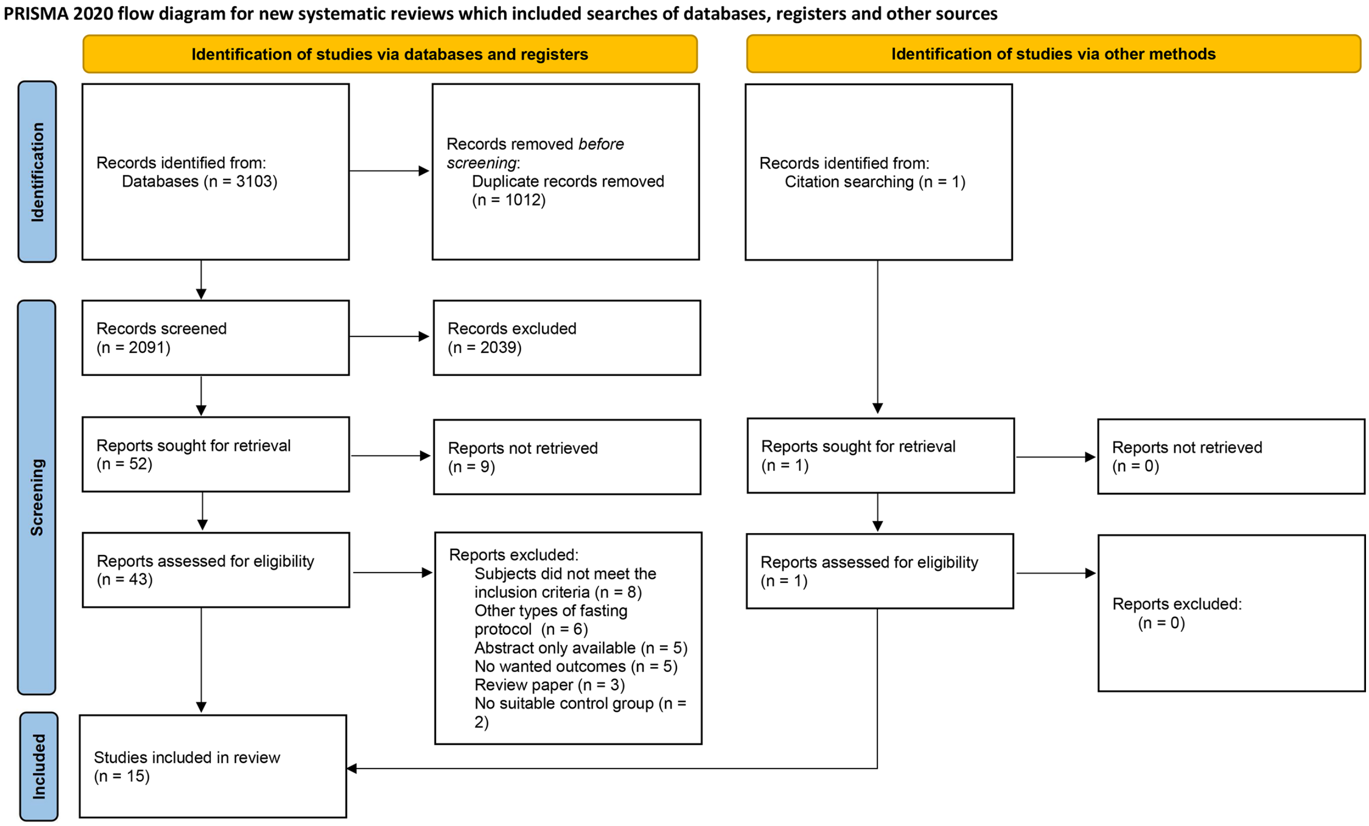

Figure 1 Flowchart of publications included in systematic review and meta-analysis (Preferred Reporting Items for Systematic Reviews and Meta-Analyses).

Study characteristics

The systematic review included a total of 15 RCTs involving 361 participants, all of whom were healthy adults. Among these studies, four specifically focused on athletes, such as professional runners and elite cyclists. Two studies included distance-trained individuals, three recruited in-school physical education students, four included physically active individuals and two studies enrolled a general population of healthy adults. Furthermore, two studies exclusively included women, while eleven studies included only men.

Eight studies included in our review were RCTs, and seven studies were randomised crossover studies. All the studies included an intervention group that followed a TRF diet and a control group that ate whenever they wanted. For the duration of the intervention, the studies ranged in length from 11 days to 4 weeks, 8 weeks and 12 months. The key characteristics (participants, study design, intervention and outcome information) of these eligible studies are summarised below (see online supplemental table S1).

