REVIEW ARTICLE

CONTENTS

Exercise-related dysglycemia in type 1 diabetes: Endocrine counterregulation, exercise modality, risk modifiers and technology – supported prevention

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ABSTRACT

Aim: To summarise the current state of knowledge regarding how physical activity may stimulate counter-regulatory responses in type 1 diabetics and which clinical features can enhance the risk of either hyper - or hypoglycaemia.

Materials and Methods: A targeted and evidence-based summary of articles published in PubMed from 2022 to 2026, regarding the physiological responses to exercise, continuous glucose monitoring (CGM) systems, automated insulin delivery (AID) systems in regular physical activity among type 1 diabetics.

Results: Type 1 diabetics experience a delayed reduction in the amount of insulin that can be reduced at the onset of exercise. Their body's production of glucagon and sympathetic-adrenal responses tend to be lower than normal. There is an increased risk for developing hypoglycemia due to this imbalance. The most significant factors that affect dysglycemic responses during physical activity include: how much "insulin on board" is present, when an individual's last meal bolus was taken, the amount of glucose within the bloodstream at the onset of physical activity and its trend and intensity of physical activity being performed.

Conclusions: Type 1 diabetes exercise management should be tailored to the individual and the nature of the exercise, as well as the patient's level of insulin exposure at that time and the dynamic blood glucose levels. The use of technology is most successful when it is used in conjunction with formal educational programs for patients and when a pre-exercise plan is put into place by health care providers.

KEYWORDS: type 1 diabetes, hypoglycemia, hyperglycemia, continuous glucose monitoring, insulin infusion systems

Wiad Lek. 2026;79(9):2278-2283. doi: 10.36740/WLek/225421 DOI

INTRODUCTION

Many people who have type 1 diabetes have stated that taking part in some form of physical exercise can produce several very good changes within their body (i.e. better heart/lung functions and more sensitive to insulin). As a result of these positive physiological changes that occur from participating in physical exercise, many individuals who suffer from diabetes state that the overall quality of their lives improve. However, although many individuals suffering from diabetes have made great improvements in their physiological well-being through exercising regularly, most still fail to continue doing so on a consistent basis. The main reasons why most diabetics will not take up a "healthy" lifestyle of activity is because they fear developing low blood glucose or what is medically referred to as hypoglycemia [1-4]. Patients with type 1 diabetes require exogenous insulin to manage their blood glucose levels while engaging in physical activities. Unlike other individuals who naturally secrete insulin, patients with type 1 diabetes lack the ability to self-regulate their own body's response to their own metabolic systems [1, 4-6].

AIM

The main purpose of this investigation was to examine whether there has been recent research into how people with type 1 diabetes respond with their endocrine system during physical activity, investigate the changes that occur in blood glucose levels resulting from a variety of commonly practiced forms of physical activity and to present information regarding how glucose monitors and insulin pumps may be used as preventive measures against low blood glucose (hypoglycemic episodes).

MATERIALS AND METHODS

This review was designed as a focused narrative review. A search of the PubMed database for all available ar-

ticles published in the period from 2022 to 2026 that included the use of the following search terms: "type 1 diabetes", "exercise", "hypoglycemia", "hyperglycemia", "counterregulatory response", "continuous glucose monitoring" and "automated insulin delivery" was performed. Additionally, a review of reference lists for relevant articles and current professional guidelines and recommendations were reviewed. International guidelines, systematic reviews, randomized controlled trials, observational studies were given priority when selecting articles. Articles were selected if at least one of the following areas were being discussed: endocrine response to hypoglycemia, glycemic effects by type of exercise, risk modifiers, pre-exercising safety, diabetes technology use during exercise, behavioral barriers to physical activity.

The authors used AI-assisted resources to improve writing clarity, grammar and formatting, as well as assist with a review process. All remaining authorship responsibilities included interpretation of data, source selection, synthesis of all study results and final approval of the written manuscript.

