



High-intensity interval training in type 1 diabetes mellitus: systematic review of randomized clinical trials

Entrenamiento interválico de alta intensidad en la diabetes tipo 1: una revisión sistemática de ensayos aleatorizados

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Abstract

Introduction: Patients with type 1 diabetes (T1DM) may experience reduced cardiorespiratory capacity and impaired metabolic variables. As an adjunct, high-intensity interval training (HIIT) may be a viable and safe option, capable of influencing relevant outcomes and potential risk factors for this population.

Objective: To systematically review the effects of HIIT in T1DM, compared to a control group or moderate-intensity continuous training (MICT), on the outcomes of cardiorespiratory fitness, glycemic profile, lipid profile, body composition, and blood pressure.

Methodology: Searches were conducted in the MEDLINE (PubMed), EMBASE, Cochrane CENTRAL, Web of Science, PEDro, and SPORTDiscus databases, and studies published up to February 2025 were considered. The meta-analysis was conducted using random-effects models and presented as mean difference (MD) with 95% confidence intervals (95% CI).

Results: Five hundred and ninety studies were identified, and after selection, four studies remained for analysis. HIIT increased oxygen consumption (VO₂) by 3.62 ml/kg/min (95% CI 1.01, 6.23) when compared to the control group. There was no difference in the comparison between HIIT and MICT (MD 2.06 ml/kg/min, 95% CI -0.90, 5.01). Compared to the control group, HIIT showed no differences in the other outcomes.

Conclusion: Our results suggest that HIIT is a potential tool for improving cardiorespiratory fitness and demonstrating effects similar to MICT in individuals with T1DM.

Keywords

Cardiorespiratory fitness; endocrine system diseases; high-intensity interval training; meta-analysis.

Resumen

Introducción: Los pacientes con diabetes tipo 1 (DM1) pueden experimentar una capacidad cardiorrespiratoria reducida y alteraciones en las variables metabólicas. Como complemento, el entrenamiento interválico de alta intensidad (HIIT) puede ser una opción, capaz de influir en resultados relevantes y factores de riesgo para esta población.

Objetivo: Revisar sistemáticamente los efectos del HIIT en DM1, en comparación con un grupo de control o entrenamiento continuo de intensidad moderada (MICT), sobre los resultados de aptitud cardiorrespiratoria, perfil glucémico, perfil lipídico, composición corporal y presión arterial.

Metodología: Se realizaron búsquedas en las bases MEDLINE (PubMed), EMBASE, Cochrane CENTRAL, Web of Science, PEDro y SPORTDiscus, y se consideraron estudios publicados hasta febrero de 2025. El metaanálisis se realizó utilizando modelos de efectos aleatorios y se presentó como diferencia de medias (DM) con intervalos de confianza del 95% (IC del 95%).

Resultados: Se identificaron quinientos noventa estudios y, tras la selección, cuatro estudios quedaron para el análisis. El HIIT aumentó el consumo de oxígeno (VO₂) en 3,62 ml/kg/min (IC del 95 %: 1,01, 6,23) en comparación con el grupo control. No hubo diferencia en la comparación entre HIIT y MICT (DM 2,06 ml/kg/min, IC del 95 %: -0,90, 5,01). En comparación con el grupo control, el HIIT no mostró diferencias en los demás resultados.

Conclusión: Nuestros resultados sugieren que el HIIT es una herramienta potencial para mejorar la aptitud cardiorrespiratoria y demostró efectos similares a los del MICT en individuos con DM1.

Palabras clave

Capacidad cardiovascular; enfermedades del sistema endocrino; entrenamiento de intervalos de alta intensidad; metanálisis.

Introduction

Historically diagnosed in childhood, 1,211,900 individuals under the age of 20 live with type 1 diabetes mellitus (T1DM) worldwide (International Diabetes Federation, 2021), but there is a substantial burden of adults diagnosed with this disease (Harding et al., 2022), because 64% of people living with T1DM being between the ages of 20 and 59 (Gregory et al., 2022). This pathology generates a deficit in insulin secretion and hyperglycemia, requiring exogenous insulin and lifelong monitoring. Associated with genetic and environmental factors, T1DM is characterized by the destruction of pancreatic beta cells, which occurs through an immune-mediated mechanism, due to the presence of autoantibodies, or idiosyncratically (ADA, 2024; Atkinson et al., 2014; Katsarou et al., 2017; Skyler et al., 2017).

