SAĞLIK BİLİMLERİ ÜNİVERSİTESİ HEMŞİRELİK DERGİSİ
University of Health Sciences Journal of Nursing
Cilt / *Volume* 8 • Sayı / *Number* 2 • Ağustos / *August* • 2026

Derleme makale / Review • **DOI: 10.48071/sbuhemsirelik.1938758**

The Effect of Exercise-Based Interventions on HbA1c in Children with Type 1 Diabetes: A Systematic Review and Meta-Analysis

Tip 1 Diyabetli Çocuklarda Egzersiz Temelli Müdehalelerin HbA1c Üzerindeki Etkisi: Sistematik Bir Derleme ve Meta-Analiz

Harun ÖZBEY[1]

Yazarların ORCID numaraları / ORCID IDs of the authors:
H.Ö.: 0000-0001-9827-0655

[1]Erciyes University, Faculty of Health Sciences, Department of Nursing, Kayseri, Türkiye

Sorumlu yazar / Corresponding author: Harun ÖZBEY
E-posta: harunozbey@erciyes.edu.tr

Geliş tarihi / Date of receipt: 27.04.2026
Kabul tarihi / Date of acceptance: 30.06.2026

Atıf / Citation: Özbey, H. (2026). The effect of exercise-based interventions on HbA1c in children with type 1 diabetes: A systematic teview and meta-analysis. *UHS Journal of Nursing, 8*(2), 185-194. doi: 10.48071/sbuhemsirelik.1938758

ABSTRACT

This study aimed to determine the effect of exercise-based interventions on glycated hemoglobin A1c levels in children and adolescents with Type1 diabetes, and to systematically examine how different types of exercise, intervention duration, and intensity moderate this relationship. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 guidelines were followed in conducting the systematic review and meta-analysis. A systematic search of eight electronic databases was performed. Intervention studies that applied exercise-only interventions in children with Type1 diabetes aged 19 years and under and reported glycated hemoglobin A1c as an outcome measure were included. Studies including nutritional interventions, observational studies, review articles, and studies involving adult populations were excluded. A total of 18 studies (n = 569 participants) were included in the meta-analysis. Exercise interventions produced a statistically significant reduction in glycated hemoglobin A1c levels compared with the control group (Hedges' g = -0.38; 95% CI: -0.66 to -0.11; mean difference = -0.62%). Subgroup analyses showed that combined exercise (aerobic + resistance training) yielded the highest effect size (g = -0.63). Interventions lasting 24 weeks or longer (g = -0.92), programs with session durations of 60 minutes or more (g = -0.71), and high-intensity exercise protocols (g = -0.43) were associated with greater reductions in glycated hemoglobin A1c. Exercise-based interventions significantly improve glycated hemoglobin A1c levels in children and adolescents with Type1 diabetes. In clinical practice, the recommendation of high-intensity combined exercise programs lasting at least 24 weeks, with sessions of 60 minutes or more, at least 3 days per week.

Keywords: Type 1 diabetes; exercise; HbA1c; glycemic control; meta-analysis.

ÖZ

Bu çalışma, Tip1 diyabetli çocuk ve ergenlerde egzersiz temelli müdahalelerin glikozillenmiş hemoglobin A1c düzeyleri üzerindeki etkisini belirlemeyi ve farklı egzersiz türlerinin, müdahale süresinin ve yoğunluğunun bu ilişkiyi nasıl etkilediğini sistematik olarak incelemeyi amaçlamıştır. Sistematik derleme ve meta-analiz, Sistematik Derlemeler ve Meta-Analizler için Tercih Edilen Raporlama Öğeleri 2020 kılavuzlarına uygun olarak gerçekleştirilmiştir. Sekiz elektronik veri tabanında sistematik bir tarama yapılmıştır. 19 yaş ve altı Tip1 diyabetli çocuklarda sadece egzersiz müdahaleleri uygulayan ve sonuç ölçütü olarak HbA1c'yi bildiren müdahale çalışmaları dahil edilmiştir. Beslenme müdahalelerini içeren çalışmalar, gözlemsel çalışmalar, derleme makaleleri ve yetişkin popülasyonlarını içeren çalışmalar hariç tutulmuştur. Meta-analize toplam 18 çalışma (n = 569 katılımcı) dahil edilmiştir. Egzersiz müdahaleleri, kontrol grubuna kıyasla glikozillenmiş hemoglobin A1c düzeylerinde istatistiksel olarak anlamlı bir azalma sağladı (Hedges' g = -0,38; %95 CI: -0,66 ila -0,11; ortalama fark = -0,62%). Alt grup analizleri, kombine egzersizin (aerobik + direnç antrenmanı) en yüksek etki büyüklüğünü sağladığını gösterdi (g = -0,63). 24 hafta veya daha uzun süren müdahaleler (g = -0,92), seans süresi 60 dakika veya daha fazla olan programlar (g = -0,71) ve yüksek yoğunluklu egzersiz protokolleri (g = -0,43), glikozillenmiş hemoglobin A1c'de daha büyük düşüşlerle ilişkilendirilmiştir. Egzersiz temelli müdahaleler, Tip1 diyabetli çocuk ve ergenlerde glikozillenmiş hemoglobin A1c düzeylerini önemli ölçüde iyileştirmektedir. Klinik uygulamada en az 24 hafta süren, seans süresi 60 dakika veya daha fazla olan ve haftada en az 3 gün uygulanan yüksek yoğunluklu kombine egzersiz programlarının önerilmesi desteklenmektedir.

Anahtar Kelimeler: Tip 1 diyabet; egzersiz; HbA1c; glisemik control; meta-analiz.

Introduction

Type 1 diabetes (T1D) is a chronic metabolic disease characterized by absolute insulin deficiency resulting from the autoimmune destruction of pancreatic beta cells, and it is among the most common endocrine disorders of childhood (Atkinson et al., 2014). According to the 11th edition of the International Diabetes Federation (IDF) Diabetes Atlas, as of 2025, approximately 9.5 million people worldwide are living with T1D, of whom 1.8 million are children and adolescents under 20 years of age (Ogle et al., 2025). The incidence of childhood T1D is increasing by approximately 3-5% per year, gradually heightening the disease's importance as a global public health concern (Danne et al., 2007). In Türkiye, the incidence of childhood T1D shows a rising trend and constitutes a significant burden on the healthcare system.

