QUALITY IN SPORT
eISSN 2450-3118 · Open Access · Peer-reviewed
apcz.umk.pl/QS Nicolaus Copernicus University in Toruń

BROWARSKA, Emilia, SUPERSON, Katarzyna, MIEMCZYK, Katarzyna, GAJEWSKA, Nicole, MSZYCA, Igor, AKSAMIT,Anna, WOŁEK, Filip, MULARCZYK, Karolina, KUCHARSKI, Kacper and MICHALSKI, Łukasz. Continuous Glucose Monitoring (CGM) as a Tool for Training Quality Optimization: A Systematic Review of Metabolic Management in Non-Diabetic Athletes. Quality in Sport. 2026;67:74262. https://doi.org/10.12775/QS.2026.67.74262

ARTICLE TIMELINE
Received: 12.07.2026. Revised: 03.08.2026. Accepted: 03.08.2026. Published: 10.08.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines assigned: Economics and finance (Field of social sciences); Management and Quality Sciences (Field of social sciences).
Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).

Continuous Glucose Monitoring (CGM) as a Tool for Training Quality Optimization: A Systematic Review of Metabolic Management in Non-Diabetic Athletes

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Abstract

Introduction. Continuous Glucose Monitoring (CGM) has transitioned from a clinical diabetes management tool to a prominent technology in sports science. While glucose availability is critical for endurance performance and recovery, the application of CGM metrics in non-diabetic athletes remains debated. There is a pressing need to bridge the gap between clinical glycemic monitoring and its potential for optimizing training quality and physiological adaptation.

Research objective. This review synthesizes current knowledge on glycemic regulation in endurance athletes, the diagnostic challenges of interpreting CGM metrics, and the integration of AI into multi-sensor physiological monitoring. The study aims to delineate the distinction between physiological metabolic adaptation and clinical dysglycemia, providing evidence-based insights for metabolic management in athletic cohorts.

Methodology. The review is based on a structured search of peer-reviewed literature through July 2026. Keywords included: "continuous glucose monitoring", "endurance athletes", "metabolic flexibility", "glycemic variability", and "training load". Priority was given to randomized controlled trials, systematic reviews, and international consensus documents. Articles were analyzed for their relevance in distinguishing acute biochemical responses from long-term exercise-induced adaptations.

Conclusions. CGM is a valuable descriptive tool for assessing metabolic load. However, its role as an autonomous decision-making system is limited by the absence of sport-specific reference ranges and inherent technical constraints during high-intensity exertion. Future metabolic management necessitates a contextualized, integrative approach that combines CGM data with multi-sensor feedback and clinical expertise to enhance training quality while avoiding the pitfalls of data overinterpretation.

Keywords: Continuous Glucose Monitoring; Endurance Athletes; Metabolic Flexibility; Glycemic Variability; Training Load Monitoring; Precision Sports Nutrition; Physiological Adaptation.

Content

1. Introduction

Continuous glucose monitoring (CGM) is no longer just a specialized tool reserved exclusively for diabetes clinics. In recent years, this technology has been making increasingly steady inroads into the worlds of sports, healthy living, and wellness in the broadest sense [1, 2, 3]. Athletes striving to optimize their training as much as possible are increasingly seeking solutions that provide precise, real-time insights into their metabolic profiles [1, 4, 5]. While the literature contains extensive studies on individual parameters affecting athletic performance, there remains a lack of research evaluating technologies that directly optimize athletes' physiological performance. Devices that enable a personalized approach to the athlete and their unique physiology are particularly promising.

In endurance sports, where glucose availability is a critical factor in performance and recovery, CGM offers justified hope for deeply personalized nutrition strategies [5, 6]. Although the physiology of carbohydrate metabolism during exercise is well documented, there remains a lack of clear guidelines for the practical interpretation of sensor data by athletes with normal carbohydrate metabolism [7, 8]. Applying metrics derived directly from diabetes care—such as time in range—to competitive sports raises numerous interpretive challenges that the scientific literature is only beginning to address [7, 17].

