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Original Research

The “Ups” and “Downs” of a Bike Race in People with Type 1 Diabetes: Dramatic Differences in Strategies and Blood Glucose Responses in the Paris-to-Ancaster Spring Classic

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ABSTRACT

Objective: Recommendations for insulin adjustments and carbohydrate intake exist for individuals with type 1 diabetes who are undertaking moderate exercise. Very few guidelines exist for athletes with type 1 diabetes who are competing in events of higher intensity or longer duration. This observational study reports the strategies adopted by 6 habitually active men with type 1 diabetes (glycated hemoglobin = 8.3%±2.0%) undertaking a relatively intense endurance cycling event.
Methods: Participants wore continuous glucose monitoring (CGM) sensors for 24 hours before competition, while racing and overnight postrace. They were asked to eat their regular meals and snacks and make their usual insulin adjustments before, during and after competition. All food intake and insulin adjustments were recorded in detail.
Results: Participants used a variety of adjustments for exercise. Of 6 participants, 4 decreased their insulin dosages and all participants consumed carbohydrates during the race (mean = 87±57 g). In spite of these strategies, 3 of the 6 participants experienced mild to moderate hypoglycemia (not requiring assistance) during the event. Hyperglycemia was seen in all participants 3 hours postexercise. There were no incidents of nocturnal hypoglycemia.
Conclusions: Individuals with type 1 diabetes can compete in intensive long-distance athletic events using a variety of nutrition- and insulin-adjustment strategies. In addition to finely tuned insulin adjustments and increased carbohydrate intake, vigilance will always be required to maintain some semblance of glycemic control during events of extended duration.

RÉSUMÉ

Objectif : Il existe des recommandations sur les ajustements de l'insuline et l'apport en glucides destinées aux individus souffrant du diabète de type 1 qui entreprennent de faire de l'exercice modéré. En revanche, il existe très peu de lignes directrices destinées aux athlètes souffrant du diabète de type 1 qui participent à des épreuves d'intensité très élevée ou de très longue durée. Cette étude observationnelle fait état des stratégies adoptées par 6 hommes habituellement actifs souffrant du diabète de type 1 (hémoglobine glyquée = 8,3 % ± 2,0 %) qui ont entrepris une épreuve cycliste relativement intense.
Méthodes : Les participants ont porté des capteurs pour la surveillance de la glycémie en continu (SGC) 24 heures avant la compétition, pendant la course et au cours de la nuit suivant la course. On leur a demandé de prendre leurs repas et leurs collations régulièrement, et de faire leurs ajustements habituels d'insuline avant, pendant et après la compétition. Tous les apports d'aliments et les ajustements d'insuline ont été enregistrés minutieusement.
Résultats : Les participants ont eu recours à divers ajustements pour faire l'exercice. Parmi les 6 participants, 4 ont diminué leurs doses d'insuline, mais tous ont consommé des glucides durant la course (moyenne = 87 ± 57 g). En dépit de ces stratégies, 3 des 6 participants ont eu une hypoglycémie légère à

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modérée (qui n'a pas exigé d'assistance) durant l'épreuve. Une hyperglycémie a été observée chez tous les participants 3 heures après l'exercice. Il n'y a pas eu d'épisodes d'hypoglycémie nocturne.
Conclusions : Les individus souffrant du diabète de type 1 peuvent participer aux épreuves sportives de longue distance à intensité élevée en ayant recours à diverses stratégies d'ajustement de la nutrition et de l'insuline. En plus de bien ajuster les doses d'insuline et d'augmenter l'apport en glucides, la vigilance est toujours de mise pour maintenir un certain semblant de régulation glycémique durant les épreuves de longue durée.

Introduction

Physical activity is a common challenge to blood glucose control in individuals with type 1 diabetes. Moderate aerobic exercise is known to cause rapid declines in blood glucose (1), thereby increasing the risk for hypoglycemia, both during and after exercise. Meanwhile, short periods of high-intensity activity have been associated with increases in blood glucose concentration in early recovery, and there exists the potential for hyperglycemia both during and after activity (2–4). Some recent studies have attempted to duplicate the physical stresses of intense field sports by examining how short, high-intensity bouts of exercise affect blood glucose levels when combined with moderate aerobic activity (5–7). Unfortunately, controlled laboratory conditions probably fail to reflect the true physical and psychological stresses of competition, leaving athletes with type 1 diabetes with little information about how to manage blood glucose levels for competitive events in which exercise intensity and duration are variable in nature.