Achieving glycemic control is a primary therapeutic goal in the management of Type 1 diabetes. Glycated hemoglobin A1c (HbA1c) is a measure that reflects the average blood glucose level over the past 2-3 months and is recognized as the gold-standard indicator of long-term glycemic control (American Diabetes Association [ADA], 2024). The Diabetes Control and Complications Trial (DCCT) and its follow-up, the EDIC study, have definitively demonstrated that maintaining HbA1c levels around 7% reduces microvascular complications (retinopathy, nephropathy, neuropathy) by 35-76% (Nathan et al., 2014). Moreover, it has been shown that every 1% increase in HbA1c more than doubles the risk of retinopathy and increases the risk of nephropathy by 80% (Kilpatrick, Rigby & Atkin, 2008). These findings underscore the critical importance of achieving optimal glycemic control during childhood for lifelong health outcomes.

Physical activity and exercise are recognized as integral components of T1D management. The American Diabetes Association (ADA) recommends that children and adolescents with T1D engage in at least 60 minutes of moderate-to-vigorous aerobic physical activity per day and perform muscle-strengthening exercises on at least three days per week (Adolfsson et al., 2022). However, children with T1D are less active and lead more sedentary lifestyles than their healthy peers; fear of hypoglycemia, glycemic variability, and difficulties with insulin management have been identified as the main barriers to participation in physical activity (Riddell et al., 2017). This situation contributes to lower cardiovascular fitness levels, impaired metabolic control, and increased risk of long-term complications in children with T1D.

Studies investigating the effect of exercise on HbA1c in children with T1D have produced inconsistent findings. While some studies have reported significant reductions in HbA1c following exercise interventions (Salem, AboElAsrar, Elbarbary, ElHilaly & Refaat, 2010), others have failed to confirm this effect (Roberts, Jones & Fournier, 2002; D'hooge et al., 2011). Existing meta-analyses have also reached differing conclusions: Kennedy et al. (2013) reported a non-statistically significant reduction in HbA1c (SMD = -0.25), whereas García-Hermoso et al. (2023) detected a moderate, significant effect (Hedges' g = -0.38). These inconsistencies stem from the heterogeneity of the included studies, the failure to disaggregate exercise types (aerobic, resistance, combined), and age differences across study populations.

A review of the literature reveals the need for an up-to-date meta-analysis specific to children with T1D that evaluates the effect of exercise-only interventions on HbA1c (excluding nutritional interventions), assesses different types of exercise (aerobic, resistance, combined, Pilates) separately, and comprehensively examines the modulating roles of intervention duration, intensity, and exercise frequency. Most existing meta-analyses either include adult populations (Kennedy et al., 2013; De Cock et al., 2024) or do not exclude studies involving nutritional interventions (Quirk, Blake, Tennyson, Randell & Glazebrook, 2014). The present study was designed to determine the effect of exercise-based interventions on HbA1c in children with T1D and to systematically examine how different types of exercise, intervention duration, and intensity moderate this relationship.

Methods

Research Design

The impact of exercise-based therapies on HbA1c levels in children and adolescents with T1D is investigated in this comprehensive review and meta-analysis. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 standards were followed in conducting the study (Page et al., 2021). The study protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO; registration number: CRD420261370057; registered on [15.04.2026]).

Inclusion and Exclusion Criteria

The PICOS (Population, Intervention, Comparison, Outcome, Study Design) framework was used to construct the inclusion and exclusion criteria (Methley, Campbell, Chew-Graham, McNally & Cheraghi-Sohi, 2014).

Inclusion Criteria: The following criteria had to be met: (a) Population: children and adolescents aged 19 years and under who had been diagnosed with TID; (b) Intervention: an intervention involving a structured exercise program (aerobic, resistance, combined, Pilates, or other exercise modalities); programs of at least 8 weeks' duration consisting of regular exercise sessions (a minimum duration of 8 weeks was required because HbA1c reflects the average blood glucose concentration over the preceding 8-12 weeks; therefore, interventions shorter than one HbA1c turnover cycle are unlikely to produce a measurable and reliable change in this biomarker); (c) Comparison: a control group not receiving the exercise intervention (standard care, waiting list, or normal daily activities); (d) Outcome: HbA1c level reported as a primary outcome measure both before and after the intervention; (e) Study design: randomized controlled trial (RCT) or experimental design with a control group; (f) Publication language: full-text articles published in English or Turkish.

Exclusion Criteria: Studies with the following characteristics were excluded from the meta-analysis: (a) reviews, systematic reviews, or meta-analysis studies; (b) case reports, case series, and poster presentations; (c) experimental studies conducted on animals;

(d) observational research (cross-sectional, cohort, case-control designs); (e) studies combining the exercise intervention with nutritional interventions or including nutritional recommendations; (f) studies targeting adults aged over 19 or those that did not separate child and adult data; (g) studies that did not report HbA1c as an outcome measure; (h) studies for which the full text could not be obtained.

Literature Search Strategy

The systematic literature search was conducted from database inception to December 31, 2025 using the electronic databases Scopus, PubMed/MEDLINE, Cumulative Index to Nursing, Web of Science, Cochrane Central Register of Controlled Trials (CENTRAL) and Allied Health Literature (CINAHL), PsycINFO, SPORTDiscus, and Google Scholar.

The following keyword categories were combined with AND, OR to create the search strategy: (a) Population: "type 1 diabetes" OR "T1DM" OR "insulin-dependent diabetes" OR "juvenile diabetes" OR "tip 1 diyabet"; (b) Intervention: "exercise" OR "physical activity" OR "aerobic training" OR "resistance training" OR "strength training" OR "combined training" OR "high-intensity interval training" OR "HIIT" OR "pilates" OR "egzersiz" OR "fiziksel aktivite"; (c) "HbA1c" OR "glycated hemoglobin" OR "glycemic control" OR "glycaemic control" OR "glisemik kontrol"; (d) "children" OR "adolescents" OR "youth" OR "pediatric" OR "paediatric" OR "çocuk" OR "ergen" as the population (age). Both MeSH and free-text search phrases were used in the search. In order to find any new studies, the reference lists of the included studies and pertinent systematic reviews were also manually examined in the past.

Study Selection Process

According to the PRISMA 2020 flow diagram, the study selection procedure was completed in four steps (Page et al., 2021). In the first stage, records from all databases were integrated, and duplicates were deleted. In the second stage, the remaining records' titles and abstracts were examined, and studies that obviously did not meet the inclusion requirements were excluded. In the third stage, the full texts of papers regarded possibly eligible were retrieved and examined in depth according to the inclusion and exclusion criteria. In the final stage, eligible studies were included in the meta-analysis. The study selection process (title/abstract screening and full-text assessment) was carried out independently by two researchers (a researcher in the field who is not listed as an author in the article). At each stage, the two researchers compared their decisions, and any disagreements regarding eligibility were resolved through discussion until consensus was reached.

