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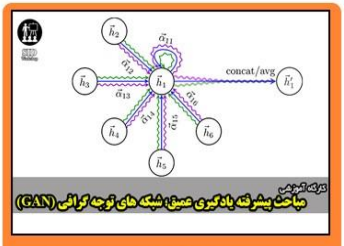

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کارگاه آنلاین مقاله نویسی IEEE و ISI
ویژه فنی و مهندسی

Int J Endocrinol Metab. 2016 April; 14(2):e36091. doi: 10.5812/ijem.36091.

Published online 2016 March 26. **Review Article**

Care of the Athlete With Type 1 Diabetes Mellitus: A Clinical Review

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Received 2016 January 06; **Revised** 2016 February 24; **Accepted** 2016 March 01.

Abstract

Context: Type 1 diabetes mellitus (T1DM) results from a highly specific immune-mediated destruction of pancreatic β cells, resulting in chronic hyperglycemia. For many years, one of the mainstays of therapy for patients with T1DM has been exercise balanced with appropriate medications and medical nutrition. Compared to healthy peers, athletes with T1DM experience nearly all the same health-related benefits from exercise. Despite these benefits, effective management of the T1DM athlete is a constant challenge due to various concerns such as the increased risk of hypoglycemia. This review seeks to summarize the available literature and aid clinicians in clinical decision-making for this patient population.

Evidence Acquisition: PubMed searches were conducted for "type 1 diabetes mellitus AND athlete" along with "type 1 diabetes mellitus AND exercise" from database inception through November 2015. All articles identified by this search were reviewed if the article text was available in English and related to management of athletes with type 1 diabetes mellitus. Subsequent reference searches of retrieved articles yielded additional literature included in this review.

Results: The majority of current literature available exists as recommendations, review articles, or proposed societal guidelines, with less prospective or higher-order treatment studies available. The available literature is presented objectively with an attempt to describe clinically relevant trends and findings in the management of athletes living with T1DM.

Conclusions: Managing T1DM in the context of exercise or athletic competition is a challenging but important skill for athletes living with this disease. A proper understanding of the hormonal milieu during exercise, special nutritional needs, glycemic control, necessary insulin dosing adjustments, and prevention/management strategies for exercise-related complications can lead to successful care plans for these patients. Individualized management strategies should be created with close cooperation between the T1DM athlete and their healthcare team (including a physician and dietitian).

Keywords: Type 1 Diabetes Mellitus, Exercise, Hypoglycemia, Hyperglycemia

1. Context

Type 1 diabetes mellitus (T1DM) results from a highly specific immune-mediated destruction of pancreatic β cells, resulting in chronic hyperglycemia (1). Individuals living with T1DM require chronic injection of exogenous insulin for survival (2). Today, with the advent of many advances in insulin therapy and delivery, along with improvements in blood glucose (BG) monitoring, individuals with T1DM are seeing improvements in life expectancy (3) and participating at the highest levels of competitive athletics (4-6).

For many years, one of the mainstays of therapy for patients with T1DM has been exercise balanced with appropriate medications and medical nutrition (7). Compared to healthy peers, athletes with T1DM experience nearly all the same health-related benefits from exercise (8). These include improvements in health-related quality of life, reduction in blood pressure, improvement in lipid abnormalities (9), increased insulin sensitivity, decreased insulin requirements, lower hemoglobin A1c (HbA1c) levels (10), improved endothelial function (11), and improvement in cardiorespiratory fitness (12). Despite these benefits, effective management of the T1DM athlete is a constant challenge due to various concerns such as the increased risk of hypoglycemia. Recent data demonstrates that the incidence of T1DM is increasing (13). As the number and life expectancy of T1DM patients increases, it is important for clinicians to understand appropriate management strategies for patients participating in athletic pursuits. This review seeks to summarize the available literature and aid clinicians in clinical decision-making for this patient population.

2. Evidence Acquisition

2.1. Methods

PubMed searches were conducted for "type 1 diabetes mellitus AND athlete" along with "type 1 diabetes mellitus AND exercise" from database inception through November 2015. All articles identified by this search were reviewed if the article text was available in English and related to management of athletes with type 1 diabetes mellitus. All titles and abstracts of papers identified by the searches were assessed for inclusion by one reviewer. Subsequent reference searches of retrieved articles yielded additional literature included in this review.