Several organizations offer guidelines related to managing blood glucose during exercise for individuals with type 1 diabetes (8,9). Recommendations include decreasing insulin dosage, increasing carbohydrate intake or using a combination of both of these strategies (8,9). Unfortunately, most of these guidelines assume that individuals will be performing moderate exercise for a relatively short time (30 to 60 minutes) and at a fairly constant intensity. In actuality, many team sports (e.g. basketball, volleyball, soccer, etc.) and individual sports (e.g. cycling, running, cross-country skiing, etc.) involve both training sessions and competitions of extended duration (>90 minutes) during which periods of high-intensity work may be interspersed with slightly less intense activity. Finding the right balance of insulin reduction and increased carbohydrate intake is essential for preventing both hypo- and hyperglycemia, both of which can influence performance in sports. Having too much insulin or insufficient carbohydrate intake prior to or during exercise commonly results in hypoglycemia (10), which can lead to decreases in performance, at best (11), or to serious medical problems requiring medical assistance (12) at worst. Conversely, hyperglycemia can result from withholding insulin, from consuming excess carbohydrates (13) or from intense activities above the anaerobic threshold (14). Prolonged hyperglycemia can lead to the production of ketones, which can subsequently cause dehydration (15), thereby increasing the risk for muscle cramp and heat stress during intense activity (16).

Because a great deal of inter- and intraindividual variability exists in terms of the hormonal responses to various types and intensities of training and competition, it is difficult for general insulin adjustment and carbohydrate supplementation recommendations to be made. In these situations, athletes must often adopt a trial-and-error approach in devising a strategy appropriate for the duration and intensity of the exercise they are about to undertake, based on past experience of their blood glucose responses to similar activities. Very few of these strategies have been documented in the literature, leaving novice athletes who have type 1 diabetes with very few resources at their disposal. This observational study follows 6 athletes, varying from recreational to elite in their competitive experiences, during a long-distance on- and off-road cycling race, in order to document how differing insulin and carbohydrate strategies influence blood glucose outcomes during competition.

Methods

This study was approved by the York University Human Participants Review Committee. Six male athletes with type 1 diabetes participated in the 2013 Paris-to-Ancaster Bicycle Race (Ontario, Canada) in order to take part in this observational study. All participants were habitually active in endurance-based sports. Four participants took part in regular cycling or triathlon competition, and 2 of them participated at an elite level. Participants ranged in age (36.3±9.3 years; range, 24 to 46 years) and duration of diabetes (15.7±11.8 years; range, 2 to 31 years). All participants had moderate to excellent blood glucose control (Table 1). Of the participants, 2 were using multiple daily insulin injections (MDI), 3 were using continuous subcutaneous insulin infusion (CSII) and 1 participant used a combination of both MDI and CSII. For comparison purposes, 1 nondiabetic athlete agreed to be monitored during competition. Subjects were provided with instructions concerning the experimental procedures, and they provided informed consent in agreement with York University ethics policies.

On the day before the race, participants were provided with continuous glucose monitoring (CGM) sensors. Data were recorded by a separate CGM device for individuals using MDI, while participants using CSII recorded the CGM data on their insulin pumps.

Table 1
Insulin adjustments and carbohydrate intake before and during event

Participant	A1C	Insulin delivery	Prerace CHO (g)	Prerace insulin adjustment	Ride time (mins)	Race CHO (g)	Hypoglycemia during race (y/n)
1	N/A	N/A	68	N/A	179	102	N/A
2	11.7	MDI	120	Evening glargine ↓ 33%	227	105	No
3	9.5	MDI	34	None	244	7	No
4	7.6	MDI + CSII	54	20% ↓ prerace evening glargine, basal rate suspended during race	123	53	Yes
5	6.9	CSII	115	↓ basal rate to 25% 1-hour prerace	135	165	Yes
6	7.4	CSII	33	None	177	156	Yes
7	6.6	CSII	53	↓ basal rate to 40% 1-hour prerace	176	103	No

A1C, glycated hemoglobin; *CHO,* carbohydrates; *CSII,* continuous subcutaneous insulin infusion; *MDI,* multiple daily insulin injections.

