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Optimizing Physical Activity for Glycemic Control in Type 1 Diabetes: Strategies and Risks

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Abstract

Type 1 diabetes mellitus (T1DM) is a chronic autoimmune condition characterized by the destruction of insulin-producing beta cells in the pancreas, necessitating lifelong insulin therapy. This study explores the impact of physical activity on glycemic control and overall health in individuals with T1DM. Despite its proven benefits, including improved cardiovascular health, lower HbA1c levels, and reduced insulin requirements, over 60% of T1DM patients do not engage in regular exercise. Different types of physical activities—such as aerobic, anaerobic, and high-intensity interval training (HIIT)—affect metabolic responses differently. Aerobic exercises and HIIT have shown significant improvements in health-related quality of life (HRQoL) and reduced incidence of severe complications, such as

diabetic ketoacidosis. However, exercise-induced hypoglycemia remains a significant risk, especially if exercise follows recent severe hypoglycemic episodes. Proper management strategies include adjusting insulin doses, monitoring glucose levels, and carbohydrate intake. The study highlights the importance of tailored exercise plans and preventive measures to mitigate risks such as nocturnal hypoglycemia and elevated ketones. Ultimately, effective integration of physical activity into diabetes management can lead to enhanced overall health and quality of life for individuals with T1DM.

Keywords: diabetes mellitus type 1, physical activity, exercise-induced hypoglycemia, cardiovascular benefits, insulin management

1. INTRODUCTION

Type 1 diabetes mellitus (T1DM) is a persistent condition resulting from the immune system's destruction of insulin-producing beta cells in the pancreas, which leads to elevated blood glucose levels. Due to this autoimmune attack, the pancreas cannot produce insulin, making it necessary for individuals with T1DM to administer insulin via injections or an insulin pump. Unlike naturally produced pancreatic insulin, subcutaneous insulin does not adjust dynamically to the body's needs, often causing insulin levels in the blood to be higher than required, especially during physical activities (Cockcroft, Narendran, and Andrews, 2020). As reported by the International Diabetes Federation and the World Health Organization, T1DM affects 25-45 million adults globally over the age of 20, which is expected to rise by 25% by 2030 (Gomez et al., 2015).

Managing T1DM effectively requires a combination of insulin therapy, dietary planning, and lifestyle changes, including regular exercise. Physical activity is particularly beneficial for individuals with T1DM, as it enhances cardiovascular health, increases insulin sensitivity, and helps maintain better control over blood sugar levels. However, exercise poses unique challenges for this population, primarily due to the risk of hypoglycemia induced by physical

activity. Therefore, understanding how to safely integrate exercise into the lives of those with T1DM is essential for improving their overall health and quality of life. This study aims to examine the relationship between physical activity and glycemic control in individuals with T1DM, providing insights into safe and effective exercise practices.

2. METHODOLOGY

This paper presents an analysis of the literature in PubMed and Google Scholar scientific databases from 2006 to 2024 on type 1 diabetes mellitus, physical activity, exercise-induced hypoglycemia, and insulin requirements.

3. RESULTS AND DISCUSSION

Types of physical activity

Understanding the metabolic and neuroendocrine responses to various types of exercise is crucial for developing effective nutrition and insulin management strategies for individuals with type 1 diabetes. Exercise can be classified into aerobic and anaerobic categories based on the primary energy systems they engage, although many exercises use a combination of both [Table 1]. Aerobic activities, like walking, cycling, jogging, and swimming, involve continuous, repetitive movements of large muscle groups and rely primarily on aerobic energy systems. On the other hand, resistance training, which includes exercises with free weights, machines, bodyweight, or resistance bands, mainly uses anaerobic energy systems. High-intensity interval training (HIIT) involves short bursts of intense exercise followed by recovery periods at lower intensity (Batacan et al., 2017). Both aerobic and anaerobic exercises are recommended for most individuals with diabetes (Colberg et al., 2016; Robertson et al., 2014).

The World Health Organization (WHO) guidelines suggest that children and adolescents aged 5 to 17 should engage in at least 60 minutes of moderate- to vigorous-intensity physical activity daily, primarily aerobic, throughout the week. Additionally, vigorous-intensity aerobic activities and activities that strengthen muscles and bones should be included at least three times a week (WHO, 2020).

