

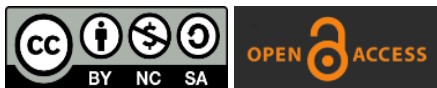
# Dietary Approaches in Endurance Athletes with Diabetes – Nutritional Support

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Received: July 03, 2024; Accepted: September 12, 2024; Published: September 28, 2024



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## Abstract

Significant advancements in understanding the need of glycemic control in physically active individuals with diabetes contributed to the development of exercise-specific nutritional and life-style recommendations ensuring the optimal performance and recovery. The main aim of this article is to review and present the update guidance for endurance athletes with certain metabolic disturbance, particularly diabetes type 1. post-exercise recovery in athletes with diabetes, particularly type 1 diabetes, who are often left to develop their own strategies or rely on guidelines designed for individuals without diabetes. Evidence to date indicated that employing nutritional strategies along the life-style habits can enhance sport performance in individuals with diabetes, while facilitating post-exercise recovery and glycemic management. Consequently, optimizing exercise protocols is essential for efficient recovery and appropriate training adaptations. The post-exercise period is particularly critical, as it presents challenges due to altered insulin sensitivity, post-exercise hyperglycemia, and other metabolic disturbances observed. Therefore, the key nutritional considerations include carbohydrate intake to replenish glycogen stores, fluid management to maintain hydration and thermoregulation, protein intake to promote muscle repair and glycogen synthesis, and caffeine intake to potentially mitigate exercise-associated hypoglycemia. Furthermore, it is emphasized that specific recommendations for carbohydrate intake, including timing, quantity, and quality, as well as exercise duration and intensity, are crucial for managing glycemic responses. The inclusion of fiber is also recommended. Additionally, fluid management, protein intake, and caffeine consumption play significant roles in optimizing post-exercise recovery for athletes with diabetes. Future research should aim to define optimal nutritional interventions tailored to the unique needs of this population, taking into account individual variations in glycemic responses and metabolic profiles. Future research should focus on defining optimal nutritional interventions tailored to this population's unique needs, considering individual variations in glycemic responses and metabolic profiles.

**Keywords:** Diet, Endurance athletes, Type1 diabetes, Diet therapy, Nutrition.

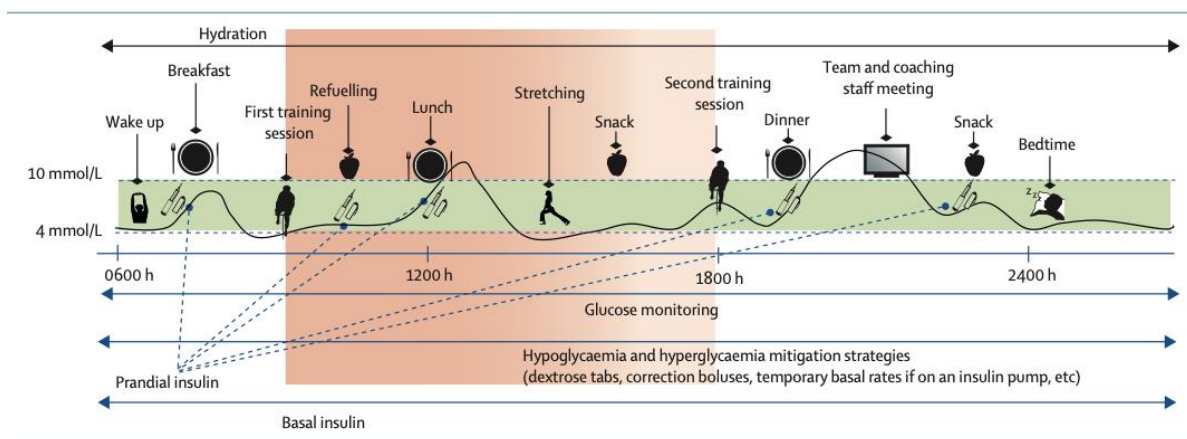
**Citation:** Jurek JM. Dietary Approaches in Endurance Athletes with Diabetes – Nutritional Support. Case Rep Rev Open Access. 2024;5(2):143.

