

Originales

## Resistance training does not reduce blood glucose levels in adults with type 1 diabetes: a systematic review and meta-analysis



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### ABSTRACT

This study aims to evaluate whether resistance exercise can improve blood glucose levels in adults with type 1 diabetes. Methods: A review was conducted of studies indexed in PubMed, Scopus, and Embase, including randomized clinical trials published between 2002 and 2025. Methodological quality was assessed using the Jadad scale, and risk of bias was evaluated using the Cochrane RoB 2.0 tool. The meta-analysis was performed with RevMan 5.4 software using a random-effects model. The results reported four studies involving adults diagnosed with type 1 diabetes mellitus were included. The analysis indicated that other interventions are more effective in promoting a reduction in blood glucose immediately after exercise ( $p < 0.05$ , 95% CI = 5.62–10.20;  $I^2 = 95\%$ ). Moreover, no difference was observed when assessing the effect on glycated hemoglobin ( $p = 0.32$ ; 95% CI = -0.06–0.02). Therefore, the findings suggest that resistance exercise alone is not effective in promoting a significant improvement in glycemic control in adults.

**Keywords:** Type 1 diabetes mellitus; Resistance training; Glucose; Glycated hemoglobin.

### Exercício resistido não reduz a glicemia em adultos com diabetes tipo 1: revisão sistemática com metanálise

### RESUMO

O presente estudo propõe avaliar se o exercício físico resistido pode melhorar a glicemia de adultos com diabetes tipo 1. Trata-se de uma revisão de estudos indexados nas bases PubMed, Scopus e Embase, com inclusão de ensaios clínicos randomizados publicados entre 2002 e 2025. A qualidade metodológica foi avaliada pela escala Jadad e o risco de viés pela ferramenta Cochrane RoB 2.0. A metanálise foi conduzida com o software RevMan 5.4, utilizando modelo de efeitos aleatórios. Foram incluídos quatro estudos com adultos diagnosticados com diabetes mellitus tipo 1, com idade entre 18 e 60 anos. A análise indicou que o exercício físico resistido não promoveu redução significativa na glicemia pós-intervenção em comparação aos grupos controle (diferença média: 7,91 mg/dL; IC 95%: 5,62 - 10,20;  $I^2 = 95\%$ ). Também não foram observadas alterações significativas nos níveis séricos de hemoglobina glicada ( $p = 0,32$ ; IC 95%: -0,06–0,02). Os achados sugerem que o exercício físico resistido, de forma isolada, não é eficaz para promover melhora significativa do controle glicêmico em adultos com diabetes tipo 1.

**Palavras-chave:** Diabetes mellitus tipo 1; Exercício resistido; Glicose; Hemoglobina glicada.

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## El ejercicio de resistencia no reduce la glucemia en adultos con diabetes tipo 1: revisión sistemática con metaanálisis

### RESUMEN

El presente estudio propone evaluar si el ejercicio físico de resistencia puede mejorar la glucemia en adultos con diabetes tipo 1. Se realizó una revisión de estudios indexados en las bases de datos PubMed, Scopus y Embase, que incluyó ensayos clínicos aleatorizados publicados entre 2002 y 2025. La calidad metodológica se evaluó mediante la escala de Jadad y el riesgo de sesgo con la herramienta Cochrane RoB 2.0. El metaanálisis se llevó a cabo con el software RevMan 5.4, utilizando un modelo de efectos aleatorios. Se incluyeron cuatro estudios con adultos diagnosticados con diabetes mellitus tipo 1. El análisis indicó que otras intervenciones son más eficaces para promover la reducción de la glucemia inmediatamente después del ejercicio ( $p < 0,05$ ; IC 95% = 5,62–10,20;  $I^2 = 95\%$ ). Además, no se observó diferencia al evaluar el efecto crónico sobre la hemoglobina glicosilada ( $p = 0,32$ ; IC 95% = -0,06–0,02). Por lo tanto, los hallazgos sugieren que el ejercicio físico de resistencia, de forma aislada, no es eficaz para promover una mejora significativa en el control glucémico en adultos.