REVIEW

COUNTERREGULATION AND SUSCEPTIBILITY TO EXERCISE-RELATED HYPOGLYCEMIA

The effects of physical activity on non-diabetic people is that their circulating insulin levels decrease while their circulating glucagon, catecholamine (epinephrine/adrenaline), corticosteroid (cortisol) and growth hormone increase. Each of these hormones can cause an elevation in blood glucose by releasing it from the liver, thus they serve as a protective response to prevent dangerously low blood glucose. However, patients with type 1 diabetesbexperience a disruption in their body's physiological responses to low blood glucose during periods of physical activity. Therefore, T1D patients' ability to physiologically decrease their exogenous administration of insulin is less than their bodies' natural rate of reduction of endogenous insulin production. Furthermore, the glucagon and other symptoms associated with low glucose levels are often diminished in long-standing T1D patients who have been afflicted with the disease for longer than 5 years, particularly those experiencing repeated episodes of hypoglycemia [1,8,9]. A systematic review of stepped hypoglycemic clamp studies showed that counterregulatory hormone and symptom thresholds occur at lower glucose concentrations in people with type 1 diabetes than in individuals without diabetes [8]. The Hypo-RESOLVE clamp study further confirmed reduced glucagon and epinephrine responses and weaker symptom perception in type 1 diabetes [9].

EXERCISE MODALITY AND ACUTE GLYCEMIC RESPONSES

Exercise modality was identified as an important determinant of acute glycemic response. In the T1DEXI study, adults with type 1 diabetes experienced the greatest glucose declines during aerobic exercise, followed by interval exercise, whereas resistance exercise was associated with the smallest decreases [5]. A meta-analysis similarly found that high-intensity interval exercise leads to more heterogeneous glucose responses than continuous aerobic exercise and is not uniformly protective against hypoglycemia [7]. A recent synthesis of postprandial exercise management found that prandial state may influence glycemic response more strongly than exercise intensity alone [12, 16]. Even interval-based exercise may therefore be followed by a substantial glucose decline when a recent meal bolus remains active.

KEY MODIFIERS OF EXERCISE-RELATED DYSGLYCEMIA

Among the clinical variables identified, insulin on board was the strongest predictor of exercise-induced hypoglycemia. Analyses from T1DEXI and risk-prediction models showed that residual bolus insulin, recent glucose decline and recent time below range increase the likelihood of hypoglycemia during exercise [6, 25, 26]. Meal timing was also consistently associated with glycemic outcomes. Exercise performed within 2 hours of a meal bolus was linked to greater hypoglycemia risk, especially during aerobic activity [12-16]. Pre-exercise glucose level alone was not sufficient for risk assessment, glucose trend and surrounding clinical context were also relevant. The effect of time of day was less consistent. Some smaller studies suggested a smaller acute glucose drop during morning exercise, whereas larger datasets indicated that time of day had less predictive value than insulin exposure, exercise type and pre-exercise glucose dynamics [14, 24, 27]. Additional factors such as habitual fitness and selected patient characteristics may contribute to interindividual variability [24].

HYPERGLYCEMIA, KETONES AND PRE-EXERCISE SAFETY

Exercise did not have a uniform lowering effect on blood glucose levels. Because the short intense or

psychologic nature of the exercise may cause an initial increase in glucose due to increased catecholamine release which results in an excessive amount of glucose being produced by the liver compared to the peripheral tissues that can take it up from the blood [7, 12]. On the other hand, when there is some level of relative insulin deficiency during exercise, this may lead to worsening hyperglycemia with the promotion of ketosis rather than improvement of glycemic control [1,4]. The 2025 EASD/ISPAD position statement recommended postponing exercise when hyperglycemia is accompanied by elevated ketones or suspected pump failure [4]. Therefore, mild hyperglycemia without ketoacidosis was not considered an absolute contraindication for exercise as long as the individual had sufficient insulin delivery and were otherwise metabolically stable.

