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Human Kinetics
METHODOLOGY REVIEW

The Use of Continuous Glucose Monitors in Sport: Possible Applications and Considerations

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This review discusses the potential value of tracking interstitial glucose with continuous glucose monitors (CGMs) in athletes, highlighting possible applications and important considerations in the collection and interpretation of interstitial glucose data. CGMs are sensors that provide real time, longitudinal tracking of interstitial glucose with a range of commercial monitors currently available. Recent advancements in CGM technology have led to the development of athlete-specific devices targeting glucose monitoring in sport. Although largely untested, the capacity of CGMs to capture the duration, magnitude, and frequency of interstitial glucose fluctuations every 1–15 min may present a unique opportunity to monitor fueling adequacy around competitive events and training sessions, with applications for applied research and sports nutrition practice. Indeed, manufacturers of athlete-specific devices market these products as a "fueling gauge," enabling athletes to "push their limits longer and get bigger gains." However, as glucose homeostasis is a complex phenomenon, extensive research is required to ascertain whether systemic glucose availability (estimated by CGM-derived interstitial glucose) has any meaning in relation to the intended purposes in sport. Whether CGMs will provide reliable and accurate information and enhance sports nutrition knowledge and practice is currently untested. Caveats around the use of CGMs include technical issues (dislodging of sensors during periods of surveillance, loss of data due to synchronization issues), practical issues (potential bans on their use in some sporting scenarios, expense), and challenges to the underpinning principles of data interpretation, which highlight the role of sports nutrition professionals to provide context and interpretation.

Keywords: continuous glucose monitor, interstitial glucose, carbohydrate availability, low energy availability

The performance of sport and other physical activities, particularly those involving prolonged submaximal or intermittent high-intensity exercise, is impaired by low carbohydrate (CHO) availability (Karelis et al., 2010), which is defined as an insufficient glycogen concentration and inadequate blood glucose (BG) supply in comparison with the fuel needs of an exercise session (Burke, Hawley, et al., 2018; Impey et al., 2018). Targets for CHO intake, to optimize performance and support health and well-being, in the everyday diet and during competition are a prominent feature of sports nutrition guidelines (Thomas, Erdman, et al., 2016). The evolution of these guidelines has included the concept of specificity to the athlete and to the exercise scenario (personalization) and differences in intake between and within days according to the fuel requirements and goals of each session of exercise (periodization; Burke, Hawley, et al., 2018; Impey et al., 2018). More recently, sports nutrition guidelines have incorporated recommendations relating to energy availability (EA), matching energy intake (EI) according to the energy demands of exercise to ensure that body metabolism and function are optimized (Mountjoy et al., 2018). Fluctuations in energy and CHO availability may be undertaken deliberately or inadvertently and may be advantageous or deleterious, according to the scenario and the athlete's goals. Tools and biomarkers that monitor energy and CHO status are of benefit to athletes, coaches, and sports nutrition professionals. Continuous glucose monitors (CGMs), which monitor interstitial glucose concentrations in real time, are a recent addition to the athlete's toolbox.

Although CGMs were initially designed to assist in the clinical management of both insulin-dependent and noninsulin-dependent diabetes, there is now interest in the application of real-time glucose monitoring to athletic populations (Petrovski et al., 2004). Several case studies have incorporated the use of CGMs to report interstitial glucose responses to exercise in an effort to characterize CHO availability of athletes when participating in endurance and ultra-endurance events (Doering et al., 2019; Francois et al., 2018; Ishihara et al., 2020; Sengoku et al., 2015). However, manufacturers of CGM devices have either identified or created a wider interest among athletes to maintain optimal glucose levels during training (Abbott Laboratories, 2020) and now market these products as a tool to enable athletes to "push their limits longer and get bigger gains" (Supersapiens INC, 2021). Whether this is a justified need, creating value to the athlete, or simply represents clever marketing of existing technology to an audience that is receptive to real-time data requires interrogation.

The primary aim of this paper is to explore the use of CGMs among athletic populations, highlighting possible applications and important considerations in the collection and interpretation of interstitial glucose data to optimize health, well-being, and performance. This article will provide an overview of currently available CGM devices, the potential applications of their use within sport-focused scenarios, and expected challenges associated with the use and interpretation of CGM data among athletes. Although the initial focus of CGM use has been the manipulation of CHO intake to meet CHO availability goals around exercise, we will also consider its potential for monitoring EA status.

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CGM Technology

CGMs are medical devices that provide the user and their health care professional with a continuous measurement of interstitial glucose across 24-hr periods (DeSalvo & Buckingham, 2013). CGM technology enables the user and practitioner to view interstitial glucose responses to dietary intake, including CHO ingestion and physical activity. The devices also allow observation of nocturnal interstitial glucose with (near) real-time information, allowing undesirable changes to be appropriately managed via adjustments to dietary intake, prescribed medications, and/or insulin (Forde et al., 2019; Klonoff, 2005). Such devices may be used in the management of diabetes mellitus, providing an opportunity to monitor and respond to glucose fluctuations on an ambulatory basis (Monsod et al., 2002).

Traditionally, BG data have been collected either via self-monitoring of capillary BG using a glycemic reader or through venous blood samples analyzed for BG concentration in the laboratory or hospital ward (Rydén et al., 2013). These point-in-time assessments are typically used to reflect on BG data retrospectively, making it difficult for individuals with diabetes and athletes to adjust daily dietary intake in response to glucose fluctuations. In contrast, CGM devices capture time series data that are representative of recent food intake and exercise, providing an opportunity to adjust insulin dosing and dietary intake in (near) real time. CGM technology provides an alternative method of collecting an estimate of BG levels and has been shown to provide glucose estimates that are comparable with self-monitoring BG values using venous sampling in normoglycemic individuals (Akintola et al., 2015). Unlike the aforementioned techniques, CGMs report accumulated averages of interstitial glucose every 1–15 min, providing the user with near real-time interstitial glucose data (Mauras et al., 2013). However, as CGM devices measure interstitial glucose rather than BG concentrations, a notable 5–10 min delay exists between actual BG and reported CGM glucose readings (Schmelzeisen-Redeker et al., 2015).

Currently available CGMs require the user to insert an indwelling sensor into the subcutaneous tissue (e.g., abdominal wall, upper buttocks, or back of the upper arm) to indirectly measure BG via the interstitial fluid (Danne et al., 2017; Klonoff, 2005; Vaddiraju et al., 2010).The most common CGMs utilize a glucose oxidase-soaked electrode that is inserted into the subcutaneous tissue of the user and ultimately catalyzes the glucose oxidase reaction, producing an electrical current that is equivalent to the concentration of glucose in the interstitial fluid (Figure 1). Interstitial glucose concentration is used to estimate BG concentrations through algorithmic estimations that are proprietary to the manufacturers of each device (Acciaroli et al., 2018; Hoss & Budiman, 2017). CGMs can last anywhere from 3 to 14 days depending on the type of sensor used.

To effectively convert the electrical current generated by the glucose oxidase reaction into a useful glucose value, CGM technology requires either factory calibration in the laboratory during manufacture or user-facilitated calibration of the sensor in vivo via BG testing using a glucometer (Hoss & Budiman, 2017). Typically, sensors that rely upon user-facilitated calibration require glucose readings from a glucometer between one to four times per day (Rodbard, 2016).

When inserted into the subcutaneous tissue, the sensor delivers glucose information via wireless technology from a reusable transmitter and/or a disposable sensor to a data receiver or smartphone application. Depending on the manufacturer, glucose data may either synchronize automatically or require manual swiping of the receiver (smartphone) over the sensor to avoid data loss. The accompanying smartphone applications, developed by the CGM manufacturer or a third party, enable the user to view a glucose snapshot, 24-hr periods of continuous glucose data, daily glucose patterns, and hypoglycemic episodes either in real time or retrospectively. Although most smartphone applications also allow the user to record daily CHO intake and exercise events, the ability to further analyze these data alongside interstitial glucose remains limited. At the completion of the collection period, data can be downloaded for analysis directly from the mobile application or via computer-based software. Specifications of popular CGMs currently approved for use within Australia are outlined in Table 1.

