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RS Global Sp. z O.O.
ISNI: 0000 0004 8495 2390

Dolna 17, Warsaw,
Poland 00-773
+48 226 0 227 03
editorial_office@rsglobal.pl

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THE MULTIDIMENSIONAL IMPACT OF HIGH-INTENSITY INTERVAL TRAINING (HIIT) ON GLYCEMIC CONTROL, CARDIORESPIRATORY FITNESS, BODY COMPOSITION, AND METABOLIC AND INFLAMMATORY MARKERS IN PATIENTS WITH TYPE 2 DIABETES: A REVIEW OF EVIDENCE AND CLINICAL IMPLICATIONS

Paulina Mikulec *(Corresponding Author, Email: paulamikulec@gmail.com)*
Zagłębie Oncology Center in Dąbrowa Górnicza, 13 Szpitalna Street, Dąbrowa Górnicza, Poland
ORCID ID: 0009-0003-9900-3008

Kamil Kerknawi
Zagłębie Oncology Center in Dąbrowa Górnicza, 13 Szpitalna Street, Dąbrowa Górnicza, Poland
ORCID ID: 0009-0009-9739-9954

Emilia Loch
Zagłębie Oncology Center in Dąbrowa Górnicza, 13 Szpitalna Street, Dąbrowa Górnicza, Poland
ORCID ID: 0009-0000-2666-8269

Michalina Zagalska
Independent Public Clinical Hospital named Andrzej Mielęcki of the Silesian Medical University in Katowice, Francuska 20-24 Street, Katowice, Poland
ORCID ID: 0009-0002-7312-0065

Marta Turek
Independent Public Clinical Hospital named Andrzej Mielęcki of the Silesian Medical University in Katowice, Francuska 20-24 Street, Katowice, Poland
ORCID ID: 0009-0005-7713-6875

ABSTRACT

Introduction: Type 2 Diabetes Mellitus (T2DM) is a major global health burden, marked by chronic hyperglycemia and complications. Physical activity is central to management, with High-Intensity Interval Training (HIIT) emerging as a time-efficient, evidence-based approach. This review examines HIIT's impact on glycemic control, cardiorespiratory fitness, body composition, and inflammation, also addressing safety and feasibility.
Methods: A narrative review was conducted via PubMed using terms such as"Type 2 Diabetes, ""glycemia, ""HbA1c, ""physical activity, " and"HIIT." From forty articles screened, nineteen met inclusion criteria.
Results and Discussion: HIIT effectively improves T2DM outcomes. It lowers HbA1c, fasting and postprandial glucose, and enhances insulin sensitivity and beta-cell function. Compared to moderate-intensity continuous training (MICT), HIIT often yields superior VO_2max improvements. It also reduces BMI, total and visceral fat, and improves lipid profiles. HIIT is associated with lower inflammatory markers. Implementation is feasible and safe, even for older adults, with high adherence and minimal adverse events.
Conclusion: HIIT is a potent non-pharmacological tool in T2DM management, offering benefits across metabolic and cardiovascular domains. Its ability to improve glycemic control, fitness, body composition, and inflammation underscores its clinical relevance. Current evidence supports integrating HIIT into standard care for T2DM patients.

KEYWORDS

Type 2 Diabetes, Glycemia, HIIT, Physical Activity, HbA1c, High-Intensity Interval Training

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Introduction

Type 2 Diabetes Mellitus (T2DM) is a chronic metabolic disease characterized by persistent hyperglycemia, stemming from insulin resistance or relative insulin deficiency [1, 13, 15, 19]. It presents a substantial global health burden, being a leading cause of morbidity and mortality [1, 13, 15, 17, 18, 19]. In 2014, over 422 million people worldwide had diabetes, a number projected to reach 552 million by 2030 [18]. In some nations, like Spain, nearly 14% of the population suffers from diabetes, with 95% of these cases being T2DM, a figure that continues to rise [4].

Poor glycemic control increases morbidity and mortality [10, 13, 16, 18, 19] and is associated with severe macro- and microvascular complications, including cardiovascular disease [1, 2, 15, 13, 16, 18, 19], diabetic nephropathy [13,19], retinopathy [13,19], and neuropathy [13]. Low cardiorespiratory fitness is also a strong, independent predictor of mortality in men with T2DM [1, 6, 14].

Given the increasing economic and social burden of T2DM management, effective and accessible lifestyle interventions are crucial [1, 18]. Physical exercise is a fundamental component of T2DM management, often recommended as a primary intervention for newly diagnosed patients [1, 13, 19]. The American Diabetes Association (ADA) recommends at least 150 minutes of moderate-to-vigorous aerobic activity weekly, spread across 3 to 7 days, with no more than two consecutive days without exercise; daily exercise is suggested to maximize insulin action [1, 17, 18]. Physical training, encompassing aerobic, resistance, and combined modalities, improves insulin sensitivity and overall glycemic control [1].