TECHNOLOGY-SUPPORTED PREVENTION

Recent studies have shown that using the existing forms of technology related to diabetes can provide a safer environment to engage in physical activity by those with diabetes. The American Diabetes Association (ADA) states as part of their 2026 Standards of Care that Continuous Glucose Monitoring (CGM) systems should be used by every individual diagnosed with diabetes as soon as they are prescribed insulin. Also, the ADA stated Automated Insulin Delivery (AID) systems as their preferred form of insulin delivery for almost all people with type 1 diabetes [2]. CGMs provides users with real time glucose trends, predictive alert notifications and increases the likelihood of detecting asymptomatic and nocturnal hypoglycemic events occurring while exercising in comparison to capillary glucose testing [2, 10]. At the same time, limitations were reported. Sensor lag may become more relevant during rapid glucose changes and factors such as sweating, heat and signal interruption may reduce measurement accuracy [4, 11]. AIDs improves time in range and reduces treatment burden, but does not replicate physiological counterregulation [4, 11]. In the PACE trial a predictive hypoglycemia alert reduced exposure to clinically significant hypoglycemia overall and within 24 hours after exercise [10]. A 2025 trial examining the timing of a temporary elevated glucose target before exercise found favorable glycemic outcomes regardless of target timing and did not demonstrate a significant difference in time below range in a well controlled cohort [14].

EDUCATION, ADHERENCE AND FUTURE-ORIENTED FINDINGS

Fear of hypoglycemia remained the main perceived barrier to physical activity despite the increasing availability of diabetes technologies [3, 18, 23]. A systematic review and meta-analysis showed that diabetes technologies reduce fear of hypoglycemia, although the effect size was small to moderate [18]. Educational and behavioral interventions were also shown to improve exercise readiness and reduce fear of hypoglycemia [19, 20]. Predictive models based on CGM have shown promise in forecasting exercise-related glycemic events and may contribute to practical decision-support tools in the future [22].

DISCUSSION

The findings of this review indicate that exercise-related dysglycemia in type 1 diabetes results from the interaction between impaired endocrine counterregulation, persistent exogenous insulin action and the specific metabolic demands of different exercise modalities. The reduced glucagon and sympatho-adrenal responses observed in type 1 diabetes help explain why many individuals remain vulnerable to hypoglycemia during and after exercise, even when they are aware of the potential risk.

The reviewed evidence also suggests that exercise modality alone is not sufficient to predict glycemic response. Although aerobic exercise is generally associated with the largest glucose decline, postprandial status and insulin on board appear to modify glycemic response more strongly than exercise intensity in many real-world situations. This is clinically important because it shifts attention from simplistic exercise classification toward individualized metabolic context.

Among all modifiers, insulin exposure appears to have the greatest practical relevance. A residual bolus of insulin, current downward trending glucose levels and most recently spent in hypoglycemic zone (time below range) are all individually predictive of increased likelihood of subsequent hypoglycemia. Therefore, preventing hypoglycemia is best achieved through adjusting the amount of basal insulin as an anticipatory measure for potential falls in blood glucose rather than solely providing corrective amounts of carbohydrates after the glucose level begins falling. Additionally, assessing a patient's blood glucose before exercise should be based upon more than just a single static value.

The review also highlights that hyperglycemia before exercise should not be interpreted uniformly. Although mild hyperglycemia with sufficient available insulin is likely to be tolerated. However, exercising while being relatively insulin deficient will likely increase the risk for ketosis and worsening metabolic instability. Therefore, it is reasonable that an individual's exercise should undergo a more detailed safety evaluation prior to

engaging in physical activity, particularly in individuals using pumps.