When there are alterations in blood glucose levels, the risk of cardiovascular disease increases, which is also mediated by other factors such as triglycerides, cholesterol and blood pressure (Bebu et al., 2020). Therefore, there is a higher risk of mortality from cardiovascular disease over time in this population, as well as a higher number of primary and recurrent cardiovascular events (Bebu et al., 2020; Miller et al., 2016). Level of physical activity has a negative correlation with HbA1c (glycated hemoglobin), dyslipidemia, BMI (body mass index), hypertension and microvascular complications (Bohn et al., 2015; Huerta-Urbe et al., 2023). Therefore, controlling risk factors seems to bring results. In this regard, physical exercise is recommended (Holt et al., 2021; Pereira et al., 2022), with positive effects on HbA1c, aerobic capacity and cholesterol (De Cock et al., 2024; García-Hermoso et al., 2023; Wu et al., 2019) in different modalities, intensities and types of exercise.

High-intensity interval training (HIIT) is a likely alternative to conventional training and is characterized by alternating periods of low intensity or periods of rest (Gibala et al., 2012). This type of training generates physiological adaptations at the mitochondrial level with an increased amount of glucose transporter type 4 (Gibala et al., 2012; Hood et al., 2011). Compared to moderate-intensity training, it presents similar results by increasing the aerobic energy supply capacity (Gibala, 2021). In health, this type of exercise has been investigated in special populations compared to MICT (moderate-intensity continuous training) with similar and even superior results when cardiorespiratory fitness is assessed (Leal et al., 2020; Soberi et al., 2026; Su et al., 2019).

Some studies highlight the effects of HIIT on T1DM and, in addition to bringing benefits to quality of life and sleep (Alarcon-Gomez et al., 2021), cardiorespiratory fitness (Alarcón-Gómez et al., 2021; Boff et al., 2019) and endothelial function (Boff et al., 2019) it is shown to be safe in minimizing the risk of hypoglycemia (Alarcon-Gomez et al., 2021; Farrell et al., 2024; Lee, Way, et al., 2020). Recent meta-analyses have demonstrated significant benefits of HIIT in T2DM in relation to HbA1c, oxygen uptake (VO₂), and lipid profile (Cavalli et al., 2024; de Mello et al., 2022). Furthermore, to our knowledge, no systematic reviews of randomized trials have been published to summarize the effects of a program with HIIT. Therefore, this study aimed to review the overall effects of HIIT in patients with T1DM on VO₂ max, glycemic parameters, lipid profile, body composition, and blood pressure outcomes.

Method

Registered on the PROSPERO platform (CRD42024607707), a systematic review of randomized clinical trials and meta-analysis were conducted. This method was based on the recommendations suggested by the Preference Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021) and the Cochrane Handbook recommendations (Higgins et al., 2024).

Search strategy

Using the descriptors "Diabetes Mellitus, Type 1" and "High-Intensity Interval Training," the search strategy was adapted for each database used: MEDLINE (PubMed), EMBASE, Cochrane CENTRAL, Web of Science, PEDro, and SPORTDiscus. Data from inception until February 2025 were included, with no restrictions on publication year or language. The search strategies are available in Supplementary Table S1.

Eligibility criteria



Two independent reviewers, after excluding duplicates using the EndNote reference manager, selected the studies by title and abstract. Randomized controlled clinical trials were included that had participants diagnosed with T1DM, HIIT group and a comparison group (control or MICT), and that contained at least one of the following outcomes: VO₂, HbA_{1c}, fasting glucose, BMI, lean mass, body fat, total cholesterol, HDL, LDL, triglycerides, systolic blood pressure (SBP), and diastolic blood pressure (DBP).

HIIT was defined as periods of brief, intermittent vigorous activity alternating with periods of rest or low-intensity exercise (Gibala et al., 2012). Those with $\geq 64\%$ VO₂max, $\geq 77\%$ HRmax or $\geq 60\%$ HR reserve were categorized as vigorous or high-intensity training, and those with 46–63% VO₂max, 64–76% HRmax or 40–59% HR reserve were categorized as moderate-intensity training (Garber et al., 2011). Studies with a single HIIT group or those evaluated in combination with another exercise modality, and those that assessed only the acute effect, were excluded at this stage. A third reviewer resolved disagreements where there was no consensus.