**Palabras clave:** Diabetes mellitus tipo 1; Entrenamiento de resistencia; Glucosa; Hemoglobina glicosilada.

### INTRODUCTION

Diabetes mellitus (DM) is advancing rapidly and silently worldwide. Recent estimates indicate that approximately 589 million people live with the disease, which exerts significant pressure on health and social security systems globally, with costs exceeding US\$ 1 trillion<sup>1</sup>.

Among the types of DM, type 1 (T1DM) is less prevalent than type 2. However, the glycemic disorder resulting from this condition can lead to serious complications, such as diabetic retinopathy, amputations related to diabetic vasculopathy, and diabetic nephropathy<sup>2,3</sup> earlier than in other types of DM. In the United Kingdom, individuals with T1DM have a life expectancy reduced by 11 to 13 years compared with non-diabetics individuals<sup>4</sup>.

The main objective in the treatment of individuals with T1DM is to maintain blood glucose within the established target in order to prevent complications associated with the disease. Insulin therapy remains the main therapeutic strategy<sup>5</sup>. However, some patients have difficulty achieving glycemic targets and require complementary therapies<sup>6</sup>.

In this context, physical exercise emerges as an important adjuvant due to its multiple health benefits. According to Reddy et al., resistance exercise (RE) can improve glycemic control in adults with T1DM, regardless of adjustments in insulin dosage or diet<sup>7</sup>.

On the other hand, other studies question the effectiveness of RE in promoting glycemic reduction. McCarthy et al. highlight that impaired gluoregulation becomes more evident in individuals with T1DM when exercise is performed in the postprandial period, increasing the risk of hypoglycemia<sup>8</sup>.

In addition to this divergence, meta-analyses investigating the impact of RE on glycemic control in individuals with T1DM do not adequately delimit the study population, including individuals ranging from adolescents to adults<sup>9,10</sup>. Study designs such as these do not take into account that the intervention may present conflicting responses due to the greater physiological reserve in a younger individual, or that it may present a different magnitude of effect with limited clinical relevance.

In light of this, the aim of this review is to determine whether RE can improve blood glucose in adult individuals diagnosed with T1DM based on revision of the current evidence.

### METHODOLOGY

#### Study design

This is a literature review with meta-analysis, using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) strategy. The protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under number CRD42024542701.

The research question was defined using the PICOS strategy, an acronym for Population (P) = Adults (18–60 years) with type 1 diabetes, Intervention (I) = Adults (18–60 years) with T1DM, Control (C) = Other interventions, Outcomes (O) = Improved blood glucose levels, and Study Design (S) = Randomized clinical trials. Thus, the guiding question was structured as follows: what is the effect of resistance exercise on the blood glucose of adult individuals with type 1 diabetes mellitus?

#### Search strategy in electronic databases

Searches were carried out in the virtual libraries PubMed®/ Medline, Scopus, and Embase by DBF, using the following Health Sciences descriptors: 'type 1 diabetics', 'Type 1 diabetes', 'resistance training', and "Strength training". The descriptors were combined with the Boolean operators AND, for the simultaneous occurrence of topics, and OR, for the occurrence of one topic or another. In addition, filters were applied for: time frame; selection of randomized clinical trials; and languages, with articles published in Portuguese and English.

#### Inclusion and exclusion criteria

The inclusion criteria were: randomized, controlled clinical studies with adult individuals aged 18 to 60 years, diagnosed with T1DM and subjected to RE protocols whose intensity ranged from light to vigorous, published in scientific journals between 2002 and 2025, in Portuguese or English. Publications that did not correspond to the research topic were excluded, as well as those without full text; duplicate publications; and publications in the following categories: literature reviews, editorials, reviews (book reviews), case reports and experience reports, theoretical reflections, dissertations, theses, monographs, and abstracts published in conference proceedings.

#### Study screening

After removal of duplicate publications, two researchers, TSCW and TWP, independently and blindly evaluated the titles and abstracts. Disagreements between the researchers were submitted to the most experienced researcher in the group (MFPG) for a tie-

breaking judgment. Finally, 22 articles were read in full, of which 4 were included in the sample.