In the studies included in this meta-analysis, the duration of fasting during TRF varied among the different interventions. A total of 12 studies[8 10 14 16 17 20 31–36] implemented a fasting period of 8 hours, where participants consumed their meals within an 8 hour window and abstained from caloric intake for the remaining 16 hours of the day. One study[21] employed a fasting duration of 10 hours, with participants adhering to a 10-hour eating window and a 14-hour fasting period. Another study[37] explored a more restricted fasting duration of 2 hours, allowing participants to consume their meals within a 2 hour window and maintaining a fasting period of 22 hours. Lastly, one study[38] used a fasting duration of 4 hours, where participants consumed their meals within a 4 hour window and abstained from caloric intake for the remaining 20 hours of the day. Additionally, seven studies[10 14 17 31 32 36 38] implemented ad libitum TRF, wherein participants were allowed to consume food freely within the designated feeding window. Seven studies[8 16 20 21 33 34 37] used the isocaloric TRF modality, participants adhered to a TRF schedule while maintaining an equal caloric intake throughout the day. One study[35] in our analysis employed the calorie restriction TRF modality.

Results of data synthesis

Physical performance

Strength performance

Strength performance included one-repetition maximum (1RM) performance in the bench press or leg press, handgrip strength and other strength-related metrics. Seven RCTs[8 16 21 31 35 36 38] were included. There was no significant difference in strength performance between the TRF group and the ND group (SMD=0.09, 95% CI −0.13 to 0.30, p=0.43, I^2=31.9%). Furthermore, no significant difference was found in strength-related performance in the subgroup analysis based on intervention duration (figure 2A).

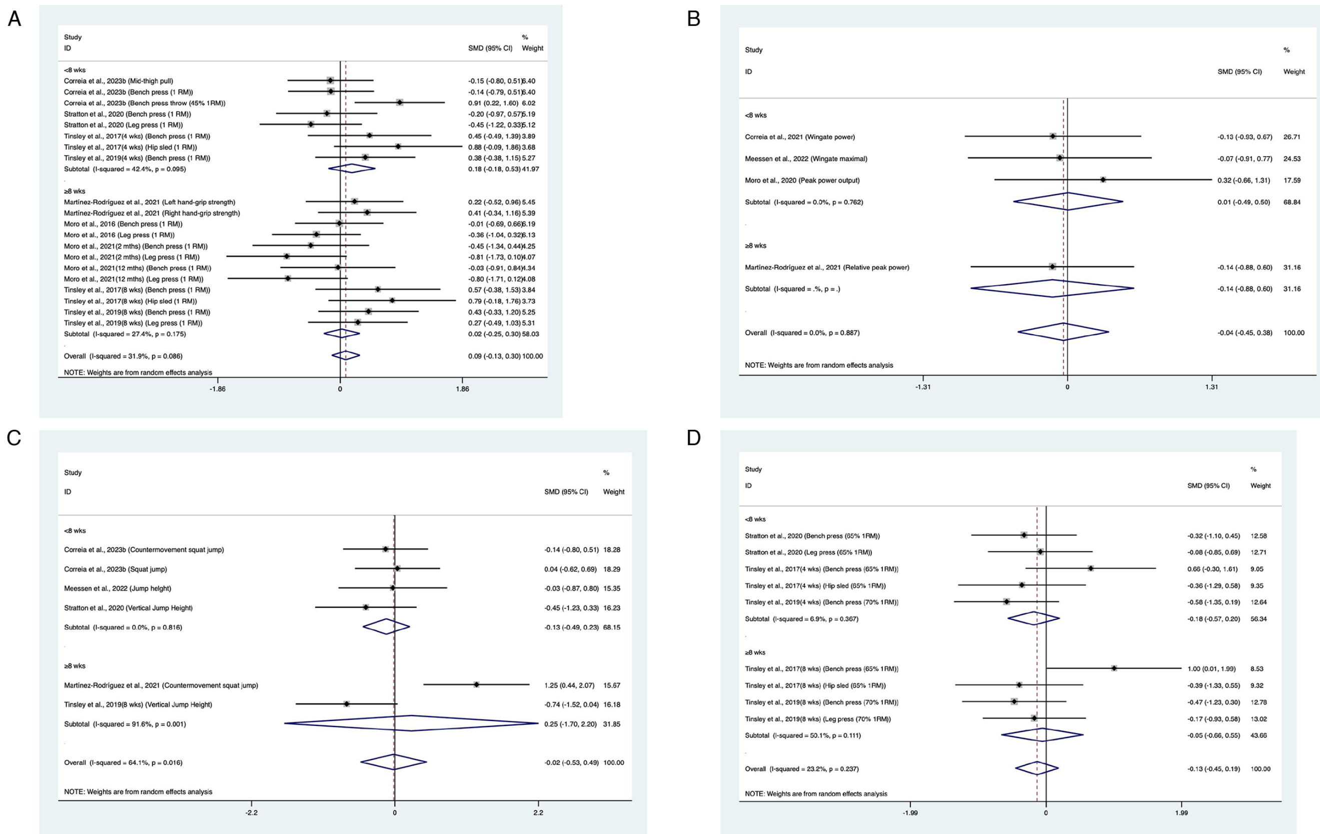

Figure 2 Meta-analysis of the effects of time-restricted feeding combined with exercise versus controls on (A) strength performance, (B) power performance, (C) muscular endurance performance, (D) aerobic capacity performance and (E) jump performance. SMD (standard mean difference) indicates the mean difference in the post-test value of the time-restricted feeding versus the control groups. Effects for the subgroups are based on the duration of the intervention (less than 8 weeks vs 8 weeks or more). The plotted points are the SMDs and the horizontal error bars represent the 95% CIs.