Methods of Assessing CGM Data

CGMs produce a large volume of data within very short time frames, presenting users and practitioners with the challenge of reviewing and interpreting relevant glucose readings (Rodbard, 2016). To

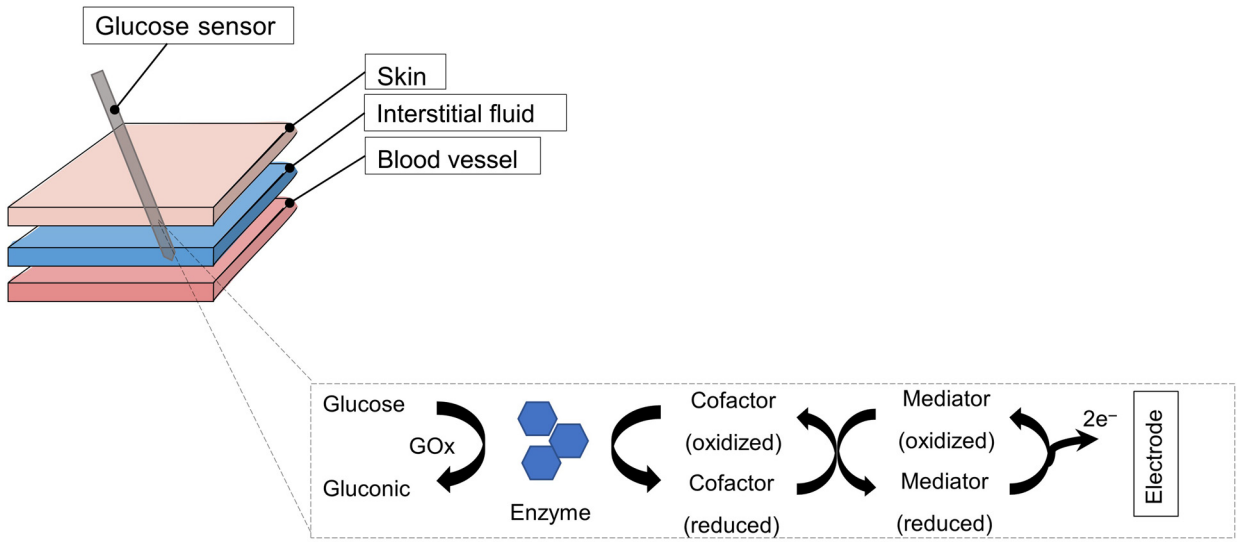

Figure 1 — The monitoring principle of continuous glucose monitors. *Note*. GOx = glucose oxidase.

Table 1 Specifications of Commercially Available CGM Systems

Model	Accuracy (MARD)	Indications for use	Sample rate	Sensor lifetime	Body position	Calibration requirement	Data storage	Smart device capability	Waterproof	Price (AUD)	TGA approved
Abbott Freestyle Libre	11.4% [28]	NIDDM or IDDM	15 min	14 days	Back of upper arm	Not required	8 hr	Y—Freestyle LibreLink app	Y—1 m for up to 30 min	$92.50	Y
Abbott Freestyle Libre 2	9.3% [29]	NIDDM or IDDM	15 min	14 days	Back of upper arm	Not required	8 hr	Y—Freestyle LibreLink app	Y—1 m for up to 30 min	$92.20	Y
Abbott Libre Sense Glucose Sport Biosensor	Not available	Athletes	1 min	14 days	Back of upper arm	Not required	8 hr or constant data via Bluetooth	Y—Supersapiens app	Y—1 m for up to 30 min	$163	N
Dexcom G5	9.0% [30]	NIDDM or IDDM	5 min	7 days	Abdomen or upper buttocks	12 hourly	30 days	Y—Dexcom G5 Mobile System	Y—Water resistant 2.4 m for 24 hr	$110	Y
Dexcom G6	9.0% [31]	NIDDM or IDDM	5 min	10 days	Abdomen or upper buttocks	Not required	30 days	Y—Dexcom G6 app	Y—Water resistant 2.4 m for 24 hr	$110	Y
Medtronic Guardian Sensor 3	9.6% [32]	IDDM or NIDDM	Nil	6 days	Abdomen or upper buttocks	12 hourly	Nil—Retrospective	Y—Guardian Connect app	Y—2.5 m for up to 30 min	$75[a]	Y

Note. MARD = mean absolute relative difference; CGM = continuous glucose monitoring; App = application; TGA = therapeutic goods administration; Y = yes; N = no; NIDDM = noninsulin dependent diabetes mellitus; IDDM = insulin dependent diabetes mellitus.
[a]Requires additional hardware.

reduce this burden, it is important that straightforward and clinically useful estimates of glycemic variability are established.

Several indices of glycemic variability have been proposed to assist in the interpretation of CGM data (Table 2); these include *SD*, interquartile range, mean of daily differences (MODD), and mean amplitude of glucose excursion (MAGE; Ceriello et al., 2008; Hill et al., 2011, Kilpatrick et al., 2006, Service et al., 1987). MAGE is a useful parameter for quantitating major fluctuations in glucose that occur within a 24-hr period (Service et al., 1987) and is complemented by MODD, which calculates the mean of differences between glucose values on consecutive days at the same time. Higher MODD values represent larger differences in day-to-day whole-body glycemia and have been associated with complications in individuals with diabetes, including increased oxidative stress, endothelial dysfunction, and cardiovascular events (Ceriello et al., 2008; Kilpatrick et al., 2006).

Within-day (MAGE) and day-to-day (MODD) measures of glycemic variability need to be interpreted against the background of the accuracy and performance of the device itself. The mean absolute relative difference (MARD) averages the absolute error that exists between the values produced by the CGM and the reference values provided by the gold standard measurement system (e.g., Yellow Springs Instrument), with a lower mean absolute relative difference value implying better agreement between the two measurement systems (Danne et al., 2017). However, it is unclear whether current methods that convert the large data sets that CGMs provide into single, easily interpreted metrics are optimal, and more sophisticated analytical methods required to provide meaningful insight enhance the practical utility of CGM data for athletes.

Use of CGMs in Diabetes Management

The use of CGMs in the management of diabetes mellitus has been reviewed extensively elsewhere (Maiorino et al., 2020) and, therefore, will not be a major focus of this review. Briefly, however, assessment of glycemic control either through self-monitoring of capillary glucose or continuous measurement of interstitial glucose is important for the management of diabetes mellitus (American Diabetes Association, 2020). Unlike traditional methods of glucose monitoring, CGMs are a consumer-facing tool that may identify unsolicited episodes of hyperglycemia and hypoglycemia in real time, providing an opportunity for people living with diabetes to promptly respond to undesirable changes in glucose by adjusting dietary intake and/or insulin dosing accordingly (Mauras et al., 2013). Furthermore, this information may allow health professionals to adjust medication doses, prescribed exercise regimes, and dietary intake accordingly. As a result of more frequent, accurate, and reliable tracking of glucose enabled by CGMs, users have reported substantial decreases in 24-hr glycemic variability, subsequently resulting in an overall reduction in hypoglycemic episodes and glycated hemoglobin (Pickup et al., 2011). In particular, the frequent monitoring of interstitial glucose (every 1–15 min for 6–14 days) via CGMs has enabled an increase in the accuracy of insulin doses that are prescribed to those with diabetes mellitus (Vashist, 2013).

Use and Application of CGMs in Sport

Although the application of monitoring glucose via CGMs has been largely untested in sport, existing CGM technology has been applied

Table 2 Measures of Glycemic Variability (Hill et al., 2011)

Measure of glycemic variability	Description	Formulae	Variables
MAGE	Describes major fluctuations in whole-body glycemia	$\text{MAGE} = \sum \frac{\lambda}{\chi}$ if $\lambda > v$	λ = blood glucose changes from peak to nadir χ = number of valid observations v = 1 *SD* of mean glucose for a 24-hr period
MODD	Describes between-day variability in glucose	$\text{MODD} = \sum_{t=t_1}^{t_k} \frac{\sum_{t=t_1}^{t_k} G_{t-G_{t-1,440}}}{k}$	k = number of observations with an observation 24 hr ago G = glucose measured t = time (in minutes)
MARD	Assesses the accuracy of the CGM	$\text{MARD} = \text{mean}\left(\text{abs}\left(\frac{\text{CGM} - \text{BG}}{\text{BG}}\right)\right) \times 100$	abs = absolute CGM = continuous glucose monitor BG = blood glucose

Note. MAGE = mean amplitude of glycemic excursion; MODD = mean of daily differences; MARD = mean absolute relative difference.