Data extraction

Data extraction was performed by two independent reviewers using standardized forms. In addition to study identification data (authors, country, year of publication), mean and standard deviation data were collected for sample characteristics, intervention and comparison groups, and outcomes.

Risk of bias and quality of evidence assessment

Using the Cochrane Handbook RoB 2.0, version 6.5 (Higgins et al., 2024) which has five domains, the risk of bias was assessed as "low," "high," or "some concerns." According to the GRADE (Grading of Recommendations Assessment, Development and Evaluation) methodology (Balshem et al., 2011), six criteria for each outcome were analyzed to define the certainty of evidence, classifying it as "high," "moderate," "low," or "very low."

Data analysis

A meta-analysis with random-effects model was conducted, and the data were presented as mean difference (MD) and 95% confidence intervals (95% CI). Post-intervention values were used to calculate the difference between means and standard deviations of the groups. The chi-square test and I-squared test (I²) assessed heterogeneity (Higgins et al., 2003). The software used was RevMan (Review Manager 5.4), which generates the forest plots presenting the results.

Results

Description of studies

As demonstrated in the study flowchart (Figure 1), five hundred and ninety studies with potential for inclusion were identified. For the quantitative and qualitative analyses, four studies were included (Alarcón-Gómez et al., 2021; Boff et al., 2019; Lee, Johnson, et al., 2020; Murillo et al., 2022).

Table 1 presents the sample characteristics and the outcomes assessed for the four included studies. A total of 103 individuals with type 1 diabetes were analyzed, of whom 44.7% were male, the age in years of the HIIT group was 35±6.3, MICT 29.6±8.3 and control 34±12.7. Only two studies compared HIIT versus MICT, while the others compared HIIT with no-exercise control. Regarding HIIT e MICT, the training was primarily conducted on a cycle ergometer and with a frequency of 3 times a week.