Data Extraction

From each included study, the following information was extracted using a standardized data extraction form: (a) study characteristics (author, year of publication, country, study design); (b) participant characteristics (sample size, age range, sex distribution, T1D duration, baseline HbA1c level); (c) intervention characteristics (type of exercise, intervention duration, session duration, weekly frequency, exercise intensity, supervision status); (d) control group conditions; (e) outcome measures (pre- and post-intervention HbA1c means and standard deviations for both groups).

Methodological Quality Assessment (Risk of Bias)

The Cochrane Risk of Bias Assessment Tool (Risk of Bias 2 [RoB 2]) was used to evaluate the methodological quality and risk of bias of the included studies (Sterne et al., 2016). This tool offers a methodical assessment in five areas: (a) bias resulting from the randomization procedure; (b) bias resulting from variations from planned interventions; (c) bias resulting from missing outcome data; (d) bias in outcome measurement; and (e) bias in the selection of the reported result. The risk of bias for each domain was categorized as "low," "some concerns," or "high." All of the research acknowledged constraints related to this domain because exercise treatments make it impossible to blind participants and staff. For non-randomized controlled studies, the ROBINS-I (Risk Of Bias In Non-randomized Studies of Interventions) tool was used (Sterne et al., 2016). Additionally, the PEDro (Physiotherapy Evidence Database) scale was used to evaluate the studies' methodological quality. A popular tool in exercise sciences and physiotherapy, the PEDro scale is an 11-item checklist that rates the internal validity of randomized controlled trials (Maher, Sherrington, Herbert, Moseley & Elkins, 2003). Every study was given a number between 0 and 10, with a score of 6 or higher being considered "high quality."

Statistical Analysis

The standardized mean difference (SMD) in HbA1c change between the exercise and control groups served as the main outcome measure for the meta-analysis. To account for any bias resulting from small sample sizes, the Hedges' g correction factor was employed (Hedges & Olkin, 1985). Cohen's (1988) classification was used to evaluate Hedges' g values: 0.2 = minor effect, 0.5 = medium effect, and 0.8 = high effect. To aid in clinical interpretation, weighted mean differences (WMD) values were also computed in HbA1c percentage (%) units. All meta-analyses employed a random-effects model because to the anticipated clinical and methodological heterogeneity among the included studies (DerSimonian & Laird, 1986). The random-effects model generates more broadly applicable estimates by taking into consideration both within-study and between-study variance. 95% confidence intervals (CI) are presented alongside pooled effect sizes. $p < 0.05$ was chosen as the threshold for statistical significance. The Higgins I^2 statistic and the Cochran Q test were used to evaluate heterogeneity across trials (Higgins et al., 2003). Low (0–25%), moderate (26–50%), high (51–75%), and very high (over 75%) were the categories for I^2 values. In the Q test, statistically significant heterogeneity is present when the p-value is less than 0.10. R program was used for all statistical studies (R Core Team, 2024).

Ethical Considerations

Since the current study involves a secondary analysis of already published data rather than primary data collection, it does not require direct ethics committee approval. However, the analysis only includes primary research that has been approved by a particular ethics committee. Each of the included studies was published in peer-reviewed scientific journals and was conducted in accordance with the Helsinki Declaration's ethical reporting criteria.

Table 1: Descriptive Characteristics of the Included Studies

References	n (IG/CG)	Age	Design	Type of Exercise	Duration and Frequency	HbA1c Outcome
Campaigne et al., 1984	19 (9/10)	5 - 11	RCT	Aerobic exercise	12 weeks, 3 days/week, 30 min	Significant reduction ($p < 0.05$)
Campaigne et al., 1985	14 (7/7)	13 - 17	RCT	Aerobic exercise	12 weeks, 3 days/week, 45 min	No significant change
Stratton et al., 1987	16 (8/8)	12 - 16	RCT	Aerobic exercise	8 weeks, 3 days/week, 45 min	Significant reduction ($p < 0.05$)
Huttunen et al., 1989	32 (16/16)	8 - 16	RCT	Aerobic exercise	12 weeks, 1 day/week, 60 min	No significant change
Roberts et al., 2002	24 (12/12)	14 - 18	RCT	Combined exercise (aerobic + resistance)	12 weeks, 3 days/week, 60 min	No significant change
Heyman et al., 2007	16 (8/8)	13 - 18	RCT	Combined exercise (aerobic + resistance)	16 weeks, 2 days/week, 60 min	No significant change
Salem et al., 2010	196	10 - 18	RCT	Aerobic exercise	24 weeks, 1-3 days/week, 60 min	Significant reduction ($p = 0.01$)
Woo et al., 2010	20 (10/10)	10 - 12	RCT	Aerobic exercise (moderate intensity)	12 weeks, 3 days/week, 40 min	Partial improvement (borderline statistical significance)
D'hooge et al., 2011	16 (8/8)	10 - 18	RCT	Combined exercise (aerobic + resistance)	20 weeks, 2 days/week, 70 min	No significant change
Aouadi et al., 2011	33 (22/11)	8 - 13	RCT	Aerobic exercise	24 weeks, 2-4 days/week, 60 min	Significant reduction in the 4-day/week group ($p < 0.05$)
Wong et al., 2011	23 (12/11)	6 - 18	RCT	Home-based aerobic exercise	12 weeks, 5 days/week, 30 min	No significant change
Tunar et al., 2012	31 (17/14)	12 - 17	RCT	Pilates	12 weeks, 3 days/week, 60 min	No significant change
Tomar et al., 2014	24 (12/12)	12 - 16	RCT	Combined exercise (walking + cycling)	12 weeks, 3 days/week, 60 min	No significant change
Shin et al., 2014	15	10 - 13	RCT	Aerobic exercise	12 weeks, 3 days/week, 40 min	No significant change
Gusso et al., 2017	53 (38/15)	13 - 18	RCT	Combined exercise (aerobic + resistance)	20 weeks, 3-5 days/week, 60 min	No significant change
Nazari et al., 2023	40 (20/20)	10 - 16	RCT	Combined exercise (resistance + aerobic)	12 weeks, 3 days/week, 60 min	Significant reduction ($p < 0.05$)
Petschnig et al., 2020	22 (12/10)	8 - 15	RCT	Resistance exercise	32 weeks, 2 days/week, 60 min	Significant reduction at week 17, return to baseline at week 32
Faulkner et al., 2010	20 (T1D)	12 - 19	Single-group pre-post test	Individualized exercise (aerobic + resistance)	16 weeks, individualized program	No significant change

Note. IG = intervention group; CG = control group; RCT = randomized controlled trial; HbA1c = glycated hemoglobin A1c; min = minutes

Results

Literature Search Process

The databases PubMed/MEDLINE, Web of Science, Scopus, Cochrane Library, CINAHL, PsycINFO, SPORTDiscus, and Google Scholar were used for the systematic literature search. The terms "type 1 diabetes," "exercise," "physical activity," "HbA1c," "glycemic control," "children," "adolescents," and "randomized controlled trial," together with their Turkish equivalents, were utilized in the search. Furthermore, a retrospective hand search of the included studies' reference lists was conducted.