Table 3 Applications Developed to Facilitate CGM Use in Athletic Populations

Mobile application	Indications for use	Intended outcome	Affiliated CGM	Features	Data storage, hr	Approved use
Supersapiens https://www.supersapiens.com	Athletes	Fueling for exercise	Abbott Libre Sense Glucose Sport Biosensor	Instant glucose readings via Bluetooth technology, logging of "events" (e.g., meal and activity times) via mobile application	8	Ireland, Italy, France, Germany
Veri https://www.veri.co	Healthy individuals	Metabolic health	Abbott Freestyle Libre	Logging of "events" (e.g., meal and activity times) via mobile application	8	EU, United Kingdom, United States, Switzerland, Iceland, Norway
Levels https://www.levelshealth.com	Healthy individuals	Metabolic health	Abbott Freestyle Libre	Logging of "events" (e.g., meal and activity times) via mobile application	8	United States
Ultrahuman https://ultrahuman.com	Healthy individuals, athletes	Fueling for exercise, metabolic health	Abbott Freestyle 2	Logging of "events" (e.g., meal and activity times) via mobile application	8	India

Note. CGM = continuous glucose monitor.

to sports nutrition with the advent of athlete-specific devices, such as the Abbott Libre Sense Glucose Sport Biosensor (Abbott Diabetes Care Inc.). Furthermore, advances in the development of software platforms offer interpretations suited to sports and health nutrition goals, most specifically using glucose as a proxy for the adequacy of fueling during exercise or a marker of metabolic health (Table 3). Companies claim that real-time glucose tracking can help to optimize training and recovery, providing a minute-by-minute energy management system to ensure you will "never bonk again" (Supersapiens INC, 2021). Given the current hype around the potential use of CGMs in sport and the recent increase in accessibility of these devices to athletes, it is important to explore possible applications of CGMs in sport while maintaining a conservative approach to the practical utility of these devices until an approrpiate evidence base is established. To date, a small number of studies have investigated athletes' glucose responses to CHO intake during endurance activities using CGM-derived glucose data with the hope of providing athletes, coaches, and sports nutrition professionals with insight into optimizing fueling strategies. Indeed, as a reduction in fasting BG has been observed after 5–6 days of exposure to low EA (LEA; Koehler et al., 2016; Loucks, 2006; Loucks & Thuma, 2003), an additional use of CGMs may be to provide a biomarker for fluctuations in metabolic homeostasis associated with energy imbalances. However, due to the complexities of the interactions between CHO ingestion and exercise, CHO availability, EA, and systemic glucose, further research is required to determine the utility of CGM technology as a tool to assess fueling strategies and EA among athletes (Figure 2).

CGM and Exercise Fuel Targets

Almost a century ago, reductions in BG were reported in association with impaired performance in marathon runners (Levine et al., 1924). Subsequently, it was shown that strategies involving CHO intake during a race could prevent hypoglycemia and its associated clinical symptoms and improve race outcomes (Gordon et al., 1925). Although BG has historically been used as a proxy for CHO availability and utilization in sport as a fuel for the contracting muscle or a precursor for muscle glycogen synthesis, it is noted that circulating concentrations fail to illustrate the dynamic changes in rates of BG appearance from the liver or gastrointestinal tract and subsequent uptake into tissues (Doering et al., 2019). Nevertheless,

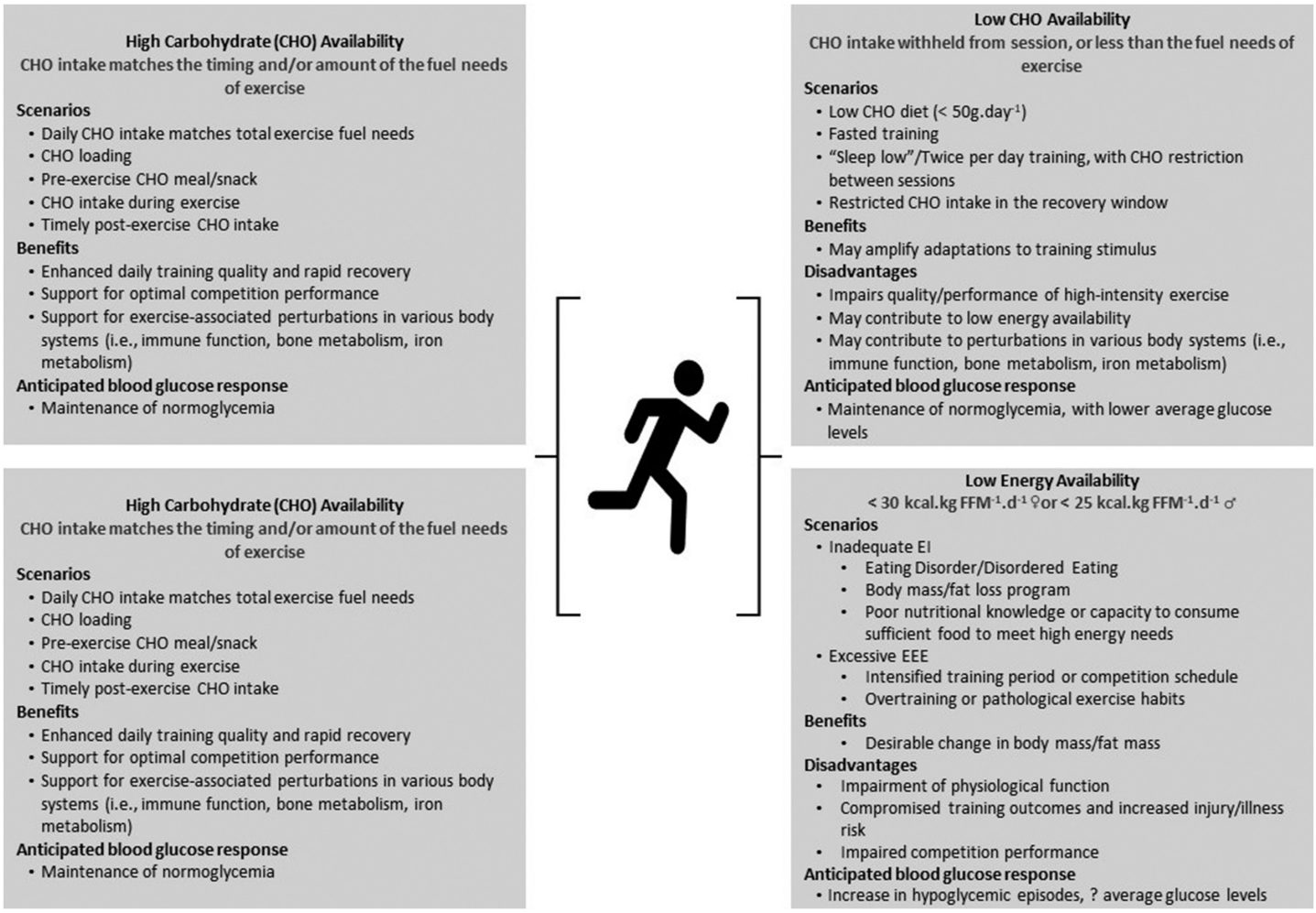

Figure 2 — Scenarios and considerations around CHO availability and energy availability in athletes. CHO = carbohydrate; EI = energy intake; EEE = exercise energy expenditure; FFM = fat free mass.

it has been assumed that higher or sustained BG concentrations during exercise reflect the success of within-session CHO intake in preventing hypoglycemia, providing an ongoing substrate for muscle contraction to spare or replace dwindling muscle glycogen supplies, and supporting liver glycogen storage (Karelis et al., 2010; Rollo et al., 2020).

Classical laboratory protocols for investigating fuel availability and utilization during exercise monitor BG concentrations via the serial sampling of venous or capillary blood, which often requires a brief pause in exercise to allow sample collection. In contrast, CGM potentially offers the capability to obtain information on interstitial glucose during continuous laboratory and field-based exercise, including real-life sporting competitions. In the instance that monitoring interstitial glucose via CGMs provides insight into fuel availability, researchers may undertake more sophisticated investigations of high-performance athletes in real-world events and with real-world nutrition strategies. CGM devices may allow practitioners, coaches, and athletes to gain feedback on individual training and nutrition practices and make adjustments in response to undesirable interstitial glucose changes during both training and competition. Indeed, it is this utility as a "personal nutrition coach" that dominates the marketing of the sports-specific devices and platforms, with companies suggesting that athletes can hone their choice of the timing, amount, and type of CHO sources consumed during exercise toward an optimal fueling pattern (Supersapiens INC, 2021). For example, CGMs may be of use in detecting and preventing perturbations to glucose concentrations at the onset of exercise following the intake of pre-session CHO (e.g., reactive hypoglycemia; Jeukendrup & Killer, 2010). In addition, the intake of CHO in the recovery period after or between events might be manipulated to support sustained glycemia commensurate with maximal glycogen resynthesis (Burke et al., 2017). It is important to note that, despite the enthusiastic marketing and athlete testimonials about the use of CGMs for these purposes, there is a lack of evidence that CGMs can identify optimal fueling practices or improve athlete fueling practices.