Table 1. ***Types of Physical Activity and their Characteristics.***

Type of Activity	Description	Effect on the body	Examples
Aerobic	Cardio training, continuous, rhymical and repetitive movements of large muscle groups	Increase heart rate, increase oxygen use	Walking, running, swimming, cycling, cardio equipment, dancing
Anaerobic	Exercises with weights, shorter and more intense	Involves glycolysis, in which glucose is converted to adenosine triphosphate (ATP) without using oxygen	Strength training, sprints, HIIT

Role of physical activity in diabetes type 1 treatment

Regular physical activity significantly benefits physical, mental, and social health, yet over 60% of individuals with type 1 diabetes (T1D) do not engage in it regularly (Justine et al., 2013). Active adults with T1D often achieve better HbA1c and blood pressure levels, maintain a healthier BMI, and experience reduced daily insulin needs, along with lower risks of coronary artery disease, myocardial ischemia, and stroke (Pierre-Louis et al., 2014). A study of 18,028 adults with T1D found that those exercising at least twice a week had improved HbA1c levels, healthier BMIs, and fewer complications like retinopathy and microalbuminuria (Bohn et al., 2015). Physical activity's effect on HbA1c is particularly notable for young individuals with T1D (Quirk et al., 2014).

A six-week high-intensity interval training (HIIT) program has demonstrated significant benefits for previously inactive individuals with T1D, including enhanced well-being, exercise adherence, and health-related quality of life (HRQoL) (Alarcón-Gómez et al., 2021). HIIT, which involves short bursts of high-intensity exercise followed by recovery periods, is time-efficient compared to moderate-intensity continuous training (MICT) (Buchheit and Laursen, 2013; Wewege et al., 2017). Participants reported improvements in sleep quality,

enjoyment, and motivation, along with fewer incidents of diabetic ketoacidosis and severe hypoglycemia.

Despite these benefits, there is a risk of developing diabetic retinopathy or nephropathy, making early preventive measures essential (Czenczek-Lewandowska, Grzegorczyk, and Mazur, 2018). While exercise is crucial for enhancing HRQoL in T1D, it may negatively impact sleep quality due to the risk of nocturnal hypoglycemia (Reddy et al., 2018).

Cardiovascular benefits

Regular physical activity significantly reduces cardiovascular disease risk and HbA1c levels by approximately 0.3% in pediatric patients with type 1 diabetes (T1D). Exercise also improves the blood lipid profile, including total cholesterol and triglycerides, and enhances endothelial function (Quirk et al., 2014). Michaliszyn and Faulkner found that physical activity in T1D patients led to reductions in total cholesterol, LDL cholesterol, and triglycerides, though moderate activity was linked to a decrease in HDL cholesterol (Michaliszyn and Faulkner 2010).

These cardiometabolic improvements are crucial, as cardiovascular disease is the leading cause of morbidity and mortality in young individuals with T1D (Miller et al., 2016; Katz, Giani, and Laffel, 2015). Individuals with T1D have double the risk of developing cardiovascular disease compared to those without diabetes (Soedamah-Muthu et al., 2006). To ensure safe and effective exercise, proper dietary preparation and insulin dose adjustments are necessary. However, the most effective types of exercise for improving cardiometabolic control in T1D patients are still being investigated (Yardley et al., 2014).

Insulin requirement

Regular physical activity reduces daily insulin requirements in individuals with type 1 diabetes (Sideraviciūte et al., 2006; D'Hooge et al., 2011). Sideraviciūte et al. observed that swimming led to a decrease in the total daily insulin dose. Long-term physical activity resulted in reductions in both short-acting and long-acting insulin doses,

with the decrease in short-acting insulin being statistically significant. Notably, the total daily insulin dose did not correlate with the duration of diabetes in female participants (Sideraviciūte et al., 2006).

OPTIMAL MANAGEMENT STRATEGY

Risk of hypoglycaemia

Fear of hypoglycemia, along with limited knowledge of preventive strategies, is a common reason for avoiding exercise among individuals with type 1 diabetes (Brazeau, 2008). Hypoglycemia, defined as a plasma glucose concentration of ≤70 mg/dl (≤3.9 mmol/l), can be severe, requiring assistance to administer treatments. Severe hypoglycemia episodes increase the risk of mortality by 3.4 times over five years (Cockcroft, Narendran, and Andrews, 2020). Studies show that 83% of children with T1D experience a decrease in plasma glucose during exercise, with 30% experiencing hypoglycemia during or immediately after (Tansey et al., 2006). Hypoglycemia typically develops within 45 minutes of starting aerobic exercise. In children, even 30 minutes of moderate-intensity activity increases the risk of nocturnal hypoglycemia by 30% (Metcalf et al., 2014).

Fear of hypoglycemia can lead to reduced insulin dosage, resulting in poor glucose management and a higher risk of complications (Cryer, 2008). Preventive measures include education on food intake, glucose control, and insulin administration, as well as ensuring adequate fuel and fluid replacement before exercise (Cockcroft, Narendran, and Andrews, 2020).

Prior hypoglycemia

Severe hypoglycemia within the preceding 24 hours is a contraindication for starting exercise due to the heightened risk of another severe episode during physical activity. If an individual has experienced a self-treated hypoglycemic episode within the last 24 hours, the risk of hypoglycemia during exercise increases. In such cases, additional precautions should be taken, and exercise should be postponed (Galassetti and Riddell, 2013).