3. Results

3.1. Exercise and Glucoregulation

Exercise is a metabolic challenge with a synchronized endocrine response (14). Metabolic responses to exercise are determined primarily by the intensity, duration, and environmental conditions (i.e. temperature, humidity, time of day) (1). Skeletal muscle plays a critical role in glycemic control and metabolic homeostasis and is the predominant site of glucose disposal under insulin-stimulated conditions (15, 16). Skeletal muscle is also the largest glycogen storage organ, having an approximate 4-fold greater glycogen storage capacity than the liver (15). AMP-activated protein kinase (AMPK) is a serine/threonine kinase that serves as a sensor of cellular energy status (15, 17). AMPK modulates cellular metabolism via phosphorylation of metabolic enzymes (18) and transcriptional regulation (19, 20). AMPK activation is chiefly regulated by cellular energy deficits, which are reflected by increases in the adenosine monophosphate (AMP)/adenosine triphosphate (ATP) and creatine (Cr)/phosphocreatine (PCr) ratios (21). Given the high rate of ATP turnover during muscle contraction, exercise increases AMPK phosphorylation and enzymatic activity in an intensity-dependent manner (22, 23). AMPK activation acts to conserve ATP by inhibiting biosynthetic and anabolic pathways, while simultaneously stimulating catabolic pathways to restore cellular energy stores (21). In skeletal muscle, acute AMPK activation suppresses glycogen (18) and protein synthesis (24), but promotes glucose transport (25) and lipid metabolism (26).

Muscles use glucose as their primary source of fuel in the initial stages of exercise (14). During moderate-intensity exercise (40% - 59% of maximal oxygen consumption [VO_2 max] or 55% - 69% of maximal heart rate), the fuel for muscular contraction is gained almost exclusively from aerobic metabolism- by using a mixture of carbohydrate (CHO) from muscle glycogen stores and circulating free fatty acids (FFA) as fuel (1). Most endurance sports are performed within the moderate-intensity range (i.e. long-distance running and cycling) (1). As muscle glycogen stores are depleted, a balance develops between glucose production (primarily via hepatic glycogenolysis (27)) and glucose uptake by exercising muscle (14). Insulin secretion concurrently falls (28, 29) as muscle glucose uptake increases due to exercise stimulating the translocation of GLUT-4 receptors to the cell surface (30). A slight increase in catecholamines combined with the decrease of insulin promotes lipolysis in exercise, permitting the use of FFA as fuel (14), and later gluconeogenesis (31, 32).

High-intensity exercise (85 to 100% VO_2 max or greater than 90% maximal heart rate), sustained for 10 to 30 minutes or intermittent bouts of 3 to 5 minutes, is common in team-oriented sports, such as lacrosse, football, hockey, soccer, track and field, and swimming (1). Exercise to VO_2 max is primarily sustained by aerobic metabolism, including oxidative phosphorylation and, to a lesser extent, beta oxidation (1). High-intensity, supramaximal-effort (> VO_2 max) activities sustained for only 3 to 30 seconds, such as sprinting, utilize the anaerobic energy system. In either scenario, high-intensity exercise is highly dependent on glucose as fuel, derived from either hepatic or muscle glycogenolysis (1). Additionally, exercise at high-intensity is characterized by marked lactate accumulation and a substantial increase in catecholamine concentrations, approximately 14- to 18-folds above basal levels (33).

Once exercise stops, insulin levels rapidly increase both in response to high BG levels and removal of circulating catecholamines (1). As a result, hyperglycemia and hyperinsulinemia combine postexercise to provide ideal homeostatic metabolic conditions for the replenishment of muscle glycogen (14). This promotes rapid recovery and primes the athlete for repeated bouts of high-intensity exercise.