Power performance

Power performance encompasses various metrics, such as peak power output assessed through evaluations like the Wingate test and graded exercise test. Four RCTs[14 21 33 37] were included in the analysis, with three RCTs using the Wingate test to assess peak power and one RCT employing the graded exercise test for peak power assessment. No significant difference was observed in peak power performance between the TRF group and the ND group (SMD=−0.04, 95% CI −0.45 to 0.38, p=0.85, I^2=0.0%). No significant difference was observed between groups when conducting subgroup analysis based on the duration of the intervention and the type of exercise employed (figure 2B).

Muscular endurance performance

Muscular endurance performance included measures of endurance in specific exercises or activities, such as bench press endurance or any other endurance-based tests. Muscular endurance was assessed in two RCTs[35 38] by performing repetitions to failure at 65% of the 1-RM, while one RCT[36] employed repetitions to failure at 70% of the 1-RM. Overall, pooled data from three RCTs showed no significant difference in muscular endurance performance between the TRF group and the ND group (SMD=−0.13, 95% CI −0.45 to 0.19, p=0.42, I^2=23.2%). For subgroup analysis, no significant difference was observed, as shown in figure 2C.

Aerobic capacity performance

Aerobic capacity performance encompassed assessments such as VO_{2max}, which serves as an indicator of aerobic capacity or cardiovascular fitness. To assess VO_{2max}, all five RCTs used the incremental exercise test, with three RCTs[10 17 20] employing treadmill tests and two RCTs[33 37] employing ergometer bike tests. There was no significant difference observed between the TRF group and the ND group (SMD=−0.10, 95%CI −0.27 to 0.47, p=0.59, I^2=0.0%) (figure 2D).

Jump performance

Jump performance included metrics such as jump height and vertical jump performance, which evaluate explosive power and lower-body strength. Five RCTs were included in the analysis, with three RCTs[21 31 37] using the countermovement squat jump to assess jump performance, two RCTs[35 36] using the vertical jump and one RCT[31] employing the squat jump for assessment. The TRF group would not result in a significant difference by comparing with the ND group (SMD=−0.02, 95%confidence interval