Glucose level at the start of exercise

Before starting any physical activity, it is crucial to check glucose levels. The ideal blood glucose concentration before exercise should be personalized. Generally, a suitable range for most patients engaging in aerobic exercise for up to an hour is 7–10 mmol/L (126–180 mg/dL)

(Riddell et al., 2017). This range balances performance and the risk of hypoglycemia. In some instances, higher concentrations may be acceptable to provide additional protection against low blood sugar. The glycemic response to exercise varies based on factors like exercise duration and intensity, initial blood sugar levels, and insulin concentration (Campbell et al., 2014; Dubé et al., 2006). Anaerobic exercise and high-intensity interval training can start with lower glucose levels of about 5–7 mmol/L (90–126 mg/dL) since glucose levels tend to remain stable or slightly increase, unlike continuous aerobic exercise. For aerobic activities lasting over 30 minutes, additional carbohydrates are likely needed. If glucose levels are too high due to insulin omission, there is a risk of ketosis and further hyperglycemia, increasing the perceived effort of the exercise (Berger et al., 1977).

Nutrition

Adjusting carbohydrate intake and insulin is essential for managing blood glucose levels during exercise. Methods include reducing the pre-exercise bolus insulin dose by 30-50% up to 90 minutes before aerobic activity (Franc et al., 2015), consuming 30-60 grams of high glycemic index carbohydrates per hour during exercise, and replenishing carbohydrates after anaerobic exercise.

A practical strategy for preventing exercise-induced hypoglycemia in individuals with type 1 diabetes is the 'ExCarb' method, which involves consuming oral carbohydrates to replace those used during exercise. A baseline of 30 grams of carbohydrates per hour of exercise should be adjusted every 20 minutes to maintain stable glucose levels. Another approach is to base carbohydrate intake on body weight: 0.5 grams per kilogram per hour for moderate-intensity activities and 1 gram per kilogram per hour for high-intensity activities (Franc et al., 2015).

Regarding caffeine, a study found that a single dose of 6.0 mg/kg reduced glucose decline during aerobic exercise but caused nocturnal hyperglycemia and morning hypoglycemia. Thus,

caffeine consumption is not recommended for glucose control during exercise (Zaharieva et al., 2016).

Insulin adjustments

Adjusting insulin doses based on planned exercise can help reduce the need for extra carbohydrate intake. For people using insulin pumps, reducing pre-meal insulin doses by 50% when exercise is planned within 90 minutes after eating can effectively prevent exercise-induced hypoglycemia (Campbell et al., 2013). More advanced strategies consider the intensity and duration of the exercise. Pump users can decrease their basal insulin by about 80% starting 40 minutes before exercise and continuing until the exercise is finished (Roy-Fleming et al., 2019).

Combined strategies involving insulin adjustment and consuming low glycemic index carbohydrates have shown effectiveness. For instance, a 20% reduction in total basal insulin along with 1.0 g/kg of body weight in carbohydrates one hour before exercise can reduce the risk of hypoglycemia over 24 hours (Campbell et al., 2015). Reducing mealtime insulin boluses by 50% post-exercise and consuming a low glycemic index snack in the evening can help mitigate overnight hypoglycemia risks. For those using multiple daily injections, a 20% decrease in nighttime basal insulin effectively lowers the incidence of hypoglycemia (Campbell et al., 2015). Similarly, insulin pump users benefit from a 20% reduction in basal rates for 6 hours post-bedtime to achieve similar outcomes (Taplin et al., 2010).

Effective management of insulin and glycemia is crucial for safe physical activity in individuals with type 1 diabetes. Table 2 outlines strategic approaches to adjust insulin and carbohydrate intake before, during, and after exercise to optimize glucose control.

Table 2. ***Insulin and Glycemia Management Strategies in the Context of Physical Activity.***

Strategy	Description	Examples
Before exercise	Check glucose levels, adjust insulin dose	Target glucose levels are 7-10 mmol/L for aerobic, 5-7 mmol/L for anaerobic.
During exercise	Carbohydrate intake, monitor glucose levels	30-60g of carbohydrates per hour for aerobic exercise. Monitor glucose levels every 30 minutes and adjust carbohydrate intake as needed.
After exercise	Reduce insulin dose, consume low GI snacks	20% reduction in nighttime basal insulin to prevent nocturnal hypoglycaemia. After high-intensity exercise, consume a low glycemic index snack.

Timing of exercise

The timing of physical activity is crucial in preventing hypoglycemia. Exercising in a fasting state can help maintain stable glucose levels compared to postprandial exercise, which typically lowers blood glucose levels (Biankin et al., 2003). Research shows that morning exercise results in fewer hypoglycemic events than afternoon exercise, possibly due to lower cortisol levels in the afternoon that increase hypoglycemia risk (Gomez et al., 2015).