### Assessment of study quality and risk of bias

To assess the methodological quality of the studies, the Jadad scale was used. Studies scoring 3 or higher are considered “studies with high methodological quality”. In contrast, studies scoring 2 or less are considered “studies with low methodological quality”<sup>11</sup>.

The analysis of risk of bias was conducted using the Rob 2.0 tool, a Cochrane instrument<sup>12</sup>. The tool evaluates 5 components of the studies: the randomization process; deviations from the intended intervention; incomplete outcome data; outcome measurement; and selection of the reported results. Studies can be classified as having low risk of bias, some concerns, or high risk of bias<sup>13</sup>. Disagreements among the researchers regarding quality and risk-of-bias assessment were extensively discussed among the researchers (TSCW, TWP, and MFPG).

### Statistical analysis

The analysis was conducted using the RevMan 5.4 software. For this purpose, data were extracted from the original articles, obtaining values of total N, mean, standard deviation, and relative frequency (%). The statistical method used was inverse variance. In addition, standardized mean difference was chosen to analyze the effect size. A Z-test was conducted, adopting a p-value lower than 0.05 as indicative of a statistically significant difference.

The analysis model used was a random-effects model, and the R-sq ( $I^2$ ) value was examined to determine imprecision or heterogeneity of the analyses, adopting the following categories: low association = 25%; moderate association 25%–<50%; and high association = 50%.

## RESULTS

A total of 3,766 records were identified in the databases, of which 645 were excluded due to duplication. After screening the titles and abstracts of 3,131 articles, 22 studies were selected for full-text reading. Subsequently, 8 studies were excluded due to inappropriate study design, 7 due to irrelevant outcomes, and 3 because the population did not meet the predefined eligibility criteria.

Ultimately, 4 studies were included in this review, as shown in the PRISMA flow diagram in Figure 1.

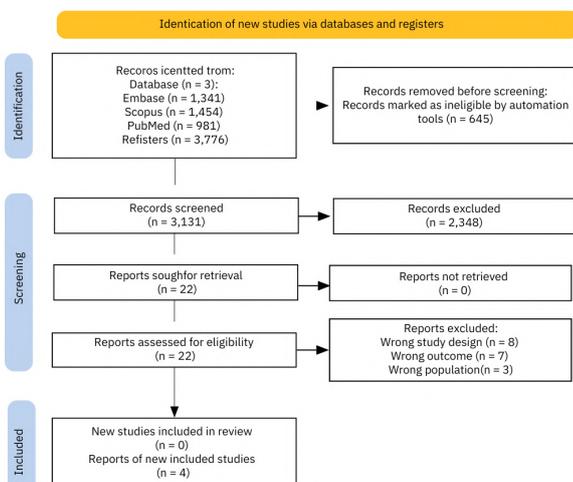


Figure 1. PRISMA flow diagram of the study identification, screening, eligibility, and inclusion process.

The synoptic table (Table 1) was constructed based on information extracted from the included studies. The total sample comprised 88 individuals with medical clearance to engage in physical activity. There were no sex-based restrictions, and the mean age of participants was 29.9 years. None of the studies excluded physically active individuals. Regarding common exclusion criteria, the studies generally excluded underage individuals and those with chronic complications resulting from T1DM. With respect to the resistance exercise programs evaluated, Jimenez *et al.* implemented a high-intensity protocol (80% of 1RM), consisting of five sets of six repetitions for the quadriceps and hamstring muscles, with 4-minute rest intervals between sets<sup>14</sup>. In the study by Carvalho *et al.*, intensity was moderate (60% of 1RM), and two distinct programs were applied, both using three sets of 10 to 12 repetitions with rest intervals of 50 to 60 seconds and an approximate cadence of three seconds. The difference between them consisted in the exercise selection. Program A included bench press, leg press, biceps curl, leg extension, shoulder press, hip adduction, and floor abdominal curls, whereas Program B involved lat pulldown, seated leg curl, triceps cable pushdown, horizontal leg curl, upright row, hip abduction, and isometric plank<sup>15</sup>. Moreover, in the study by Sigal *et al.*, the program was performed three times per week over 26 weeks, with intensity determined by the 8RM method. Two programs were carried out on alternating days: the first included 8 repetitions of abdominal crunches, leg extensions, shoulder press, seated row, and seated biceps curl, as well as 15 repetitions of leg press and supine bench press; the second included 8 repetitions of abdominal crunches, leg curls, upright row, lat pulldown, and triceps pushdown, as well as 15 repetitions of leg press and seated chest press<sup>16</sup>.

