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REVIEW OF "CONTINUOUS GLUCOSE MONITORING AND GLYCEMIC METRICS DURING PHYSICAL ACTIVITY IN INDIVIDUALS WITH TYPE 1 DIABETES"

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ABSTRACT

Introduction: Type 1 diabetes requires continuous monitoring of blood glucose levels and careful adjustment of insulin therapy to maintain optimal metabolic control. Physical activity is widely recommended for individuals with type 1 diabetes due to its beneficial effects on metabolic health and cardiovascular risk reduction; however, exercise may lead to significant fluctuations in blood glucose levels, including both hypoglycemia and hyperglycemia. Continuous glucose monitoring (CGM) systems have emerged as an important technological advancement that enables real-time assessment of glucose variability and supports safer participation in physical activity. The glycemic impact of exercise differs according to exercise type, with aerobic activity more often associated with falling glucose levels and anaerobic or mixed activity showing greater variability [5].

Objective: To review the current scientific literature on the use of continuous glucose monitoring systems and CGM-derived glycemic metrics during physical activity in individuals with type 1 diabetes.

Methods: A narrative review of scientific literature was conducted using PubMed/MEDLINE, Scopus, and Embase databases. Clinical studies, review articles, and consensus statements published between 1993 and 2026 were analyzed. The review focused on the role of CGM systems and glycemic metrics, such as Time in Range (TIR), Time Below Range (TBR), and Time Above Range (TAR), in assessing glucose control during physical activity.

Conclusions: Continuous glucose monitoring systems significantly improve the ability to assess glycemic variability and support safer management of physical activity in individuals with type 1 diabetes. The use of CGM-derived metrics, particularly Time in Range, provides valuable insights into glucose dynamics during exercise and may contribute to better therapy individualization. Integration of CGM technology with modern diabetes management strategies represents an important step toward improving metabolic control and enhancing patient safety.

KEYWORDS

Continuous Glucose Monitoring, Type 1 Diabetes, Physical Activity, Time in Range, Glycemic Variability, Exercise, Diabetes Technology

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1. Introduction

Type 1 diabetes is a chronic autoimmune disease characterized by the destruction of pancreatic β-cells and an absolute insulin deficiency, which results in the need for lifelong insulin therapy. Despite considerable advances in diabetes treatment, maintaining stable glycemic control remains a major challenge for many patients. Inadequate metabolic control may lead to both acute complications, such as hypoglycemia and diabetic ketoacidosis, and long-term complications, including cardiovascular disease, nephropathy, and retinopathy [1], [2], [3].

Physical activity is an important component of type 1 diabetes management and is widely recommended as part of a healthy lifestyle. Regular exercise may improve insulin sensitivity, support body weight control, and reduce the risk of cardiovascular complications. At the same time, physical activity is associated with considerable fluctuations in blood glucose levels, including episodes of hypoglycemia and transient hyperglycemia, particularly after intense exercise. For this reason, appropriate glucose monitoring before, during, and after exercise is essential for the safety of individuals with type 1 diabetes [4], [5].Importantly, glycemic responses to physical activity are highly dependent on the type, intensity, and duration of exercise, with aerobic activity being more often associated with declining glycemia, whereas anaerobic or high-intensity efforts may attenuate this fall or even transiently increase blood glucose levels [5].

In recent years, significant progress in diabetes technology has led to the introduction of continuous glucose monitoring (CGM) systems, which enable ongoing assessment of glucose levels and real-time analysis of glycemic trends. In contrast to traditional fingerstick glucose measurements, CGM systems provide detailed information on glucose variability and allow the analysis of new glycemic control metrics, such as Time in Range (TIR) [6], [7].

The importance of CGM technology has also been emphasized in current clinical guidelines for diabetes management. The recommendations of the Polish Diabetes Association highlight the growing role of continuous glucose monitoring systems in individualizing therapy and improving treatment safety in people with diabetes [8].

This study aims to review the current scientific literature on the use of continuous glucose monitoring systems and CGM-derived metrics to assess glycemic control during physical activity in individuals with type 1 diabetes.

