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The Role of Physical Activity in Diabetes Management: Benefits, Risks, and Recommendations-review

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Abstract
Regular physical activity plays a key role in managing type 1 (T1D) and type 2 diabetes (T2D), improving insulin sensitivity, glycemic control, and metabolic health. Exercise helps maintain a healthy body weight, reduces the risk of cardiovascular diseases, and enhances mental well-being. For individuals with T2D, physical activity decreases insulin resistance, while for those with T1D, it increases the risk of hypoglycemia, requiring adjustments in insulin doses and carbohydrate intake. Continuous glucose monitoring (CGM) systems facilitate the detection of hypoglycemia, especially at night. A combination of aerobic and resistance training is recommended for optimal glycemic control and HbA1c reduction. In individuals at risk of T2D, such as those with prediabetes, regular exercise can delay or prevent disease onset. Tailored exercise programs and education on glucose management are essential for safe and effective implementation. Future research should focus on individualized exercise plans and long-term effects of physical activity on diabetes progression and complications. In conclusion, integrating regular physical activity into diabetes management significantly improves health outcomes and quality of life for patients with T1D and T2D, though challenges like hypoglycemia must be carefully managed.

Keywords: Physical activity; Type 2 diabetes; HbA1c levels; Hypoglycemia; Aerobic exercise, Resistance training

Introduction, pathophysiology, epidemiology

Diabetes mellitus (DM) is a chronic metabolic disorder characterized by elevated blood glucose levels resulting from defects in insulin secretion, insulin action, or both. It affects millions of individuals worldwide and is a leading cause of morbidity and mortality due to its association with severe complications, including cardiovascular disease, kidney failure, retinopathy and neuropathy (Piepoli et al., 2016). According to the International Diabetes Federation (IDF), as of 2021, approximately 537 million adults aged 20–79 years were living with diabetes and this number is projected to rise to 643 million by 2030 (Sun et al., 2022). By 2045, it is estimated that 783 million people will have diabetes globally, highlighting the escalating nature of this epidemic (Saeedi et al. 2019; Sun et al., 2022). This global crisis is driven by factors such as aging populations, urbanization, sedentary lifestyles, and the increasing prevalence of obesity (Zimmet et al., 2016; Sun et al. 2022). The two primary forms of diabetes are Type 1 diabetes (T1D) and Type 2 diabetes (T2D), each with distinct pathophysiological mechanisms, risk factors and treatment approaches (Tuomi 2005; Sun et al,. 2022). Type 1 diabetes (T1D) is an autoimmune condition that typically manifests in childhood or adolescence. It results from the immune-mediated destruction of insulin-producing beta cells in the pancreas, leading to an absolute deficiency of insulin (Atkinson et al., 2014). This form of diabetes accounts for approximately 5–10% of all diabetes cases and requires lifelong insulin therapy for glucose regulation (Atkinson et al., 2014). The exact cause of T1D remains unclear, but it is believed to involve a combination of genetic predisposition and environmental triggers, such as viral infections.

Without exogenous insulin, individuals with T1D cannot regulate their blood glucose levels, leading to acute complications like diabetic ketoacidosis (DKA) and long-term complications such as microvascular and macrovascular diseases (Atkinson et al., 2014; Papatheodorou et al., 2017; Sun et al., 2022). In contrast, Type 2 diabetes (T2D) is characterized by insulin resistance, where the body's cells do not respond effectively to insulin and a progressive decline in insulin secretion by the pancreas (Tuomi, 2005). T2D accounts for approximately 90–95% of all diabetes cases and is strongly associated with modifiable risk factors, including obesity, physical inactivity and poor dietary habits (Kahn et al., 2014; Piepoli et al., 2016) while T2D traditionally occurs in adults. Rising prevalence of childhood obesity has led to an increasing incidence of T2D among younger populations (Sun et al., 2022). Unlike T1D, T2D can often be managed initially through lifestyle modifications, such as increased physical activity and dietary changes, although many patients eventually require oral hypoglycemic agents or insulin therapy as the disease progresses (Tuomi 2005; Fagour et al., 2013).The pathophysiology of T2D involves a complex interplay of genetic, metabolic, and environmental factors (Kharroubi, Darwish 2015). Insulin resistance, often exacerbated by obesity leads to compensatory hyperinsulinemia, which over time results in beta-cell dysfunction and failure. This progressive decline in beta-cell function distinguishes T2D from T1D, where beta-cell destruction occurs rapidly and is irreversible (Tuomi, 2005). Both forms of diabetes, however, share common long-term complications, including cardiovascular disease, nephropathy, retinopathy and neuropathy, which significantly impacts patients' quality of life and increase healthcare costs (Pedersen, Saltin., 2015; Gregg et al., 2016; Sun et al., 2022).