3.2. Nutritional Recommendations for Peak Performance

3.2.1. Daily Macronutrient Needs for Exercise

Diabetic athletes have unique nutritional requirements that should be met to aid in peak performance. Proper understanding of current recommendations for caloric and fluid intake before, during, and after exercise is necessary for successful BG management and prevention of hypo- and hyperglycemia. Energy and macronutrient needs, especially CHO and fat, must be met to maximize training effects and maintain health (14). The recommended balance of these nutrients for athletes does not differ significantly from recommendations for the general population, though additional calories and fluids may be required for diabetic athletes and varies based on circumstances (exercise intensity, total energy expenditure, type

of exercise/training program, duration of exercise, gender, and environmental factors) (1). Current guidelines recommend 5 - 12 g of CHO per kilogram of body mass per day (14, 34). Table 1 details daily CHO recommendations for athletes by training load (14, 35).

Table 1. Guidelines for Daily CHO Intake for Fuel and Recovery in Type 1 Diabetic Athletes[a]

Training Load	CHO Recommendation (g/kg/day)
Very light training (low intensity exercise or skill-based exercise)	3 - 5
Moderate intensity exercise for 1 hour/day	5 - 7
Moderate-to-high intensity exercise for 1 - 3 hours/day	7 - 10
Moderate-to-high intensity exercise for 4 - 5 hours/day	$\geq$ 10 - 12

Abbreviation: CHO, carbohydrate.
[a]Adapted with permission from references (14) and (35).

A joint position statement by the American Dietetic Association, Dietitians for Canada, and the American College of Sports Medicine recommends the following general energy requirements for competitive athletes (36):

1. CHO consumption range of 6 - 10 g/kg body weight per day.

2. Protein consumption range for endurance and strength-trained athletes of 1.2 - 1.7 g/kg body weight per day. This recommendation can generally be met through diet alone, without the use of dietary supplements.

3. Fat consumption range of 20% - 35% of total energy intake. Consuming $\leq$ 20% of energy from fat intake does not benefit performance.

CHO consumption is necessary to maintain BG levels during exercise and replace muscle glycogen (1). Protein is needed for tissue repair and muscle growth while fat provides needed calories as well as fat-soluble vitamins and essential fatty acids (36). Box 1 summarizes recommendations for CHO and fluid intake during exercise (14, 35).

3.2.2. Timing of Nutrient and Fluid Intake

The primary goals for nutrient intake during training and competition are to replace fluid losses and provide CHO for maintenance of BG levels (14). Food and fluid choices to be utilized before, during, and after exercise are influenced by various factors, including intensity and duration of training, environmental conditions, and individual characteristics of the athlete.

3.2.3. Special Considerations for the Diabetic Athlete

Uncomplicated T1DM does not reduce physical performance (38, 39) and exercise capacity is equivalent to that

Box 1. Recommendations for CHO and Fluid Intake During Exercise in Type 1 Diabetic Athletes[a]

Duration of Event
30-60 minutes
Primary goal is fluid replacement
Begin exercise well-hydrated
Drink at a rate that is comfortable and practical to replace fluid lost by sweating
CHO intake is beneficial for the performance of high-intensity exercise of about 1 hour duration (37)
1 - 3 hours
Primary goal is fluid replacement + CHO intake
30 grams CHO per hour of exercise
Drink at a rate that is comfortable and practical to replace fluid lost by sweating
$\geq$ 3 hours
Primary goal is fluid replacement + CHO + sodium intake
30 - 60 grams CHO per hour of exercise; when greater than 70 g CHO per hour are required, use a mixture of CHO sources (i.e. 2:1 ratio of glucose and fructose)
Drink at a rate that is comfortable and practical to replace fluid lost by sweating

Abbreviation: CHO, carbohydrate.
[a]Adapted with permission from references (14) and (35).

of healthy individuals (40, 41). However, several complications can be seen with exercise in this patient population. T1DM athletes frequently experience hypoglycemia during endurance exercise due to augmented insulin absorption, impaired glucagon secretion, and reduced catecholamine responses (42-45). Exercise also specifically increases the risk of hypoglycemia 6 - 15 hours after exercise is completed (46) due to increased insulin sensitivity resulting from a prolonged increase in GLUT-4 transporter translocation to the cell surface (47-49). It should also be noted that not all forms of exercise lead to hypoglycemia, as some forms of intense exercise have been identified as potential causes of hyperglycemia (50). With these factors in mind, it is important for T1DM athletes to consume appropriate amounts of carbohydrates and coordinate food intake with timing of exercise and insulin dosing. This approach is critical for optimizing glycemic control and exercise performance, maintenance of muscle and liver glycogen stores, and prevention of fatigue and complications (1).