2. Methodology

This narrative review provides an analysis of the current scientific literature on the use of continuous glucose monitoring (CGM) systems during physical activity in individuals with type 1 diabetes. This review aimed to identify studies describing the impact of physical activity on glycemic control and the role of CGM-derived metrics, such as Time in Range (TIR), in evaluating the effectiveness of glucose monitoring.

The literature review was conducted by searching the PubMed/MEDLINE, Scopus, and Embase databases. The search strategy included combinations of the following keywords: continuous glucose monitoring, type 1 diabetes, exercise, physical activity, time in range, and glycemic control. Articles published in English between 1993 and 2026 were included in the analysis, encompassing clinical studies, review articles, and consensus statements addressing the impact of physical activity and CGM technologies on glycemic control in individuals with type 1 diabetes [5], [6], [8].

3. Physical Activity and Glycemic Responses in Type 1 Diabetes

Physical activity is an important element of type 1 diabetes therapy and is widely recommended as part of a healthy lifestyle. Regular exercise improves insulin sensitivity, supports body weight control, and reduces the risk of cardiovascular complications. Despite its numerous health benefits, physical activity in individuals with type 1 diabetes may lead to significant fluctuations in blood glucose levels, which represents an important challenge in daily disease management [4], [5].

The glycemic response to exercise depends on many factors, including the intensity and duration of activity, pre-exercise glucose level, insulin dose, and carbohydrate intake. Aerobic exercise, such as running or cycling, usually leads to a gradual decrease in blood glucose levels due to increased glucose uptake by muscles and enhanced insulin sensitivity. In contrast, anaerobic or high-intensity interval exercise may attenuate the fall in glycemia or even induce a transient increase in blood glucose, mainly due to increased concentrations of counter-regulatory hormones and lactate [5].

According to the consensus statement by Riddell et al., glycemic responses to exercise in individuals with type 1 diabetes differ substantially depending on the predominant metabolic character of the activity [5]. Aerobic exercise is generally associated with a decrease in blood glucose, whereas anaerobic exercise and high-intensity interval efforts may attenuate this decline or even induce a transient rise in glycemia due to increased concentrations of counter-regulatory hormones and lactate [5]. Mixed forms of exercise are often linked with greater glucose stability than continuous aerobic activity alone [5]. Importantly, the final glycemic effect is not determined solely by exercise type, but also by exercise duration and intensity, circulating insulin levels, the insulin-to-glucagon ratio, nutritional status, physical fitness, and pre-exercise glucose concentration [5].

One of the most common problems associated with physical activity in individuals with type 1 diabetes is the risk of exercise-induced hypoglycemia. It may occur both during physical activity and for several hours after its completion, especially with prolonged aerobic exercise. Therefore, appropriate glucose monitoring and adjustment of insulin dose and carbohydrate intake before, during, and after exercise are essential for the safe participation in physical activity [4], [5].

In recent years, continuous glucose monitoring systems have played an increasingly important role in monitoring glycemic changes during exercise. These technologies enable real-time tracking of glycemic trends and analysis of glucose variability, allowing faster responses to changes in glucose levels and significantly improving the safety of physical activity in individuals with type 1 diabetes [9], [10].

Figure 1 presents an adapted overview of the typical glycemic trends associated with aerobic, mixed, and anaerobic exercise in individuals with type 1 diabetes [5].

