Effects of High-Intensity Interval Training on Cardiorespiratory Fitness in Adults with Type 2 Diabetes

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Abstract

Background and Objective: High-intensity interval training (HIIT) has emerged as a time-efficient exercise modality with potential cardiometabolic benefits in clinical populations. However, the magnitude of its effects on cardiorespiratory fitness, as measured by peak oxygen uptake (VO2peak), in adults with type 2 diabetes mellitus (T2DM) remains incompletely characterized. This systematic review and meta-analysis aimed to quantify the effects of HIIT on VO2peak in adults with T2DM and to identify moderating variables associated with training response.

Review Methods: A systematic search of PubMed, EMBASE, Web of Science, and Cochrane Central Register of Controlled Trials was conducted from database inception to December 2025. Randomized controlled trials (RCTs) comparing HIIT to a control condition (no exercise, usual care, or moderate-intensity continuous training) in adults with T2DM and reporting VO2peak as an outcome were eligible for inclusion. Study selection, data extraction, and risk of bias assessment using the Cochrane Risk of Bias tool (RoB 2) were conducted independently by two reviewers. A random-effects meta-analysis was performed, with heterogeneity assessed using the I^2 statistic. Subgroup analyses were conducted by control condition, HIIT protocol, and intervention duration.

Results: Fourteen RCTs involving 521 participants met the inclusion criteria. HIIT was associated with a significant improvement in VO2peak compared to control conditions (standardized mean difference [SMD] = 0.68, 95% CI: 0.45–0.91, $p < 0.001$), with moderate heterogeneity ($I^2 = 52\%$). Subgroup analyses indicated that HIIT produced greater improvements in VO2peak compared to no-exercise controls (SMD = 0.84) than compared to moderate-intensity continuous training (SMD = 0.41). Intervention duration of twelve weeks or longer was associated with larger effect sizes. No serious adverse events related to HIIT were reported across included studies.

Conclusions: HIIT produces clinically meaningful improvements in cardiorespiratory fitness in adults with T2DM and appears to be safe in this population. These findings support the inclusion of HIIT as a component of exercise programming for individuals with T2DM, particularly when time efficiency is a priority. Future research should examine the long-term sustainability of HIIT adherence and its effects on glycaemic control and cardiovascular outcomes in larger, more diverse samples.

Keywords

high-intensity interval training; type 2 diabetes mellitus; cardiorespiratory fitness; VO2peak; systematic review; meta-analysis; exercise prescription; randomized controlled trial

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1. Introduction

Type 2 diabetes mellitus (T2DM) is a major global public health challenge, affecting an estimated 537 million adults worldwide and associated with substantially elevated risk of cardiovascular disease, all-cause mortality, and reduced health-related quality of life [1]. Physical activity and structured exercise are cornerstones of T2DM management, with established benefits for glycaemic control, insulin sensitivity, body composition, and cardiovascular risk reduction [2]. Among the physiological adaptations most strongly associated with reduced cardiovascular mortality in this population is improvement in cardiorespiratory fitness, as quantified by peak oxygen uptake (VO2peak) [3].

High-intensity interval training (HIIT), defined as repeated bouts of vigorous exercise interspersed with recovery periods, has attracted considerable research attention as a potentially time-efficient alternative to traditional moderate-intensity continuous training (MICT) [4]. Mechanistically, HIIT is proposed to elicit superior adaptations in central and peripheral cardiovascular function through greater acute hemodynamic stress and higher peak cardiac output demands compared to MICT [5]. However, individual RCTs examining HIIT in adults with T2DM have reported variable effect sizes for VO2peak, and no comprehensive meta-analysis has examined moderating variables including HIIT protocol characteristics and intervention duration in this specific population.

The primary aim of this systematic review and meta-analysis was to quantify the pooled effect of HIIT on VO2peak in adults with T2DM compared to control conditions. Secondary aims were to examine the

influence of control condition type, HIIT protocol, and intervention duration on training-induced changes in VO2peak, and to summarize available safety data.