Physical activity plays a crucial role in the management of both T1D and T2D. For individuals with T2D, exercise improves insulin sensitivity, aids in weight management, and enhances overall metabolic health (Colberg et al., 2016). It also reduces the risk of cardiovascular diseases by lowering blood pressure and improving lipid profiles (Fagour et al., 2013; Pedersen, Saltin, 2015; Hamasaki, 2016). In T1D, physical activity can improve glycemic control, reduce insulin requirements and enhance cardiovascular fitness (Yardley et al., 2016). However, exercise in T1D requires careful management to avoid hypoglycemia witch is a common risk due to increased insulin sensitivity during and after physical activity (Iscoe et al., 2008; Yurkewicz et al., 2016).

Despite the differences in the underlying mechanisms of T1D and T2D, regular physical activity is universally beneficial for individuals with diabetes (Shugart et al., 2010; Colberg et al., 2010). However, engaging in exercise while managing diabetes presents unique challenges and risks that necessitate careful planning and monitoring (Piepoli et al., 2016). For individuals with T1D, the risk of hypoglycemia during and after exercise is a significant concern (Riddell et al., 2017). Hypoglycemia can impair physical performance, cognitive function and overall well-being, making it essential for athletes and active individuals to closely monitor their blood glucose levels and adjust insulin doses and carbohydrate intake accordingly (Yurkewicz et al., 2016; Riddell et al., 2017). Continuous glucose monitoring systems (CGMS) have emerged as valuable tools for real-time glucose tracking, helping to mitigate the risk of hypoglycemia and optimize exercise performance (Iscoe et al., 2008; Kulzer et al., 2024).

For individuals with T2D, while the risk of hypoglycemia is generally lower, other factors such as cardiovascular risk, joint health, and overall fitness must be considered (Hordern et al., 2011). Physical activity can help manage blood glucose levels and reduce the need for medication, but it also requires a balanced approach to avoid overexertion and injury (Nadella et al., 2017). Moreover, the presence of comorbidities, such as hypertension or neuropathy, may necessitate tailored exercise programs to ensure safety and effectiveness (Hordern et al., 2011; Colberg et al., 2016; Beck et al., 2017).

Physical activity is not only a cornerstone of diabetes management but also a powerful tool in preventing the onset of type 2 diabetes (T2D) (Aune et al., 2015; Colber et al 2016). Regular exercise has been shown to improve insulin sensitivity, reduce body fat and lower blood glucose levels, all of which are critical in reducing the risk of developing T2D, particularly in individuals with prediabetes or other risk factors such as obesity or a sedentary lifestyle (Hawley et al.,2014; Smith et al., 2016). Studies, including large-scale interventions like the Diabetes Prevention Program (DPP), have demonstrated that lifestyle modifications, including at least 150 minutes of moderate-intensity physical activity per week, can reduce the risk of developing T2D by up to 58% in high-risk individuals (Knowler et al., 2002; Aune et al., 2015). This preventive effect is attributed to the ability of exercise to enhance glucose uptake by muscles, improve pancreatic beta-cell function, and reduce systemic inflammation, all of which contribute to better metabolic health (Pedersen, Saltin., 2015; Hamasaki., 2016; Sparks et al., 2018).

Aim of study

The aim of this review is to comprehensively examine the role of physical activity in the management of diabetes, with a focus on its impact on glycemic control, insulin sensitivity, and the prevention of complications in both Type 1 Diabetes (T1D) and Type 2 Diabetes (T2D). This review also aims to explore the challenges and risks associated with exercise in diabetes management, such as hypoglycemia and to provide evidence-based recommendations for optimizing physical activity interventions. Additionally, the study seeks to highlight the preventive potential of regular exercise in delaying or preventing the onset of T2D, particularly in high-risk populations and to discuss the long-term benefits of physical activity in reducing diabetes-related complications. By synthesizing current evidence, this review aims to offer practical guidance for healthcare providers and patients on integrating safe and effective exercise programs into diabetes care to improve health outcomes and quality of life.