Although new technology that helps people living with diabetes safely participate in physical activities has been developed to help make diabetes-related risks less likely by allowing individuals to see how high or low their blood glucose levels are at a given time, warn individuals of impending low blood glucose episodes, allow individuals to alter their insulin dosing, etc. The new technology does not remove all of the physiological risks associated with hypoglycemia caused by physical activity. New technology can only be as good as the information, education and experience the individual receives through structured educational programs and the collaborative development of personal plans and decisions based upon the individual's specific needs. This reality is evident because despite the increased availability of advanced technology, many people still fear having a hypoglycemic episode.

The collective evidence suggests a personalized approach to managing type 1 diabetes during and after each specific type, duration, intensity and frequency of exercise. The plan for management will need to account for all of the above factors as well as what has worked previously for this particular individual. The most effective strategy for protecting against hyperglycemia or hypoglycemia would appear to include a structured regimen of adjusting insulin doses, consuming carbohydrates to stabilize blood glucose levels, utilizing CGMs in real time before and after exercising and performing regular surveillance on blood glucose levels after each exercise session.

Future studies need to concentrate a great deal more on real life exercise as opposed to strictly regulated lab-based methods. Additional data is required on uncontrolled (or unplanned) physical activities, varying meal intake, distinctions in patient subgroups and whether or not predictive decision support systems will be useful over time.

CONCLUSIONS

How often hypoglycemia occurs in an athlete using exogenous insulin for their diabetes prior to participating in a physical activity depends on several variables. For example, one variable is the amount of insulin in the athlete's system when they have a hypoglycemic episode ("insulin on board"); another variable is if the athlete ate something previously to prevent their blood glucose from dropping during the activity; yet another variable is what kind of activity the athlete is doing compared to continuous aerobic activity and (if applicable) the athlete's response to a hypoglycemic episode through consumption of carbohydrates.

The use of modern technologies for managing type 1 diabetes may potentially increase safety and enable individualized approaches to managing type 1 diabetes. However, the potential of the technological tools will be optimized with pre-planning, the development of an individualized carbohydrate plan, timely modification of the insulin regimen and instruction as to how to monitor and manage blood glucose levels during physical activity.

REFERENCES

1. Adolfsson P, Taplin CE, Zaharieva DP, Forsander G, Pacaud D, Bratina N, et al. ISPAD Clinical Practice Consensus Guidelines 2022: Exercise in children and adolescents with diabetes. Pediatr Diabetes. 2022;23(8):1341-1372. doi:10.1111/pedi.13452. DOI
2. American Diabetes Association Professional Practice Committee. 7. Diabetes Technology: Standards of Care in Diabetes-2026. Diabetes Care. 2026;49(Suppl 1):S150-S165. doi:10.2337/dc26-S007. DOI
3. American Diabetes Association Professional Practice Committee. 5. Facilitating Positive Health Behaviors and Well-being to Improve Health Outcomes: Standards of Care in Diabetes-2026. Diabetes Care. 2026;49(Suppl 1):S89-S131. doi:10.2337/dc26-S005. DOI
4. Moser O, Riddell MC, Eckstein ML, Adolfsson P, Rabasa-Lhoret R, van den Boom L, et al. The use of automated insulin delivery around physical activity and exercise in type 1 diabetes: a position statement of the European Association for the Study of Diabetes and the International Society for Pediatric and Adolescent Diabetes. Diabetologia. 2025;68:255-280. doi:10.1007/s00125-024-06308-z. DOI
5. Riddell MC, Li Z, Gal RL, Beck RW, Jacobs PG, Arbiter B, et al. Examining the acute glycemic effects of different types of structured exercise sessions in type 1 diabetes in a real-world setting: the Type 1 Diabetes and Exercise Initiative (T1DEXI). Diabetes Care. 2023;46(4):704-713. doi:10.2337/dc22-1721. DOI
6. Bergford S, Riddell MC, Jacobs PG, Brimberry L, Lal RA, Buchanan CM, et al. The Type 1 Diabetes and EXercise Initiative: Predicting hypoglycemia risk during exercise for participants with type 1 diabetes using repeated measures random forest. Diabetes Technol Ther. 2023;25(9):602-611. doi:10.1089/dia.2023.0140. DOI
7. McClure RD, Coyle K, Zaharieva DP, Alcantara-Cordero FJ, Weseen E, Nitz C, et al. Systematic review and meta-analysis of blood glucose response to high-intensity interval exercise in adults with type 1 diabetes. Can J Diabetes. 2023;47(2):171-179. doi:10.1016/j.jcjd.2022.11.006. DOI
8. Verhulst CEM, Cokuw N, Gosmanov AR, Reddy M, Jones TW, McAulay V, et al. Glycaemic thresholds for counterregulatory hormone and symptom responses to hypoglycaemia in people with and without type 1 diabetes: a systematic review. Diabetologia. 2022;65(10):1601-1612. doi:10.1007/s00125-022-05749-8. DOI