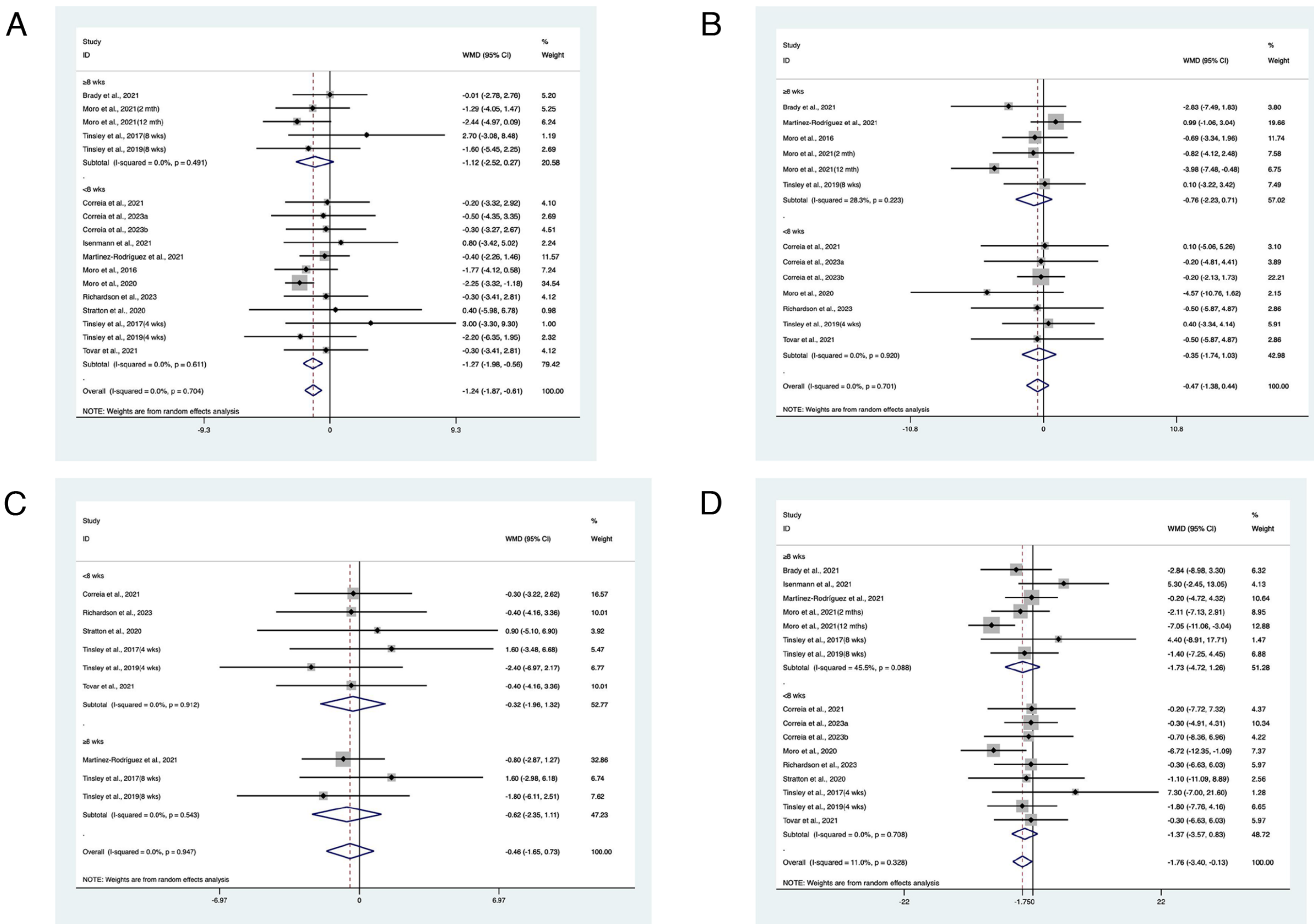

Figure 3 Meta-analysis of the effects of time-restricted feeding combined with exercise versus controls on (A) fat mass, (B) fat-free mass, (C) body fat and (D) body weight. MD (mean difference) indicates the mean difference in the post-test value of the time-restricted feeding versus the control groups. Effects for the subgroups are based on the duration of the intervention (less than 8 weeks vs 8 weeks or more). The plotted points are the weighted MDs and the horizontal error bars represent the 95% CIs.

−0.53 to 0.49, p=0.93, I^2=64.1%). In addition, no significant difference was observed in the subgroup analysis (figure 2E).

Body composition

Fat mass

FM, as an indicator, was the most frequently used measure, with 13 RCTs[12 14 15 24–28 30 31] included in the analysis. In long-term intervention studies lasting 8 weeks or more, a significant difference was observed between the TRF group and the ND group (MD=−1.24 kg, 95% CI −1.87 to −0.61, p<0.001, I^2=0.0%). For short-term intervention (less than 8 weeks), the TRF group demonstrated a significant reduction compared with the ND group (MD=−1.24 kg, 95% CI −1.87 to −0.61, p<0.001, I^2=0.0%) (figure 3A). Furthermore, TRF plus endurance training (MD=−1.47 kg, 95% CI −2.48 to −0.46, p<0.001, I^2=7.5%) or resistance training (MD=−1.24 kg, 95% CI −2.37 to −0.11, p=0.03, I^2=0.0%) demonstrated significant effects in reducing FM when compared with ND plus endurance training or resistance training (figure 4A).

Fat-free mass

The analysis included a total of 11 RCTs,[8 10 14 16 17 20 21 31 33 34 36] and the meta-analysis results revealed that there is no significant effect on FFM based on the pooled data between the TRF and ND group (MD=−0.47 kg, 95% CI −1.38 to 0.44, p=0.31, I^2=0.0%). For subgroup analysis, no significant difference was observed, as shown in figure 3B and figure 4B.

Body fat

A total of seven RCTs[14 20 21 34–36 38] have been included in the meta-analysis. Regarding the effects of TRF regimens on body fat (BF), no significant effect was observed (MD=−0.46%, 95% CI −1.65 to −0.73, p=0.45, I^2=0.0%). For the subgroup analysis, no significant difference was observed, as shown in figure 3C and figure 4C.

Body weight

Body weight (BW) data were available in 12 RCTs,[10 14 16 17 20 21 31–36 38] there was a significant overall difference in the TRF groups when compared with the