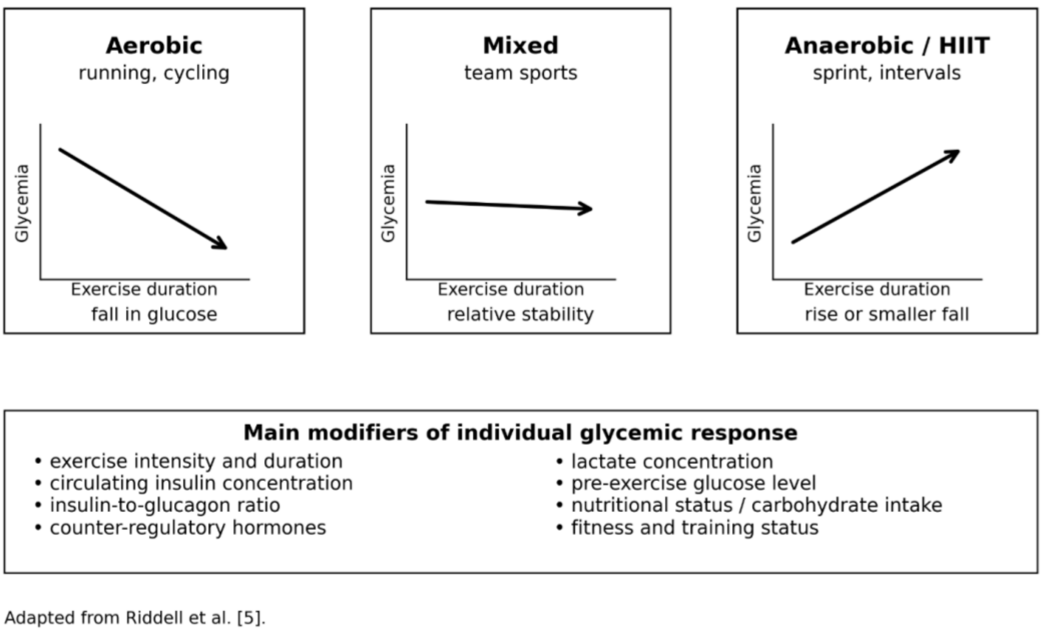

Fig. 1. *Typical glycemic responses to different forms of exercise in individuals with type 1 diabetes.*

Aerobic exercise is generally associated with a reduction in glycemia, anaerobic or high-intensity interval exercise is more often associated with a rise in glycemia or a smaller decline, whereas mixed forms of exercise are typically linked with greater glucose stability. Individual glycemic responses depend on multiple variables, including exercise intensity and duration, circulating insulin concentration, insulin-to-glucagon ratio, counter-regulatory hormones, lactate concentration, physical fitness, nutritional status, and initial glucose concentration. Adapted from Riddell et al. [5].

4. Continuous Glucose Monitoring Technology in Diabetes Management

Technological progress in diabetes management over the past two decades has significantly changed how glycemia is monitored in individuals with diabetes. Traditional methods of self-monitoring blood glucose were mainly based on point-in-time capillary glucose measurements with glucometers, which provide only limited information about current glucose levels. However, this method does not allow assessment of dynamic glycemic changes or identification of glycemic trends throughout the day and night [11].

Continuous glucose monitoring (CGM) systems enable a much more comprehensive assessment of metabolic control by measuring glucose concentration in interstitial fluid at regular intervals, usually every few minutes. The data obtained in this way allow analysis of glycemic trends, identification of hypoglycemic and hyperglycemic episodes, and evaluation of therapy effectiveness [6].

Modern CGM systems may function either as real-time continuous glucose monitoring (rtCGM) or intermittently scanned continuous glucose monitoring (isCGM). In both cases, the user gains access to detailed glucose data that both the patient and healthcare professionals may analyze. The introduction of these technologies has also enabled the development of new methods for analyzing glycemic data, such as the Ambulatory Glucose Profile (AGP), which provides a graphical presentation of glucose changes throughout the day [11].

The use of CGM systems in clinical practice significantly increases the possibilities for individualizing diabetes therapy. Access to detailed glycemic data allows more precise adjustment of insulin therapy and nutritional strategies, which may lead to improved metabolic control and a reduced risk of complications. For this reason, CGM technologies are increasingly recommended in clinical guidelines for diabetes management as an important tool supporting therapeutic decision-making [8].

CGM systems are particularly important in situations where glucose levels may change rapidly and unpredictably, such as during physical activity. By enabling real-time monitoring of glycemic trends, CGM systems may support the safe participation in exercise by individuals with type 1 diabetes, allowing earlier detection of potential hypoglycemic episodes and more appropriate therapy adjustments.

5. CGM Metrics and Their Clinical Significance

The development of continuous glucose monitoring technology has enabled the introduction of new indicators for assessing metabolic control that complement the traditional parameter of glycated hemoglobin (HbA1c). Although HbA1c remains an important marker of average glucose levels over several months, it does not provide information on short-term glycemic fluctuations or on the frequency of hypoglycemic and hyperglycemic episodes. For this reason, CGM-derived metrics that describe the distribution of glucose values over time are now receiving increasing importance [6].