Physical Activities in Diabetes Type 2

The role of physical activity in type 2 diabetes is significant for diabetes control (Umpierre et al., 2011). It helps patients achieve substantial benefits in improving metabolic control of diabetes, reducing body weight and also cardiovascular risk (Fargour et al., 2012; Piepoli et al., 2016; Sigal et al., 2018). The study titled Experimental study on physical exercise in diabetes: pathophysiology and therapeutic effects demonstrated that exercising twice a week positively impacts HbA1c levels, body weight and glycemic control (Messina et al., 2023).

The results of this study showed that patients with type 2 diabetes who engaged in regular exercise alongside conventional treatment achieved better therapeutic outcomes compared to those who relied solely on conventional treatment. In the physically active group, significant reductions in HbA1c levels, body weight, blood glucose levels and improvements in lipid profiles were observed over a six-month period (Mesina et al., 2023). Another study, *The relationship between mortality and daily number of steps in type 2 diabetes*, provided further evidence of the benefits of regular physical activity . Participants were divided into three groups based on the number of steps taken daily. Out of 3,072 individuals participating in the study, 1,017 had been diagnosed with type 2 diabetes (Charles et al., 2022). Among patients with diabetes overall mortality was 30% higher compared to individuals without diabetes. However, patients who demonstrated higher levels of physical activity, particularly those who took more than 7,500 steps per day, had mortality rates similar to those observed in the control group (Charles et al., 2022). Patients with diabetes who fell into the moderate 5,000–7,500 steps per day or higher (≥7,500 steps per day) had a 44% and 80% lower risk of all-cause mortality compared to less active individuals. Both studies clearly demonstrate the importance of regular physical activity in the treatment of patients with type 2 diabetes (Charles et al., 2022, Messina et al., 2023).

In a 2020 study titled *Significant Dose-Response between Exercise Adherence and Hemoglobin A1c Change*, the relationship between exercise consistency and the reduction in glycated hemoglobin (HbA1c) levels were analyzed and it was found that patients who engaged in a greater amount of exercise achieved a more significant reduction in HbA1c levels (Bengham et al., 2020). This dose-response relationship was particularly evident in aerobic training and combined training (aerobic and resistance trainings), which aligns with clinical recommendations for these forms of exercise in patients with diabetes. However, no such relationship was observed for resistance training alone (Bengham et al., 2020). These findings suggest that both aerobic training and a combination of aerobic and resistance training are particularly effective in improving metabolic control in patients with type 2 diabetes (Bengham et al., 2020).

Each of the mentioned studies indicates that regular physical activity has a beneficial effect on metabolic control in patients with type 2 diabetes, as measured by HbA1c levels (Bengham et al., 2020; Charles et al., 2022; Messina et al., 2023). This improvement translates to better diabetes management, reduced cardiovascular, macro- and microvascular risks complications, such as kidney disease, retinopathy, and neuropathy (Papatheodorou et al., 2018). Physical exercise leads to an improvement in the overall condition and fitness of patients, which is crucial in the context of a chronic disease such as diabetes (Pedersen, Saltin, 2015). For patients with type 2 diabetes, exercising for 150 minutes per week helps achieve better HbA1c results compared to a lesser amount of exercise (Umpiere et al., 2011).

The Issue of Hypoglycemia in Athletes with Type 1 Diabetes

The issue of blood glucose fluctuations during exercise in individuals with diabetes, particularly children and adolescents, has been extensively studied. Nocturnal hypoglycemia is a problem associated with increased insulin sensitivity following physical activity (Nadella et al.,2017). This phenomenon can lead to a reluctance among children and adolescents with diabetes to engage in regular physical activity due to the fear of hypoglycemia. To address this, the authors emphasize the importance of educating patients on how to regulate their blood glucose levels during exercise, enabling them to safely reap the benefits of regular physical activity (Yardley et al., 2014; Nadella et al., 2017). For individuals with type 1 diabetes, strategies such as reducing basal insulin doses and consuming meals with slowly absorbing carbohydrates before bedtime are recommended to mitigate the risk of nocturnal hypoglycemia. While the risk of hypoglycemia during exercise is lower in type 2 diabetes it remains a consideration. Despite these risks, at least 60 minutes of moderate to vigorous physical activity daily is recommended for patients with diabetes (Nadella et al., 2017), this recommendation is supported by the American Diabetes Association (Colberg et al., 2010).