Figure 1. Flowchart of study selection process

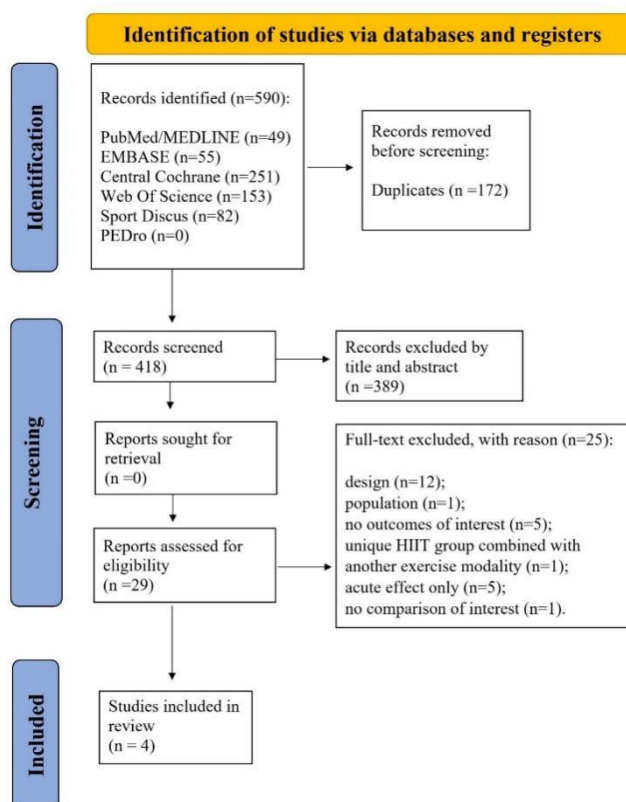


Table 1. Characteristics of included studies

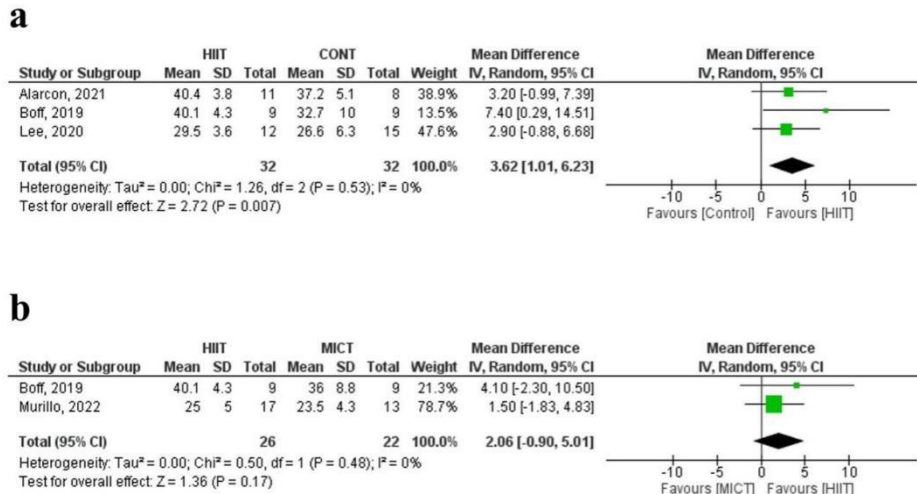
Study		Training Protocol									
First Author, year	Population	Groups (n analyzed)	Age Mean±SD	Male (n)	Training period (weeks)	Intensity	Work Interval		Session length (min)	Outcomes	Dropouts
							Nº of reps	Duration (s)			
Alarcón-Gómez, 2021	Inactive adults with T1DM	HIIT (11) CON (8)	38±5.5 35±8.2	5 4	6	85% PPO	Week 1-2= 12 Week 3-4= 16 Week 5-6= 20	30	Week 1-2= 18 Week 3-4= 24 Week 5-6= 30	VO ₂ max, fasting blood glucose and body composition	0 0
Boff, 2019	Patients >18 years old with T1DM	HIIT (9) MICT (9) CON (9)	26±7.8 23.7±5.8 20.8±2.6	3 5 4	8	Week 1-2= 50% HRmax Week 3-4= 80% HRmax Week 5-8= 85% HRmax	Week 1-2= 0 Week 3-4= 4 Week 5-8= 6	Week 1-2= 0 Week 3-4= 60 Week 5-6= 60	Week 1-2= 30 Week 3-4= 34 Week 5-6= 40	VO ₂ peak, HbA1c, fasting blood glucose, total cholesterol, HDL, LDL, triglycerides and blood pressure	3 3 3
Lee, 2020	T1DM people who are overweight and obese	HIIT (12) CON (15)	40.5±10 46.1±10.5	6 10	12	85-95% HRmax	4	240	33	VO ₂ peak, HbA1c, total cholesterol, LDL, HDL, triglycerides, blood pressure and body composition	3 0
Murillo, 2022	Sedentary individuals with T1DM	HIIT (17) MICT (13)	35.4±6.3 35.5±12.2	6 3	3	100-120% VO ₂ max	10	30	35	VO ₂ max and body composition	NR

n = sample size, SD = standard deviation, NR = not reported, T1DM = type 1 diabetes mellitus, HIIT = high intensity interval training, MICT = moderate intensity continuous training, CON = control group, PPO=power peak output, HRmax= VO₂max = maximal oxygen uptake, VO₂peak = peak oxygen consumption, HbA1c = glycated hemoglobina, HDL = high density lipoprotein, LDL = low density lipoprotein.

Cardiorespiratory fitness

When compared with a control group (3 studies, n=64), the VO₂ mean difference was 3.62 ml/kg/min in favor of HIIT (95% CI 1.01 to 6.23, p=0.007, I²=0%), as shown in Figure 2a. Two studies (n=48) compared HIIT and MICT and there was no difference between the interventions (MD 2.06 ml/kg/min, 95% CI -0.90 to 5.01, p=0.17, I²=0%) (Figure 2b).

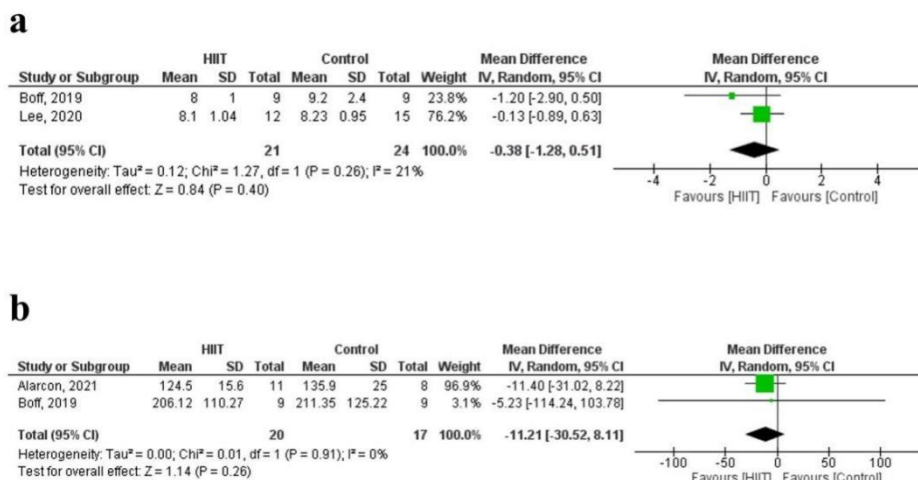
Figure 2. Results in mean difference (95% CI) of VO₂ (ml/kg/min); HIIT vs Control (a) and HIIT vs MICT (b)