In recent years, High-Intensity Interval Training (HIIT), also known as High-Intensity Training (HIT), has gained popularity as a potentially effective and time-efficient alternative to traditional physical activity [1, 12, 13, 15, 16, 17, 18]. HIIT involves short, intense bursts of exercise interspersed with periods of rest or low-intensity activity [4, 12, 13, 16, 17, 18]. Typical HIIT protocols may include 4 to 6 repetitions of 30-second maximal efforts, separated by 30-60 seconds of rest [1, 12], or treadmill sessions of 5 cycles (3 minutes at 70% heart rate reserve (HRR) + 3 minutes at 30% HRR) [10]. HIIT intensity usually ranges from 65-90% maximal oxygen uptake (VO2max) or 75-95% maximal heart rate (HRmax) [15].

The application of HIIT in glycemic control for T2DM patients demonstrates significant benefits:

- **Improved Glycemic Control:** HIIT more effectively lowers blood glucose levels both during and after exercise compared to moderate-intensity continuous training (MICT) [10, 14, 15, 17]. Meta-analyses indicate a significant reduction in glycated hemoglobin (HbA1c) by an average of 0.8% compared to control groups [15, 16, 17]. Some studies also suggest HIIT may lead to greater HbA1c reductions than MICT (by 0.37%), though results are inconclusive [1, 16, 17, 18]. Furthermore, HIIT improves other glycemic parameters such as fasting glucose [14, 15, 17, 19], fasting insulin [14, 15, 17, 18], and HOMA-IR [14, 17].
- **Cardiorespiratory Fitness (VO2max):** HIIT is superior in increasing VO2max compared to both control and MICT groups [12, 13, 16, 17, 18].
- **Body Composition:** HIIT leads to reductions in body weight, BMI, and fat mass, including abdominal and visceral fat, which is crucial for metabolic diseases [1, 3, 11, 13, 15, 17, 18]. Regarding the lipid profile, HIIT can lower total cholesterol (TC), triglycerides (TG), and LDL cholesterol while increasing HDL cholesterol [15, 17, 19].
- **Insulin Sensitivity and Beta-Cell Function:** Physical training improves insulin sensitivity [1, 11, 13, 14, 17, 18, 19]. Moreover, functional high-intensity training can improve pancreatic beta-cell function in T2DM patients [1, 13, 19]. Molecular studies indicate that intense exercise activates key signaling pathways, such as AMPK and PGC-1α, and increases GLUT4 protein content in skeletal muscles, leading to better glucose uptake [1, 10, 11, 12, 14, 17, 19]. The role of exerkines, molecules secreted by muscles during exercise, also contributes to improved metabolic control and anti-inflammatory effects [8, 11, 13].

Despite their intensity, HIIT protocols have been shown to be feasible, well-tolerated, and safe for middle-aged and older T2DM patients [2, 6, 10, 14, 17,18]. The fact that low-volume HIIT can yield comparable physiological adaptations to traditional training with significantly less time commitment makes it an attractive

option for patients who often cite "lack of time" as a barrier to regular physical activity [1, 2, 3, 11, 12, 13, 14, 15, 17, 18, 19]. However, it is crucial to consider the patient's cardiovascular health before initiating intense training [2, 6, 14, 17] and, where possible, participate in supervised exercise programs [1, 5, 6, 10, 17, 19].

Aim

The primary aim of this work is to conduct a comprehensive review and synthesis of current scientific evidence regarding the multifaceted impact of High-Intensity Interval Training (HIIT) on patients with Type 2 Diabetes Mellitus (T2DM). Specifically, this objective encompasses a detailed assessment of how HIIT affects glycemic control, analyzing changes in glycated hemoglobin (HbA1c), fasting blood glucose (FBG), 2-hour postprandial glucose (2h-PG), fasting insulin (FINS), HOMA-IR index, and improvement in pancreatic beta-cell function. The study also aims to investigate HIIT's efficacy in enhancing cardiorespiratory fitness (CRF), measured as maximal oxygen uptake (VO2max/VO2peak), compared to MICT and control groups. Additionally, the impact of HIIT on body composition is analyzed, with particular attention to reductions in total fat mass, visceral adipose tissue (VAT), and changes in body mass index (BMI) and body weight. A crucial component of this work is to determine changes in metabolic and inflammatory markers, including lipid profile (i.e., total cholesterol (TC), triglycerides (TG), LDL-C, and HDL-C), levels of various exerkines (including interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), resistin, leptin, adiponectin, and FGF-21), improvements in heart rate variability (HRV) and endothelial function (measured as FMD), as well as blood pressure (SBP and DBP). Finally, this work aims to confirm the feasibility and safety of HIIT programs for T2DM patients, including middle-aged and older individuals and sedentary patients, and to indicate the clinical implications of these findings for optimizing physical activity recommendations and training programs in T2DM management.