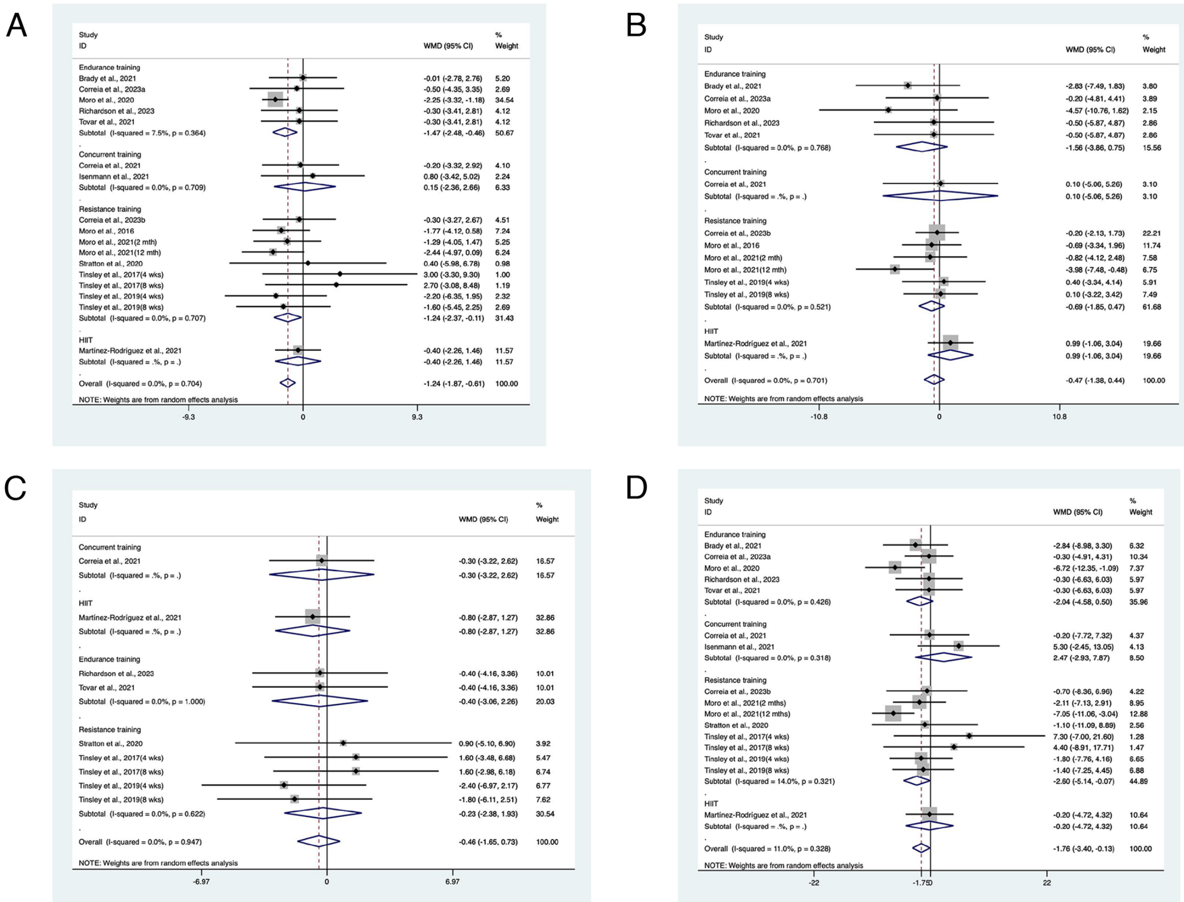

Figure 4 Meta-analysis of the effects of time-restricted feeding combined with exercise versus controls on (A) fat mass, (B) fat-free mass, (C) body fat and (D) body weight. MD (mean difference) indicates the mean difference in the post-test value of the time-restricted feeding versus the control groups. Effects for the subgroups are based on different types of exercise (endurance training, resistance training, concurrent training and high-intensity interval training). The plotted points are the weighted MDs, and the horizontal error bars represent the 95% CIs.

ND group (MD=−1.76 kg, 95% CI −3.40 to −0.13, p=0.03, I^2=11.0%). Among the subgroups based on exercise types, only TRF plus resistance training demonstrated a significant reduction in BW when compared with ND plus resistance training (MD=−2.60 kg, 95% CI −5.14 to −0.07, p=0.04, I^2=14%) as depicted in figure 4D.

Risk of bias in studies

The ROB 2 was employed to assess the risk of bias for each publication. A summary of the overall assessments for all five domains of bias is presented in table 1. One study[37] was deemed to have a high risk of bias, while one study[36] was considered to have a low risk of bias. It is worth noting that all the studies included in our analysis were randomised trials; however, only three studies[10 16 36] provided thorough details on the randomisation process. Similarly, only the three studies explicitly stated that participants remained blinded until they arrived at the laboratory to complete the trials. One study was identified as having a high risk of bias, primarily due to concerns related to baseline differences between the intervention groups at the beginning of the first period. The studies were rated as having some concerns due to a lack of detailed information on the randomisation process, and deviations from the intended intervention may have occurred due to contextual factors within the trials.

Overall certainty of evidence

The overall certainty of evidence was assessed using the GRADE tool and is presented in online supplemental table S13. We downgraded the certainty of evidence to low, for the following outcomes: fat mass, fat-free mass, body fat, power performance, aerobic capacity performance and jump performance. Body weight, strength performance and muscular endurance performance were downgraded with the certainty of evidence to moderate, indicating that we believe the true effect is probably close to the estimated effect.