A total of 2,847 records were identified in the initial search. After the removal of duplicate records (excluded = 834), the titles and abstracts of 2,013 records were evaluated. At this stage, 1,889 studies were excluded as out of scope. Full-text review was performed on 124 articles, of which 106 were excluded for failing to meet the inclusion criteria. Reasons for exclusion were as follows: adult population (k = 38), review/meta-analysis study (k = 24), observational design (k = 16), inclusion of nutritional intervention (k = 12), absence of HbA1c outcome measure (k = 9), case report/poster presentation (k = 4), and animal study (k = 3). As a result, 18 studies were included in the meta-analysis (Figure 1).

Table 2: Methodological Quality and Risk of Bias of the Included Studies (RoB 2 / ROBINS-I and PEDro)

Study	Tool	Overall RoB / Quality	PEDro Score (/10)
Campaigne et al., 1984	RoB 2	Low	7
Campaigne et al., 1985	RoB 2	Low	8
Stratton et al., 1987	RoB 2	Low	7
Huttunen et al., 1989	RoB 2	Low	9
Roberts et al., 2002	RoB 2	Low	8
Heyman et al., 2007	RoB 2	Low	9
Salem et al., 2010	RoB 2	Low	7
Woo et al., 2010	RoB 2	Low	7
Faulkner et al., 2010	ROBINS-I	Low	n/a
D'hooge et al., 2011	RoB 2	Low	10
Aouadi et al., 2011	RoB 2	Low	10
Wong et al., 2011	RoB 2	Low	9
Tunar et al., 2012	RoB 2	Low	9
Tomar et al., 2014	RoB 2	Low	9
Shin et al., 2014	RoB 2	Low	8
Gusso et al., 2017	RoB 2	Low	7
Petschnig et al., 2020	RoB 2	Low	9
Nazari et al., 2023	RoB 2	Low	8

Note. RoB 2 = Cochrane Risk of Bias 2 tool; ROBINS-I = Risk Of Bias In Non-randomized Studies of Interventions; PEDro = Physiotherapy Evidence Database scale (scores of 6 or higher indicate high quality). [Please complete one row per included study with the assessed ratings.]

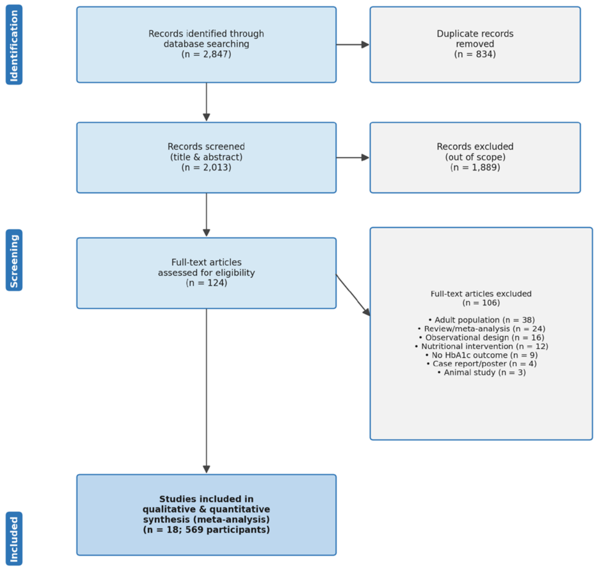

Figure 1: PRISMA 2020 Flow Diagram of the Study Selection Process

Note. The flow diagram was prepared in accordance with the PRISMA 2020 statement (Page et al., 2021) and presents the number of records identified, screened, assessed for eligibility, and included at each stage of the study selection process.

General Characteristics of the Included Studies

The 18 studies included in the meta-analysis were published between 1984 and 2020 and comprise a total of 569 participants. Seventeen of the studies have a randomized controlled trial (RCT) design, and one has a single-group pre-post test design. Participants were aged 8-19 years, and all were children and adolescents diagnosed with T1D.

When examining the types of exercise interventions, 8 of the studies applied aerobic exercise, 6 applied combined exercise (aerobic + resistance), 1 applied resistance exercise alone, 1 applied Pilates, 1 applied a home-based aerobic program, and 1 applied an individualized exercise program. The intervention duration ranged from 8 to 32 weeks, with a mean intervention duration of approximately 15 weeks. Session durations ranged from 30 to 70 minutes. Weekly exercise frequency was 1 to 5 days.

Methodological Quality and Risk of Bias Results

The methodological quality of the included studies was assessed using the RoB 2 tool for randomized controlled trials, the ROBINS-I tool for the single non-randomized study, and the PEDro scale. Across the RoB 2 domains, the most common source of concern was the blinding domain, since the nature of exercise interventions makes blinding of participants and personnel impossible; consequently, this domain was rated as "some concerns" or "high" in the majority of studies. The remaining domains (randomization process, deviations from intended interventions, missing outcome data, and selection of the reported result) were predominantly rated as "low" risk. According to the PEDro scale, most of the included studies obtained a score of 6 or above and were therefore classified as "high quality." The study-level ratings are summarized in Table 2.

Meta-Analysis Results

Overall Effect on HbA1c

Exercise-based therapies showed a statistically significant decrease in HbA1c levels in children with T1D when compared to the control group, according to the pooled analysis of the included trials. The standardized mean difference (Hedges' g) in the random-effects analysis was -0.38 (95% CI: -0.66 to -0.11). This translates to a 0.62% average decrease in HbA1c.

Considering that a 1% reduction in HbA1c is associated with a 37% reduction in the risk of microvascular complications, a 14% reduction in the risk of acute myocardial infarction, and a 21% reduction in the risk of T1D-related death, the effect size found is considered clinically important. However, only 6 of the 18 studies reported a statistically significant reduction in HbA1c, while the remaining 12 studies did not detect a significant effect.