Glycemic parameters

Two studies evaluated HbA1c results (n=45) and there was no difference between HIIT and control (MD -0.38, 95% CI -1.28 to 0.51, p=0.40, I²=21%) (Figure 3a). Comparing HIIT and MICT, one study (Boff et al., 2019) assessed this outcome and no difference was found between groups (MD -0.10, 95% CI -0.98 to 0.78). Fasting glucose did not change when compared with control (2 studies, n=37) (MD -11.21 mg/dl, 95% CI -30.52 to 8.11, p=0.26, I²=0%) (Figure 3b). Boff et al. (2019) evaluated the effects compared with MICT and reported no difference in fasting blood glucose (MD 31.52 mg/dl, 95% CI -49.50 to 112.54).

Figure 3. Results in mean difference (95% CI) of HbA1c (%) (a) and fasting glucose (mg/dl) (b).



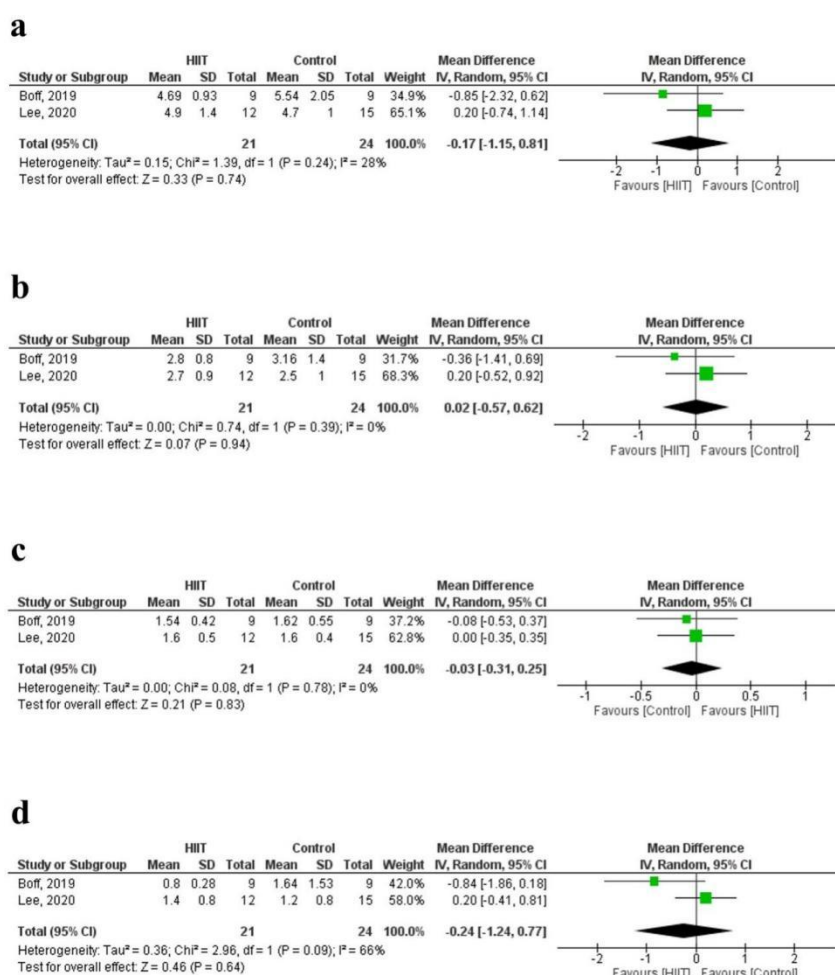
Lipid profile

Total cholesterol (Figure 4a) was similar between HIIT and control (MD -0.17 mmol/L, 95% CI -1.15 to 0.81, $p=0.74$, $I^2=28\%$). The total sample comprised 45 individuals across two studies. For this outcome, one study (Boff et al., 2019) evaluated the comparison of HIIT versus MICT, with no difference between them (MD 0.65 mmol/L, 95% CI -0.43 to 1.73).