Sensitivity analyses and publication bias

The results of sensitivity analyses, where studies with a high risk of bias were excluded, showed no significant impact on the overall findings. Eighty percent of studies showed some concerns in the field of the randomisation process. A series of sensitivity analyses were performed by removing each of the studies. The result indicated that

Table 1 Risk-of-bias assessment in the observational studies included in the systematic review

Study	Randomisation process	Risk-of-bias domain Bias arising from period and carryover effects	Deviations from intended interventions	Missing outcome data	Measurement of outcome	Selection of reported results	Overall risk of bias
Brady *et al*[10] 2021	Low	N/A	Some concerns	Low	Low	Low	Some concerns
Correia *et al*[14] 2021	Some concerns	Some concerns	Some concerns	Low	Low	Low	Some concerns
M. Correia *et al*[17] 2022	Some concerns	Low	Some concerns	Low	Low	Low	Some concerns
Correia *et al*[31] 2023	Some concerns	Low	Some concerns	Low	Low	Low	Some concerns
Isenmann *et al*[32] 2021	Some concerns	N/A	Some concerns	Low	Low	Low	Some concerns
Martínez-Rodríguez *et al*[21] 2021	Some concerns	Low	Some concerns	Low	Low	Low	Some concerns
Meessen *et al*[37] 2022	High	Low	Some concerns	Low	Low	Low	High
Moro *et al*[8] 2016	Some concerns	N/A	Some concerns	Low	Low	Some concerns	Some concerns
Moro *et al*[33] 2020	Some concerns	N/A	Some concerns	Low	Low	Low	Some concerns
Moro *et al*[16] 2021	Low	N/A	Some concerns	Low	Low	Some concerns	Some concerns
Richardson *et al*[34] 2023	Some concerns	Low	Some concerns	Low	Low	Low	Some concerns
Stratton *et al*[35] 2020	Some concerns	Some concerns	Low	Low	Some concerns	Some concerns	Some concerns
Tinsley *et al*[38] 2017	Some concerns	N/A	Some concerns	Low	Low	Some concerns	Some concerns
Tinsley *et al*[36] 2019	Low	N/A	Low	Low	Low	Low	Low
Tovar *et al*[20] 2021	Some concerns	Low	Some concerns	Low	Low	Low	Some concerns

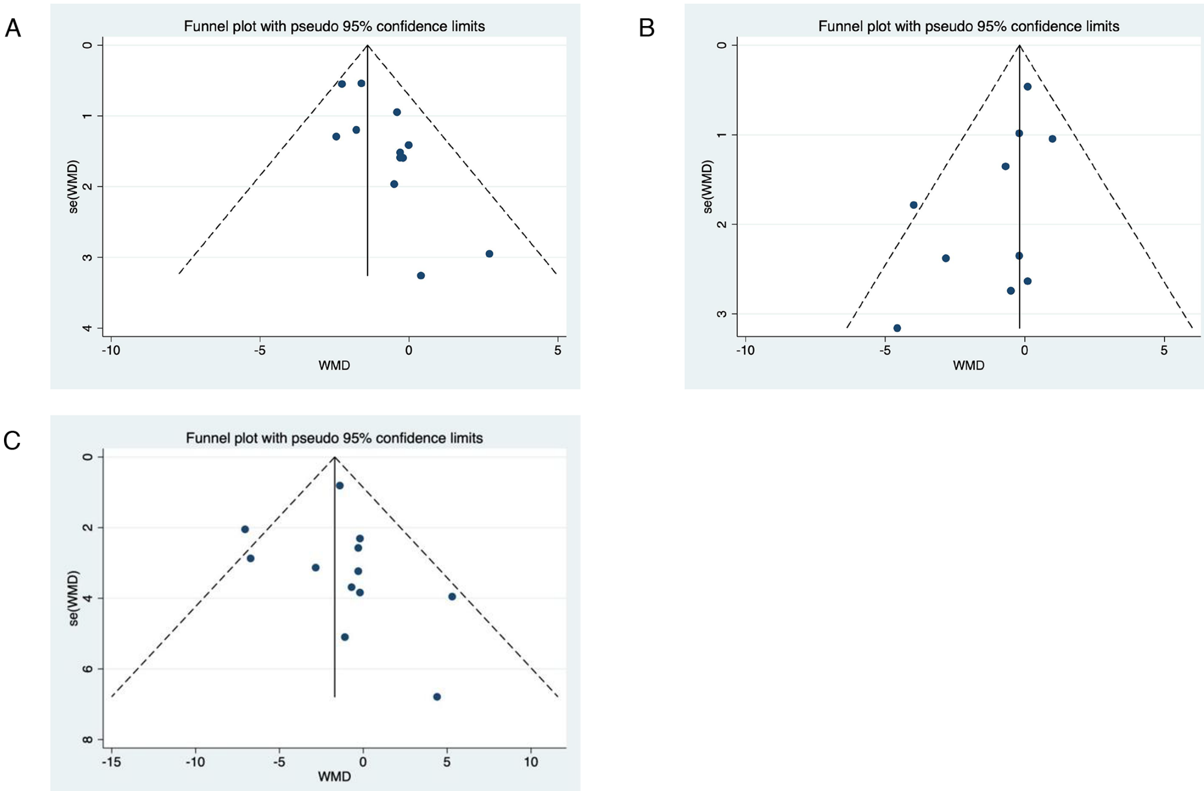

Figure 5 Funnel plot for publication bias detection on (A) fat mass, (B) fat-free mass and (C) body weight. The funnel plot shows the observed mean differences (on the x-axis) against standard errors (on the y-axis).

excluding one study by Tinsley *et al*[36] reduces heterogeneity when a meta-analysis of strength performance and muscular endurance performance is conducted, but this did not substantially change the results.