Methods

This narrative literature review systematically searched the PubMed database using keywords such as "Type 2 Diabetes," "glycemia," "HIIT," "physical activity," and "HbA1c." This initial search yielded forty articles. Subsequently, rigorous inclusion criteria were applied to ensure the relevance and quality of the selected publications. Articles had to be published between 2012 and 2025, written in English, available in full text, and represent specific study designs such as literature reviews or randomized controlled trials. The application of these criteria reduced the initial pool of articles to nineteen. The final selection involved a manual review of each article by the authors, and content inconsistent with the core topic of the paper or exhibiting thematic redundancy was excluded, thereby ensuring the coherence and conciseness of the narrative review.

Results

This section presents a detailed analysis of the impact of High-Intensity Interval Training (HIIT) on glycemic control, cardiorespiratory fitness, body composition, and metabolic and inflammatory markers in patients with Type 2 Diabetes (T2DM), based on a review and synthesis of current scientific evidence.

1. Impact on Glycemic Control

- **Glycated Hemoglobin (HbA1c):**

o Meta-analyses consistently demonstrate that HIIT significantly improves HbA1c levels compared to non-exercising control groups, with weighted mean differences (WMD) ranging from -0.83% to -0.39% [17]. Exercise training generally leads to HbA1c reduction, with a 100-minute weekly increase in physical activity associated with an average HbA1c change of -0.16% [18].

o Compared to moderate-intensity continuous training (MICT), HIIT also leads to HbA1c improvement (WMD: from -0.37% to -0.07%) [17]. While some studies did not show significant differences between these two training types in the context of HbA1c [16], others emphasize that HIIT may offer additional benefits [18].

o Greater HbA1c reductions after HIIT were observed in subgroups of patients under 40 years and with disease duration under 5 years [15]. The optimal training intensity for HbA1c reduction was determined to be in the range of 80-89% HRmax [15]. Training programs of medium to long duration (over 8 weeks) also showed more significant effects [15].

- **Fasting Blood Glucose (FBG):**
  - HIIT significantly lowers FBG levels compared to control groups, with weighted mean differences (WMD) from -1.15 to -0.74 mmol/L [17]. A large effect size for HIIT in lowering FBG (MD: -0.55) was found [15].
  - Compared to other exercise interventions, HIIT (SUCRA=87.4) may have the best effect on FBG [19]. A study showed a 0.7 mmol/L reduction in fasting glucose after 3 months of HIIT [14].
- **2-hour Postprandial Glucose (2h-PG):**
  - HIIT significantly lowers postprandial glucose levels, with a meta-analysis indicating a large effect size (MD: -0.36) [15]. Particularly beneficial effects were observed with exercise intensity ≥90% and duration ≤30 minutes [15].
  - Short-term HIIT effectively reduces 24-hour blood glucose concentration and postprandial glycemic excursions in T2DM patients.
- **Fasting Insulin (FINS) and HOMA-IR Index:**
  - HIIT effectively improves FINS and HOMA-IR levels compared to control groups, with WMD for FINS at -2.27 μIU/mL and for HOMA-IR from -0.88 to -0.18 units [17].
  - HIIT has an overall FINS-lowering effect (MD: -0.41), which is significant for patients aged 40-60 years [15]. Three months of HIIT reduced HOMA-IR by 25% [14]. However, some meta-analyses did not show significant differences in FINS or HOMA-IR between HIIT and MICT groups [18].
- **Pancreatic Beta-Cell Function:**
  - Evidence indicates that a relatively short (8-week) HIIT program improved beta-cell function in T2DM patients [1, 11, 13]. Similarly, a 6-week functional high-intensity training program also contributed to improved beta-cell function [1, 10, 13].
- **Impact of Training Time:**
  - A study showed that afternoon HIIT was more effective than morning HIIT in improving 24-hour blood glucose levels in men with T2DM [9]. Morning HIIT, in some cases, raised glucose concentrations compared to the pre-training period. This phenomenon is modality and population-dependent [9].