3.2.4. Carbohydrate Intake Recommendations for the Diabetic Athlete

Intense exercise at the time of peak insulin activity is associated with glucose disposal into muscle of approximately 1 g glucose/kg/h of exercise (14, 51). As demonstrated

in Box 1, general recommendations for CHO intake during exercise are 30 - 60 g CHO per hour of exercise. A recent study by Francescato et al. confirmed the utility of a recently proposed customizable algorithm (Ecres) for estimating the amount of carbohydrates necessary to prevent glycemic imbalances during moderate-intensity aerobic physical activity (52). Box 2 summarizes recommendations for CHO intake before, during, and after exercise in T1DM athletes (1).

Box 2. CHO Intake Recommendations Before, During, and After Exercise in the Athlete With Type 1 Diabetes Mellitus[a]

Recommendations
Pre-Exercise
Athletes with diabetes who "CHO load" (200 - 350 g per meal) to increase glycogen stores before athletic events should monitor BG levels regularly and adjust insulin doses accordingly.
Recommended pre-event CHO intake is approximately 1 g CHO/kg body weight one hour before exercise. Low-fat CHO foods, such as crackers, toast, fruit, and/or yogurt instead of sugary sweets are ideal choices.
If the exercise is of short duration (< 45 mins), a pre-exercise snack of ~ 15 g CHO eaten 15 to 30 minutes before the event is adequate.
During Exercise
During prolonged (> 45 - 60 minutes) or intense exercise (> 80% maximal heart rate), an intake of 30 g CHO for every 60 minutes of activity is a safe starting guideline.
Solid or liquid forms of CHO may be consumed. Each form has distinct advantages. Liquids provide fluid for hydration whereas solids may reduce or prevent hunger. For exercise lasting > 60 - 90 minutes, a liquid CHO form is most recommended since it is more practical and contributes to adequate hydration.
Post-Exercise
Consuming CHO immediately after exercise as opposed to waiting for a period of time has been shown to replace CHO stores more efficiently.
Intake of 1.5 g CHO/kg body weight within 30 minutes after an extended exercise session (> 90 minutes in duration) and intake of an additional 1.5 g CHO/kg body weight one to two hours later will replete glycogen to pre-exercise levels and reduce risk of post-exercise hypoglycemia.
BG levels should be monitored at 1- or 2-hour intervals to assess response to exercise and make any necessary adjustments in insulin dosing and/or food intake.

Abbreviations: CHO, carbohydrate; BG, blood glucose.
[a] Created from recommendations found in reference (1).

While the above recommendations serve as a useful guide for determining CHO needs, many other factors should be considered and advice tailored to individual needs of the diabetic patient, including:

1. Form of treatment: Insulin pump therapy, or continuous subcutaneous insulin infusion (CSII), provides the athlete a greater degree of flexibility for making basal rate adjustments before, during, and after exercise. This differs from multiple daily injection (MDI) and twice daily insulin regimens, which provide little room for on-the-fly basal rate adjustments, therefore needs during exercise are likely to differ (14).

2. Timing of exercise relative to insulin bolus: If exercise is within 90 - 120 minutes of an insulin bolus, the athlete should be able to adjust the meal insulin bolus and consequently CHO needs during exercise will be reduced, otherwise exercising within 2 hours of a bolus may require taking more CHO than the recommended 30 - 60 g/h (14, 51).

3. BG when initiating exercise: If the BG level is below 126 mg/dL (7 mmol/L), a 15 - 30 g CHO snack may be required. When the BG level is 180 mg/dL (10 mmol/L) or above, CHO intake during exercise should be delayed (14).

4. Antecedent hypoglycemia and prolonged moderate exercise: Both of these factors have been shown to cause similar blunting effects of the counter-regulatory responses during subsequent exercise, thereby making the athlete more susceptible to hypoglycemia. Davis et al. (53) demonstrated that nearly three-fold greater exogenous glucose infusion rates were needed to preserve euglycemia during exercise following a day of antecedent hypoglycemia when compared to a day without hypoglycemia (14).