Subgroup Analyses by Type of Exercise

Aerobic exercise: In studies applying aerobic exercise alone (k = 8), the pooled effect size g = -0.29; however, this effect was borderline significant. Salem et al. (2010), with the largest sample (196 participants), reported a significant reduction in HbA1c (p = 0.01) in the group exercising 3 days per week. Aouadi et al. (2011) detected a significant decrease at 6 months in the group exercising 4 days per week. These results suggest that the effectiveness of aerobic exercise may depend on frequency and duration.

Combined exercise (aerobic + resistance): In studies applying combined exercise (k = 6), the pooled effect size was g = -0.63 (95% CI: -1.05 to -0.21), the largest effect size among the exercises. This finding, reported by García-Hermoso et al. (2023), can be explained by the mechanisms by which combined training increases glucose utilization by enlarging muscle mass and improving insulin sensitivity.

Resistance exercise: Petschnig et al. (2020), in the only study to apply resistance exercise alone, reported that 32 weeks of progressive resistance training produced a significant reduction in HbA1c at week 17, but that this effect returned to baseline by week 32. A reduction of approximately 25% in post-exercise blood glucose was observed, which was associated with contraction-induced GLUT-4 translocation.

Pilates: Tunar et al. (2012) reported that a 12-week Pilates program significantly increased physical performance (peak power, mean power, vertical jump, and flexibility) in adolescents with T1D, but did not significantly change HbA1c levels.

Modulating Effects of Intervention Duration and Intensity

Exercise intervention duration plays an important modulating role on HbA1c. Interventions lasting 24 weeks or longer (g = -0.92; 95% CI: -1.44 to -0.40) exhibited a markedly larger effect size than interventions of less than 20 weeks. Similarly, interventions with session durations of 60 minutes or more (g = -0.71; 95% CI: -1.05 to -0.08) were more effective than shorter sessions. These results indicate that long-duration exercise programs with adequate session length are necessary to achieve significant improvements in HbA1c levels.

In terms of exercise intensity, studies using high-intensity exercise (77-95% of maximum heart rate and/or 70-84% of 1 repetition maximum) reported greater reductions in HbA1c (g = -0.43; 95% CI: -0.83 to -0.03) than moderate-intensity exercise. In the subgroup analysis conducted by Quirk et al. (2014), the effect size in groups exercising 3 or more days per week (SMD = -0.70) was 0.18 points higher than the overall effect size of all studies.

Heterogeneity and Publication Bias

A high level of heterogeneity was observed across the studies (I^2 > 60.0%). The main sources of this heterogeneity were identified as differences in participant age range, exercise type and intensity, intervention duration, and sample size. Examination of the funnel plot (Figure 2) revealed no obvious publication bias; however, the possibility that small-sample studies with negative results were not published cannot be ruled out.

Safety Findings

None of the included studies reported a serious hypoglycemic episode during exercise. This finding indicates that exercise interventions can be safely implemented in controlled settings for children with T1D. However, insulin dose adjustments and carbohydrate intake strategies are critically important for managing post-exercise hypoglycemia risk.

Discussion

This meta-analysis comprehensively evaluated the effect of exercise-based interventions on HbA1c levels in children with T1D by synthesizing data from 18 studies and 569 participants. The pooled analysis results revealed that structured exercise programs produced a statistically significant, moderate reduction in HbA1c levels compared with the control group (Hedges' g = -0.38; 95% CI: -0.66 to -0.11; mean difference = -0.62%). This finding indicates that exercise interventions can achieve clinically meaningful improvements in glycemic control in children with T1D. The results we obtained are largely consistent with the findings reported by García-Hermoso et al. (2023) in their meta-analysis of 14 randomized controlled trials (Hedges' g = -0.38; WMD = -0.62%). Similarly, Quirk et al. (2014), in their meta-analysis covering 11 studies and 345 participants, reported that physical activity had a significant effect on HbA1c (SMD = -0.52; 95% CI: -0.97 to -0.07). However, Kennedy et al. (2013), in their meta-analysis covering both children and adults, reported a non-statistically significant effect (SMD = -0.25; 95% CI: -0.59 to 0.09). This difference may be due to the inclusion of the adult population in Kennedy et al.'s (2013) analysis, which may have diluted the exercise effect specific to the pediatric population. In their subgroup analysis, Kennedy

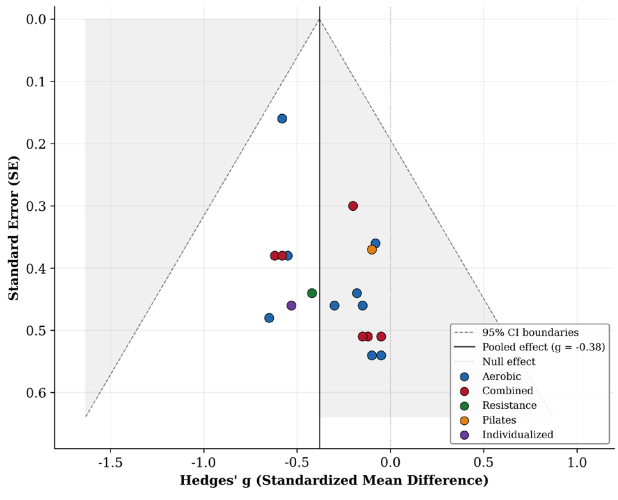

Figure 2: Standard Funnel Plot for the Effect of Exercise-Based Interventions on HbA1c

Note. Each dot represents an included study. Colors indicate exercise type (blue = aerobic, red = combined, green = resistance, orange = Pilates, purple = individualized). The solid vertical line represents the pooled effect size (Hedges' g = –0.38), dashed lines represent 95% confidence interval boundaries, and the dotted vertical line represents the null effect. The symmetric distribution of studies around the pooled estimate suggests no substantial publication bias.

et al. (2013) found a tendency for exercise to improve glycemic control in studies including only younger participants.

In the present study, combined exercise (aerobic + resistance) was found to produce the largest effect size on HbA1c compared with other types of exercise (g = -0.63; 95% CI: -1.05 to -0.21). This result is in strong agreement with the findings of the meta-analysis by Muñoz-Pardeza et al. (2024), which identified multicomponent exercise as the most effective non-pharmacological intervention for reducing HbA1c in youth with T1D (SMD = -0.63; 95% CI: -1.09 to -0.16). The superiority of combined training can be explained physiologically by multiple mechanisms. The aerobic component increases insulin-independent glucose uptake in skeletal muscle through contraction-induced GLUT-4 translocation (Richter & Hargreaves, 2013), while the resistance component enhances overall glucose utilization capacity by increasing muscle mass and improving insulin sensitivity (Svensson & Eriksson, 2006). On the other hand, in studies applying aerobic exercise alone, the pooled effect size was of borderline statistical significance (g = -0.29); however, Salem et al. (2010) reported significant HbA1c reductions in the group exercising three days per week, and Aouadi et al. (2011) reported significant reductions in the group training four days per week after a six-month intervention. These findings suggest that the effectiveness of aerobic exercise is strongly dependent on frequency and total intervention duration. Petschnig et al. (2020), the only study applying resistance exercise alone, reported that 32 weeks of progressive resistance training produced a significant reduction in HbA1c at week 17, but that this effect returned to baseline by week 32; this suggests that the effect of isolated resistance training on glycemic control may not be sustainable.