Currently, interest in CGM systems in the sports community far outpaces the existing evidence base. There is a clear knowledge gap regarding how glycemic parameters should inform specific training decisions [7, 10]. Furthermore, the specific nature of physical exertion—including variations in sensor accuracy during exercise and the high heterogeneity of glycemic profiles among athletes—makes comparing results across studies complex [10, 18, 19]. At the same time, the increasingly frequent integration of CGM with artificial intelligence algorithms opens up entirely new perspectives in monitoring physiological stress, making this research area particularly dynamic [2, 6].

In this context, it is warranted to conduct a systematic review to critically synthesize the current state of knowledge. The aim of this study is to evaluate the use of CGM as a tool to support metabolic management in athletes without diabetes. We aim to distinguish between purely physiological data and its actual translation into measurable improvements in training quality and performance. To this end, we will analyze the technical and interpretive limitations that require practitioners—coaches and sports nutritionists—to exercise great caution when drawing final conclusions.

2. Pathophysiological and Metabolic Context

Continuous glucose monitoring (CGM) in a sports setting is primarily used to characterize metabolic load; however, interpreting the data requires a clear distinction between exercise physiology and diabetes pathophysiology. Although the physiological rationale for using CGM in sports is strong, current interpretive guidelines remain significantly less well-established than those in diabetology [7, 20, 21].

In athletes without diabetes, blood glucose is tightly regulated by physiological mechanisms. Despite this, its pattern during training and recovery differs significantly from clinical patterns in physically inactive individuals. As for the group of patients for whom glucose control is of the utmost importance, these are undeniably people with diabetes, for whom CGM is primarily intended. In type 1 diabetes, the pathophysiological challenge is a deficiency of endogenous insulin, which impairs glucose control mechanisms, increasing the risk of episodes of hypo- and hyperglycemia [20]. In healthy athletes, deviations in CGM readings primarily reflect adaptation to exercise, the dynamics of carbohydrate intake, and neuroendocrine stress, rather than metabolic dysfunction [7, 22]. Data analysis shows that endurance athletes often exhibit greater glycemic variability than sedentary individuals [7, 23]. Studies of para-cyclists have shown that 91% of the time, blood glucose levels remain within the euglycemic range, with episodes of hyperglycemia being closely correlated with meal intake and exercise intensity [24]. It should be emphasized that during extreme exercise, values exceeding 140 mg/dL may represent a physiological response rather than a pathological condition [22].

Glucose plays a central role in the energy metabolism of working muscles, especially under conditions of increased intensity, which limits the efficiency of fat oxidation. Current literature confirms that glucose availability directly correlates with exercise performance and the ability to maintain the desired exercise intensity [7, 25]. Nevertheless, CGM does not measure muscle glycogen levels or directly assess carbohydrate flux and therefore cannot be treated as a simple indicator of fuel levels [26]. Because only a limited pool of glucose is available in the bloodstream, its homeostasis must be maintained within a very narrow range [25]. Studies confirm that higher carbohydrate intake before and during exercise is associated with improved performance parameters; however, intense exercise can also elevate blood glucose levels through catecholamine-mediated increases in hepatic glucose production [22, 27].

The greatest challenge in working with CGM is that there is no single “standard” blood glucose profile for an athlete. Even among two athletes with similar body types and the same training plan, readings can vary significantly because metabolic responses are shaped by unique genetic predispositions, lifestyle, and current recovery status. In practice, this means that CGM most often reveals each athlete’s “metabolic fingerprint,” making universal, averaged nutritional recommendations of little use for personalized planning [27, 28, 29].

The impact of diet on this profile is clear, but it does not always translate into athletic performance. For example, low-carbohydrate (LCHF) diets lead to a flatter blood glucose curve and reduced glucose variability (CV), which at first glance appears to be "ideal stability," but does not necessarily mean better performance during high-intensity exercise [29]. Similarly, consuming foods with a low glycemic index effectively smooths the blood glucose curve, though this often does not yield a measurable improvement in performance [30]. On the other hand, attempts to "control" blood glucose during exercise using CGM yield more stable readings; however, stabilizing blood glucose levels alone does not always translate into a meaningful increase in power or endurance [28]. It is also important to remember that the blood glucose profile itself changes with athletic condition—during periods of training overload (overreaching), we often observe lower glucose levels and a reduced ability of muscles to utilize carbohydrates during moderate exercise, which demonstrates that the CGM curve is a dynamic record of the body's current condition, rather than a static indicator [31].