## 1. Introduction

The reported in the last years substantial progress in the understanding glycemic control in the context of exercise and diabetes, led to development of exercise specific guidelines. Many people with diabetes now live an active lifestyle, and achieve incredible feats of physical endurance, even reaching the highest level of competition in their sport. Nevertheless, research focusing on the post-exercise recovery routine in individuals with metabolic disturbances is crucial. Most existing studies concentrate on periods before or during the exercise bout, or both. This focus is significant as the post-exercise recovery period offers an opportunity to maximize training adaptations, enhance recovery, and manage glycemia effectively during rest and overnight. Consequently, the lack of research in this area represents a gap in our understanding and management of post-exercise recovery in individuals with metabolic disturbances [1]. Therefore, the key aim of following article is to provide an updated guidance on evidence-based nutritional strategies which can benefit sport performance of endurance athletes with diabetes, while aiding their post-exercise recovery and glycemic management.

## 2. The Rationale for Optimizing Nutritional Strategies in Athletes With Diabetes

The need of developing behaviors to optimize nutrition before, during, and after exercise has great importance for efficient recovery practices, while ensuring appropriate training adaptations for all athletes, including those with diabetes. For individuals with metabolic disturbances, managing glycemia during post-exercise recovery is challenging due to altered insulin sensitivity, post-exercise hyperglycemia, depleted glycogen stores, dehydration, and impaired glucose counterregulation. Therefore, careful management is essential to maintain appropriate blood glucose concentrations. Consequently, athletes with diabetes must take measures to prevent potentially life-threatening severe hypoglycemia or ketoacidosis, which can also prolong recovery, as outlined in Fig 1. In comparison to those without such conditions, these athletes must be meticulous with their post-exercise nutrition. Replenishing glycogen stores is not solely dependent on carbohydrate absorption in the gut and muscle but also on maintaining blood glucose concentrations within the target range (4–10 mmol/L). This adds an additional layer of complexity, requiring vigilance, frequent monitoring, and often insulin dose titration.



**Fig. 1.** A day in life of endurance athlete with diabetes. Adopted from Scott et al. [1].

### 3. Nutritional Strategies for the Post- Exercise Recovery in Athletes With Diabetes

Athletes without diabetes, in comparison to those with diabetes, do not need to consider their blood glucose concentration in their post exercise nutrition, as their replenishment of glycogen stores is not only limited to carbohydrate absorption in the gut and glucose uptake in the muscle, as the maintain the glucose concentration within target range (4–10 mmol/L) adds an additional complexity that requires vigilance, frequent monitoring, and often insulin dose titration. To ensure and maximise the rates of glycogen resynthesis and muscle protein synthesis after the exercise certain strategies of nutritional timing, quantity, and quality were developed, which along with lifestyle practices, such as cool down, ice baths, and sleep could be used to simultaneously manage glycaemia and the rate of recovery in endurance athletes with diabetes [1].

#### 3.1 Carbohydrates

The quantity of carbohydrates consumed after exercise is critical, particularly within a short time span. Post-exercise carbohydrate intake is essential for optimal recovery, with recommendations to consume 1.0–1.3 g of carbohydrates per kg per hour for the first 4 hours, followed by a return to regular meal patterns to meet ongoing nutritional needs [5]. Carbohydrate-rich foods that are low in fiber and easily consumed, such as white rice or pasta, are recommended.

However, it is important to note that the addition of other nutrients, such as fiber or protein, will alter the glycemic profile. The requirements for carbohydrate intake post-exercise are similar, but the impact on glycemia must be carefully managed to optimize recovery and maintain appropriate blood glucose levels [6]. Although, a fat-based meals seem to have no significant effects on postprandial glycemia, a tendency toward an increase in the long term have been reported [3], as that high-fat meals require more insulin than meals with less fat and the same carbohydrate content, supporting the need for alternative insulin dosing algorithms for high-fat meals [3], [4].