Participants were asked to take at least 4 capillary glucose readings each day of sensor wear, during periods of relative glycemic stability, for CGM calibration purposes. The athletes did not perform any exercise or consume any alcohol in the 24 hours prior to the race. Participants were asked to follow their regular prerace routines with respect to insulin dosage and food intake, but they were also asked to record their food intake before, during and after competition on race day with as much detail as possible. On the day following the race, CGM data and capillary glucose values of participants were uploaded using a website associated with the CGM devices.

Observations

The event took place the morning of Sunday, April 15, 2013. The course consisted of mixed terrain, including asphalt, dirt or gravel roads and off-road single- and double-track trails involving a substantial amount of deep mud (i.e. cyclocross-style racing). Four participants and the nondiabetic control participant completed the ~70 km route from Paris, Ontario, to Ancaster, Ontario, while the other 2 participants took part in the ~40 km route from St. George, Ontario, to Ancaster, Ontario. All participants completed the event successfully, with completion time for the participants ranging from 176 minutes to 244 minutes for the 70 km route and from 123 to 135 minutes for the 40 km route.

Insulin adjustments and carbohydrate intake

Details of each participant's insulin adjustments and carbohydrate intakes both before and during the race can be found in Table 1 and details of insulin adjustments and carbohydrate intake post-race can be found in Table 2. CGM tracings for the race, 12 hours postrace and overnight postrace for all 6 participants with diabetes, along with those of the control participant without diabetes, can be found in Figure 1. Two (1 MDI, 1 CSII) of the 6 participants did not make any adjustments to insulin dosage and chose instead to rely solely on "extra" carbohydrate intake (Ex carbs) (i.e. without insulin administration) during the race to prevent hypoglycemia. The other 2 participants, each using a long-acting insulin injection, decreased their evening injections by 20% and 33%, respectively, on the evening before the race and consumed Ex carbs. Of the 3 remaining participants using CSII, 2 decreased their basal insulin infusion rates approximately 1 hour prior to the race, while 1 chose to suspend the basal insulin infusion completely at the start of the race. All 3 also used a modified Ex carb approach, which takes into account reductions in insulin administration (17). The differing insulin adjustment strategies and the resulting blood glucose outcomes of all participants, along with their CGM glucose profiles, can be found in Figure 2.

As mentioned above, all participants consumed additional carbohydrate both before and during competition. Prerace carbohydrate intake varied from 33 to 120 g (Table 1), while carbohydrate intake during the race varied greatly, from as little as 7 g in 1 participant who struggled with severe hyperglycemia during the race, to 165 g in another participant who struggled with hypoglycemia. Of the 6 participants with diabetes, 4 consumed more than 100 g of carbohydrate during the event, in line with the 30 to 60 g of carbohydrate per hour that are generally recommended for athletes during endurance events (18).

Blood glucose levels

Interstitial glucose levels as measured by CGM show that 2 participants (participants 4 and 5 in both Figure 1 and Figure 2) experienced mild to moderate hypoglycemia during the event. Interstitial glucose levels for participant 6 were measured at between 6 and 12 mmol/L during the race, but the participant performed a capillary glucose test with a handheld meter after