5. Type of exercise: High intensity (i.e. sprinting) and intermittent high intensity (i.e. football) exercise may result in hyperglycemia during and/or after the exercise; therefore, CHO intake during these forms of exercise is likely to be problematic. General CHO intake recommendations for athletes should be adapted during these activities (14). Refer to Table 1, Boxes 1 and 2 for further details.

3.3. Management Strategies for the Athlete with Type 1 Diabetes

3.3.1. Education

Glycemic control in the diabetic athlete is dependent upon both the athlete and healthcare provider having an appropriate understanding of the pathophysiology of diabetes and its nuances with respect to athletic activity. The cornerstone of management for T1DM athletes is prevention of glycemic excursions (both hypo- and hyperglycemia) while maintaining adequate energy balance for exercise performance (1). All diabetic athletes should be counseled on the importance of establishing a daily pattern of consistency for all aspects of diabetes management. This pattern of consistency would ideally include a routine of insulin administration, consistent caloric intake, regimented exercise program, and frequent monitoring of BG levels (1). Each athlete is unique and will likely require personalized adjustments until an optimal routine can be established (1). Education of those working with these athletes is just as important as educating the athletes themselves. For those T1DM athletes who participate in scholas-

tic competition or team sports, it is vital to ensure that parents, coaches, teammates, teachers, and other adults understand the importance of timed meals, snacks, and adequate fluid intake, as well as recognizing the features and management of hypoglycemia (54, 55).

3.3.2. Glycemic Control and Target Values in Athletics

General recommendations suggest that T1DM athletes exhibiting poor glycemic control (Hemoglobin A1c > 9%) should refrain from moderate-to-high intensity exercise until adequate glycemic control has been obtained (1). This is advisable because it helps decrease the risk of exacerbating hyperglycemia and minimizes the risk of progression to frank diabetic ketoacidosis (DKA) (56).

In athletes with T1DM, glucose production from the liver, regardless of prior CHO intake, does not match the elevated rates of glucose disposal into muscle during exercise and in recovery (57). This leads to an increased fluctuation in BG levels (58). Adjustments in both dietary intake and insulin dosing are necessary for prevention of these BG fluctuations. Waiting 60 to 90 minutes after a meal before exercising and monitoring BG levels both during and after exercise/athletic competition are important baseline management measures (1). CHO-rich, low-glycemic index meals should be consumed 1 to 3 hours prior to exercise (59, 60). Immediately before and during athletic activity, consumption of additional CHO (17 g at initiation and 17 g every 15 minutes for 60 minutes of exercise at 65% VO_2 max) has proven beneficial in maintaining BG levels both during and after exercise in patients with T1DM (61).

Consumption of low-glycemic index diets has been shown to improve metabolic regulation (62) as these foods require less insulin for optimal glucose utilization (1). These foods give a "low and slow" elevation in glucose when consumed and include non-starchy vegetables, fruits, nuts, milk, fructose, and lactated sugars (63). Examples of high-glycemic index foods that lead to rapid increases in BG include white bread and glucose sugars (63). It should also be noted that as long as the diet contains adequate CHO to maintain normal glycogen levels, low-calorie diets can be used in this patient population without affecting exercise tolerance (64).

The general guidelines for glycemic targets during exercise are 120 to 180 mg/dL (6.7 to 10 mmol/L), though BG goals should always be individualized to meet the specific patient's needs (58). If pre-exercise BG is 100 - 250 mg/dL, it is generally safe to begin exercising (65). The American Diabetes Association has published guidelines (54) for regulating the glycemic response to exercise which include the following recommendations: avoid exercise if fasting BG > 250 mg/dL and ketosis is present, use caution if BG > 300 mg/dL without ketosis present, and ingest extra CHO if BG < 100 mg/dL. Monitoring BG levels using a glucometer or continuous glucose monitor (CGM) frequently during exercise is essential (1). It is also imperative that athletes keep detailed BG records during athletic activity, so they may understand their glycemic response to exercise, learn to make appropriate exercise-related management decisions, and evaluate the effectiveness of these decisions over time (58).