Because of the recent advent of CGM use by athletes, there are few published studies and case histories of its use (summarized in Table 4). The most popular study theme has been monitoring of athlete glucose profiles during single-day (Ishihara et al., 2020; Sengoku et al., 2015) and multi-day (Francois et al., 2018) ultra-endurance events. During a single-day 165-km ultra-trail race, athletes who consumed less CHO throughout the race tended to have lower glucose levels and took longer to complete the race (Ishihara et al., 2020). Training status has also been observed to influence glucose variability as a recreational marathon runner exhibited greater fluctuations in glucose concentration when compared with an elite runner who maintained normal glucose levels

Table 4 Studies of Glucose Using Continuous Glucose Monitors in Various Endurance Sporting Events

Publication	Subjects	Glucose monitor	Response measured	Comments
Ishihara et al. (2020)	Trained long-distance runners (four males + three females)	Freestyle Libre FGM inserted for approximately 48 hr (24 hr prior to and for the duration of the 165 km 2019 Ultra-Trail Mt Fuji race)	Glucose profile and CHO intake during ultramarathon race	All participants (except one) within normoglycemic range (3.4–13.3 mmol·L^{-1}) during the race with CHO supplying ~78% of total energy intake. CHO intakes ranged from 0.27 to 1.14 g·kg^{-1}·hr^{-1} during the race. Runners who consumed less than 0.8 g·kg^{-1}·hr^{-1} of CHO tended to have slower running speed associated with lower interstitial glucose levels
Doering et al. (2019)	Trained cyclists (six males + one female)	Medtronic iPro2 CGM with Enlite Sensor inserted for a total of 9 days	Glucose and muscle glycogen response to repeated CHO loading (10 g·kg^{-1}·day^{-1} for 4 days each)	No difference in postexercise glucose concentration between cycling trials (4.1 ± 0.6 mmol·L^{-1}). Interstitial glucose AUC significantly higher during CHO Load 1 (390.2 ± 28.9 mmol·L^{-1}·hr^{-1}) than Load 2 (376.8 ± 31.1 mmol·L^{-1}·hr^{-1})
Francois et al. (2018)	Trained adventure racers (six males + two females)	Medtronic iPro2 CGM with Enlite Sensor inserted for the duration of the 326 km 2012 GodZone adventure race (5 days)	Glucose profile during 5-day adventure race	No significant difference in mean glucose during the race. Variability in 24 hr interstitial glucose significantly higher during the race compared with prerace (0.5 ± 0.1 mmol·L^{-1} vs. 0.7 ± 0.3 mmol·L^{-1}, p = .02). Minimum interstitial glucose during the race was significantly lower than prerace (4.1 ± 0.3 mmol·L^{-1} vs. 3.7 ± 0.2 mmol·L^{-1}, p = .05). Three CGMs dislodged during the race. Although no dietary intakes were recorded, it was anticipated that competitors did not meet their energy (and CHO) requirements throughout the race
Thomas, Pretty, et al. (2016)	Trained cyclists (seven males + three females)	2 × Medtronic iPro2 and 1 × Medtronic guardian CGM inserted per athlete for 6 days	Glucose profile during 6 days free living	Four of the participants recorded glucose levels >6.0 mmol·L^{-1} for ~70% of the total time, whereas six participants had glucose levels of 4.0–6.0 mmol·L^{-1} for 85% of the time. CHO supplied ~45% to 65% of total energy intake. Individual tolerance of CHO intake may influence glucose variability
Sengoku et al. (2015)	Well-trained/trained ultramarathon runners (two males)	Medtronic MiniMed CGM inserted for approximately 45 hr (35 hr prior to and for the duration of the 100 km Tsurunuma ultramarathon race)	Glucose profile and CHO intake during 100 km ultramarathon race	The elite ultramarathon runner maintained a normal glucose level (~5.3–8.0 mmol·L^{-1}) despite consuming less CHO (249 g) than the other runner throughout the race. The recreational runner had greater glucose variability throughout the race (~3.4 to 7.6 mmol·L^{-1}) and experienced a rapid decline in glucose (hypoglycemia) toward the end of the race despite a higher CHO intake (366 g)

Note. AUC = area under the curve; CGM = continuous glucose monitor; FGM = flash glucose monitoring; CHO =carbohydrate.

throughout the race despite consuming less CHO (Sengoku et al., 2015).

CGMs have also been used to quantify glucose responses to repeated CHO loading interventions in trained cyclists (Doering et al., 2019). Although no difference was apparent in glucose concentrations between cycling trials, glucose area under the curve was higher among cyclists during the first CHO loading intervention (390.2 ± 28.9 mmol·L^{-1}·hr^{-1}) compared with the subsequent intervention (376.8 ± 31.1 mmol·L^{-1}·hr^{-1}). Despite this difference, muscle glycogen supercompensation was similar between trials. These findings suggest that the observed change in glucose response measured via a CGM was not reflective of differences in glycogen restoration per se and, thus, did not provide a direct indication of substrate storage or availability (Doering et al., 2019). A final study investigated the accuracy (previously described as mean absolute relative difference) and performance metrics of CGM devices in athletes. Although CGM-measured interstitial glucose was within ~10% of BG in athletes (Thomas et al., 2015), it is important to consider whether CGMs are sufficiently sensitive to reflect subtle changes in fueling status and exercise that have meaningful implications on athlete health and performance. In addition, as individual athletes respond differently to the ingestion of CHO (Thomas et al., 2016), caution should be used when interpreting CGM-derived glucose data as a gauge for fueling adequacy during exercise.

LEA and Existing Screening Tools

LEA refers to a state of energy deficiency resulting from a mismatch between dietary EI and exercise energy expenditure, leading to a reduction in the available energy to support primary physiological systems, with its numerical calculation expressed relative to an athlete's fat-free (metabolically active) mass (FFM; Logue et al., 2020). LEA is the key exposure variable underpinning the syndromes commonly known as relative energy deficiency in sport (Mountjoy et al., 2018) and the female athlete and male athlete triad (De Souza et al., 2022). Periodic exposure to energy deficits within and between days is an inherent part of life and may be experienced during activities known to enhance sports performance (e.g., body composition manipulation or intensified training). However, the severity and duration of exposure to LEA can be associated with disturbances to normal physiological functioning, often resulting in an increased risk of illness and injury, and a decrease in well-being, training adaptation, and sporting performance (De Souza et al., 2022). These syndromes can have substantial long-term repercussions for an athlete with the potential to prematurely end their sporting career and cause chronic health problems, such as premature osteoporosis (Mountjoy et al., 2018).

Because of the substantial impact of relative energy deficiency in sport or the triad on an athlete's health and career, there is interest in early detection and prevention of problematic LEA (Bowler et al., 2022). Screening tools include the LEA in females questionnaire (Melin et al., 2014) and its male counterpart (Lundy et al., 2022), which might be followed up with assessments of metabolic health (e.g., resting metabolic rate), reproductive health, bone mineral density, and other health issues (Logue et al., 2020). Meanwhile, calculations of EA can be made by gathering information on the individual's EI, exercise energy expenditure, and FFM (Burke, Lundy, et al., 2018). However, considerable time, resources, and financial investment are required to assess an athlete's EA status from health checks (Mountjoy et al., 2018), and limitations of EA estimates include a high level of burden on the athletes and the health professional, disconnect between the period of assessment and the time course of the development of health problems, and substantial errors in calculations (Heikura et al., 2021). Therefore, to promote early identification and management of athletes with LEA, new approaches or innovative use of existing technologies are required (Dipla et al., 2021).

CGM and LEA

It is understood that acute reductions in BG occur as a result of imbalances between EI and total energy expenditure and, thus, may be an important early warning sign that LEA is disturbing metabolic homeostasis (Koehler et al., 2016; Loucks, 2006; Loucks & Thuma, 2003). The effect of an acute (2 days), severe energy deficit (EI 270 kcal/day; total daily energy expenditure ~4,000 kcal/day) on interstitial glucose responses using CGMs has been investigated in 23 healthy military personnel (Smith et al., 2016). Interstitial glucose concentrations were lower (4.1 ± 0.8 mmol·L^{-1} vs. 5.0 ± 1.2 mmol·L^{-1}) and mean percentage of time in hypoglycemia (< 3.9 mmol·L^{-1}) higher (38.7% ± 25.0% vs. 13.6% ± 13.7%) during severe energy deficit compared with energy balance, indicating perturbations to interstitial glucose control following a period of restricted EI coupled with increased exercise energy expenditure (Smith et al., 2016).