In a 2014 systematic review and meta-analysis of exercise interventions in adults with type 1 diabetes, the importance of individualized adjustments to insulin and carbohydrate intake was emphasized to prevent hypoglycemia during and after physical activity. They also highlighted the utility of continuous glucose monitoring (CGM) as a valuable tool for real-time glucose management during exercise (Yardley et al., 2014). Similar conclusions were presented in the findings of other studies that analyzed the occurrence of nocturnal hypoglycemia in individuals with type 1 diabetes at a sports camp (Iscoe, et.al 2008).

Their study, which utilized Continuous Glucose Monitoring Systems (CGMS), revealed that 60% of hypoglycemic episodes occurred at night, emphasizing the heightened risk of nocturnal hypoglycemia in physically active individuals with T1D. The study underscores the vulnerability of these athletes to low blood sugar levels, particularly during periods of rest following physical activity (Iscoe et al., 2008). The mechanism responsible for drops in blood sugar levels after physical activity is increased insulin sensitivity (Kulzer et al., 2024).Traditional methods like fingerstick tests often fail to capture nocturnal hypoglycemia, leaving individuals unaware of potentially dangerous drops in blood sugar (Iscoe et al., 2008; Brar et al., 2024). CGMS, with its ability to provide real-time, continuous glucose readings, offers a critical tool for athletes with T1D to better manage their condition. By alerting users to low glucose levels, particularly at night, CGMS can help prevent severe hypoglycemia and its associated risks (Brar et al., 2024). Regular monitoring and adjustments based on exercise intensity and duration are essential to optimize performance and safety (Brar et al., 2024; Yardley et al., 2014).

In conclusion, the management of blood glucose levels during and after exercise is a critical concern for individuals with diabetes, particularly those with type 1 diabetes. The aforementioned publications all emphasize the importance of tailored strategies, including insulin adjustments, carbohydrate management and the use of advanced monitoring technologies like CGMS (Iscoe et al., 2008; Yardley et al., 2014; Nadella et al., 2017; Brar et al., 2024). These measures are essential for reducing the risk of hypoglycemia, particularly nocturnal episodes and enabling individuals with diabetes to safely engage in physical activity. By leveraging continuous glucose monitoring technology and implementing targeted interventions, athletes and active individuals with T1D can enhance their performance, maintain better overall health and reduce the risks associated with blood glucose fluctuations during exercise (Colberg et al., 2010; Kulzer et al., 2024).

The intensity of exercise and improvement in metabolic control outcomes in type 2 diabetes.

In the study by Balducci et al. (2012), titled "*Effect of an Intensive Exercise Intervention Strategy on Modifiable Cardiovascular Risk Factors in Subjects with Type 2 Diabetes Mellitus: A Randomized Controlled Trial*" published in the Archives of Internal Medicine, the researchers investigated the impact of exercise intensity on metabolic control in individuals with type 2 diabetes mellitus (T2DM). The exercise group engaged in supervised, high-intensity workouts combined with counseling, while the control group received only counseling and achieved the recommended physical activity levels without supervision. The results revealed that the high-intensity exercise group experienced significantly greater improvements in HbA1c levels, systolic and diastolic blood pressure, waist circumference and body mass index compared to the control group. This suggests that individuals with T2DM may benefit from exercising at intensities higher than the general recommendations to achieve optimal metabolic and cardiovascular outcomes (Balducci et al., 2012). These findings are supported by other studies that emphasize the importance of exercise intensity in diabetes management. For example, a 2010 publication demonstrated that a combination of aerobic and resistance training led to greater reductions in HbA1c levels compared to standard care, highlighting the role of structured and intensive physical activity in improving glycemic control (Church et al., 2010). Similarly, a 2012 study recommends personalized exercise guidelines for individuals with type 2 diabetes, advocating for a combination of moderate-to-vigorous aerobic activity and resistance training to optimize health outcomes (Hordern et al., 2011). Recent research further underscores the benefits of higher-intensity exercise. A 2020 study also found that there is a significant dose-response relationship between exercise adherence and improvements in HbA1c, suggesting that greater exercise intensity and consistency lead to better metabolic control (Benham et al., 2020). Additionally, An important point is that higher-intensity exercise not only improves glycemic control but also reduces the risk of diabetes-related complications, such as cardiovascular disease and neuropathy (Messina et al., 2023).