Elevated blood ketones

Elevated blood ketones (≥1.5 mmol/L) or urine ketones (≥2+ or 4.0 mmol/L) are contraindications for exercise. It's essential to address elevated ketones with insulin and carbohydrates before starting physical activity. The underlying cause of elevated ketones, such as illness, dietary changes, recent prolonged physical activity, or missed insulin doses, must be identified. Activities like marathons or low-carbohydrate diets can raise blood ketone levels without significantly affecting blood glucose. Ketone levels of 3.0 mmol/L or higher require immediate medical attention (Riddell et al., 2017).

Bone mineral density

People with type 1 diabetes are at a higher risk of developing osteoporosis and sustaining fractures due to reduced bone mineral density (BMD). A systematic review by Janghorbani et al. indicates that type 1 diabetes is linked to lower BMD, increasing fracture vulnerability. Chronic high blood sugar levels and potential insulin insufficiency contribute to this increased risk (Janghorbani et al., 2007).

In summary, managing physical activity in individuals with type 1 diabetes involves a thorough understanding of associated risks and contraindications. Table 3 provides a clear overview of these key factors and offers practical preventive measures for safe and effective exercise.

Table 3. ***Risk Factors and Contraindications for Exercise.***

Risk Factor	Description	Preventive Measures
Hypoglycemia	Low blood glucose (≤70 mg/dl or ≤3.9 mmol/l) during or after exercise. Symptoms: shakiness, sweating, confusion, and, in severe cases, loss of consciousness.	• Monitor blood glucose levels before, during, and after exercise. • Adjust insulin doses and carbohydrate intake accordingly. • Consume fast-acting carbohydrates if needed during exercise. • Avoid exercise within 24 hours of a severe hypoglycemic episode.
Postprandial hypoglycemia	Exercising after a meal can led to a significant drop in blood glucose levels due to increased insulin sensitivity and glucose uptake by muscles during exercise.	• Monitor blood glucose levels before and after meals and exercise. • Adjust insulin doses and carbohydrate intake. • Consider timing exercise to avoid peak insulin activity periods.
Nocturnal hypoglycemia	Moderate-intensity exercise can increase the risk of nocturnal hypoglycemia due to prolonged insulin sensitivity and glucose uptake.	• Monitor blood glucose levels before bedtime and overnight. • Reduce nighttime basal insulin doses • Consume a low glycemic index snack

		before bed.
Hyperglycemia during exercise	Exercise, can cause an initial increase in blood glucose levels due to the release of stress hormones (adrenaline, cortisol), which stimulate glucose production in the liver.	• Monitor blood glucose levels before, during, and after exercise. • Adjust insulin doses and carbohydrate intake. • Avoid high-intensity exercise if blood glucose levels are already elevated and ketones are present.
High ketone levels	Elevated blood ketone levels (≥1.5 mmol/L) indicate inadequate insulin levels, leading to the breakdown of fats for energy and the production of ketones, can cause diabetic ketoacidosis (DKA).	• Check ketone levels before exercising if blood glucose is high. • Administer insulin and consume carbohydrates if ketone levels are elevated. • Avoid exercise if ketone levels are significantly high (≥3.0 mmol/L).
Low bone mineral density	Higher risk of reduced bone mineral density (BMD), leading to an increased risk of osteoporosis and fractures.	• Engage in regular weight-bearing and resistance exercises to strengthen bones. • Monitor bone density periodically. • Ensure adequate intake of calcium and vitamin D.

4. CONCLUSION

Incorporating regular physical activity into the management of Type 1 diabetes offers substantial benefits, including improved glycemic control and cardiovascular health. However, it is crucial to address the risks of exercise-induced hypoglycemia and manage insulin and carbohydrate intake carefully. Personalized exercise plans, mindful of individual glucose levels and insulin adjustments, are essential for maximizing the benefits while minimizing risks. Future research should continue to refine strategies for safe exercise to improve outcomes and quality of life for those with T1DM.

Author's Contribution

Paulina Przybysz – Conceptualization, writing- rough preparation, methodology, investigation

Maja Kucharska - Writing - Visualization, data curation

Adrian Kruszewski – Formal analysis, data curation

Monika Szyszka – Methodology, investigation

Kacper Kwiliński – Metodolody, review and editing

Natalia Paduszyńska – Conceptualization, methodology

Anna Dąbrowska – Review and editing, supervision

Karolina Błaszczak – Review and editing, supervision

Barbara Wawrzyńska – Data curation, visualization

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Conflict of interest

The authors declare that there are no conflicts of interest.

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Not applicable.

Informed consent

Not applicable.

Data materials availability

All data sets collected during this study are available upon reasonable request from the corresponding author.

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