Current data indicate that CGM is a useful tool for describing metabolic load; however, sport-specific interpretation thresholds are lacking [7, 21]. An additional limitation is measurement precision—CGM accuracy during exercise is lower than at rest, which results, among other things, from the physiological delay between blood and interstitial fluid [24, 32]. For this reason, readings in athletes should not be interpreted in clinical terms as they are for patients with diabetes [20, 32]. In the active population, most fluctuations in blood glucose are considered physiological responses to training stress rather than clinical abnormalities [22, 30].

3. Diagnostic and Interpretational Challenges of CGM in Elite Athletes

The main barrier to the widespread implementation of CGM in elite sports is the lack of standardized sports benchmarks. Clinical metrics, such as Time in Range (TIR) and glycemic variability, were developed based on the risk of diabetes complications and have gained broad consensus within the diabetes community [11, 21, 33]. Meanwhile, athletes lack analogous reference points; their metabolic profiles are highly atypical and closely correlated with training load, carbohydrate availability, and physiological stress [7]. Furthermore, in diabetes care, these thresholds are primarily used to prevent clinical events, whereas in sports we seek to understand how glucose affects performance, making a simple transfer of these metrics methodologically risky [9, 33].

An additional challenge is systemic variability—studies indicate that even when using different devices on the same athlete, we obtain divergent results, which makes it difficult to establish consistent reference databases [17, 34]. Technical challenges cannot be overlooked either. Sensor accuracy during exercise is lower than at rest, due to both the physiological lag between blood and interstitial fluid and mechanical disturbances such as microvibrations or fluctuations in skin temperature [5, 10, 35]. Although innovative sweat sensors aim to eliminate these shortcomings by integrating biochemical and thermal parameters, their practical application in field conditions is still limited by individual differences in sweat secretion intensity [35, 36]. As a result, distinguishing between physiological training adaptation and the onset of metabolic dysfunction requires considerable expertise—what might be considered a pathology in a clinical setting is often merely the body's normal response to extreme exertion in a competitive athlete [5, 7].

4. Nutritional Optimization and Training Quality Control

The use of CGM in sports is primarily effective as a supportive tool, allowing for in-depth observation of glycemic responses to specific nutritional strategies. Although we currently lack evidence to consider sensor readings a direct indicator of optimal real-time carbohydrate availability, these systems are becoming a valuable component of broadly defined monitoring [12, 21]. Integrating CGM into an athlete's routine enables precise correlation of blood glucose trends with meal timing, which facilitates, among other things, optimizing the rate at which blood glucose returns to baseline after the most intense training sessions [2, 21].

From an educational perspective, CGM functions similarly to clinical systems, significantly increasing an athlete's self-awareness [13]. Observations confirm that the ability to continuously track metabolic responses to specific foods promotes behavioral changes and leads to more informed dietary choices [4]. It is worth noting, however, that the role of CGM is limited here to an educational function, rather than serving as an authoritative indicator of performance [12]. Integrating this data with training load provides sports dietitians with a much more effective tool for personalizing strategies, which is crucial for effective post-exercise glycogen resynthesis [2, 21].

5. Technological Integration: AI and Future Perspectives

The most promising direction for the development of metabolic monitoring is a shift away from analyzing a single glycemic signal toward integrated decision-support systems. Due to the ambiguity of glucose readings, the future lies with models that use artificial intelligence (AI) to synthesize data from multiple sources in real time, including heart rate (HR), heart rate variability (HRV), body temperature, and dietary data [2, 21]. This approach makes it much easier to distinguish between physiological adaptation and warning signs—such as low energy availability (REDs) or overtraining—which can be impossible to interpret unambiguously from a single CGM reading [7, 21].