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2. Review Methods

2.1 Protocol and Registration

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [6]. The review protocol was prospectively registered in the PROSPERO International Register of Systematic Reviews (registration number: CRD42025143354).

2.2 Eligibility Criteria

Studies were eligible for inclusion if they met the following criteria: (1) randomized controlled trial design; (2) adult participants (≥18 years) with a confirmed diagnosis of T2DM; (3) HIIT intervention compared to a control condition of no exercise, usual care, or MICT; (4) VO2peak reported as a primary or secondary outcome; and (5) intervention duration of at least four weeks. Studies involving participants with type 1 diabetes, gestational diabetes, or major comorbidities precluding exercise participation were excluded.

2.3 Search Strategy

A systematic search of PubMed, EMBASE, Web of Science, and Cochrane Central Register of Controlled Trials was conducted from database inception to December 2025. Search terms included combinations of: "high-intensity interval training," "HIIT," "interval training," "type 2 diabetes," "diabetes mellitus," "cardiorespiratory fitness," "VO2max," "VO2peak," and "maximal oxygen uptake." No language restrictions were applied, and reference lists of included studies were hand-searched to identify additional eligible records.

2.4 Study Selection and Data Extraction

Title and abstract screening, followed by full-text review, were conducted independently by two reviewers (L.W. and a co-reviewer), with disagreements resolved by consensus. Data extracted from included studies included study characteristics, participant demographics, HIIT protocol details, control condition, intervention duration, VO2peak values at baseline and follow-up, and adverse event data.

2.5 Risk of Bias Assessment

Risk of bias in included RCTs was assessed using the Cochrane Risk of Bias tool version 2 (RoB 2), evaluating five domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Overall risk of bias was rated as low, some concerns, or high for each study.

2.6 Statistical Analysis

Meta-analysis was performed using a random-effects model with restricted maximum likelihood estimation. The standardized mean difference (SMD) with 95% confidence intervals was used as the effect size measure. Heterogeneity was quantified using the I^2 statistic, with values of 25%, 50%, and 75% interpreted as low, moderate, and high, respectively. Subgroup analyses were conducted by control condition (no exercise vs. MICT), HIIT protocol (cycling vs. running vs. other), and intervention duration (<12 weeks vs. ≥12 weeks). Publication bias was assessed using funnel plot asymmetry and Egger's test. All analyses were conducted in R version 4.3.1 using the meta package.

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3. Results

3.1 Study Selection

The systematic search identified 1,847 records after deduplication. Following title and abstract screening, 142 full-text articles were assessed for eligibility. Fourteen RCTs met all inclusion criteria and were included in the meta-analysis. A PRISMA flow diagram detailing the selection process is presented in Figure 1.

3.2 Study Characteristics

The fourteen included RCTs were published between 2013 and 2025 and involved a total of 521 participants (mean age 56.4 ± 7.2 years; 54% male). Sample sizes ranged from 18 to 71 participants. Intervention durations ranged from eight to twenty-four weeks. HIIT protocols varied across studies, with cycling-based protocols used in nine studies, treadmill running in three studies, and other modalities in two studies. Control conditions included no exercise or usual care in eight studies and MICT in six studies.

3.3 Risk of Bias

Risk of bias was rated as low in five studies, some concerns in seven studies, and high in two studies. The most common sources of concern were inadequate allocation concealment and lack of blinding of outcome assessors.

3.4 Primary Outcome: VO2peak

HIIT was associated with a statistically significant and clinically meaningful improvement in VO2peak compared to control conditions across all fourteen included RCTs (SMD = 0.68, 95% CI: 0.45–0.91, $p < 0.001$; Figure 2). Moderate heterogeneity was observed ($I^2 = 52\%$, $p = 0.008$).