Also, the type and form of carbohydrates should be considered when managing the post-exercise recovery and glycaemia. Although the solid versus liquid form of ingested carbohydrates does not significantly affect the rate of glycogen resynthesis, the type of carbohydrate is crucial due to differing digestion and absorption rates, which are key determinants of their glycemic effect [1]. Post-exercise ingestion of glucose–fructose mixtures, as opposed to glucose alone, significantly enhances glycogen repletion, approximately doubling the rate compared to ingesting glucose alone. For athletes with type 1 diabetes, alternative carbohydrates such as fructose, isomaltulose, and galactose appear beneficial in reducing the risk of exercise-associated hypoglycemia due to the lower amount of insulin required to cover their intake [7]. In addition, the appropriate nutrient managements is crucial for reducing insulin and consuming additional carbohydrates to avoid hypoglycemia and enhance endurance performance in prolonged exercise in athletes with diabetes [2]. Unfortunately, the limited number of studies does not allow to fully assess the glycaemic effects of these carbohydrates after exercise in athletes with diabetes or the possible effect on glycogen resynthesis (liver or muscle).

### 3.2 Fluid management

To preserve homeostasis, optimal body function, and wellbeing, athletes should aim to have fluid management strategies for before, during, and after exercise depending on the type and duration of exercise, as well as the environment. Athletes with diabetes will have to consider what they drink (i.e. if it contains carbohydrates), in addition to how much they consume, to manage glycaemia and hydration. In addition, athletes with diabetes may have an impaired thermoregulation during exercise, particularly under hot and humid conditions, therefore when exercising at higher workloads ( $\geq 250$  watts per metre squared of body surface area) in the heat ( $35^{\circ}\text{C}$  at 20% humidity), the sweating response in those with diabetes seems to be lower and their core body temperature appears to be higher compared with athletes without diabetes. Athletes with diabetes may experience altered thirst perception due to high blood osmolality, which likely signals an increased thirst sensation [8]. Therefore, to ensure effective rehydration, these athletes require a greater volume of fluid intake, approximately 125–150% (or 1.25–1.50 L of fluid for every 1 kg of bodyweight lost).

### 3.3 Protein

Carbohydrate ingestion induces insulin secretion, and for individuals without diabetes, the combination of protein and carbohydrate intake can further influence insulin production. Athletes without diabetes often co-ingest protein and carbohydrates post-exercise to accelerate recovery and take advantage of insulin's anabolic effects.

When protein is consumed with carbohydrates below the threshold for maximal glycogen storage, it can enhance glycogen synthesis. However, when the carbohydrate intake meets the required threshold (e.g., 1.2 g of carbohydrates per kg per hour), the co-ingestion of protein does not provide an additional effect on glycogen synthesis.

The benefits of such nutritional strategies are well described for athletes with diabetes. For instance, consuming 0.8 g of carbohydrates per kg per hour in combination with 0.4 g of protein per kg per hour improves exercise performance compared to 1.2 g of carbohydrates per kg per hour alone [9] [10]. This indicates that while protein intake does not influence endogenous insulin production in athletes with diabetes, it might increase their insulin requirements.

Insulin administration can be a useful tool for managing protein-rich foods, as a high intake of protein (around 60 g) approximately 18 hours after exercise contributes to glycogen resynthesis and increases net muscle protein balance.

### 3.4 Caffeine

Caffeine is naturally found in many foods and is frequently added to sports supplements because of its ergogenic effects in a range of sporting events. Caffeine has many physiological effects, including increased lipolysis in adipose tissues and hepatic glucose production, alongside a decrease in glucose uptake in skeletal muscle. In athletes without diabetes, caffeine intake before exercise increases glucose concentration (0.5 mmol/L) during moderate intensity endurance exercise, and slightly more (1.0–1.5 mmol/L) after maximal effort time; suggesting that acute caffeine intake might attenuate exercise-associated hypoglycaemia in people with diabetes [11]. Therefore, the ingestion of modest amounts

of caffeine (200–250 mg, equivalent to three or four cups of coffee) has been shown to enhance awareness of hypoglycemia, improve hormonal responses, and increase catecholamine release in individuals with diabetes (Watson et al., 2000). Regular caffeine ingestion has also been shown to reduce the frequency of moderate episodes of overnight hypoglycemia in individuals with long-standing type 1 diabetes [13].