Prolonged severe energy deficits result in the activation of gluconeogenic pathways that utilize lipids and amino acids to generate a glucose supply and maintain circulating BG levels in the absence of exogenous CHO intake (Gelfand & Sherwin, 1983). As gluconeogenesis consists of a series of complex reactions, production of glucose may be significantly slower than when obtained from dietary intake (Cahill, 2006). It is also possible that the absolute or relative reductions in dietary CHO intake associated with LEA decrease exogenous substrate availability with downstream effects on glucose metabolism. Although daytime BG fluctuates in response to training and food and fluid intake, nocturnal BG may provide greater insight to underlying changes in glucose metabolism. Athletes with Type 1 diabetes have previously been reported to have an increased incidence of CGM-measured hypoglycemic episodes overnight (Iscoe et al., 2008). Tracking interstitial glucose continuously may provide insight into an athletes' ability to match EI to total energy expenditure, which largely varies in response to changes in daily training. However, as glucose homeostasis is a complex phenomenon, extensive research is required to ascertain the true value of utilizing CGM devices to interpret EA status in athletes.

A recent pilot study undertaken by members of this writing team characterized interstitial glucose responses in elite endurance athletes using CGMs during acute exposure to LEA (ACU HREC; no. 2020-238HC). Elite race walkers ($n = 10$) participated in a 3-week research-embedded training camp, during which CGM data were successfully collected ($n = 7$). Dietary standardization was undertaken in the final 2 weeks of the training block, including 6 days with adequate EI (baseline; $n = 7$, EA ~ 40 kcal·kg FFM^{-1}·day^{-1}) followed by a 9-day intervention as either a continuation of high EA (HEA; $n = 4$, EA 43.2 ± 2.3 kcal·kg FFM^{-1}·day^{-1},CHO 8.5 ± 0.6 g·kg^{-1}·day^{-1}) or LEA ($n = 3$, EA 15.7 ± 1.0 kcal·kg FFM^{-1}·day^{-1}, CHO 4.8 ± 0.2 g·kg^{-1}·day^{-1}). Throughout the dietary intervention, participants also undertook standardized training protocols specific to the dietary intervention (HEA, 115.3 ± 7.8 km "on legs training," 12.8 ± 2.7 hr; LEA, 114.4 ± 11.3 km, 10.0 ± 1.2 hr). Abbott Freestyle Libre 2 CGM devices were worn by participants to capture interstitial glucose data throughout the standardized period. Mean nocturnal (00:00–07:00 hr) interstitial glucose concentration (Figure 3a) and total interstitial glucose area under the curve (Figure 3b) were not different between groups across the dietary intervention period. Nocturnal interstitial glucose variability (previously described as MAGE), although lower, was not significantly different across the 9-day intervention period in the LEA group (1.2 ± 0.9 mmol·L^{-1}) compared with the HEA group (1.9 ± 0.5 mmol·L^{-1}; Figure 3c). Consistent with previously published work (Smith et al., 2016), subjects in the LEA intervention experienced a nonstatistical trend toward an increase in hypoglycemic episodes, suggesting a shift in interstitial glucose control during an acute period of LEA (Figure 4). As this study was a proof of concept, the small number of participants and subsequent data set limit any firm conclusions on the influence of acute periods of LEA on glucose control.

Although further work with larger samples sizes and more robust data collection seems warranted, we note practical problems with chronic use of CGM sensors in real-life scenarios. Indeed, we experienced issues with synchronization, accidental removal of CGM sensors, and displacement of the sensor due to heavy sweat losses during exercise in this study, which resulted in the loss of glucose data across each 24-hr period and challenges to statistical analysis and interpretation. Despite these limitations, initial findings suggest that further research should be undertaken to determine the influence of altered EA on BG responses in athletic populations and whether this can be used to distinguish acute

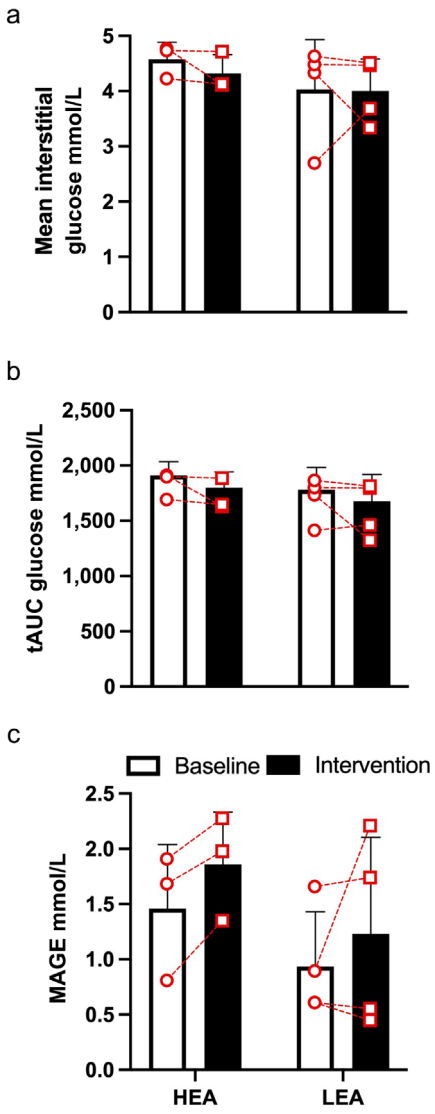

Figure 3 — Nocturnal glucose control in athletes during dietary harmonization (control) or intervention in athletes allocated to either HEA ($n = 3$) or LEA diets ($n = 4$). (a) Mean nocturnal interstitial blood glucose, (b) tAUC, and (c) MAGE. Reported as mean ± *SD*. tAUC = total area under the curve; MAGE = mean amplitude of glycemic excursion; HEA = high energy availability; LEA = low energy availability.

changes due to reduced CHO and EI from more systematic changes indicative of disturbed metabolic function.

Potential Limitations With CGM Use in Sport

There are several theoretical, technical, and practical caveats that need to be taken into account with the introduction of CGM technology into the sports nutrition world. First and foremost, theoretical caveats relate to the as yet untested hypothesis that glucose data derived from CGMs can provide information on the success of various sports nutrition strategies implemented to optimize performance outcomes. In the case of the application of CGMs to guide fueling practices, there is currently no evidence that CGM-derived data can identify glucose values that denote optimal CHO availability or differentiate optimal and suboptimal CHO intake practices. Indeed, as previously noted, rather than measuring BG, CGM devices measure interstitial glucose concentrations, which lag behind BG values and are unable to identify rates of appearance and disappearance of blood-borne substrates. Despite some preliminary evidence that interstitial glucose decreases in response to severe energy restriction, more work is needed to investigate the utility of interstitial glucose values derived from CGMs as an early marker of disturbed metabolic function secondary to LEA.

Furthermore, it is important to understand and validate the algorithms or logic behind the interpretative data provided by present mobile applications for athletes and to distinguish scenarios in which experts in sports nutrition/exercise metabolism can filter information and provide wholistic or sophisticated feedback to athletes and coaches. Further research is warranted to understand the reliability and validity of CGM-derived data before we can be certain that this information is meaningful to athletes who are likely susceptible to marketing hype or simplistic interpretations. For example, it is likely that athletes would attribute postexercise hyperglycemia as a response to a particular strategy of CHO intake rather than viewing it as a normal and transient uncoupling of hepatic glucose output and muscle glucose uptake or an increased hepatic escape of any postexercise CHO feeding (Burke et al., 1993).

Technical limitations in research and free-living environments include CGM sensor durability, software design, usability, and influences of external environmental variables, such as the immersion of the CGM in water, extreme climatic conditions, high sweat rates, and direct physical contact with others. The adhesive film on the sensors will likely deteriorate when immersed in water for extended periods of time, which increases the likelihood of dislodging the sensor in water-based athletes (i.e., swimmers, triathletes, kayakers, rowers). Furthermore, the ambient temperature and humidity level reduce sensor durability as higher rates of sweating present challenges for securing the CGM, which prevents transmission of data from the sensor to the CGM receiver (Englert et al., 2014). Indeed, studies have reported the dislodging of CGM devices during endurance events, resulting in the subsequent loss of glucose data (Francois et al., 2018).