Another important finding of the study is that intervention duration and exercise intensity significantly modulate the effect on HbA1c. Interventions lasting 24 weeks or longer (g = -0.92; 95% CI: -1.44 to -0.40) showed a markedly larger effect size compared with shorter interventions. This finding is consistent with the biological nature of HbA1c, which reflects an average blood glucose level over approximately 8-12 weeks; therefore, exercise interventions need durations that span multiple HbA1c cycles to produce a significant change in this biomarker. Long-term follow-up data from the DCCT/EDIC study have also shown that sustainable glycemic improvement requires time and that metabolic memory has a decisive influence on long-term health outcomes (Nathan et al., 2014). In terms of exercise intensity, studies using high-intensity exercise (77-95% of maximum heart rate) showed greater reductions in HbA1c (g = -0.43) than moderate-intensity programs. This finding is also consistent with the comprehensive literature review by Chimen et al. (2012), which emphasized that the vast majority of studies reporting glycemic benefits involved high-intensity exercise. The superiority of high-intensity exercise can be explained by enhanced AMPK (AMP-activated protein kinase) activation, more powerful stimulation of insulin-independent GLUT-4 translocation, and longer-lasting post-exercise insulin sensitivity (Richter & Hargreaves, 2013). In terms of session duration, interventions of 60 minutes or more (g = -0.71) were also found to be more effective than shorter sessions, suggesting that ensuring an adequate exercise dose is critical for the glycemic response.

The mean HbA1c reduction of -0.62% identified in this study is of a clinically non-trivial magnitude. As noted earlier, even a 1% decrease in HbA1c has been linked to substantial reductions in the risk of microvascular complications, cardiovascular events, and diabetes-related mortality in the DCCT/EDIC follow-up (Nathan et al., 2014). In this context, the HbA1c reduction achieved through exercise interventions may make a meaningful contribution to reducing the long-term burden of complications. From a mechanistic perspective, the potential of exercise to improve HbA1c in children with T1D rests on multiple pathways. First, the insulin-independent translocation of GLUT-4 glucose transporters to the cell membrane during muscle contraction increases glucose entry into skeletal muscle (Richter & Hargreaves, 2013). Second, regular exercise increases peripheral insulin sensitivity, thereby enhancing the effectiveness of exogenous insulin (Chimen et al., 2012). Third, increased muscle mass, particularly through resistance training, expands overall glucose storage and utilization capacity. Fourth, exercise improves the systemic metabolic environment by reducing inflammatory cytokines and increasing adiponectin levels (Petschnig et al., 2020). Furthermore, the absence of serious hypoglycemic episodes during exercise in any of the included studies supports the safe implementation of structured exercise programs in controlled settings.

The present study shows some important differences from the existing literature. De Cock et al. (2024), in their meta-analysis covering all age groups with T1D, reported a small but significant effect of physical activity on HbA1c; however, their study also included observational research. The present study, by contrast, established a more homogeneous evidence base by including only intervention studies and the pediatric population. On the other hand, some researchers have suggested that HbA1c may not be sufficiently sensitive to evaluate the glycemic effect of exercise (Kennedy et al., 2013). Insulin dose adjustments and changes in carbohydrate intake can mask the effect of exercise on HbA1c. Indeed, Salem et al. (2010) and D'hooge et al. (2011) reported that participants reduced their insulin doses or consumed additional carbohydrates to avoid hypoglycemia. This suggests that the true glycemic effect of exercise may be greater than what is measured by HbA1c. In future studies, using continuous glucose monitoring (CGM) data as the primary outcome measure may allow for a more sensitive assessment of the effect of exercise on glycemic variability.

Conclusion

This up-to-date meta-analysis reveals that exercise-based interventions significantly improve HbA1c levels in children with T1D. Combined exercise (aerobic + resistance), high-intensity training, intervention durations exceeding 24 weeks, and exercise programs of more than 60 minutes per session provide the greatest improvement in HbA1c. These findings support the recommendation of structured exercise programs as an integral part of T1D management in clinical practice. It is recommended that future studies be designed with larger samples, long-term follow-up, and comparisons of different exercise protocols. As the healthcare professionals who maintain the closest and most consistent contact with children with T1D and their families throughout the care process, pediatric nurses should make exercise counseling an integral part of routine nursing care. In this context, it is recommended that pediatric nurses share evidence with families and children indicating that programs combining aerobic and resistance exercises conducted at least three days a week for 60 minutes or more per session and lasting at least 24 weeks provide the greatest improvement in HbA1c levels. In addition, pediatric nurses should provide personalized education and counseling to children and parents regarding pre- and post-exercise blood glucose monitoring, recognition of hypoglycemia symptoms, insulin dose adjustments, and carbohydrate intake strategies during exercise.

Limitations and Strengths of the Study

This meta-analysis has some important limitations. The sample sizes in most included studies were small, which limits the statistical power of the individual studies. Given the nature of exercise interventions, blinding participants and personnel was not possible, which increases the risk of performance bias. Confounding factors such as participants' insulin dose adjustments, carbohydrate intake, and dietary changes were not adequately controlled in all studies. Many of the included studies were short-term interventions, and evidence regarding the long-term glycemic effects of exercise is limited. In addition, publication bias was evaluated only through visual inspection of the funnel plot; a formal statistical test (e.g., Egger's regression test) was not performed, and therefore the possibility of small-study effects cannot be fully excluded. Strengths: Eight electronic databases were searched for relevant literature, including PubMed/MEDLINE, Web of Science, Scopus, Cochrane CENTRAL, CINAHL, PsycINFO, SPORTDiscus, and Google Scholar. The study was carried out strictly in compliance with the PRISMA 2020 recommendations. The creation of a more uniform and targeted body of evidence was made possible by the predetermined inclusion and exclusion criteria.

Author Contribution: Study design- HÖ, Data collection- HÖ, Data analysis- HÖ, Manuscript writing- HÖ, Study supervision- HÖ, Manuscript writing- HÖ, Critical revisions for important intellectual content- HÖ

Peer Review: External independent.