9. Fabricius TW, Cengiz E, Choudhary P, Czupryniak L, DeVries JH, Frier BM, et al. Counterregulatory hormone and symptom responses to hypoglycaemia in people with type 1 diabetes, insulin-treated type 2 diabetes or without diabetes: the Hypo-RESOLVE hypoglycaemic clamp study. Acta Diabetol. 2024;61(5):623-633. doi:10.1007/s00592-024-02239-8. DOI
10. Rilstone S, Oliver N, Godsland I, Brown K, Hunter S, Gates B, et al. A randomized controlled trial assessing the impact of continuous glucose monitoring with a predictive hypoglycemia alert function on hypoglycemia in physical activity for people with type 1 diabetes (PACE). Diabetes Technol Ther. 2024;26(2):95-102. doi:10.1089/dia.2023.0376. DOI
11. Zaharieva DP, Morrison D, Paldus B, McAuley SA, de Bock M, Castle J, et al. Practical aspects and exercise safety benefits of automated insulin delivery systems in type 1 diabetes. Diabetes Spectr. 2023;36(2):127-136. doi:10.2337/dsi22-0018. DOI
12. Helleputte S, Stautemas J, Jansseune L, Maho C, Tits J, Cokay A, et al. Glycemic management around postprandial exercise in people with type 1 diabetes: challenge accepted. J Clin Endocrinol Metab. 2024;109(8):2039-2052. doi:10.1210/clinem/dgae079. DOI
13. Da Prato G, Csermely A, Pilati M, Molveau J, Myette-Cote E, Guedet C, et al. A randomized crossover trial comparing glucose control during postprandial moderate aerobic activity and high-intensity interval training in adults with type 1 diabetes using an advanced hybrid closed-loop system. J Diabetes Sci Technol. 2024;18(5):1256-1257. doi:10.1177/19322968241258444. DOI
14. Morrison DJ, Vogrin S, Zaharieva DP, Manos G, Halim B, O'Neal D. Glycaemic impact of the pre-exercise timing of an elevated glucose target implemented using an automated insulin delivery system in adults with type 1 diabetes. Diabetes Obes Metab. 2025;27(9):5160-5170. doi:10.1111/dom.16567. DOI
15. Molveau J, Myette-Cote E, Guedet C, Csermely A, Da Prato G, Joubert M, et al. Impact of pre- and post-exercise strategies on hypoglycemic risk for two modalities of aerobic exercise among adults and adolescents living with type 1 diabetes using continuous subcutaneous insulin infusion: a randomized controlled trial. Diabetes Metab. 2025;51(1):101599. doi:10.1016/j.diabet.2024.101599. DOI
16. Yardley JE. Reassessing the evidence: prandial state dictates glycaemic responses to exercise in individuals with type 1 diabetes to a greater extent than intensity. Diabetologia. 2022;65(12):1994-1999. doi:10.1007/s00125-022-05781-8. DOI
17. de Lima VA, de Menezes FJ Jr, da Rocha Celli L, de Carvalho Neto RL, de Sa Ribeiro A, de Souza CF, et al. Effects of resistance training on the glycemic control of people with type 1 diabetes: a systematic review and meta-analysis. Arch Endocrinol Metab. 2022;66(4):533-540. doi:10.20945/2359-3997000000487. DOI
18. Talbo MK, Birkebaek NH, de Beaufort C, Choudhary P, Czupryniak L, Dovc K, et al. Effect of diabetes technologies on the fear of hypoglycaemia among people living with type 1 diabetes: a systematic review and meta-analysis. EClinicalMedicine. 2023;62:102119. doi:10.1016/j.eclinm.2023.102119. DOI