The publication biases of three outcomes, namely, FM, FFM and BW, are shown in figure 5. Funnel plots showed no indication of publication bias in FFM (p=0.08) and BW (p=0.64). However, it showed publication bias on FM (p=0.00).

DISCUSSION

To the best of our knowledge, no prior systematic review with meta-analysis has been conducted to specifically compare the effects of TRF versus ND on physical performance and body composition in healthy adults with regular exercise habits. In total, 15 studies were identified, and all were available for meta-analysis. In the meta-analysis, we specifically investigated whether TRF could serve as a more efficacious nutritional approach compared with an ND when individuals in both groups undergo an identical exercise training regimen. Our findings suggest that the combination of TRF with regular exercise training does not result in significant changes or improvements in physical performance outcomes when compared with ND with the same exercise training programme. However, it successfully achieves a significant fat loss outcome.

In this meta-analysis, it is important to note that the indicator of aerobic capacity performance in all the included studies was assessed using the indicator of VO_{2max}, which is considered a critical indicator for the assessment of aerobic performance.[39–41] Our findings revealed that the combination of TRF with regular exercise training did not lead to a significant change in aerobic capacity performance compared with the ND group. This contrasts with the conclusions of a previous systematic review conducted by Correia *et al*, which reported a positive impact of TRF on VO_{2max}.[1] Additionally, our meta-analysis indicated that the combination of TRF and regular exercise training did not have a significant influence on power performance, a critical factor closely linked to athletic performance and essential for incremental tests.[14 18 42] Subgroup analysis further showed that the combination of TRF with regular exercise training exhibited no significant influence on either aerobic capacity or power performance, regardless of the intervention duration (less than 8 weeks and 8 weeks or more). These findings emphasise that key performance indicators such as oxygen utilisation and power output are not reduced or physiologically affected following the implementation of such interventions. Discrepancies between our review and a previous systematic review[24] can be attributed to differences in study characteristics. Our meta-analysis specifically focused on the 16/8 TRF strategy, consisting of a consistent 16-hour fasting period followed by an 8 hour eating window, maintained for 4 to 8 weeks. In contrast, the previous systematic review[24] encompassed a broader range of IF strategies with varying durations and fasting periods, which may have led to diverse physiological adaptations among participants.[10] Robust and comprehensive conclusions regarding the effectiveness of combining TRF with exercise on aerobic capacity and power performance in future clinical research necessitate well-designed large-scale studies.

Despite the existence of a narrative review[43] and a systematic review[1] on the topic, there is a lack of a meta-analysis in the literature examining the effects of the TRF programme in combination with daily exercise training on indicators related to muscle performance. Correia *et al*'s previous meta-analysis on IF and muscle strength reported non-significant effects. However, it is important to acknowledge the limitations of that study, including a limited number of included studies and the incorporation of diverse IF regimens (eg, Ramadan IF, TRF), which may not have fully taken into account the potential differences between the two fasting approaches.[24] In our meta-analysis, we found no significant comparative effects of TRF versus non-TRF on muscle performance-related indicators, including strength performance, muscular endurance performance and jump performance in healthy adults with regular exercise habits. These findings indicate that the incorporation of TRF as a nutritional intervention alongside daily exercise training regimens may not have a significant impact on certain aspects of muscle performance when compared with the ND group. However, the existing RCTs on this topic have yielded mixed findings. For instance, the RCT conducted by Moro *et al* demonstrated that TRF plus resistance training resulted in no change in muscle cross-sectional area of the arm and thigh as well as maximal strength after an 8 week intervention by comparing to the ND with the same amount of exercise,[8] while another study found a greater increase in lower body strength with TRF combined with resistance training.[38] Furthermore, our subgroup analysis, which stratified the studies based on intervention duration, revealed a slight improvement in strength performance when TRF was combined with exercise. However, this increase was not statistically significant, suggesting that the effects of TRF on physical performance may diminish over time, potentially due to adaptive changes and the development of tolerance to TRF.[43]

In athletics, the optimisation of body composition and the adjustment of physical condition play vital roles. The meticulous management and equilibrium between lean muscle mass and fat are critical factors that substantially influence sports-related performance, particularly in sports such as boxing, weightlifting and others that rely heavily on strength and power.[44] Our findings indicate that including TRF with regular exercise training is effective in achieving significant reductions in weight and FM with no significant difference in FFM compared with ND with regular exercise training. The potential benefits of TRF on body composition can be attributed to two main reasons. First, TRF may promote a reduction in daily calorie intake. When individuals are faced with time constraints, restricting food consumption becomes a practical strategy for reducing calorie intake, particularly when compared with the time-consuming tasks of meal preparation, cooking and calorie counting.[3] In contrast, traditional dieting's continuous calorie counting often leads to participant attrition. However, TRF offers an alternative approach by emphasising time rather than calorie monitoring. Previous studies have shown that differences in weight loss were not statistically significantly different between the TRF and daily calorie restriction.[5 45] Moreover, TRF has been found to reduce overall calorie intake by approximately 25–38%,[3] although individual responses to fasting may vary.[1] Those characteristics of TRF enhance long-term adherence and enable sustainable weight control.[9 45 46] Second, another reason may relate to metabolic benefits observed in the context of TRF, which can be attributed to the improved synchronisation of eating patterns with the individual's biological circadian clock.[47] Aligning eating patterns with the circadian clock has been associated with reduced fasting glucose concentration, improved insulin resistance and positive changes in lipid profiles.[48 49] The slight improvements in glucose and lipid metabolism indicators observed with TRF could be partly attributed to the associated slight weight loss.[47]