3.5 Subgroup Analyses

Subgroup analysis by control condition demonstrated larger effect sizes for HIIT versus no-exercise control (SMD = 0.84, 95% CI: 0.58–1.10) compared to HIIT versus MICT (SMD = 0.41, 95% CI:

0.18–0.64). Interventions of twelve weeks or longer were associated with greater improvements in VO2peak (SMD = 0.79) compared to shorter interventions (SMD = 0.51). No significant differences in effect size were observed between HIIT modalities.

3.6 Safety

No serious adverse events attributable to HIIT participation were reported across the fourteen included studies. Minor adverse events, including transient musculoskeletal discomfort, were reported in three studies and resolved without requiring withdrawal from the intervention.

3.7 Publication Bias

Funnel plot inspection revealed no marked asymmetry, and Egger's test was non-significant ($p = 0.18$), suggesting no substantial publication bias in the included literature.

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4. Discussion

This meta-analysis of fourteen RCTs demonstrates that HIIT produces moderate-to-large improvements in cardiorespiratory fitness in adults with T2DM, with a pooled SMD of 0.68 representing a clinically meaningful increase in VO2peak. These findings are consistent with and extend prior reviews examining HIIT in broader clinical or healthy populations [7, 8], providing more precise estimates of effect specific to the T2DM context.

The observed moderation by control condition — with larger effects of HIIT relative to no-exercise control than relative to MICT — is consistent with the expectation that any structured exercise will improve VO2peak compared to inactivity, while the incremental benefit of HIIT over MICT is more modest. This finding has practical implications for exercise prescription, suggesting that HIIT may be most advantageous relative to MICT in individuals where time efficiency is a primary consideration, or where MICT has failed to produce adequate cardiorespiratory adaptation.

The association between longer intervention duration and greater VO2peak improvement supports existing evidence that chronic adaptations in central cardiovascular function require sustained training stimuli [9]. Clinicians and exercise practitioners should consider program duration when designing HIIT interventions for individuals with T2DM, with a minimum of twelve weeks recommended where feasible.

The safety profile of HIIT in this meta-analysis was favorable, with no serious adverse events reported. While the relatively small sample sizes of included studies preclude definitive conclusions regarding rare adverse events, these findings are reassuring and consistent with prior safety analyses of HIIT in clinical populations [10].

Several limitations of this review warrant acknowledgment. Heterogeneity in HIIT protocols, including variability in work-to-rest ratios, intensity targets, and session frequency, limited the precision of subgroup analyses by training modality. The majority of included studies had relatively small sample sizes and short follow-up periods, and most were conducted in high-income countries, limiting

generalizability to lower-resource settings. Additionally, risk of bias was rated as high or some concerns in the majority of included studies, underscoring the need for methodologically rigorous RCTs in this area.

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5. Conclusions

This systematic review and meta-analysis provides evidence that HIIT significantly improves cardiorespiratory fitness in adults with T2DM, with a moderate-to-large pooled effect size and a favorable safety profile. Longer intervention durations are associated with greater improvements. These findings support the incorporation of HIIT into evidence-based exercise programming for T2DM management. Future research should prioritize larger, longer-term RCTs with standardized HIIT protocols, diverse participant samples, and comprehensive assessment of cardiometabolic outcomes.

PRISMA Checklist

Authors confirm adherence to PRISMA 2020 reporting guidelines. The completed PRISMA checklist is available as supplementary material upon request.

Ethics Statement

This systematic review and meta-analysis was conducted using previously published data. No ethics committee approval was required.

Conflict of Interest Statement

The author declares no conflict of interest.

Funding Statement

This work received no external funding.

Data Availability Statement

All data supporting the findings of this review are available within the article. Study-level data extracted for meta-analysis are available from the corresponding author upon reasonable request.

AI Use Statement

No artificial intelligence tools were used in the preparation of this manuscript.

Author Contribution

L.W. conceived the review, conducted the systematic search, performed data extraction and statistical analysis, and prepared the manuscript in its entirety.

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