However, the limited studies investigating the effects of caffeine on exercise-associated hypoglycemia in athletes with diabetes do not provide sufficient data to support its use during the recovery period in this population. If caffeine is found to be useful for post-exercise recovery, future research should aim to define the minimum effective dose required to reduce the risk of hypoglycemia while considering potential disadvantages, such as impaired sleep quality.

#### 4. Case Study: Nutritional Strategies for Athlete With Type 1 Diabetes During 217km Ultramarathon Race

A 36-y-old male athlete who was diagnosed with type 1 diabetes about 15 years earlier was participated in 217 km long ultramarathon race in Brazil. The athlete completed the race in 51 h 18 min. He consumed a total of 15.0 MJ (3593 kcal), 532 g carbohydrate, 166 g protein, 92 g lipid, and 14 L of water during the race. Glycemic values ranged from 3.6 to 18.2 mmol·L<sup>-1</sup>. Most glycemic values (47%) ranged from 3.9 to 10 mmol·L<sup>-1</sup>, whereas 5% were <3.9 mmol·L<sup>-1</sup>, 16% were >10 to 13.9 mmol·L<sup>-1</sup>, and 32% were >13.9 mmol·L<sup>-1</sup>.

The examples of employed foods were as follows (Table 1):

**Table 1:** An Example of Proposed Nutrition Breakdown for an Athlete Aiming for Appropriate Glycemic Control on Race Day.

Race day	Day 1 post race	Day 2 post race
<ul style="list-style-type: none"> <li>- Propel hydractive gel</li> <li>- Mashed potatoes</li> <li>- Energy gel (carb-loaded)</li> <li>- Jelly gummy</li> <li>- Gatorade (drink)</li> <li>- White wheat bread with salami</li> <li>- Regular coke</li> <li>- Potato chips</li> <li>- Sports beans</li> <li>- Spaghetti bolognaise</li> <li>- Chocolate protein bar</li> </ul>	<ul style="list-style-type: none"> <li>- Spaghetti with garlic and oil</li> <li>- Chicken with tomato sauce</li> <li>- Propel hydractive gel</li> <li>- Chocolate protein bar</li> <li>- Bread roll white</li> <li>- Salami</li> <li>- Apple</li> <li>- Canned tuna fish</li> <li>- Regular coke</li> </ul>	<ul style="list-style-type: none"> <li>- Cream cracker</li> <li>- Mayonnaise</li> <li>- Energy gel</li> </ul>
Kcal: 1957 Carbohydrates: 372 g Fat: 38 g Protein: 33 g	Kcal: 1374 Carbohydrates: 123 g Fat: 40 g Protein: 130 g	Kcal: 288 Carbohydrates: 37 g Fat: 14 g Protein: 3 g

Although the athlete implemented strategies that differed from those recommended in the literature, the food and nutrient intake and the glycemic management strategy adopted enabled him to successfully complete the race [15].

### 5. Case Study: Recovery Phase Nutrition for Distance Runner With Type 1 Diabetes

A female collegiate long distance runner diagnosed with type 1 diabetes was subjected for a moderate-carbohydrate diet and 24 h insulin adjustment during recovery phases for improved glycemic control and reduced use of acute strategies. During an 8-day period, she followed a moderate-carbohydrate diet providing ~4 g/kg/day and she was performing a daily training in the fasted state at 6:00 a.m. and included additional exercise strategies to reduce glycemic variability when needed.