About LDL (Figure 4b) and HDL (Figure 4c), two studies ($n=45$) also compared HIIT versus control, with no response to HIIT (LDL: MD 0.02 mmol/L, 95% CI -0.57 to 0.62, $p=0.94$, $I^2=0\%$; HDL: MD -0.03 mmol/L, 95% CI -0.31 to 0.25, $p=0.83$, $I^2=0\%$). LDL was compared in response to HIIT and MICT (MD 0.99 mmol/L, 95% CI -0.05 to 2.03) by Boff et al. (2019) only, as well as HDL (MD 0.17 mmol/L, CI 95% -0.26 to 0.60), and there was also no difference.

Triglycerides levels (Figure 4d) were evaluated comparing HIIT vs. control by two studies ($n=45$) and no difference was found (MD -0.24 mmol/L, 95% CI -1.24 to 0.77, $p=0.64$, $I^2=66\%$). Compared with MICT, only one study (Boff et al., 2019) evaluated and showed a favorable result for HIIT on triglyceride levels (MD -1.06 mmol/L, 95% CI -1.27 to -0.85).

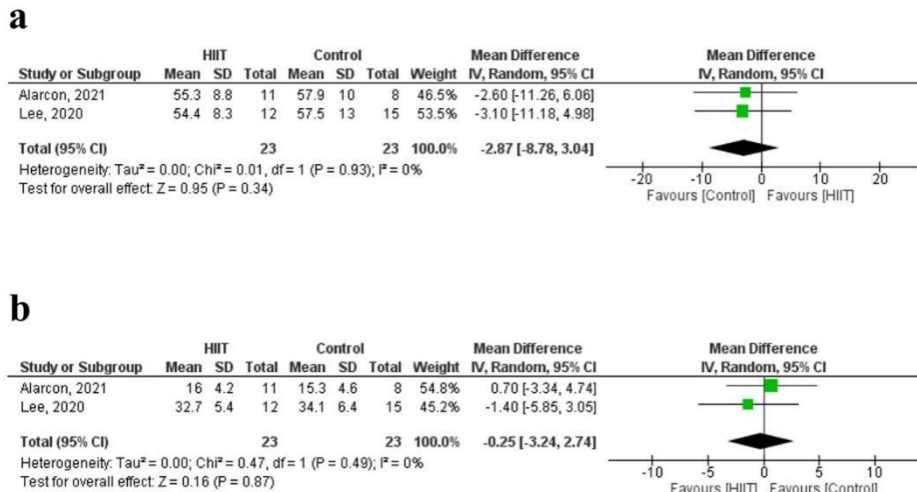
Figure 4. Results in mean difference (95% CI) (mmol/L) of total cholesterol (a), LDL (b), HDL (c) and triglycerides (d).



Body composition

There was no difference in the HIIT vs. control comparison ($n=46$ in two studies) in lean body mass (MD -2.87 kg, 95% CI -8.78 to 3.04, $p=0.34$, $I^2=0\%$; Fig. 5a) and body fat mass (MD -0.25 kg, 95% CI -3.24 to 2.74, $p=0.87$, $I^2=0\%$; Fig 5b). Only Murillo et al. (2022) evaluated BMI compared with MICT (MD -0.20 kg/m², 95% CI -3.12 to 2.72), but found no difference in this analysis.