2. Impact on Cardiorespiratory Fitness (CRF)

- HIIT consistently demonstrates significant improvement in CRF (measured as VO2max/VO2peak) compared to control groups, with weighted mean differences (WMD) ranging from 3.35 to 6.38 mL/kg/min [16, 17, 18].
- HIIT also surpasses MICT in improving CRF, with WMD from 1.68 to 4.12 mL/kg/min [16, 17, 18]. However, some studies, particularly those using an unloaded all-extremity exercise ergometer, reported similar effects of HIIT and MICT on aerobic performance [6].
- HIIT protocols with moderate intervals, high volume, and long training periods promoted greater increases in VO2max compared to the control group [8, 16]. In contrast, protocols with long intervals, moderate volume, and moderate duration led to greater VO2max increases compared to MICT [16].

3. Impact on Body Composition

- **Total Fat Mass and Body Fat Percentage:** HIIT leads to reductions in total fat mass [11], and one study showed significant reductions in body fat percentage (MD: -1.86%) after HIIT compared to baseline [18]. Improvements in adiposity have been observed after HIIT interventions [3].
- **Visceral Adipose Tissue (VAT) and Hepatic Steatosis:** HIIT appears to have effects at least similar to MICT in reducing VAT [11]. Exercise intensity plays a more significant role than duration in VAT reduction; higher intensity correlates with greater VAT reduction. HIIT increases insulin sensitivity in VAT. Additionally, HIIT reduces abdominal fat mass in postmenopausal women with T2DM and improves cardiac structure and function while decreasing hepatic steatosis in T2DM patients [10, 11, 15, 18].
- **Body Mass Index (BMI) and Body Weight:** HIIT showed greater improvement in body weight (MD: -1.22 kg) and BMI (MD: -0.40 kg/m^2) than MICT [18]. An overall reduction in body weight (MD: -1.93 kg) and waist circumference (MD: -3.04 cm) was also reported [8]. Exercise intervention was also more effective in maintaining lean body mass [3]. Low-volume exercise intervention did not cause significant weight loss but showed superiority in preserving lean body mass [3].

4. Impact on Metabolic and Inflammatory Markers

- **Lipid Profile:**

o HIIT generally improves lipid metabolism, specifically by lowering total cholesterol (TC), triglycerides (TG), and LDL-C, and increasing HDL-C levels [15, 17].

o Meta-analyses showed that HIIT significantly lowered TC (MD: -0.58) and TG [15]. HIIT promoted an increase in HDL (large effect size) and significantly lowered LDL-C (MD: -0.25 mmol/L) [15] compared to MICT [18].

o It is worth noting that resistance training (RT) may be most effective in lowering TC (SUCRA=90.5), while HIIT (SUCRA=25.2) shows less efficacy in this regard [19]. HIIT, however, may have the best effect on HDL (SUCRA=91.8) [19].

- **Exerkines:**

o Exercise training induces changes in adiponectin, fetuin-A, fibroblast growth factor-21 (FGF-21), IL-6, IL-10, leptin, resistin, and TNF-α levels [8]. No significant effects on apelin, IL-18, and ghrelin were reported [8].

o Physical exercise promoted large and positive changes in the exerkine pool (Hedge's g = 1.02) [8], and these changes were associated with changes in HbA1c, FBG, waist circumference, and body weight [8]. Physical exercise has been shown to act as an anti-inflammatory therapy [8].

- **Heart Rate Variability (HRV):**

o Exercise training improved HRV parameters in T2DM patients, which may reflect improved autonomic nervous system activity. Endurance (aerobic) training showed the highest level of evidence for HRV improvement. Resistance training and HIIT also show promise for HRV improvement [5].

o Patients with the longest time since T2DM diagnosis and dyslipidemia benefited most from HRV improvement [5].

- **Endothelial Function (FMD):**

o Exercise training, particularly aerobic and combined aerobic-resistance, significantly improved endothelial function (FMD) in T2DM patients (1.77% improvement). However, HIIT did not show significant FMD improvement compared to MICT in T2DM patients [7].

o FMD improvement in T2DM patients was smaller compared to non-diabetic individuals (−0.72%), suggesting an attenuated training effect due to the disease [7].

- **Blood Pressure (SBP, DBP):**

o Overall improvement in blood pressure (systolic and diastolic) was observed after HIIT [17]. Other studies reported beneficial changes in resting blood pressure after HIT [12].

- **Inflammatory Markers (C-reactive protein):**

o The HIIT-DM protocol study aims to evaluate the impact on C-reactive protein levels [2]. In meta-analyses, exercise training lowered levels of some inflammatory markers, such as IL-6, resistin, and TNF-α [8].