Finally, in the study by Soltani *et al.*, the resistance exercise protocol was performed at 60% of 1RM and included bench press, leg press, biceps curl, knee extension, shoulder press, hip adduction, and floor abdominal exercises, characterizing a typical strength-training routine commonly used in fitness centers. The program was implemented twice per week, with three sets of 10 to 12 repetitions per exercise and rest intervals of 50 to 60 seconds between sets. As the original study compared three interventions —body-weight functional exercise (BWFE), interval aerobic exercise (IAE), and RE—we opted in this review to analyze only the outcomes related to RE and IAE, since the BWFE protocol shared several characteristics with the RE program<sup>17</sup>.

Among the included studies, only the study by Jimenez *et al.* was classified as having low methodological quality (Table 2). This classification resulted from the absence of a description of the randomization method and lack of blinding<sup>14</sup>.

Regarding risk of bias, the selected studies generally showed a low risk of bias (Figure 2). The maximum score was not reached because, in the study by Jimenez *et al.*, the randomization process was not described<sup>14</sup>. Nevertheless, the study was retained in the analysis because the remaining methodological domains were adequately reported in the publication.

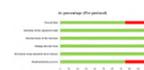


Figure 2. Risk of bias assessment of the included studies using the Cochrane RoB 2.0 tool.

Figure 3 presents the analysis of mean reductions in blood glucose immediately after the interventions. The results indicated that RE did not produce a significant improvement in glycemic control in individuals with T1DM (mean difference: 7.91 mg/dL; 95% CI = 5.62–10.20). High heterogeneity was also observed among the studies ( $I^2 = 95\%$ ), possibly influenced by higher baseline glycemic levels in the intervention group in the study by Carvalho *et al.*<sup>15</sup>.

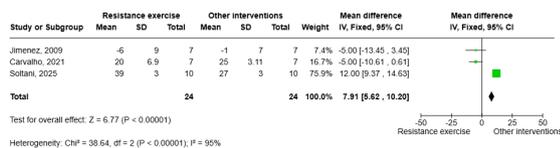
**Table 1.** Synoptic overview of the included studies.

Authors and titles	Objective	Intervention	Outcome
<b>Jimenez et al., 2009</b> Insulin-Sensitivity Response to a Single Bout of Resistive Exercise in Type 1 Diabetes Mellitus	To evaluate the acute effects of RE in individuals with T1DM.	The intervention group (n = 7) performed five sets of six repetitions of high-intensity resistance exercises (80% of 1-RM). The control group (n = 7), in turn, continued only their usual daily living activities.	A single session of resistance exercise did not promote changes in blood glucose or insulin sensitivity in individuals with T1DM.
<b>Carvalho et al., 2021</b> Sex-related glycemic changes after intensity -and duration-matched aerobic and strength exercise sessions in type 1 diabetes: A randomized cross-sectional study.	To evaluate the effect of RE on blood glucose according to sex in individuals with T1DM.	12 participants were randomized to aerobic exercise and RE programs A and B. All programs were performed at moderate intensity (60% of one 1RM) and consisted of three sessions.	Only the male participants showed a reduction in blood glucose after completing the aerobic and RE from program B.
<b>Sigal et al., 2023</b> The Resistance Exercise in Already Active Diabetic Individuals (READI) Randomized Clinical Trial	To evaluate the effect of RE on glycated hemoglobin (HbA1c), physical fitness, body composition, and cardiometabolic risk factors in individuals with T1DM.	The intervention group (n = 63) participated in a resistance exercise program performed on weight machines, three times per week, using loads set at the eight-repetition maximum (8RM). The control group (n = 50) continued only their usual routine of aerobic activities.	Adding resistance training did not affect glycemia, but it increased strength and reduced waist circumference, in individuals with T1DM
<b>Soltani et al., 2025</b> Body-weight functional exercise promotes greater and safer blood glucose reduction compared to aerobic and strength exercises in type 1 diabetics: a randomised crossover study.	To compare blood glucose, cardiovascular responses, and enjoyment levels after a 30-minute session of BWFE versus IAE and ER in patients with T1DM.	IAE: Interval aerobic exercise on a treadmill at moderate intensity, alternating between 40–60% of VO <sub>2</sub> max every minute for 30 minutes. RE: Resistance exercise at 60% of 1RM, with three sets of 10–12 repetitions per exercise and 50–60 s rest intervals, following a typical gym routine. BWFE: Body-weight functional exercises performed on the floor (plank, deep squats, bench triceps, lunges, hip adduction, moving Superman, shoulder circles), completed in three sets of 10–12 repetitions or 30–40 s, with 50–60 s rest intervals.	There was no significant difference between the interventions.