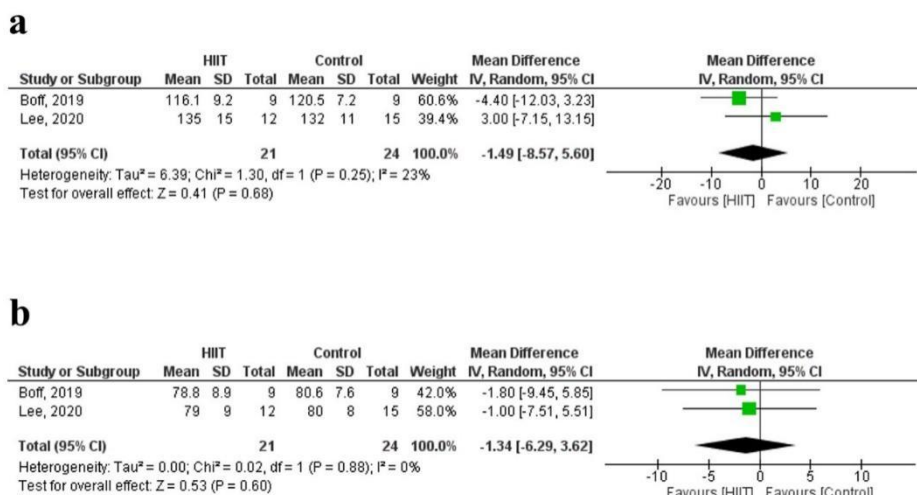
Figure 5. Results in mean difference (95% CI) (kg) of lean body mass (a) and body fat mass (b).



Blood Pressure

Systolic blood pressure (Figure 6a) did not differ compared to control (2 studies, n=45) (MD -1.49 mmHg, 95% CI -8.57 to 5.60, $p=0.68$, $I^2=23\%$). Diastolic blood pressure (Figure 6b) was assessed by two studies with a sample of 45 individuals and there was no difference between the groups (MD -1.34 mmHg, 95% CI -6.29 to 3.62, $p=0.60$, $I^2=0\%$). Also, the study by Boff et al. (2019) compared HIIT and MICT on SBP (MD -2.10 mmHg 95% CI -9.98 to 5.78) and DBP (-2.80 mmHg 95% CI -10.71 to 5.11), with no difference between groups.

Figure 6. Results in mean difference (95% CI) (mmHg) of systolic (a) and diastolic blood pressure (b).



Risk of bias and certainty of evidence

According to the RoB 2.0 assessment, the overall risk of bias was considered "some concerns" in 75% of the studies, and one was considered "high risk" (Supplementary Table S2). For most outcomes the certainty of the evidence found was very low (Supplementary Table S3).

Discussion

This systematic review with meta-analysis is unprecedented in examining the effects of HIIT in patients with type 1 diabetes, seeking robust evidence exclusively from randomized studies, without restriction regarding the year of publication. Another important factor is that relevant outcomes for monitoring this population were evaluated, such as cardiorespiratory fitness, HbA1c, fasting blood glucose, cholesterol, triglycerides, blood pressure and body composition.

There was an increase in VO₂ of 3.62 ml/kg/min following HIIT compared to the control group. The certainty of evidence was low due to the sample size and the risk of bias, however, this is the first study to demonstrate this result. The other assessed outcomes did not demonstrate favorable results for HIIT, in comparison to the control group. The findings obtained with HIIT are similar to those with MICT, corroborating results from previous studies (Milanović et al., 2015; Schleef et al., 2026; Z. J. Wu et al., 2021), but MICT is widely recommended and effective for reducing cardiovascular risk (Ross et al., 2016; Thompson et al., 2013).

This is an important finding, considering that the population with T1DM undertreats cardiovascular risk factors (Shah et al., 2020). Associated with an increased cardiovascular risk, VO₂ is a direct measure of cardiorespiratory fitness, and a decline in this variable is consequently also associated with all-cause mortality (Ross et al., 2016). An increase of 2 ml/kg/min in VO₂ appears to be clinically relevant in reducing coronary disease in the population with T2DM (Balducci et al., 2012), which is similar to that of our study and which allows us to suggest that our finding (increase of 3.62 ml/kg/min in VO₂) can be classified as clinically relevant. In different populations, HIIT appears to improve this variable (Jelleyman et al., 2015; Leal et al., 2020; McGregor et al., 2023), even when compared to MICT in older adults (Z. J. Wu et al., 2021) and in T2DM (de Mello et al., 2022), contrary to what we found in our meta-analysis. This result may be related to the small sample size, as only two studies analyzed this outcome. The mechanism underlying improvements in VO₂ may occur due to the increase in cardiac output generated by HIIT, as in hemoglobin mass and blood volume, improvement in capillarization and mitochondrial biogenesis, as well as an increase in capillary and mitochondrial density (Astorino et al., 2018; Gibala, 2021; Mandić et al., 2022).