The most important of these indicators is Time in Range (TIR), which measures the percentage of time glucose levels remain within the recommended glycemic target range. According to the international consensus on CGM data interpretation, the optimal therapeutic goal for most individuals with diabetes is to maintain TIR above 70% of the time, within the 70–180 mg/dL (3.9–10.0 mmol/L) range. Studies suggest that higher TIR values are associated with improved metabolic control and a potentially lower risk of long-term diabetes-related complications [6].

In addition to time spent within the target range, important parameters include indicators of hypoglycemia and hyperglycemia. Time Below Range (TBR) is the percentage of time when glucose levels fall below target values, whereas Time Above Range (TAR) is the time spent above the recommended glycemic range. Analysis of these parameters allows the identification of clinical situations associated with an increased risk of acute complications and enables more precise therapeutic adjustments [7].

Another important aspect of CGM data interpretation is the assessment of glycemic variability, which reflects the degree of glucose fluctuations over time. High glycemic variability may be associated with a greater risk of hypoglycemic episodes and difficulty maintaining stable metabolic control. Parameters describing glycemic variability, such as standard deviation and the coefficient of variation, allow a more comprehensive evaluation of glycemic stability and treatment effectiveness [7].

The clinical significance of CGM metrics has also been emphasized in current diabetes management guidelines. The recommendations of the Polish Diabetes Association indicate that the analysis of parameters such as TIR, TBR, and TAR may serve as an important tool to support individualized therapy and improve treatment safety, particularly in individuals at high risk of hypoglycemia or marked glycemic variability [8].

In the context of physical activity, CGM metrics are particularly important because they enable real-time assessment of the impact of exercise on glucose levels. Monitoring parameters such as TIR, TBR, and TAR during exercise and in the recovery period after its completion allows a better understanding of the body's response to physical activity and may support the optimization of insulin therapy and nutritional strategies in individuals with type 1 diabetes. Increasing evidence suggests that improvements in TIR are associated with a reduced risk of diabetes-related complications [6], [7].

6. Use of CGM During Physical Activity

Physical activity is an important element of type 1 diabetes therapy; however, it is associated with a risk of significant fluctuations in blood glucose levels. Exercise may lead to hypoglycemia, particularly during prolonged aerobic activity, as well as to transient hyperglycemia observed after intense or short-duration anaerobic exercise. For this reason, glucose monitoring during physical activity is essential to ensure patient safety and optimize therapy [5].

The consensus statement by Riddell et al. emphasizes that continuous aerobic exercise is associated with the highest risk of declining glycemia in people with type 1 diabetes, particularly when circulating insulin levels remain relatively high at the onset of activity [5]. In contrast, resistance exercise and high-intensity interval exercise may be associated with greater glucose stability or a smaller decline in blood glucose, and in some situations may even lead to transient hyperglycemia [5]. These differences are clinically relevant because they indicate that glucose management strategies should be individualized according to exercise type. For example, prolonged aerobic exercise may require greater carbohydrate supplementation and/or insulin dose reduction, whereas brief anaerobic activity or mixed exercise may require more attention to post-exercise hyperglycemia and subsequent delayed hypoglycemia [5].

Continuous glucose monitoring systems significantly increase the possibilities for observing glucose changes during exercise. By measuring glucose levels at short intervals, CGM technologies enable analysis of glycemic trends and identification of dynamic changes in glucose levels that may occur during physical activity and in the recovery period after its completion. These data enable faster responses to declines or increases in glycemia and more informed adjustments to insulin and carbohydrate intake [9].

Studies indicate that the use of CGM systems may improve the safety of physical activity in individuals with type 1 diabetes by allowing earlier detection of hypoglycemic episodes and enabling preventive interventions. CGM data analysis also makes it possible to identify individual physiological responses to different types of exercise, which may support training planning and insulin therapy individualization [9].

In the context of sports participation, CGM systems may be particularly valuable tools for glycemic management. Studies involving physically active individuals with type 1 diabetes have shown that access to CGM data allows better monitoring of glucose changes and more effective prevention of hypoglycemic episodes during training and sports competitions [10]. Moreover, the ability to analyze glycemic trends and historical data enables assessment of the impact of different forms of exercise on glycemic control.