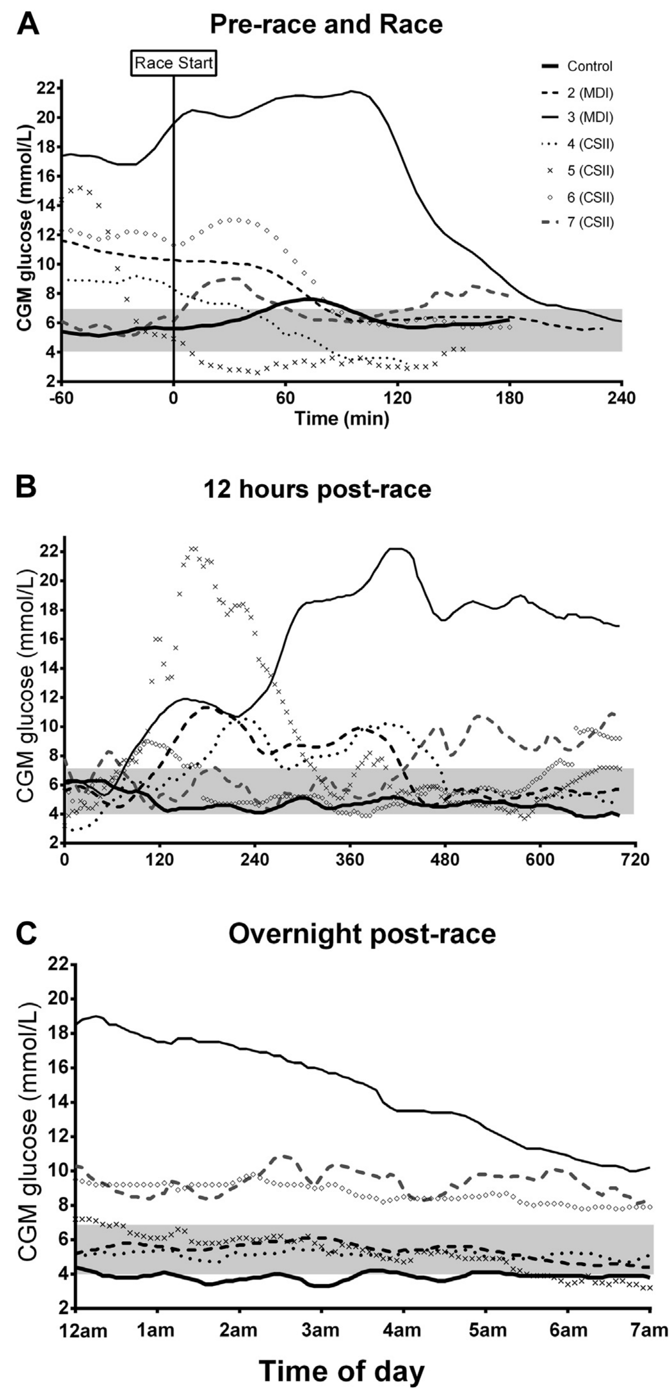

Figure 1. (A) Continuous glucose monitoring profiles as measured during the event for 1 control participant without diabetes (participant 1) and 6 individuals with type 1 diabetes (participants 2 through 7). (B) Continuous glucose monitoring profiles for all participants in the 12 hours postexercise. (C) Postrace nocturnal continuous glucose monitoring profiles for all participants.

60 minutes because he felt unwell and found that his glucose levels had dropped to below 3 mmol/L. Conversely, participant 2, who was hyperglycemic (~20 mmol/L) before the event, experienced an increase in blood glucose levels throughout the first 2 hours of competition and eventually delivered a bolus of insulin to bring his glucose levels under control. The final 2 participants (participants 2 and 7) managed to complete the event with their blood glucose levels in a "safe" glycemic range (between 6 and 10 mmol/L) from start to finish. All participants experienced some level of