Aerobic or Resistance Training in Diabetes

In the 2018 study titled *"Effect of Aerobic and Resistance Exercise on Glycemic Control in Adults With Type 1 Diabetes,"* the impact of resistance and aerobic exercise on glycemic control in adult patients with type 1 diabetes was compared. Patients who participated in aerobic training experienced a greater decrease in blood glucose levels, however, they spent less time within the target glucose range (60%) . In contrast, patients who engaged in strength training showed a smaller reduction in blood glucose levels compared to those who performed aerobic exercise but remained within the target blood glucose range for a longer duration (70%) compared to the control group (56%) and the aerobic exercise group (60%) . The findings of this study suggest that strength training may help patients with type 1 diabetes maintain more stable blood glucose levels (Reddy et al., 2019). Patients with type 1 diabetes may have a chance to improve their glycemic control by regularly performing resistance exercises, which promote better blood sugar management (Reddy et al,. 2019, Trojian et al., 2022).

In the 2010 study titled *"Effects of Aerobic and Resistance Training on Hemoglobin A1c Levels in Patients With Type 2 Diabetes"* it was shown that among patients with type 2 diabetes, the best results come from a combination of aerobic and resistance training (Church et al., 2010). In the group engaging in both types of exercise the greatest decrease in HbA1c levels over six months was observed with the average HbA1c level dropping to 7.3% compared to the control group (7.7%) (Church et al., 2010). This effect was not seen in those performing aerobic exercise alone, although the largest decrease in HbA1c occurred in the first month of regular exercise, levels began to rise again after the second month . The smallest decrease in HbA1c compared to the control group was observed in patients performing only resistance exercises. The results of this study indicate that for patients with type 2 diabetes, combining aerobic and resistance training methods is the most effective approach. This combination allows for the greatest reduction in HbA1c levels and helps maintain lower HbA1c levels over a longer period (Church et al., 2010; Hordern et al., 2011). In a comprehensive review of the role of exercise in managing chronic diseases, the authors emphasized that regular physical activity, particularly a combination of aerobic and resistance training, can significantly improve insulin sensitivity and glycemic control in individuals with type 1 and type 2 diabetes. Their findings support the idea that exercise acts as a form of "medicine" for chronic conditions, with structured and supervised programs yielding the best outcomes. Specifically, they noted that resistance training enhances muscle mass and glucose uptake, which is particularly beneficial for stabilizing blood glucose levels in patients with diabetes (Pedersen, Saltin, 2015). This aligns with other research findings, further emphasizing the importance of combining different forms of exercise for optimal diabetes management (Church et al., 2010; Pedersen, Saltin, 2015; Reddy et al., 2019).

The Impact of Physical Activity on Diabetes Complications

In a 2009 study titled *"Effects of Aerobic Exercise on Microalbuminuria and Enzymuria in Type 2 Diabetic Patients"*, researchers aimed to investigate how the introduction of regular aerobic exercise in a group of patients with type 2 diabetes would affect their level of microalbuminuria, which is the excretion of albumin in the urine (Lazarevic et al., 2009). Microalbuminuria is one of the initial stages of overt diabetic kidney disease and is a negative indicator of cardiovascular risk in patients with diabetes (Papatheodorou et al., 2017). The study showed that the level of microalbuminuria in six patients who had been diagnosed with microalbuminuria before the start of the study and regular aerobic exercise decreased after three and again after six months of exercise. This indicates that regular aerobic exercise may reduce the level of microalbuminuria, which can slow the progression of diabetic nephropathy and has a beneficial effect on cardiovascular risk in patients with diabetes (Lazarevic et al., 2009). In the article *"Effect of physical activity on reducing the risk of diabetic retinopathy progression: 10-year prospective findings from the 45 and Up Study"*, which describes a 10-year cohort study on working-age patients with diabetes, it was shown that diabetic patients with high levels of physical activity have a lower risk of developing diabetic retinopathy compared to patients with low levels of physical activity (Yan et al., 2021). Regular physical activity is also important in diabetic neuropathy, which is a microvascular complications of diabetes (Papatheodorou et al., 2017). Through exercise, patients can improve their nerve functions and reduce the symptoms of neuropathy (Tzou et al., 2016).

Physical exercise can improve microcirculation and has a positive effect on the vascular endothelium (Kolka et al, 2013) which may be beneficial in preventing diabetes complications (Lazarevic et al., 2009; Yan, 2021). Recent research has further highlighted the role of physical activity in mitigating diabetes-related complications. For instance, a 2023 experimental study on the therapeutic effects of physical exercise in diabetes demonstrated that regular physical activity not only improves glycemic control but also reduces the risk of microvascular and macrovascular complications, such as neuropathy, nephropathy and cardiovascular disease (Messina et al., 2023). Their findings suggest that exercise enhances endothelial function, reduces inflammation and improves insulin sensitivity, all of which contribute to the prevention and management of diabetes complications (Messina et al., 2023).