3.3.3. Insulin Dosing Adjustments for Athletic Activity

The development of highly specialized insulin has allowed more physiologic regimens to be used in the treatment of patients with T1DM (7). Insulin dosing adjustments for exercise are largely dependent upon the insulin regimen used by the athlete. MDI is a type of intensive insulin therapy which uses a long-acting insulin (such as insulin glargine [Lantus] or insulin detemir [Levemir]), injected once or twice daily, to provide fairly constant, low-levels of circulating insulin for basal control (7). The other component of MDI therapy includes a mealtime short-acting insulin (such as insulin analogs lispro [Humalog], aspart [Novolog], and glulisine [Apidra]) injected as a bolus immediately before eating, preferably matched to the number of calories or carbohydrates to be consumed (7). It is advisable for all T1DM athletes to avoid exercise during peak insulin activity times, if possible (1). For athletes utilizing MDI regimens, the dose of short-acting insulin should generally be decreased by 30% to 50% at the meal preceding exercise (54). For example, if a morning workout or athletic competition is expected, the short-acting insulin at breakfast should be reduced as above (1). One study has demonstrated that near euglycemia is obtainable in T1DM athletes during exercise with short-acting insulin dose reductions as high as 70% to 90% (66). It should also be noted that further insulin dose adjustments of 10% to 30% may be needed as the athlete becomes more fit (67). Insulin injection sites are also an important factor to be considered. The abdomen is regarded as the preferred site for athletes due to ease of access at mealtimes and more predictable absorption time (68).

CSII (insulin pump) therapy affords greater flexibility of insulin delivery than is currently available to those athletes using MDI regimens (14). A recent study among individuals performing regular moderate-to-heavy intensity aerobic exercise demonstrated that use of CSII helped to limit post-exercise hyperglycemia compared to MDI therapy and was not associated with increased risk for post-exercise late-onset hypoglycemia (69). T1DM athletes utilizing CSII therapy should reduce the action of the pump by 50% approximately one hour before high-intensity exercise is initiated (70). Mealtime bolus doses should also be decreased by 50% if a meal is eaten prior to competition.

For low-intensity exercise, the standard basal rate may be maintained with a small reduction in the mealtime bolus (1). If the athlete participates in a sport with contact or collision, it should be removed approximately 30 minutes prior to exercise to compensate for the persistent insulin effect after pump removal (1). For activity lasting > 1 hour, small boluses may be needed to prevent a hypoinsulinemic state (1). Boluses should be given every hour and the amount of insulin given should represent about 50% of the usual hourly basal rate (71).

3.4. Glycemic Complications in Athletes: Prevention and Management

3.4.1. Hypoglycemia

Hypoglycemia is a feared complication for T1DM athletes and can arise for many reasons in this population. Common causes include too high a daily dose of insulin, errors in dosage, increased activity duration or intensity, insufficient or delayed food intake, and alcohol intake during or immediately after exercise (1). As glycogen is used for fuel during athletic competition or exercise, the reductions in hepatic and intramuscular glycogen concentrations lead to increased insulin action (1). While the rate of CHO utilization depends upon the duration and intensity of exercise, training status, and prior diet, as glycogen stores in active muscle and liver are depleted, the risk for hypoglycemia correspondingly increases (1, 72). There are known conditions that affect the counter-regulatory response to hypoglycemia that may be encountered in athletes with T1DM: antecedent exercise (73), antecedent hypoglycemia (74), and autonomic neuropathy (75). This failed counter-regulatory mechanism is hypothesized to be the result of cortisol stimulation that occurs during a stress (such as hypoglycemia) and the effect it exerts on the central nervous system (74). These individuals maintain a higher susceptibility to hypoglycemic episodes in the future (1).