An important advantage of CGM systems is the ability to use alerts that warn of approaching hypoglycemia or hyperglycemia. This function may play a particularly important role during physical activity, when glucose levels may change rapidly and be difficult to predict. Early detection of dangerous glycemic changes allows timely action, such as carbohydrate intake or modification of exercise intensity.

Another important issue is the marked interindividual variability in glycemic responses to exercise. As highlighted by Riddell et al., even within the same broad exercise category, glucose responses may differ depending on pre-exercise glycemia, insulin concentration, previous meals, fitness level, and hormonal responses [5]. In this context, CGM is particularly valuable because it enables real-time recognition of individual glucose patterns rather than relying solely on generalized recommendations. This may improve decision-making before exercise, during training sessions, and in the post-exercise recovery period.

The use of CGM systems in clinical practice and sports also supports the analysis of glycemic metrics in the context of physical activity. Monitoring parameters such as Time in Range, Time Below Range, and glycemic variability allows the assessment of the impact of exercise on glycemic stability and the optimization of therapeutic strategies in individuals with type 1 diabetes.

In clinical practice, CGM data may be used to plan physical activity and assess the body's response to exercise. Analysis of glycemic trends before exercise enables appropriate preparation of the patient by modifying insulin dose or carbohydrate intake. During exercise, CGM data enable ongoing monitoring of glucose changes and the identification of downward or upward trends that may require intervention. In turn, analysis of post-exercise data allows evaluation of the effect of exercise on glycemic control and adjustment of therapeutic strategies during subsequent training sessions [5], [9].

7. Future Perspectives in Diabetes Technology

The rapid development of diabetes technologies in recent years has significantly changed how type 1 diabetes is monitored and treated. Continuous glucose monitoring systems currently represent one of the most important elements of modern diabetes therapy, and their integration with insulin delivery systems opens new possibilities for treatment automation. Of increasing importance are so-called closed-loop systems, which integrate CGM data with algorithms that control insulin delivery in real time [12].

These systems, often referred to as components of the "artificial pancreas," enable partial automation of glycemic control by dynamically adjusting insulin doses based on current glucose measurements. Clinical studies indicate that closed-loop technology may increase time spent in the target glycemic range and reduce the frequency of hypoglycemic episodes in individuals with type 1 diabetes [12].

In the future, further development of glucose-monitoring technologies, integration of CGM systems with insulin pumps, and the use of advanced data-analysis algorithms may contribute to even more effective individualization of diabetes therapy. These solutions may also play an important role in improving the safety of physical activity in people with type 1 diabetes by enabling more precise prediction of glucose changes and automatic treatment adjustment.

8. Conclusions

Continuous glucose monitoring systems are playing an increasingly important role in the modern treatment of type 1 diabetes, enabling more accurate assessment of metabolic control than traditional self-monitoring methods. Through continuous monitoring of glucose levels and the analysis of glycemic trends, CGM technologies allow earlier detection of hypoglycemic and hyperglycemic episodes and more precise adjustment of insulin therapy.

CGM systems are particularly important in the context of physical activity, which can lead to dynamic, difficult-to-predict glucose fluctuations. Monitoring parameters such as Time in Range, Time Below Range, and Time Above Range enables a more accurate assessment of the body's response to exercise and supports the individualization of therapeutic strategies in people with type 1 diabetes.

The available evidence also shows that glycemic responses to exercise are not uniform and depend strongly on the metabolic characteristics of the activity performed. Aerobic exercise is generally associated with a greater risk of declining glycemia, whereas anaerobic or mixed exercise may be linked with greater glucose stability or transient hyperglycemia, which highlights the need for individualized glucose management strategies [5].

Data obtained from CGM systems may also support safe physical activity by enabling earlier detection of unfavorable glycemic changes and appropriate adjustments to insulin dose or carbohydrate intake. Therefore, CGM technologies represent an important tool for diabetes management in both daily clinical practice and during sports activity.

The importance of continuous glucose monitoring systems has also been emphasized in current clinical guidelines for diabetes treatment, including those of the Polish Diabetes Association, which emphasize the growing role of CGM technologies in individualizing therapy and improving treatment safety [8].

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