Team sport or combat sport athletes involved in contact activities or those required to wear uniforms or protective garments should also be aware of the fragility of the adhesive nature of CGMs. Interstitial glucose data may also be lost, as experienced in our pilot study, as a result of protocols that require frequent synchronization of the CGM with a corresponding mobile application or receiver. Often, the sleeping habits of athletes may exceed the 8 hr syncing window inherent to some devices, resulting in loss of data that fall outside of this period. However, newer commercial devices have been developed to alleviate this issue: for example, the Abbott Libre Sense Glucose Sport Biosensor (Abbott Diabetes Care Inc.) connects continuously to the Supersapiens (Supersapiens INC, 2021) mobile application via Bluetooth technology, collecting glucose data every minute. Despite these recent advancements, loss of data regardless of the cause still represents a barrier to successful utilization and interpretation of CGM-derived data within sports contexts.

There is some wariness that unfiltered access to continuous interstitial glucose data may trigger problems in athletes who are at risk of disordered eating/eating disorders, although obsessive attention to monitoring interstitial glucose alongside daily food and fluid intake might be expected even in athletes who are free of psychological stress around their dietary intake. Currently available CGMs provide interstitial glucose as often as every minute or

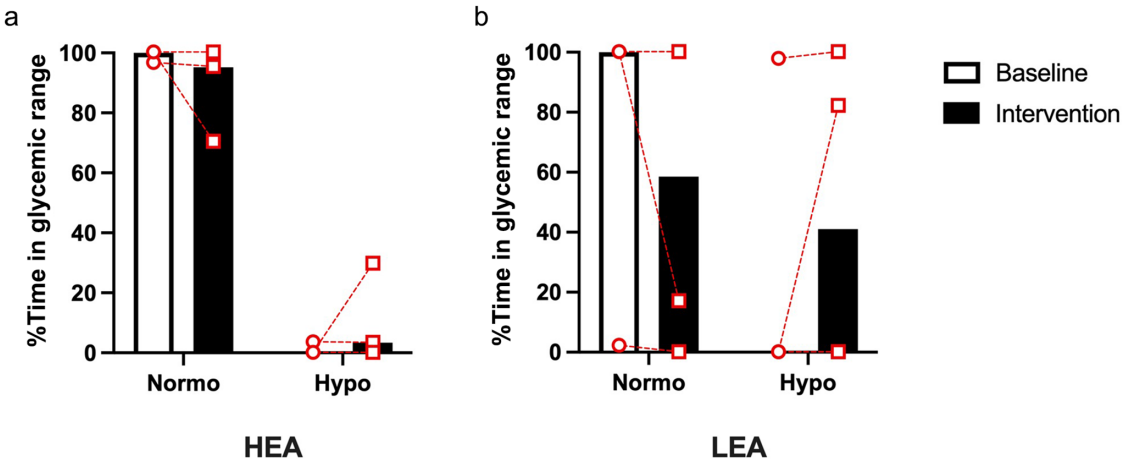

Figure 4 — Median time spent in normoglycemic (normo; 3.9–7.0 mmol·L^{-1}) and hypoglycemic (hypo; <3.9 mmol·L^{-1}) ranges during sleep for athletes allocated to (a) HEA and (b) LEA. HEA = high energy availability; LEA = low energy availability.

when the user swipes their phone, creating an endless stream of information for the user to interpret. Although intended to direct users to optimize fueling, continuous access to interstitial glucose values may lead to "glucorexia" whereby athletes become oversensitive to small, nonphysiological swings in interstitial glucose values.

Finally, there is a range of practical issues that may limit the use of CGMs in sport. The expense of monitors and subscriptions to their supporting mobile applications needs to be considered. Furthermore, the availability of CGMs is dependent not only on the commercial viability of the market but also on approval of devices by the appropriate regulatory bodies that vary between countries. For example, at the time of the preparation of this review, approval for use of the most targeted sports-related CGM device had not been granted by the Therapeutic Goods Administration in Australia or the Food and Drug Administration in the United States, limiting the use of devices to athletes in European countries.

Current policies applied within international and national sporting organizations also present a challenge to the use of CGMs in elite-level sports. For example, the no needles policy of the Australian Institute of Sport limits the use of injection equipment within its jurisdiction to individuals with documented medical conditions who have received approval from a relevant body (Australian Institute of Sport, 2018). Currently, there is uncertainty among some sporting communities as to whether CGMs should be exempt from the no needles policy or not. In environments where there is a lack of clarity, sport governing bodies should be consulted before using CGMs with athletes. In addition, in 2021, the international governing federation of cycling (Union Cycliste Internationale) introduced a ban on the use of physiological monitoring of glucose and lactate data within sanctioned races, limiting the use of CGMs to a training tool (Union Cycliste Internationale, 2021). According to the Union Cycliste Internationale innovations manager, the apparent rationale for this decision was to avoid a further evolution of road cycling to a formulaic event underpinned by real-time use of technical information: "The fans don't want to see Formula One in bike racing, they want surprises, they want unpredictability, and I think that's an important part of it" and "We feel that putting such powerful information into the hands of younger riders is taking away a skill . . . —deciding when you need to eat and learning about your body" (Arthurs-Brennan, 2021). This decision presumably does not pertain to Team Novo Nordisk, the pro cycling team composed of athletes with Type 1 diabetes.

Future Directions

The recent increase in the number of athletes using CGMs in training and competition environments provides impetus for sports nutrition researchers to investigate the efficacy of CGM use by athletic populations. To better understand the relevance of glucose data derived from CGM devices in sport, this information should be coupled with existing technologies that collect and analyze detailed dietary intake (i.e., macronutrient breakdown and timing) and training load data (i.e., mileage, duration, and energy expended) as well as metrics of performance and internal (i.e., perceived effort, heart rate) and external (i.e., work output) load. This approach would provide athletes, coaches, and sports nutrition professionals with greater insights in interpreting whether glucose data can help identify optimal fueling strategies. Similar approaches to monitoring glucose during periods of changes in EA, whether intentional or associated with changes in daily life events, should be undertaken in combination with observation of health and performance metrics to determine the utility of changes in glucose as a marker of problematic LEA. Although much of this may be happening in individual athletic practice due to the emerging commercial availability of sports-focused CGM technology, there is a need for systematic investigation of these issues using robust research methodology.

CGMs have been validated against the gold standard (venous BG) as a tool to reflect whole-body glycemia in healthy individuals and those with diabetes (Thomas et al., 2015). More specifically, CGMs are validated with specific lodgment sites—namely the rear of the upper arm, lower abdomen, or back. As such, individuals are limited as to where the devices can be placed. The nuances of regional interstitial glucose availability have not yet been reported to the best of our knowledge and require further investigation given the heavy reliance on specific muscle groups within individual sports.

Despite rapid advancements in this area, there are few scientific projects, other than case studies, that have investigated the use of CGM technology in athletic populations. We strongly

recommend that these different approaches—individual experimentation, case studies, and systematic investigations—occur in parallel and with coordination to determine the validity and usability of CGM devices in athletes. Only then will practitioners be better informed to determine whether CGMs represent an important tool that generates meaningful data for optimizing athlete health, well-being, and performance.

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References

Abbott Laboratories. (2020). *Abbott libre sense glucose sport biosensor*. https://www.libresense.abbott/en/home.html

Acciaroli, G., Vettoretti, M., Facchinetti, A., & Sparacino, G. (2018). Calibration of minimally invasive continuous glucose monitoring sensors: State-of-the-art and current perspectives. *Biosensors, 8*(1), Article 24. https://doi.org/10.3390/bios8010024

Akintola, A.A., Noordam, R., Jansen, S.W., de Craen, A.J., Ballieux, B.E., Cobbaert, C.M., Mooijaart, S.P., Pijl, H., Westendorp, R.G., & van Heemst, D. (2015). Accuracy of continuous glucose monitoring measurements in normo-glycemic individuals. *PLoS One, 10*(10), Article e0139973. https://doi.org/10.1371/journal.pone.0139973

American Diabetes Association. (2020). Glycemic targets: Standards of medical care in diabetes—2021. *Diabetes Care, 44*(Suppl. 1), S73–S84. https://doi.org/10.2337/dc21-S006

Arthurs-Brennan, M. (2021). *"The fans don't want to see formula one in bike racing": UCI's Mick Rogers on banning metabolic sensors*. https://www.cyclingweekly.com/products/should-metabolic-sensors-be-banned-from-races

Australian Institute of Sport. (2018). *No needles policy*. https://www.sportaus.gov.au/__data/assets/pdf_file/0006/687624/AIS_No_Needles_Policy_-_November_2018.pdf