The Role of Regular Physical Activity in the Prevention of Type 2 Diabetes

In the review article *"Daily Physical Activity and Type 2 Diabetes: A Review"* from 2016, it was shown, based on cited studies and literature, that regular physical activity may be a factor that can prevent type 2 diabetes in certain patients (Hamasaki, 2016). This is an additional benefit beyond reducing cardiovascular risk and mortality that patients at risk for type 2 diabetes can achieve (Hordern et al., 2012). The article *"Management of diabetes mellitus in children and adolescents: engaging in physical activity"*, emphasize that regular physical activity can inhibit the development of diabetes in children with prediabetes (Nadella et al., 2017). Lifestyle interventions, such as promoting physical activity and healthy eating are effective in improving glycemic control and reducing the risk of developing type 2 diabetes (T2DM) (Nadella et al., 2017). The optimal time to introduce such changes is during childhood, before puberty, when there is a physiological reduction in insulin sensitivity (Nadella et al., 2017). It is recommended that patients with prediabetes should exercise similarly to patients with type 2 diabetes, aiming for 210 minutes of moderate physical activity or 125 minutes of vigorous exercise per week (Hordern et al., 2012). Moreover, combining physical activity with weight loss can lead to a reduction in the incidence of type 2 diabetes by up to 58% in patients at high risk of developing type 2 diabetes, as described in *Physical Activity/Exercise and Diabetes: A Position Statement of the American Diabetes Association* (Colberg et al., 2016). This demonstrates the importance of implementing physical activity in patients at risk of type 2 diabetes (Colberg et al., 2010; Hordern et al., 2012; Colberg et al., 2016)

Summary

This review highlights the critical role of physical activity in the management of diabetes, emphasizing its benefits for both Type 1 Diabetes (T1D) and Type 2 Diabetes (T2D). Regular exercise is essential for improving insulin sensitivity, aiding in weight management, and enhancing overall metabolic health. However, integrating physical activity into diabetes management requires careful consideration of individual health statuses and potential risks, such as hypoglycemia.

Physical activity enhances the body's response to insulin, which is particularly beneficial for individuals with T2D who often experience insulin resistance. Exercise helps lower blood glucose levels, which is crucial for maintaining stable blood sugar levels in both T1D and T2D. Regular physical activity supports maintaining a healthy body weight, which is important in preventing and managing T2D. Additionally, physical activity reduces the risk of cardiovascular diseases by lowering blood pressure and improving lipid profiles. Exercise also contributes to mental health and overall well-being, which are essential for managing a chronic condition like diabetes. Regular physical activity can lower the risk of developing diabetic complications, such as nephropathy, retinopathy and neuropathy.

Individuals with T1D are at a higher risk of hypoglycemia during and after exercise due to increased insulin sensitivity. Strategies such as adjusting insulin doses and consuming carbohydrates before and after exercise can help mitigate this risk. Continuous glucose monitoring systems (CGMS) are effective in detecting hypoglycemic episodes especially at night. It is important to tailor exercise programs to individual health statuses and capabilities. Education on glucose management during exercise and the use of monitoring tools can help patients safely engage in physical activity.

Research indicates that a combination of aerobic and resistance training yields the best results in improving glycemic control and reducing HbA1c levels in patients with T2D. For T1D, strength training may help maintain more stable blood glucose levels compared to aerobic exercise. Studies have shown that regular physical activity can prevent or delay the onset of T2D in at-risk individuals, such as those with prediabetes. Lifestyle interventions, including physical activity and healthy eating habits, are most effective when implemented early, preferably during childhood.

Regular physical activity has been shown to reduce the risk of diabetic complications.

For example, aerobic exercise can decrease the level of microalbuminuria, which is an early indicator of diabetic kidney disease. Physical activity also reduces the risk of developing diabetic retinopathy. These benefits highlight the importance of incorporating regular exercise into diabetes management strategies to improve long-term health outcomes.

Future research should focus on developing individualized exercise plans and further investigating the long-term effects of physical activity on disease progression and complication rates. Additionally, research should explore the most effective strategies for integrating exercise into the daily routines of individuals with diabetes, considering their unique health needs and challenges.

Disclosure

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Informed Consent Statement

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Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article's bibliography.

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