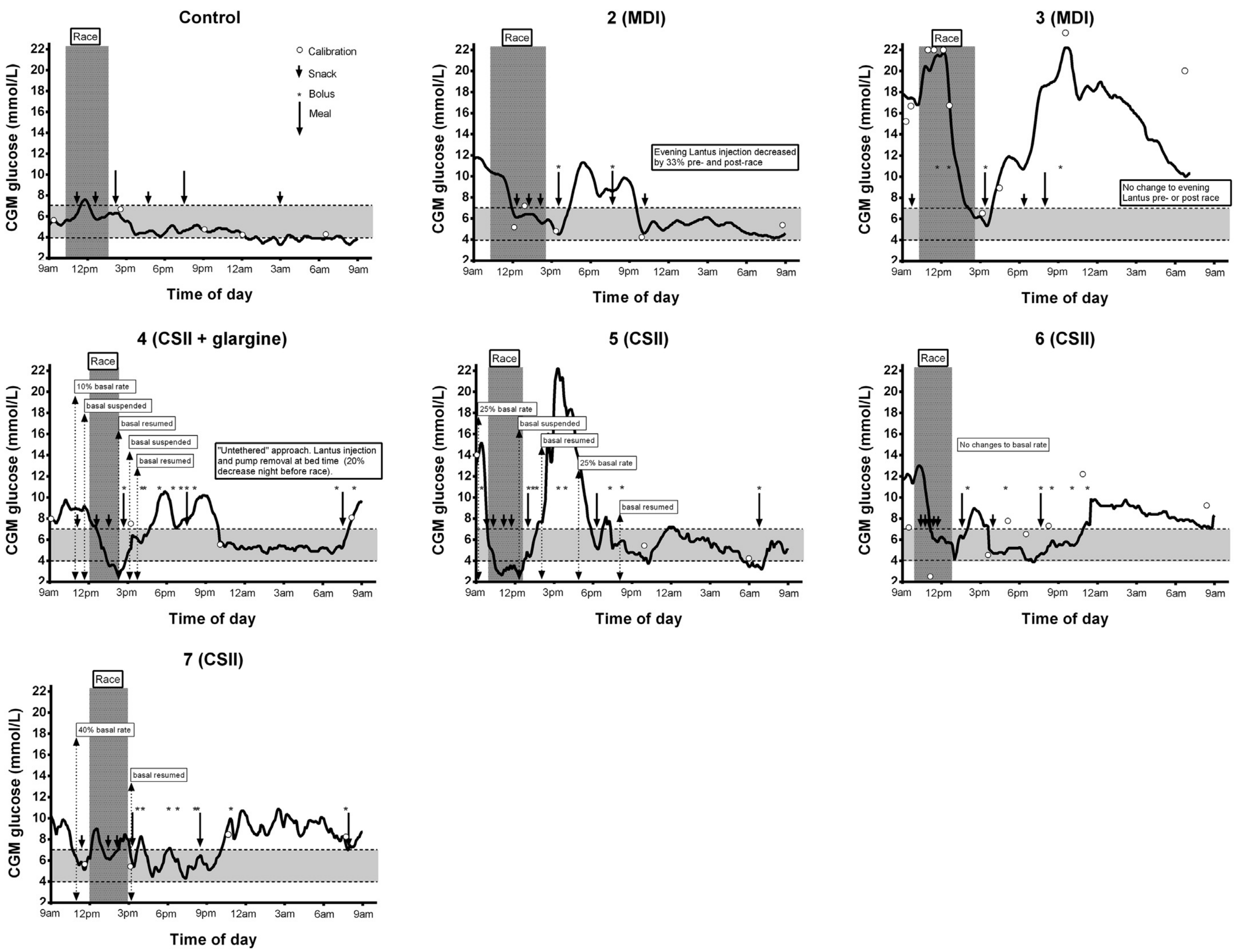

Figure 2. Continuous glucose monitoring profiles for 6 participants with type 1 diabetes demonstrating differing approaches to blood glucose management during competition as compared to a control participant without diabetes.

hyperglycemia, ranging from very mild (∼8 mmol/L) to severe (>22.2 mmol/L) in the 6 hours following the race. There were no instances of nocturnal hypoglycemia postrace.

Discussion

This observational study monitored interstitial glucose concentration by means of CGM in 6 athletes with type 1 diabetes (ranging from recreational to elite) during a long-distance intense cycling race. Because they were all taking part in the same endurance event (a cyclocross bike race), the timing, environmental conditions and race terrain were comparable for all involved. In spite of this, the 6 monitored athletes showed a great deal of intersubject variability in their approaches to competition in terms of reducing insulin intake and increasing carbohydrate consumption. All 6 athletes managed to finish the race successfully, albeit not without some difficulty (mild hypo- and hyperglycemia).

A number of guidelines exist concerning insulin adjustments and nutritional strategies during exercise and sport for patients with type 1 diabetes (8,9,17). To date, only a handful of field studies have been published evaluating the strategies of individuals with type 1 diabetes during competition (19,20). In a group of marathoners with type 1 diabetes, participants reduced both basal insulin (∼23% and 20%) and prerace breakfast insulin (∼30% and 15%) when followed in the same race for 2 consecutive years. Carbohydrate ingestion was increased from a mean of 50 g to a mean of 60 g during the race from 1 year to the next in order to prevent hypoglycemia (19). In a 75 km crosscountry ski race, excessive prerace carbohydrate loading (65 g) and a dramatic reduction in short-acting insulin (by 58%) resulted in prerace hyperglycemia, whereas in the following year, hyperglycemia was attenuated by dropping the prerace carbohydrate to 40 g with less of a reduction in short-acting insulin (by 35%) (20). In the cross-country ski field study, ∼40 g of carbohydrate per hour of exercise appeared to prevent hypoglycemia in a majority of subjects (8 of 9) in both years (20). Similarly, we found that a combination of reduced circulating insulin levels, via reductions in either basal insulin 60 to 90 minutes before the start of the race or reducing prerace bolus insulin, and the consumption of carbohydrates at a rate of about 40 to 60 g/hour of cycling helped to reduce the occurrence of hypoglycemia and did not result in hyperglycemia during the race.