Glycemic parameters did not show any changes after HIIT compared to the control group and only one study compared HIIT with MICT, making meta-analysis impossible. These findings are similar to those found in the pre and post-HIIT analysis reported in the meta-analysis by Lazic et al. (2024). García-Hermoso et al. (2023) reported better responses in HbA1c levels with high-intensity but non-interval exercise in a meta-analysis comparing different exercise modalities and intensities in T1DM. In another study, HIIT has been shown to improve insulin resistance when compared to MICT and control (Jelleyman et al., 2015). Exercise interventions may hence reduce HbA1c levels in T1DM when protocols last longer than twelve weeks and particularly when the intervention was aerobic combined with resistance training (Wu et al., 2019).

Regarding lipid profile, HIIT did not alter variables such as total cholesterol, LDL, HDL, and triglycerides, even with moderate-term training lasting eight (Boff et al., 2019) or twelve weeks (Lee, Johnson, et al., 2020). Responses in HDL have been reported in HIIT studies lasting longer than twelve weeks (Kessler et al., 2012), twenty-four to forty-four weeks of high-intensity exercise are recommended for serum lipids to be modified (Fikenzer et al., 2018). Dyslipidemia is associated with T1DM (Oza et al., 2023; Sharma et al., 2024), even with controlled blood glucose (Cai et al., 2024). In this population, aerobic training has shown controversial effects on lipid variables, as reported in a recent scoping review (Chang et al., 2023). This can be explained because fat oxidation after HIIT occurs in longer training sessions and when compared to MICT only in overweight and obese individuals (Atakan et al., 2022). Although the small number of studies may also be an important factor contributing to the lack of results, normal baseline serum lipid levels in our sample and lack of changes in body composition may help explain these findings.

Body composition, assessed by lean mass and body fat, also did not differ in the HIIT versus control comparison, in line with the findings from an RCT that compared 12-16 weeks of aerobic exercise with control group in adult men with T1DM (Laaksonen et al., 2000). However, Ostman et al. (2018) studied different exercise modalities for individuals with T1DM and there was an improvement in body mass



(kg) and BMI. In addition to blood glucose control, weight control is an emerging issue for this population (Kueh et al., 2024). However, a recent meta-analysis included different types of exercise for this population and also found no response in BMI (N. Wu et al., 2021). In overweight and obese adults, HIIT was similar to MICT in improving BMI and body fat percentage while requiring less training time (Su et al., 2019).

No changes in blood pressure response was observed after HIIT compared to control, which is similar to that reported in two other meta-analyses that included other exercise modalities (Ostman et al., 2018; Z. J. Wu et al., 2021). In hypertensive individuals, HIIT was similar to MICT in reducing resting systolic and diastolic blood pressure (Costa et al., 2018). Further robust studies are needed in order to seek alternatives to reduce blood pressure in people with T1DM, considering that hypertension is a mediator of atherosclerosis (Liu et al., 2023) and is associated with micro and macrovascular complications (Bjornstad et al., 2018, 2022).

We acknowledge several limitations in our study, primarily due to the small number of randomized controlled trials on this type of exercise in this population, which partly explains the low and very low certainty of the evidence of the results. For most outcomes included in the meta-analysis, only two studies were available, which may explain the wide confidence intervals and the negative response to HIIT compared to control. Also, the sample sizes are too small to make any statement. Additionally, was the inability to perform analyses for publication bias, due to Cochrane's recommendation not to perform it when there are less than 10 studies in the meta-analysis. Subgroup analyses and meta-regression were also not feasible. The low methodological quality of the studies can be explained by the impossibility of blinding the exercise and by some flaws in the descriptions of the data collection processes and evaluation of the results, which generated some concerns and a high risk of bias.

Conclusions

In conclusion, HIIT has a potential benefit for improving VO₂ also in individuals with T1DM. When compared to MICT, it did not demonstrate any difference, which suggests that it may be a viable alternative for this population. In glycemic parameters, lipid profile, body composition, and blood pressure, it was not possible to identify results for HIIT and we did not find enough studies to perform a comparison analysis with MICT. In this sense, we suggest conducting new robust randomized controlled clinical trials to understand the real global effects of this promising type of training compared with other most commonly used interventions, considering the young population that lives with the disease throughout their lives and the possibility of a more attractive, safe and possibly time-efficient exercise, capable of reducing cardiovascular risk and other complications.

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