5. Feasibility and Safety

- **Feasibility and Tolerance:**

o HIIT is perceived as more time-efficient than traditional endurance training, offering comparable or superior health benefits with less time commitment [12, 15, 17].

o HIIT is often perceived as more enjoyable, though simultaneously more exhaustive than MICT [12, 14].

o HIIT has been shown to be feasible, well-tolerated, and safe, even in high-risk and low initial fitness populations, including middle-aged and older individuals with T2DM [6, 17]. Hwang et al. reported an 81% completion rate for both HIIT and MICT [6].

- **Safety and Adverse Events:**

o HIIT is considered safe and has been used in cardiovascular disease rehabilitation without an increased risk of adverse events [6, 11, 14, 17].

o Studies reported no cases of hypoglycemia after single training sessions (within 24-48h post-exercise), but noted the potential risk of nocturnal hypoglycemia if exercise is performed late [4].

o Monitoring for adverse events, such as severe hypoglycemia, chest pain, arrhythmia, breathing difficulties, pain, and fatigue, is crucial, especially in studies involving T2DM patients [2].

Limitation

Research on the impact of High-Intensity Interval Training (HIIT) in patients with Type 2 Diabetes (T2DM) is primarily limited by significant heterogeneity in training protocols and the low methodological quality of many analyses, which impedes the drawing of unequivocal conclusions. There is a lack of long-term data regarding HIIT's effects and studies conducted on specific patient groups, such as older and sedentary individuals. Additionally, analyses are sometimes burdened by insufficient control of confounding factors, such as diet or medications, and a lack of standardization in measurement methods. Comprehensive data on the long-term safety and feasibility of HIIT in the daily lives of T2DM patients, including an assessment of hypoglycemia risk, are still lacking.

Conclusions

Type 2 Diabetes Mellitus (T2DM) is a chronic metabolic disease characterized by hyperglycemia resulting from insulin resistance or relative insulin deficiency, potentially leading to cardiovascular complications and worsened health outcomes. The global prevalence of diabetes is continually rising, with forecasts indicating further increases in affected individuals. Given the escalating economic and social burden associated with T2DM, effective and accessible lifestyle interventions are critical.

Physical activity is universally recognized as a cornerstone in T2DM prevention and treatment, alongside diet and behavioral modifications. Exercise training—aerobic, resistance, or combined—facilitates improved glycemic control. Among various physical activity forms, High-Intensity Interval Training (HIIT) has emerged as a rapidly developing and promising exercise strategy. HIIT is characterized by short, intense efforts interspersed with periods of rest or lower-intensity activity, enabling comparable or superior physiological adaptations with significantly less time commitment and lower total training volume.

Available evidence points to multifaceted benefits of HIIT in T2DM patients, including better glycemic control (lowered HbA1c and fasting glucose levels), improved HOMA-IR insulin resistance index, and support for enhanced pancreatic beta-cell function.

Furthermore, clinically significant improvements in Cardiorespiratory Fitness (VO2max/peak) are observed—an increase in VO2max/peak is linked to a reduced risk of cardiovascular mortality. These adaptations are comparable to those achieved through high-volume endurance training, with considerably less time investment. HIIT leads to a significant increase in maximal oxygen consumption (VO2max/peak), often demonstrating superior results to MICT or physical inactivity. Acute HIIT sessions have been shown to be more effective in lowering blood glucose levels than moderate continuous training (MICT).

Importantly, HIIT interventions contribute to fat mass reduction, including visceral adipose tissue (VAT). They can also lead to significant decreases in body weight and BMI (MD: -0.40 kg/m^2) compared to MICT. HIIT has also proven effective in reducing liver fat content (by 39% relatively) and this has been shown to correlate with changes in HbA1c and 2-hour glucose.

Additionally, HIIT increases insulin sensitivity by improving glucose transport in skeletal muscles, mediated by the GLUT4 protein, improves the lipid profile, and reduces levels of markers such as IL-6, TNF-α, resistin, and fetuin-A, while simultaneously increasing adiponectin and IL-10.

In summary, HIIT is a promising and highly effective non-pharmacological intervention for Type 2 Diabetes treatment. The available evidence strongly supports its inclusion in comprehensive disease management plans. Nevertheless, further high-quality research is essential to refine recommendations for training protocols and fully understand its long-term effects across diverse patient groups.

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Author's contribution
All authors contributed to the article.
Project administration: Kerknawi K
Conceptualization: Mikulec P
Methodology: Mikulec P, Turek M
Software: Zagalska M
Formal analysis: Loch E
Investigation: Kerknawi K, Turek M
Resources: Zagalska M, Kerknawi K
Data curation: Mikulec P, Loch E
Writing - rough preparation: Mikulec P
Writing - review and editing: Zagalska M, Turek M
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