While there is substantial evidence supporting the effectiveness of TRF with daily exercise training for fat loss, there are still divergent findings in the literature. For instance, the RCT conducted by Correia *et al* demonstrated that TRF in conjunction with regular training led to improvements in Wingate test performance but did not result in notable changes in body composition.[14] The variability in fat loss across studies may be explained by the type of exercise performed in the intervention, duration of the experiment, total energy intake and participant characteristics. Specifically, in the subgroup analysis based on exercise type within our meta-analysis, encompassing four different types of exercise, the findings indicated that only the combination of TRF with endurance training and resistance training exhibited a statistically significant reduction in FM compared with the ND groups. Furthermore, intriguingly, shorter-term interventions demonstrated greater effects on FM reduction when comparing the TRF group with the ND group, potentially attributed to physiological adaptations.

Strengths and limitations

The current systematic review used a rigorous and comprehensive search strategy encompassing physical performance and body composition indicators. Distinguishing from previous studies, our review with meta-analysis adopted a more focused approach, specifically incorporating studies that only employed TRF as the intervention. However, this study still has several limitations that need to be addressed. First, although the form of TRF used in the included studies was predominantly the 16/8 method, there were variations in the daily fasting periods employed. These differences in fasting periods have the potential to influence biological rhythms and may impact the observed results. Therefore, future studies incorporating diverse fasting periods within TRF protocols would be valuable in further elucidating the effects of TRF on the outcomes of interest. Second, for some physical performance indicators (eg, endurance and power performance), the meta-analysis included a small number of studies, reducing statistical power. Additionally, our review did not specifically discuss blood test biomarkers and their implications for overall health and well-being. Further research in this area is needed to enhance our understanding of the physiological mechanisms involved and their potential impact on overall health and well-being. Finally, for the outcome of fat mass, our study is limited by potential publication and small study bias, which may affect the validity of the findings specifically for this outcome. Our methods to assess publication bias may not capture all forms of bias accurately. Additionally, we cannot differentiate between small study bias and publication bias for fat mass, introducing uncertainty in interpreting the overall effect size for this outcome.

CONCLUSION

This meta-analysis contributes to a more comprehensive understanding of the comparative effects of TRF versus ND on physical performance and body composition in healthy adults with regular exercise habits. The study findings highlight that including TRF with daily exercise training yields significant benefits in terms of fat reduction while maintaining physical performance, compared with ND with the same exercise training programme. Moreover, the results highlight the need for further intervention studies investigating the impact of TRF and exercise on physical performance. Such research endeavours hold promise in offering valuable insights and practical applications for people with regular exercise habits and practitioners seeking optimal nutrition strategies to optimise performance outcomes and body composition.

Patient and public involvement

At what stage in the research process were patients/the public first involved in the research and how?

This study did not involve direct patient or public involvement at any stage of the research process.

How were the research question(s) and outcome measures developed and informed by their priorities, experience and preferences?

The research questions and outcome measures were developed based on a review of existing literature and expert consensus, without direct input from patients or the public.

How were patients/the public involved in the design of this study?

Patients and the public were not involved in the design of this study.

How were they involved in the recruitment to and conduct of the study?

There was no recruitment or direct conduct involving patients or the public, as this study synthesised existing research data.

Were they asked to assess the burden of the intervention and time required to participate in the research?

This was not applicable, as there was no primary data collection involving interventions or direct participation.

How were (or will) they be involved in your plans to disseminate the study results to participants and relevant wider patient communities (eg, by choosing what information/results to share, when and in what format)?

Dissemination plans primarily involve academic channels, including publication in peer-reviewed journals and presentations at conferences. There was no direct involvement from patients or the public in determining dissemination plans.

X Robin Sze-tak Ho @doctorojunior

Contributors KW assumed the lead role in this study, overseeing data access, systematic search for eligible studies, data extraction, result interpretation, manuscript drafting and serving as the guarantor. ZD, RH, WH and SW actively participated in the study's conception, design, systematic search for eligible studies, data extraction and manuscript composition. RH played a key role in drafting the manuscript and providing critical revisions. All authors thoroughly reviewed and granted approval for the final manuscript submission.

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ORCID iDs
Ke-wen Wan http://orcid.org/0009-0008-4377-3165
Robin Sze-tak Ho http://orcid.org/0000-0003-2722-4234
Stephen Heung-Sang Wong http://orcid.org/0000-0002-6821-4545

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