Bowler, A.-L.M., Coffey, V.G., & Cox, G.R. (2022). Sports dietitian practices for assessing and managing athletes at risk of low energy availability (LEA). *Journal of Science and Medicine in Sport, 25*(6), 460–465. https://doi.org/10.1016/j.jsams.2022.02.002

Burke, L.M., Collier, G.R., & Hargreaves, M. (1993). Muscle glycogen storage after prolonged exercise: Effect of the glycemic index of carbohydrate feedings. *Journal of Applied Physiology, 75*(2), 1019–1023. https://doi.org/10.1152/jappl.1993.75.2.1019

Burke, L.M., Hawley, J.A., Jeukendrup, A., Morton, J.P., Stellingwerff, T., & Maughan, R.J. (2018). Toward a common understanding of diet-exercise strategies to manipulate fuel availability for training and competition preparation in endurance sport. *International Journal of Sports Nutrition and Exercise Metabolism, 28*(5), 451–463. https://doi.org/10.1123/ijsnem.2018-0289

Burke, L.M., Lundy, B., Fahrenholtz, I.L., & Melin, A.K. (2018). Pitfalls of conducting and interpreting estimates of energy availability in free-living athletes. *International Journal of Sport Nutrition and Exercise Metabolism, 28*(4), 350–363. https://doi.org/10.1123/ijsnem.2018-0142

Burke, L.M., van Loon, L.J.C., & Hawley, J.A. (2017). Postexercise muscle glycogen resynthesis in humans. *Journal of Applied Physiology, 122*(5), 1055–1067. https://doi.org/10.1152/japplphysiol.00860.2016

Cahill, G.F. (2006). Fuel metabolism in starvation. *Annual Review of Nutrition, 26*(1), 1–22. https://doi.org/10.1146/annurev.nutr.26.061505.111258

Ceriello, A., Esposito, K., Piconi, L., Ihnat, M.A., Thorpe, J.E., Testa, R., Boemi, M., & Giugliano, D. (2008). Oscillating glucose is more deleterious to endothelial function and oxidative stress than mean glucose in normal and type 2 diabetic patients. *Diabetes, 57*(5), 1349–1354. https://doi.org/10.2337/db08-0063

Danne, T., Nimri, R., Battelino, T., Bergenstal, R.M., Close, K.L., DeVries, J.H., Garg, S., Heinemann, L., Hirsch, I., Amiel, S.A., Beck, R., Bosi, E., Buckingham, B., Cobelli, C., Dassau, E., Doyle, F.J., Heller, S., Hovorka, R., Jia, W., Jones, T., … Phillip, M. (2017). International consensus on use of continuous glucose monitoring. *Diabetes Care, 40*(12), 1631–1640. https://doi.org/10.2337/dc17-1600

De Souza, M.J., Strock, N.C.A., Ricker, E.A., Koltun, K.J., Barrack, M., Joy, E., Nattiv, A., Hutchinson, M., Misra, M., & Williams, N.I. (2022). The path towards progress: A critical review to advance the science of the female and male athletes triad and relative energy deficiency in Sport. *Sports Medicine, 52*(1), 13–23. https://doi.org/10.1007/s40279-021-01568-w

DeSalvo, D., & Buckingham, B. (2013). Continuous glucose monitoring: Current use and future directions. *Current Diabetes Reports, 13*(5), 657–662. https://doi.org/10.1007/s11892-013-0398-4

Dipla, K., Kraemer, R.R., Constantini, N.W., & Hackney, A.C. (2021). Relative energy deficiency in sports (RED-S): Elucidation of endocrine changes affecting the health of males and females. *Hormones, 20*(1), 35–47. https://doi.org/10.1007/s42000-020-00214-w

Doering, T.M., Cox, G., Areta, J., & Coffey, V. (2019). Repeated muscle glycogen supercompensation with four days' recovery between exhaustive exercise. *Journal of Science and Medicine in Sport, 22*(8), 907–911. https://doi.org/10.1016/j.jsams.2019.03.009

Englert, K., Ruedy, K., Coffey, J., Caswell, K., Steffen, A., & Levandoski, L. (2014). Skin and adhesive issues with continuous glucose monitors: A sticky situation. *Journal of Diabetes Science and Technology, 8*(4), 745–751. https://doi.org/10.1177/1932296814529893

Forde, H.E., Browne, S., Smith, D., & Tormey, W.P. (2019). Glucose sensing technology—Current practice? *Irish Journal of Medical Science, 188*(1), 125–127. https://doi.org/10.1007/s11845-018-1800-7

Francois, M.E., Cosgrove, S.D., Walker, N.M., Lucas, S.J.E., & Black, K.E. (2018). Physiological responses to a five-day adventure race: Continuous blood glucose, hemodynamics and metabolites the 2012 GODZone field-study. *Journal of Exercise Science and Fitness, 16*(3), 78–82. https://doi.org/10.1016/j.jesf.2018.07.002

Gelfand, R.A., & Sherwin, R.S. (1983). Glucagon and starvation. In P.J. Lefebvre (Ed.), *Glucagon II* (pp. 223–237). Springer. https://doi.org/10.1007/978-3-642-69019-8_12

Gordon, B., Kohn, L.A., Levine, S.A., Matton, M., Scriver, W., & Whiting, W. (1925). Sugar content of the blood in runners following a marathon race: With especial reference to the prevention of hypoglycaemia: Following observations. *Journal of the American Medical Association, 85*(7), 508–509. https://doi.org/10.1001/jama.1925.02670070028009

Heikura, I.A., Stellingwerff, T., & Areta, J.L. (2021). Low energy availability in female athletes: From the lab to the field. *European Journal of Sports Science, 22*(5), 709–719. https://doi.org/10.1080/17461391.2021.1915391

Hill, N.R., Oliver, N.S., Choudhary, P., Levy, J.C., Hindmarsh, P., & Matthews, D.R. (2011). Normal reference range for mean tissue glucose and glycemic variability derived from continuous glucose monitoring for subjects without diabetes in different ethnic groups. *Diabetes Technology & Therapeutics, 13*(9), 921–928. http://doi.org/10.1089/dia.2010/0247

Hoss, U., & Budiman, E.S. (2017). Factory-calibrated continuous glucose sensors: The science behind the technology. *Diabetes Technology & Therapeutics, 19*(Suppl. 2), S44–S50. https://doi.org/10.1089/dia.2017.0025

Impey, S.G., Hearris, M.A., Hammond, K.M., Bartlett, J.D., Louis, J., Close, G.L., & Morton, J.P. (2018). Fuel for the work required: A theoretical framework for carbohydrate periodization and the glycogen threshold hypothesis. *Sports Medicine, 48*(5), 1031–1048. https://doi.org/10.1007/s40279-018-0867-7

Iscoe, K.E., Corcoran, M., & Riddell, M.C. (2008). High rates of nocturnal hypoglycemia in a unique sports camp for athletes with type 1 diabetes: Lessons learned from continuous glucose monitoring systems. *Canadian Journal of Diabetes, 32*(3), 182–189. https://doi.org/10.1016/S1499-2671(08)23008-X

Ishihara, K., Uchiyama, N., Kizaki, S., Mori, E., Nonaka, T., & Oneda, H. (2020). Application of continuous glucose monitoring for assessment of individual carbohydrate requirement during ultramarathon race. *Nutrients, 12*(4), Article 1121. https://doi.org/10.3390/nu12041121

Jeukendrup, A.E., & Killer, S.C. (2010). The myths surrounding pre-exercise carbohydrate feeding. *Annals of Nutrition and Metabolism, 57,* 18–25. https://doi.org/10.1159/000322698

Karelis, A., Smith, J., Passe, D., & Péronnet, F. (2010). Carbohydrate administration and exercise performance what are the potential mechanisms involved? *Sports Medicine, 40*(9), 747–763. https://doi.org/10.2165/11533080-000000000-00000

Kilpatrick, E., Rigby, A., & Atkin, S. (2006). The effect of glucose variability on the risk of microvascular complications in type 1 diabetes. *Diabetes Care, 29*(7), 1486–1490. https://doi.org/10.2337/dc06-0293

Klonoff, D.C. (2005). Continuous glucose monitoring: Roadmap for 21st century diabetes therapy. *Diabetes Care, 28*(5), 1231–1239. https://doi.org/10.2337/diacare.28.5.1231

Koehler, K., Hoerner, N.R., Gibbs, J.C., Zinner, C., Braun, H., De Souza, M.J., & Schaenzer, W. (2016). Low energy availability in exercising men is associated with reduced leptin and insulin but not with changes in other metabolic hormones. *Journal of Sports Sciences, 34*(20), 1921–1929. https://doi.org/10.1080/02640414.2016.1142109