**Table 2.** Assessment of the methodological quality of randomized clinical trials.

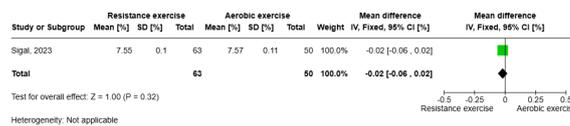
Questions	Score			
	Jimenez et al., 2009	Carvalho et al., 2021	Sigal et al., 2023	Soltani et al., 2025
1. Was the study described as randomized?	1	1	1	1
2. Was randomization described and is it appropriate?	0	1	1	1
3. Was the study described as double-blind?	0	0	0	0
4. Was the blinding method appropriate? (Were the patient and assessor correctly blinded?)	0	0	1	0
5. Was there a description of withdrawals and dropouts?	1	1	1	1
<b>Total</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>3</b>

For questions whose answers were "yes," 1 point was assigned. For questions with "no" answers, 0 points were assigned. Studies with methodological quality scores between 0-2 are considered to have low methodological quality, while those with scores between 3-5 are considered to have high methodological quality.



**Figure 3.** Meta-analysis of the immediate post-exercise effects of resistance training on blood glucose levels in adults with type 1 diabetes.

Additionally, RE did not show a significant effect on long-term outcomes (Figure 4). In the study by Sigal et al.<sup>16</sup>, no significant differences were observed in HbA1c levels between groups (p = 0.32; 95% CI = -0.06–0.02).



**Figure 4.** Meta-analysis of the effects of resistance training on glycated hemoglobin (HbA1c) levels in adults with type 1 diabetes.

**DISCUSSION**

The primary objective of this review was to evaluate whether RE reduces blood glucose levels in adult individuals with T1DM. The results obtained from the analysis of the studies indicate that RE does not significantly reduce glycemia. Except for the study by Sigal et al., the remaining trials focused on the acute effects of moderate-intensity RE on blood glucose. Acute effects of exercise are understood

as adaptive responses observed within the first 24 hours following the activity<sup>18,19</sup>.

The currently available evidence indicates that RE, when applied in isolation, is not sufficient to produce significant reductions in blood glucose levels in adults with T1DM<sup>9</sup>. This finding is supported by studies such as that of Zinman *et al.*, who did not observe improvements in glycemic control as a result of regular exercise<sup>20</sup>. Similarly, Laaksonen *et al.* reported no reduction in glycemic levels even after 12 weeks of a structured training program<sup>21</sup>. However, these findings should be interpreted with caution, given relevant methodological limitations, such as the small sample sizes of the included trials and the wide confidence intervals reported.

Regarding the high heterogeneity observed in the analysis of RE effects on glycemia (Figure 3), this methodological variability, including differences in intervention protocols, follow-up duration, and control strategies, compromises the robustness of the conclusions and hinders direct comparisons across trials. Similar evidence has been reported in studies involving individuals with type 2 diabetes mellitus (T2DM)<sup>22,23</sup> and leave-one-out sensitivity analyses indicate that the sequential exclusion of studies with lower methodological quality does not substantially alter the overall result<sup>22</sup>. Therefore, it is essential to develop research involving individuals with T1DM that adopts more standardized methodologies and rigorous control of confounding variables<sup>24</sup>.