Briefly, the nutrition programme was based on daily intake of 3 meals/day according to number of macronutrient servings specified below with 1 serving of non-starchy vegetables/meal; 1 low-carbohydrate (i.e., 10 g), high-protein (i.e., 20 g) bedtime snack/day. a 5 servings/meal (~70 g). b 4 servings/meal (~35 g). c ~1 serving/meal (~10 g). The following foods with serving portions were included (Table 2):

**Table 2:** Moderate-Carbohydrate Nutrition Program.

<b>Carbohydrate <sup>a</sup></b>	<b>Protein <sup>b</sup></b>	<b>Fat <sup>c</sup></b>
1/3 cup oats, dry	1 ounce poultry or beef	2 TBSP nuts/seeds
1/3 cup brown rice, cooked	1 ounce fish	1 TBSP nut/seed butter
1/2 cup legumes, cooked	1 large egg	1 TBSP butter
1/2 cup quinoa, cooked	1 cup milk, 1%	1 TBSP olive oil
1 cup milk, 1%	1 cup chocolate milk, 1%	1/2 avocado, medium
1/2 cup chocolate milk, 1%	1/3 cup cottage cheese, 1%	
1/2 potato, medium	1/3 cup Greek yogurt, 1%	
1/2 sweet potato, medium	1/4 cup feta crumbles	
1/4 cup low-fat granola	1/4 cup shredded cheese	
1 cup berries	1 ounce sliced cheese	
1/2 piece of fruit		
2 TBSP dried fruit		
1 medjool date		
1 TBSP honey or maple syrup		

<b>Carbohydrate <sup>a</sup></b>	<b>Protein <sup>b</sup></b>	<b>Fat <sup>c</sup></b>
Non-starchy vegetables		
2 cups leafy greens		
1 cup raw vegetables		

After the intervention was completed, the mean glucose time-in-range significantly increased (77% versus < 50%), and the magnitude of glycemic excursions decreased (from approximately 3.8–15 mmol/L to 3.0–26 mmol/L) compared to a previous comparison period. Minimal pre-exercise acute carbohydrate supplementation was utilized, and no additional supplementation was needed during exercise.

Furthermore, the athlete achieved a new lifetime best in the 5000 m run and maintained positive well-being. Overall, this case study highlights recovery phase strategies such as a moderate carbohydrate diet that can support glycemic control and enhance athletic performance in distance runners with type 1 diabetes. It also offers valuable insights into nutrition and insulin strategies that athletes and coaches can consider [16].

## 6. Summary

The summary of nutritional guidance ensuring appropriate recovery in endurance athletes with diabetes:

### 6.1 Carbohydrate Intake

- Initiate carbohydrate feeding when the glucose concentration is less than 8,0 mmol/L (144 mg/dL), particularly if glucose is decreasing.
- If aiming for rapid recovery from a long period of exercise and peak performance is required within 24 h, consume 1,0–1,3g of carbohydrates per kg per hour for the first 4 h of recovery, starting as soon as possible after exercise, with frequent feeding intervals thereafter (i.e., every 30 min).
- The use of multiple transportable carbohydrates (e.g., fructose) in combination with glucose after exercise will promote a faster liver glycogen repletion rate than glucose alone.
- Fructose and glucose co-ingestion will require a lower insulin dose compared with glucose alone

### 6.2 Protein Intake

- Daily protein intake: 1,6–1,8 g per kg-1 per day for endurance athletes.
- Adding protein to carbohydrate immediately after exercise might speed up recovery.

### 6.3 Hydration

- Effective rehydration requires the intake of a greater volume of fluid (eg, 125–150%) than the final fluid deficit (eg, 1,25–1,50 L fluid for every 1 kg of bodyweight lost).

- Hydrate with carbohydrate-free drinks if blood glucose concentration  $>10.0$  mmol/L\* \*Special caution should be made to the drinks containing high amounts of carbohydrate on the blood glucose levels.
- Dietary sodium and sodium chloride (from foods or fluids) helps to retain ingested fluids
- Take into consideration effects of environmental conditions (hot or humid conditions).
- Excessive alcohol intake in the recovery period is discouraged because of the diuretic effect and increased risk of hypoglycaemia.

#### 6.4 Caffeine

- Caffeine in a dose of 3 mg per kg (200–300 mg) might reduce the risk for hypoglycaemia during and after exercise.\*
- \*This dose can be consumed alongside glucose
- Avoid high amounts of caffeine consumption late in the day, because this can negatively affect sleep and recovery.

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**Citation:** Jurek JM. Dietary Approaches in Endurance Athletes with Diabetes – Nutritional Support. *Case Rep Rev Open Access*. 2024;5(2):143.