Levine, S., Gordon, B., & Derick, C. (1924). Some changes in the chemical constituents of the blood following a marathon race with special reference to the development of hypoglycemia. *Journal of the American Medical Association, 82*(22), 1778–1779. https://doi.org/10.1001/jama.1924.0265048.0034015

Logue, D.M., Madigan, S.M., Melin, A., Delahunt, E., Heinen, M., Donnell, S.M., & Corish, C.A. (2020). Low energy availability in athletes 2020: An updated narrative review of prevalence, risk, within-day energy balance, knowledge, and impact on sports performance. *Nutrients, 12*(3), Article 835. https://doi.org/10.3390/nu12030835

Loucks, A.B. (2006). The response of luteinizing hormone pulsatility to 5 days of low energy availability disappears by 14 years of gynecological age. *The Journal of Clinical Endocrinology and Metabolism, 91*(8), 3158–3164. https://doi.org/10.1210/jc.2006-0570

Loucks, A.B., & Thuma, J.R. (2003). Luteinizing hormone pulsatility is disrupted at a threshold of energy availability in regularly menstruating women. *Journal of Clinical Endocrinology and Metabolism, 88*(1), 297–311. https://doi.org/10.1210/jc.2002-020369

Lundy, B., Torstveit, M.K., Stenqvist, T.B., Burke, L.M., Garthe, I., Slater, G.J., Ritz, C., & Melin, A.K. (2022). Screening for low energy availability in male athletes: Attempted validation of LEAM-Q. *Nutrients, 14*(9), Article 1873. https://doi.org/10.3390/nu14091873

Maiorino, M.I., Signoriello, S., Maio, A., Chiodini, P., Bellastella, G., Scappaticcio, L., Longo, M., Giugliano, D., & Esposito, K. (2020). Effects of continuous glucose monitoring on metrics of glycemic control in diabetes: A systematic review with meta-analysis of randomized controlled trials. *Diabetes Care, 43*(5), 1146–1156. https://doi.org/10.2337/dc19-1459

Mauras, N., Fox, L., Englert, K., & Beck, R.W. (2013). Continuous glucose monitoring in type 1 diabetes. *Endocrine, 43*(1), 41–50. https://doi.org/10.1007/s12020-012-9765-1

Melin, A., Tornberg, A.B., Skouby, S., Faber, J., Ritz, C., Sjödin, A., & Sundgot-Borgen, J. (2014). The LEAF questionnaire: A screening tool for the identification of female athletes at risk for the female athlete triad. *British Journal of Sports Medicine, 48*(7), 540–545. https://doi.org/10.1136/bjsports-2013-093240

Monsod, T.P., Flanagan, D.E., Rife, F., Saenz, R., Caprio, S., Sherwin, R.S., Tamborlane, W.V. (2002). Do sensor glucose levels accurately predict plasma glucose concentrations during hypoglycemia and hyperinsulinemia. *Diabetes Care, 25,* 889–893. https://doi.org/10.2337/diacare.25.5.889Mountjoy

Mountjoy, M., Sundgot-Borgen, J., Burke, L., Ackerman, K.E., Blauwet, C., Constantini, N., Lebrun, C., Lundy, B., Melin, A., Meyer, N., Sherman, R., Tenforde, A.S., Torstveit, M.K., &Budgett, R. (2018). International Olympic Committee (IOC) consensus statement on relative energy deficiency in sport (RED-S): 2018 update. *International Journal of Sport Nutrition and Exercise Metabolism, 28*(4), 316–331. https://doi.org/10.1123/ijsnem.2018-0136

Petrovski, G., Dimitrovski, C., & Milenkovikj, T. (2004). Clinical performance of continuous glucose monitoring system in type 1 diabetics. *Diabetologia Croatica, 33*(4), 125–129.

Pickup, J.C., Freeman, S.C., & Sutton, A.J. (2011). Glycaemic control in type 1 diabetes during real time continuous glucose monitoring compared with self monitoring of blood glucose: Meta-analysis of randomised controlled trials using individual patient data. *British Medical Journal, 343,* Article 3805. https://doi.org/10.1136/bmj.d3805

Rodbard, D. (2016). Continuous glucose monitoring: A review of successes, challenges, and opportunities. *Diabetes Technology & Therapeutics, 18*(Suppl. 2), S3–S13. https://doi.org/10.1089/dia.2015.0417

Rollo, I., Gonzalez, J.T., Fuchs, C.J., van Loon, L.J.C., & Williams, C. (2020). Primary, secondary and tertiary effects of carbohydrate ingestion during exercise. *Sports Medicine, 50*(11), 1863–1871. https://doi.org/10.1007/s40279-020-01343-3

Rydén, L., Grant, P.J., Anker, S.D., Berne, C., Cosentino, F., Danchin, N., Deaton, C., Escaned, J., Hammes, H.-P., Huikuri, H., Marre, M., Marx, N., Mellbin, L., Ostergren, J., Patrono, C., Seferovic, P., Uva, M.S., Taskinen, M.-R., Tendera, M., … Xuereb, R.G. (2013). ESC Guidelines on diabetes, pre-diabetes, and cardiovascular diseases developed in collaboration with the EASD: The task force on diabetes, pre-diabetes, and cardiovascular diseases of the European Society of Cardiology (ESC) and developed in collaboration with the European Association for the Study of Diabetes (EASD). *European Heart Journal, 34*(39), 3035–3087. https://doi.org/10.1093/eurheartj/eht108

Schmelzeisen-Redeker, G., Schoemaker, M., Kirchsteiger, H., Freckmann, G., Heinemann, L., & Del Re, L. (2015). Time delay of CGM sensors: Relevance, causes and countermeasures. *Journal of Diabetes Science*

and Technology, 9(5), 1006–1015. https://doi.org/10.1177/1932296815590154

Sengoku, Y., Nakamura, K., O'gata, H., Nabekura, Y., Nagasaka, S., & Tokuyama, K. (2015). Continuous glucose monitoring during a 100-km race: A case study in an elite ultramarathon runner. *International Journal of Sports Physiology and Performance, 10*(1), 124–127. https://doi.org/10.1123/ijspp.2013-0493

Service, F.J., O'Brien, P.C., & Rizza, R.A. (1987). Measurements of glucose control. *Diabetes Care, 10*(2), 225–237. https://doi.org/10.2337/diacare.10.2.225

Smith, T.J., Wilson, M.A., Karl, J.P., Austin, K., Bukhari, A., Pasiakos, S.M., O'Connor, K.L., & Lieberman, H.R. (2016). Interstitial glucose concentrations and hypoglycemia during 2 days of caloric deficit and sustained exercise: A double-blind, placebo-controlled trial. *Journal of Applied Physiology, 121*(5), 1208–1216. https://doi.org/10.1152/japplphysiol.00432.2016

Supersapiens INC. (2021). *Supersapiens*. https://www.supersapiens.com/en-EN/

Thomas, F., Pretty, C.G., Desaive, T., & Chase, J.G. (2016). Blood glucose levels of subelite athletes during 6 days of free living. *Journal of Diabetes Science and Technology, 10*(6), 1335–1343. https://doi.org/10.1177/1932296816648344

Thomas, F., Pretty, C.G., Signal, M., & Chase, J.G. (2015). Accuracy and performance of continuous glucose monitors in athletes. *Biomedical Signal Processing and Control, 32,* 124–129. https://dx.doi.org/10.1016/j.bspc.2016.08.007

Thomas, T., Erdman, K.A., & Burke, L.M. (2016). Position of the academy of nutrition and dietetics, dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. *Journal of the Academy of Nutrition and Dietetics, 116*(3), 501–528. https://doi.org/10.1016/j.jand.2015.12.006

Union Cycliste Internationale. (2021). *Clarification guide of the UCI technical regulation*. https://assets.ctfassets.net/761l7gh5x5an/7s1ma6mVAVlFwi8rRgy0Iw/1bef531dd9e9f534c34ff016c68e3c72/Clarification_Guide_of_the_UCI_Technical_Regulation_-_20211005_-_ENG.pdf

Vaddiraju, S., Burgess, D.J., Tomazos, I., Jain, F.C., & Papadimitrakopoulos, F. (2010). Technologies for continuous glucose monitoring: Current problems and future promises. *Journal of Diabetes Science and Technology, 4*(6), 1540–1562. https://doi.org/10.1177/193229681000400632

Vashist, S.K. (2013). Continuous glucose monitoring systems: A review. *Diagnostics, 3*(4), 385–412. https://doi.org/10.3390/diagnostics3040385