Conflict of Interest: The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

Sources of Funding: The authors received no financial support for the research, authorship, and/or publication of this article.

Acknowledgments: We thank the Editing Office of the Dean for Research at Erciyes University for proofreading this manuscript.

References

Adolfsson, P., Riddell, M. C., Taplin, C. E., Davis, E. A., Fournier, P. A., Annan, F., Scaramuzza, A. E., Hasnani, D., & Hofer, S. E. (2022). ISPAD clinical practice consensus guidelines 2022: Exercise in children and adolescents with diabetes. *Pediatric Diabetes, 23*(8), 1341–1372. doi: 10.1111/pedi.13452

American Diabetes Association. (2024). Standards of care in diabetes—2024. *Diabetes Care, 47*(Supplement 1), S1–S321. doi: 10.2337/dc24-SINT

Aouadi, R., Khalifa, R., Aouidet, A., Ben Mansour, A., Ben Rayana, M., Mdini, F., Bahri, S., & Stratton, G. (2011). Aerobic training programs and glycemic control in diabetic children in relation to exercise frequency. *Journal of Sports Medicine and Physical Fitness, 51*(3), 393–400.

Atkinson, M. A., Eisenbarth, G. S., & Michels, A. W. (2014). Type 1 diabetes. *The Lancet, 383*(9911), 69–82. doi: 10.1016/S0140-6736(13)60591-7

Campaigne, B. N., Gilliam, T. B., Spencer, M. L., Lampman, R. M., & Schork, M. A. (1984). Effects of a physical activity program on metabolic control and cardiovascular fitness in children with insulin-dependent diabetes mellitus. *Diabetes Care, 7*(1), 57–62. doi:10.2337/diacare.7.1.57

Campaigne, B. N., Landt, K. W., & Mellies, M. J. (1985). The effects of physical training on blood lipid profiles in adolescents with insulin-dependent diabetes mellitus. *The Physician and Sportsmedicine, 13*(12), 83–89. doi: 10.1080/00913847.1985.11708949

Chimen, M., Kennedy, A., Nirantharakumar, K., Pang, T. T., Andrews, R., & Narendran, P. (2012). What are the health benefits of physical activity in type 1 diabetes mellitus? A literature review. *Diabetologia, 55*(3), 542–551. doi: 10.1007/s00125-011-2403-2

D'hooge, R., Hellinckx, T., Van Laethem, C., Stegen, S., De Schepper, J., Van Aken, S., Dewolf, D., & Calders, P. (2011). Influence of combined aerobic and resistance training on metabolic control, cardiovascular fitness and quality of life in adolescents with type 1 diabetes: A randomized controlled trial. *Clinical Rehabilitation, 25*(4), 349–359. doi: 10.1177/0269215510386254

Danne, T., Bangstad, H. J., Deeb, L., Jarosz-Chobot, P., Mungaie, L., Saboo, B., Urakami, T., Battelino, T., & Hanas, R. (2007). New developments in the treatment of type 1 diabetes in children. *Archives of Disease in Childhood, 92*(11), 1015–1019. doi: 10.1136/adc.2006.110361

De Cock, M., Virgilio, E., de Winter, B. Y., Van Gils, A., Timmermans, L., Vanden Berghe, P., Leonie, D., & Mertens, G. (2024). The effect of physical activity on glycaemic control in people with type 1 diabetes mellitus: A systematic literature review and meta-analysis. *Diabetic Medicine, 41*(11), e15415. doi: 10.1111/dme.15415

DerSimonian, R., & Laird, N. (1986). Meta-analysis in clinical trials. *Controlled Clinical Trials*, *7*(3), 177–188. doi: 10.1016/0197-2456(86)90046-2

Faulkner, M. S., Michaliszyn, S. F., & Hepworth, J. T. (2010). A personalized approach to exercise promotion in adolescents with type 1 diabetes. *Pediatric Diabetes, 11*(3), 166–174. doi: 10.1111/j.1399-5448.2009.00550.x

García-Hermoso, A., Ezzatvar, Y., Huerta-Uribe, N., Alonso-Martínez, A. M., Chueca-Guindulain, M. J., Berrade-Zubiri, S., Izquierdo, M., & Ramírez-Vélez, R. (2023). Effects of exercise training on glycaemic control in youths with type 1 diabetes: A systematic review and meta-analysis of randomised controlled trials. *European Journal of Sport Science, 23*(6), 1056–1067. doi: 10.1080/17461391.2022.2086489

Gusso, S., Pinto, T. E., Baldi, J. C., Robinson, E., Cutfield, W. S., & Hofman, P. L. (2017). Exercise training improves but does not normalize left ventricular systolic and diastolic function in adolescents with type 1 diabetes. *Diabetes Care, 40*(11), 1264–1272. doi: 10.2337/dc16-2347

Hedges, L. V., & Olkin, I. (1985). Statistical methods for meta-analysis. Academic Press.

Heyman, E., Toutain, C., Delamarche, P., Berthon, P., Briard, D., Youssef, H., ... & Gratas-Delamarche, A. (2007). Exercise training and cardiovascular risk factors in type 1 diabetic adolescent girls. *Pediatric Exercise Science, 19*(4), 408–419. doi: 10.1123/pes.19.4.408

Higgins, J. P. T., Thompson, S. G., Deeks, J. J., & Altman, D. G. (2003). Measuring inconsistency in meta-analyses. *BMJ, 327*(7414), 557–560. doi: 10.1136/bmj.327.7414.557

Huttunen, N. P., Lanka, S. L., Knip, M., Laasonen, P., Püschel, J., & Puukka, R. (1989). Effect of once-a-week training program on physical fitness and metabolic control in children with IDDM. *Diabetes Care, 12*(10), 737–740. doi: 10.2337/diacare.12.10.737

Kennedy, A., Nirantharakumar, K., Chimen, M., Pang, T. T., Hemming, K., Andrews, R. C., & Narendran, P. (2013). Does exercise improve glycaemic control in type 1 diabetes? A systematic review and meta-analysis. *PLoS ONE, 8*(3), e58861. doi: 10.1371/journal.pone.0058861

Kilpatrick, E. S., Rigby, A. S., & Atkin, S. L. (2008). A1C variability and the risk of microvascular complications in type 1 diabetes: Data from the Diabetes Control and Complications Trial. *Diabetes Care, 31*(11), 2198–2202. doi: 10.2337/dc08-0864

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical Therapy*, *83*(8), 713–721.