With the exception of the participant who started the race with severe hyperglycemia (blood glucose ∼20 mmol/L), all race

Table 2
Insulin adjustments and carbohydrate intake immediately postrace and in the evening after the event

Participant	Postrace CHO (g)	Postrace insulin adjustment	Total afternoon bolus insulin	Evening CHO (g)	Total evening bolus insulin	Overnight insulin adjustments	Nocturnal hypoglycemia (y/n)
1	110	N/A	N/A	144	N/A	N/A	N/A
2	170	Regular bolus for food (insulin lispro)	9	56	3	Evening glargine ↓ 33%	No
3	116	Regular bolus for food (insulin lispro)	11	117	11	None	No
4	140	Multiple small adjustments + regular bolus for food	6.9	132	6	Regular basal	No
5	10	Multiple small adjustments + regular bolus for food	13.55	66	4.55	Regular basal	No
6	160	One large adjustment + regular bolus for food	9.5	152	4.95	Regular basal	No
7	103	Multiple small adjustments + regular bolus for food	4.9	52	6.9	Regular basal	No

CHO, carbohydrate.

participants with type 1 diabetes experienced a decline in blood glucose concentration throughout the race in spite of taking in Ex carbs and/or decreasing insulin dosage. Even the patient who had hyperglycemia initially experienced a dramatic decline in blood glucose once a small insulin correction was made. In addition to the expected declines in glucose concentration during the race, 5 of 6 participants experienced steady increases in glucose levels upon completing the race, with peak glucose concentration being reached approximately 3 hours postexercise. A similar trend toward postexercise hyperglycemia was also found after 45 minutes of aerobic exercise in a study comparing aerobic and resistance exercise in individuals with type 1 diabetes in whom glucose levels were monitored by CGM for 12 hours postexercise (1). No study to date has collected hormonal or metabolic data related to this postexercise period in individuals with type 1 diabetes, so it is difficult to ascertain the cause of this phenomenon. The concentrations of plasma nonesterified fatty acids as well as the levels of lipid oxidation are both elevated after exercise, with levels increasing in proportion to exercise intensity (21) and duration (22). The exercise-induced increase in free fatty acid mobilization peaks within 2 to 3 hours of exercise cessation and can persist for up to 24 hours (23). Elevated lipid oxidation is known to suppress carbohydrate metabolism. When combined with elevated epinephrine levels' stimulating glycogenolysis for up to 2 hours postexercise (22), the result could be an increase in blood glucose concentration in individuals with type 1 diabetes unless a bolus of insulin is delivered. Consistent with this theory, the only participant who did not experience significant postexercise hyperglycemia delivered frequent insulin correction boluses in the hours following exercise.

In addition to an increase in glucose uptake by the muscles during exercise, physical activity can increase insulin sensitivity for several hours postexercise (24), thereby increasing the risk for postexercise hypoglycemia. The DirecNet consortium found that when children exercised for 75 minutes at moderate intensity, the number of nights during which nocturnal hypoglycemia (blood glucose <3.3 mmol/L) was experienced was more than double (42% vs. 16%) that experienced after a day without exercise (25). Conversely, there is evidence to indicate that in regularly active individuals with well-controlled type 1 diabetes, the frequency of nocturnal hypoglycemia is not higher after days during which exercise has been performed than it is during relatively sedentary days (26), presumably because of having developed effective prevention strategies. Participants in the present study were all habitually active and had relatively well-controlled type 1 diabetes (mean glycated hemoglobin [A1C] 8.3% ± 2.0%), which may explain why no nocturnal hypoglycemia was seen postrace. It should also be noted that the observed postexercise hyperglycemia, caused either by a transient reduction in insulin sensitivity or because of increases in energy intake that were not properly matched with appropriate insulin delivery, may help to prevent postexercise late-onset nocturnal hypoglycemia as long as corrective insulin is not administered. Indeed, postexercise hyperglycemia corrected by aggressive insulin administration has been linked to at least 1 death in a patient with type 1 diabetes (27).

In summary, athletes with type 1 diabetes are capable of taking part in high-level athletic competition successfully. Although the tools for managing and monitoring blood glucose have improved over the years, a knowledge and understanding of one's own responses to exercise intensity and competition stress is essential in the decision-making processes required for adjusting insulin dosage and carbohydrate intake. Frequent testing of capillary glucose can be used as an adjunct to real-time CGM to ensure that blood glucose levels remain in a healthy range before, during and after competition.

Author Disclosures

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Author Contributions

JY and DZ drafted the manuscript; CJ assisted in participant recruitment and data collection; JY and DZ performed the data collection and presentation; MR provided support and guidance in data collection and reviewed and edited the manuscript.

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