3.4.2. Pre-Exercise Hypoglycemia Prevention Strategies

Adjustments in insulin dosing are necessary prior to exercise initiation (and have been covered above), but appropriate CHO replacement during and after exercise appears to have the most positive effect on preventing hypoglycemia (76). If the insulin dosing is not altered prior to exercise, a CHO snack must be ingested to minimize the likelihood of hypoglycemia (77). Individualization of insulin dosing, timing, and caloric intake before, during, and after exercise is critical to hypoglycemia prevention (1). Repeated experience with glycemic control during athletic activity by the T1DM athlete should help individualize any necessary adaptations to help prevent hypoglycemia (7). Table 2 provides a general summary for prevention of exercise-associated hypoglycemia in T1DM athletes.

Table 2. Strategies for Prevention of Exercise-Associated Hypoglycemia in the T1DM Athlete [a]

Strategy	Advantages	Disadvantages
Reducing pre-exercise bolus (preferably when exercise is within 90 - 120 minutes of a bolus)	Reduces CHO requirement; Reduced hypoglycemia during exercise; beneficial for weight management	Requires proper planning; not helpful for spontaneous or late postprandial exercise; may result in starting exercise with increased BG
Adjusting pre-exercise and during exercise basal insulin rate (for patients on CSII therapy)	As above	Requires proper planning, as basal rate adjustments should be made at least 60 minutes prior to exercise
Reducing basal insulin post-exercise (possible with CSII and MDI therapy)	Reduces nocturnal hypoglycemia	May cause increase in fasting BG
CHO feeding during exercise	Useful for unplanned or prolonged exercise	Counterproductive if purpose of exercise is weight reduction/control; not practical with all sports; potential gastrointestinal discomfort
Pre-exercise or post-exercise sprint	Reduces immediate post-exercise hypoglycemia	Effect limited to shorter or less intense exercise; no effect on hypoglycemia during exercise
Caffeine intake prior to exercise	Reduced hypoglycemia during and after exercise; reduced CHO requirements	Possible impairments or alterations of fine motor control and technique; possible interference with recovery and sleep patterns

Abbreviations: BG, blood glucose; CHO, carbohydrate; CSII, continuous subcutaneous insulin infusion; MDI, multiple daily injections.
[a] Adapted with permission from Reference (14).

3.4.3. Management of Acute Hypoglycemia During Exercise

T1DM athletes who participate in athletic activity should be able to recognize the symptoms of hypoglycemia (BG < 70 mg/dL): dizziness, weakness, sweating, headache, hunger, pallor, blurred vision, slurred speech, confusion, irritability, and poor coordination (1). If hypoglycemia occurs, exercise should be stopped immediately and BG monitored every 15 minutes until it rises above 80 mg/dL (1). Acute hypoglycemia is best treated immediately with 15 g CHO (examples include 1/2 cup fruit juice, 4 glucose tablets, 6 oz sweetened carbonated beverage, or 8 oz low-fat or skim milk) (78). Severe hypoglycemia should be

treated with glucagon 1 mg subcutaneously or intramuscularly to produce a rapid release of liver glycogen (1). It should also be noted that this therapy is ineffective if liver glycogen stores have been depleted by prolonged, intense exercise (1).

3.4.4. Post-Exercise Hypoglycemia

The risk of hypoglycemia in T1DM athletes persists even after athletic competition or exercise is completed. Late-onset post-exercise hypoglycemia (LOPEH) has been seen in T1DM patients as long as 6 to 24 hours after activity (79). The mechanism of LOPEH contains two main components: after exercise is completed, muscle and hepatic glycogen stores are filled by utilizing circulating plasma glucose. This coupled with increased insulin sensitivity and glucose uptake by peripheral tissues and a blunting of the glucoregulatory response to insulin-induced hypoglycemia is believed to cause LOPEH, which is often nocturnal (56). LOPEH most commonly occurs with increases in training level or during "two-a-day" preseason practices (commonly seen in football), although it may occur at any time (1).

One study has shown that regardless of post-exercise supplementation, glucose concentrations fell after 22 hours, and pre-bedtime snacks were an important component of prevention or correction of nocturnal LOPEH (77). Consumption of nearly any commercially-available sports drink has proven to be effective in prevention and/or treatment of LOPEH; however, sports drinks with a mix of CHO, fat, and protein were associated with sustained hyperglycemia (and lack of hypoglycemia) during the post-exercise period (77). Whole milk (77) and slowly absorbed snacks (such as chips, chocolate, and fruit) (1) have also demonstrated effectiveness in preventing LOPEH.