The pursuit of multichannel analytics aims to transform raw data into meaningful information that genuinely supports the decision-making process of coaches and physicians [2]. Emerging integrated platforms enable real-time health monitoring, which, in the long term, significantly improves the quality of personalized training plans [37]. In summary, the greatest challenge for modern sports medicine is not glucose measurement itself, but assigning it a precise biological meaning that will serve as a useful guide in achieving high athletic performance.

6. Practical Implications for Sports Medicine and Training

The introduction of glucose monitoring into daily sports practice raises a number of questions for coaching staff, questions that sports medicine is only beginning to answer. CGM should not be treated as a digital "autopilot" for the athlete, but rather as a sophisticated mirror reflecting the physiological processes occurring during exercise. The key challenge here is to "read" this mirror correctly—coaches and dietitians must remember that even the most precise sensor cannot replace a deep understanding of the specific nature of a given athlete's exertion [2, 38].

Instead of reacting impulsively to every momentary spike or drop in the blood glucose curve, coaching staff should focus on identifying long-term patterns. Data from large cohorts of active individuals show that blood glucose levels during intense exercise often fall outside the clinical norm (70–140 mg/dL), which, in a healthy athlete, is a natural adaptive response rather than an alarm signal [22]. Therefore, CGM works best as a "descriptive" tool that, when combined with a food diary and a training log, allows a dietitian to design fueling strategies more effectively [2, 38]. Let's remember that in competitive sports, context determines the value of the data—the same glucose level at the 30-minute mark of a marathon and at the 30-minute mark of a leisurely bike ride means something completely different.

At the same time, we must guard against the trap of "analytical paralysis." The abundance of available indicators often obscures the goal of optimizing health and performance. Although analytical tools offer us an ever-wider range of metrics, in practice we should limit ourselves to a few key questions relevant to the training process, avoiding attempts to forcefully fit an athlete into clinical diabetes templates [14, 39, 40]. We must also maintain a healthy skepticism toward the technical aspects of measurement—errors arising from inter-serum lags or postprandial specifics can lead to erroneous conclusions if not verified through the lens of medical knowledge [41]. From a sports medicine physician's perspective, CGM achieves its highest diagnostic value when we are seeking answers to specific clinical concerns: monitoring unusual fatigue, suspecting metabolic disorders, or attempting to correlate an athlete's subjective well-being with objective exercise intensity [42, 43, 44].

7. Conclusions

In summary, continuous glucose monitoring opens up a fascinating, though still unexplored, chapter in sports medicine. This technology, adapted from the field of metabolic disease treatment, has become a window into the physiology of athletes; however, looking through it requires exceptional caution. Current scientific evidence clearly suggests that CGM is an extremely promising tool, but it still needs a "sports framework"—methodological standardization, specific reference standards, and, above all, humility in the face of the human body's complexity [2, 19, 45].

The most important conclusion from this analysis is the need to abandon attempts at a rigid, clinical approach to glycemic data in sports. Instead of searching for an "ideal line" on a graph, we should learn to interpret glycemic variability as a record of the body's struggle to maintain homeostasis under extreme conditions. The future of this monitoring does not lie in increasingly complex algorithms designed to do the thinking for us, but in the intelligent integration of CGM data with a broad spectrum of information—ranging from the athlete's subjective feelings, through clinical markers, to objective training parameters.

From the perspective of future research, it will be crucial to move away from attempts at rigid parameter quantification toward qualitative analysis, supported by artificial intelligence that can "understand" the exercise context better than current systems. CGM should remain a source of valuable hypotheses, not the sole arbiter of training or dietary quality. The role of a licensed clinician and an experienced coach remains irreplaceable in this process—it is they who, using available technology, must retain the role of final arbiters in the decision-making process. The line between safe adaptation and metabolic overload is extremely fine, and technology—though powerful—cannot abdicate responsibility for an athlete's health and career. Ultimately, CGM is just a tool; the music—that is, the strategy for achieving peak performance—is still composed by people.

Disclosure

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All authors have read and agreed with the published version of the manuscript.

Funding

This research was conducted without any external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Acknowledgments

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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