This phenomenon likely stems from the heterogeneity of the population included in the studies. Due to the difficulty in recruiting volunteers for research, many authors perform population subdivisions predominantly based on age, without adequately considering the clinical stage in which the individuals find themselves. Therefore, outcomes with distinct magnitudes are produced, which substantially contributes to the increased variability across the studies.

From a physiological standpoint, RE may promote peripheral glucose uptake through the translocation of GLUT-4 transporters to the cell membrane, independently of insulin action<sup>25,26</sup>.

However, recent evidence suggests that the hyperglycemic state may induce downregulation of these pathways in certain tissues, as demonstrated in tenocytes and glomerular epithelial cells<sup>27,28</sup>. This factor may, in part, explain the absence of significant changes in glycemic levels observed in the studies analyzed.

Despite the lack of statistical significance, it is plausible that RE may exert indirect beneficial clinical effects, such as improved body composition, increased muscle mass, and potential reduction in insulin resistance. These factors are well-recognized as relevant in the comprehensive therapeutic management of T1DM, although they were not directly measured in the studies included in this review<sup>29</sup>.

When compared with the literature on RE in individuals with T2DM, it appears that positive glycemic effects tend to be more pronounced in this latter population. This discrepancy may be explained by pathophysiological differences between the two forms of the disease, particularly the presence of residual endogenous insulin in T2DM, which enhances the effects of exercise on carbohydrate metabolism<sup>30</sup>.

The metaanalysis of 12 randomized trials comprising 452 adults with T1DM found that neither aerobic nor resistance exercise produced a statistically significant reduction in HbA1c<sup>31</sup> (Figure 4). The authors reported a roughly linear doseresponse relationship between exercise exposure and glycemic improvement, suggesting that interventions of longer duration (~25 weeks) might achieve an HbA1c decrement of approximately 0.5 %<sup>31</sup>. Implementing such prolonged protocols in clinical trials, however, poses considerable logistical and methodological challenges, including maintaining participant adherence, controlling confounding variables, and minimizing attrition. Moreover, from a clinical perspective, a 0.5 % reduction is modest relative to the effort required to attain it, and the durability of the effect—i.e., the time patients remain within their daily target glucose range—remains uncertain. Consequently,

future investigations should prioritize adequately powered, longterm designs that can clarify both the magnitude and the sustainability of exercise-induced glycemic benefits in T1DM.

The present review has several limitations that should be considered when interpreting the results. First, the limited number of included randomized clinical trials (n = 4) restricts the statistical power of the analyses and increases the imprecision of effect estimates. Additionally, substantial heterogeneity was observed among the studies, particularly regarding intervention protocols and adopted control strategies. This methodological variability hinders direct comparisons and may influence conclusions.

Another relevant aspect is that the majority of studies primarily assessed the acute effects of resistance exercise on blood glucose, with only one trial investigating long-term outcomes, such as HbA1c. Consequently, it is not possible to confidently assert whether chronic and more prolonged resistance exercise interventions could yield more consistent metabolic benefits in adults with T1DM.

Finally, the generalizability of the results should be approached with caution. The included samples consisted of adults with T1DM whose clinical characteristics and baseline glycemic control levels were not always clearly described or homogeneous, which complicates the extrapolation of findings to other patient profiles, such as individuals with long disease duration, advanced chronic complications, or varying levels of physical fitness. Therefore, future clinical trials should be conducted with larger samples, more clearly defined inclusion criteria, and more standardized intervention protocols to reduce heterogeneity and enhance the quality of available evidence.

## CONCLUSION

This review did not find consistent evidence that RE promotes a significant reduction in blood glucose levels in adults with T1DM. The analysis of the included studies revealed substantial heterogeneity among intervention protocols, as well as methodological limitations, particularly related to sample size. Although RE has well-recognized physiological benefits, the available data do not support its efficacy for glycemic control in this population. In light of this, randomized clinical trials with greater methodological rigor, more representative samples, and standardized interventions are recommended to clarify the role of resistance exercise in the integrated management of T1DM in adults.

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