19. Chatwin H, Martyn-Nemeth P, Stanescu S, Brennan M, Moser O, de Bock M, et al. Effectiveness of educational and behavioural interventions for reducing fear of hypoglycaemia among adults with type 1 diabetes: systematic review and meta-analyses. Diabet Med. 2023;40(5):e15071. doi:10.1111/dme.15071. DOI
20. Martyn-Nemeth P, Quinn L, Messman A, Mukherjee A, Dyer J, Tellez K, et al. FREE: a randomized controlled feasibility trial of a cognitive behavioral therapy and technology-assisted intervention to reduce fear of hypoglycemia in young adults with type 1 diabetes. J Psychosom Res. 2024;181:111679. doi:10.1016/j.jpsychores.2024.111679. DOI
21. Cloarec T, Ducos A, Du Pasquier-Fediaevsky L, Hartemann A, d'Ortoli TA, Hochberg G, et al. Functions, features, and psychological well-being impacts of type 1 diabetes self-management mobile and web apps: systematic review. J Med Internet Res. 2025;27:e75280. doi:10.2196/75280. DOI
22. Ma S, Coopergard R, Clements M, Chow L. Managing exercise-related glycemic events in type 1 diabetes: development and validation of predictive models for a practical decision support tool. JMIR Diabetes. 2025;10:e68948. doi:10.2196/68948. DOI
23. Guedet C, Alexandre-Heymann L, Yardley JE, Brown SA, Cengiz E, Boloor A, et al. Exploring perceived barriers to physical activity among individuals with type 1 diabetes in the era of new technologies: an analysis from the BETTER registry. Diabetes Metab. 2025;51(5):101677. doi:10.1016/j.diabet.2025.101677. DOI
24. Johansen RF, Caunt S, Heller S, Oliver N, Choudhary P, Gates B, et al. Factors influencing physical activity level in adults with type 1 diabetes: a cross-sectional study. Can J Diabetes. 2024;48(7):431-438.e1. doi:10.1016/j.jcjd.2024.06.002. DOI
25. Pemberton JS, Bally L, Yardley JE, Maahs DM, Lal RA, Agustin San Martin R, et al. Glucose-lowering effects of physical activity in type 1 diabetes: a causal modelling and matched-pair analysis approach. Diabet Med. 2025;42(10):e70146. doi:10.1111/dme.70146. DOI
26. Li Z, Calhoun P, Rickels MR, Lal RA, Gal RL, Agustin San Martin R, et al. Factors affecting reproducibility of change in glucose during exercise: results from the Type 1 Diabetes and EXercise Initiative. J Diabetes Sci Technol. 2025;19(4):958-970. doi:10.1177/19322968241234687. DOI
27. Codella R, Rizzi M, Brescianini S, Buzzetti R, Madonna R, Morano S, et al. Impact of timing, type, and intensity of physical activity on glycemic outcomes in a cohort of well-controlled youth with type 1 diabetes. J Endocrinol Invest. 2025;48(12):3003-3012. doi:10.1007/s40618-025-02690-6. DOI

CONFLICT OF INTEREST
The Authors declare no conflict of interest

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A – Work concept and design, B – Data collection and analysis, C – Responsibility for statistical analysis, D – Writing the article, E – Critical review, F – Final approval of the article

RECEIVED: 12.05.2026
ACCEPTED: 03.07.2026

CREATIVE COMMONS 4.0