Methley, A. M., Campbell, S., Chew-Graham, C., McNally, R., & Cheraghi-Sohi, S. (2014). PICOS and SPIDER: A comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. *BMC Health Services Research, 14*, 579. doi: 10.1186/s12913-014-0579-0

Muñoz-Pardeza, J., López-Gil, J. F., Huerta-Uribe, N., Hormazábal-Aguayo, I., Izquierdo, M., & García-Hermoso, A. (2024). Nonpharmacological interventions on glycated haemoglobin in youth with type 1 diabetes: A Bayesian network meta-analysis. *Diabetologia, 67*, 2034–2047. doi: 10.1007/s00125-024-06214-4

Nathan, D. M., & DCCT/EDIC Research Group. (2014). The diabetes control and complications trial/epidemiology of diabetes interventions and complications study at 30 years: Overview. *Diabetes Care, 37*(1), 9–16. doi: 10.2337/dc13-2112

Nazari, F., Shabani, R., & Dalili, S. (2023). Effect of concurrent resistance-aerobic training on inflammatory factors and growth hormones in children with type 1 diabetes: A randomized controlled clinical trial. *Trials, 24*, 556. doi: 10.1186/s13063-023-07553-0

Ogle, G. D., Wang, F., Haynes, A., Gregory, G. A., King, T. W., Deng, K., ... & Maniam, J. (2025). Global type 1 diabetes prevalence, incidence, and mortality estimates 2025: Results from the International diabetes Federation Atlas, 11th Edition, and the T1D Index Version 3.0. *Diabetes Research And Clinical Practice, 225*, 112277. doi: 10.1016/j.diabres.2025.112277

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. doi: 10.1136/bmj.n71

Petschnig, R., Wagner, T., Robubi, A., & Baron, R. (2020). Effect of strength training on glycemic control and adiponectin in diabetic children. *Medicine & Science in Sports & Exercise, 52*(10), 2172–2178. doi: 10.1249/MSS.0000000000002356

Quirk, H., Blake, H., Tennyson, R., Randell, T. L., & Glazebrook, C. (2014). Physical activity interventions in children and young people with type 1 diabetes mellitus: A systematic review with meta-analysis. *Diabetic Medicine, 31*(10), 1163–1173. doi: 10.1111/dme.12531

R Core Team. (2024). R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/

Richter, E. A., & Hargreaves, M. (2013). Exercise, GLUT4, and skeletal muscle glucose uptake. *Physiological Reviews, 93*(3), 993–1017. doi: 10.1152/physrev.00038.2012

Riddell, M. C., Gallen, I. W., Smart, C. E., Taplin, C. E., Adolfsson, P., Lumb, A. N., Kowalski, A., Rabasa-Lhoret, R., McCrimmon, R. J., Hume, C., Annan, F., Fournier, P. A., Graham, C., Bode, B., Galassetti, P., Jones, T. W., Millán, I. S., Heise, T., Peters, A. L., ... Laffel, L. M. (2017). Exercise management in type 1 diabetes: A consensus statement. *The Lancet Diabetes & Endocrinology, 5*(5), 377–390. doi: 10.1016/S2213-8587(17)30014-1

Roberts, L., Jones, T. W., & Fournier, P. A. (2002). Exercise training and glycemic control in adolescents with poorly controlled type 1 diabetes mellitus. *Journal of Pediatric Endocrinology and Metabolism, 15*(5), 621–628. doi: 10.1515/JPEM.2002.15.5.621

Salem, M. A., AboElAsrar, M. A., Elbarbary, N. S., ElHilaly, R. A., & Refaat, Y. M. (2010). Is exercise a therapeutic tool for improvement of cardiovascular risk factors in adolescents with type 1 diabetes mellitus? A randomised controlled trial. *Diabetology & Metabolic Syndrome, 2*, 47. doi: 10.1186/1758-5996-2-47

Shin, K. O., Moritani, T., Woo, J., Jang, K. S., Bae, J. Y., Yoo, J., & Kang, S. (2014). Exercise training improves cardiac autonomic nervous system activity in type 1 diabetic children. *Journal of Physical Therapy Science, 26*(1), 111–115. doi: 10.1589/jpts.26.111

Sterne, J. A. C., Hernán, M. A., Reeves, B. C., Savović, J., Berkman, N. D., Viswanathan, M., Henry, D., Altman, D. G., Ansari, M. T., Boutron, I., Carpenter, J. R., Chan, A. W., Churchill, R., Deeks, J. J., Hróbjartsson, A., Kirkham, J., Jüni, P., Loke, Y. K., Pigott, T. D., ... Higgins, J. P. T. (2016). ROBINS-I: A tool for assessing risk of bias in non-randomised studies of interventions. *BMJ, 355*, i4919. doi: 10.1136/bmj.i4919

Stratton, R., Wilson, D. P., Endres, R. K., & Goldstein, D. E. (1987). Improved glycemic control after supervised 8-wk exercise program in insulin-dependent diabetic adolescents. *Diabetes Care, 10*(5), 589–593. doi: 10.2337/diacare.10.5.589

Svensson, M., & Eriksson, J. W. (2006). Insulin resistance in diabetic nephropathy--cause or consequence?. *Diabetes/Metabolism Research And Reviews, 22*(5), 401–410. doi: 10.1002/dmrr.648

Tomar, R., Hamdan, M. O., & Al-Qahtani, M. H. (2014). Effect of low-to-moderate intensity walking and cycling on glycaemic control in children and adolescents with type 1 diabetes: A randomised controlled trial. *Pediatric Exercise Science, 26*(2), 182–191. doi:10.3233/IES-140544

Tunar, M., Ozen, S., Goksen, D., Asar, G., Bediz, C. S., & Darcan, S. (2012). The effects of Pilates on metabolic control and physical performance in adolescents with type 1 diabetes mellitus. *Journal of Diabetes and Its Complications, 26*(4), 348–351. doi: 10.1016/j.jdiacomp.2012.04.006

Wong, C. H., Chiang, Y. C., Wai, J. P. M., Lo, F. S., Yeh, C. H., Chung, S. C., & Chang, C. W. (2011). Effects of a home-based aerobic exercise programme in children with type 1 diabetes mellitus. *Journal of Clinical Nursing, 20*(5–6), 681–691. doi: 10.1111/j.1365-2702.2010.03533.x

Woo, J., Yeo, N. H., Shin, K. O., Lee, H. J., Yoo, J., & Kang, S. (2010). Antioxidant enzyme activities and DNA damage in children with type 1 diabetes mellitus after 12 weeks of exercise. *Acta Paediatrica, 99*(8), 1263–1268. doi: 10.1111/j.1651-2227.2010.01736.x