3.4.5. Hyperglycemia

Hyperglycemia in T1DM athletes (BG > 250 mg/dL) generally occurs as a result of low circulating insulin levels (commonly secondary to inadequate insulin administration), excessive food intake, physical inactivity, illness, stress, or injury (1). If pre-exercise BG is > 250 mg/dL, athletes should check for urinary ketones (54). If ketonuria is moderate-to-high, exercise should be avoided until BG improves and ketosis resolves (1, 42) Aggressive BG lowering is important, as it may prevent progression to frank DKA (1, 56). It should also be noted that T1DM athletes with BG 250 - 300 mg/dL and without ketosis may exercise or participate in athletic competition provided they monitor their BG every 15 minutes and demonstrate that BG values are falling appropriately (65).

3.5. Future Investigation

Recent technological advancements have provided new ways for patients with T1DM to monitor their BG levels. CGM is now available through several different devices (80), and many investigators are working to optimize a "closed-loop" artificial pancreas that links CGM with insulin administration through CSII pumps (81). Future studies should seek to investigate how these devices function during exercise in T1DM patients.

Recent studies have also explored the effects of endurance (45) and ultra-endurance (82) athletic competition on T1DM athletes, and results suggest individualized adaptation of therapy during training and competition is most effective. Future studies could examine these topics further and help create effective management strategies for these scenarios.

4. Conclusions

Managing T1DM in the context of exercise or athletic competition is a challenging but important skill for athletes living with this disease. While regular exercise is an important aspect of T1DM management, the demands of athletic activity can predispose T1DM athletes to dangerous complications such as hypo- and hyperglycemia. A proper understanding of the hormonal milieu during exercise, special nutritional needs, glycemic control, necessary insulin dosing adjustments, and prevention/management strategies for exercise-related complications can lead to successful care plans for these patients. Individualized management strategies should be created with close cooperation between the T1DM athlete and their healthcare team (including a physician and dietitian).

Footnotes

Authors' Contribution: William B. Horton contributed the study design, acquisition and analysis/interpretation of data, drafting and critical revision of the manuscript. Jose S. Subauste contributed the drafting and critical revision of the manuscript along with study supervision.

Financial Disclosure: Neither William B. Horton nor Jose S. Subauste have any financial disclosures to list.

References

1. Macknight JM, Mistry DJ, Pastors JG, Holmes V, Rynders CA. The daily management of athletes with diabetes. *Clin Sports Med.* 2009;**28**(3):479–95. doi: 10.1016/j.csm.2009.02.005. [PubMed: 19505628].
2. Unger J. Management of type 1 diabetes. *Prim Care.* 2007;**34**(4):791–808. doi: 10.1016/j.pop.2007.07.002. [PubMed: 18061818] vi-vii.

3. Miller RG, Secrest AM, Sharma RK, Songer TJ, Orchard TJ. Improvements in the life expectancy of type 1 diabetes: the Pittsburgh Epidemiology of Diabetes Complications study cohort. *Diabetes.* 2012;**61**(11):2987–92. doi: 10.2337/db11-1625. [PubMed: 22851572].
4. Neithercott T. Life in the fast lane. *Diabetes Forecast.* 2013;**66**(2):40–3.
5. Neithercott T. Forward motion. The NBA's Gary Forbes scores on his dreams. *Diabetes Forecast.* 2012;**65**(3):40–3.
6. Neithercott T. Rising stars. Three young athletes with diabetes at the top of their sports. *Diabetes Forecast.* 2011;**64**(7):42–5. [PubMed: 21812384].
7. Kirk SE. Hypoglycemia in athletes with diabetes. *Clin Sports Med.* 2009;**28**(3):455–68. doi: 10.1016/j.csm.2009.02.003. [PubMed: 19505626].
8. Sigal RJ, Kenny GP, Wasserman DH, Castaneda-Sceppa C, White RD. Physical activity/exercise and type 2 diabetes: a consensus statement from the American Diabetes Association. *Diabetes Care.* 2006;**29**(6):1433–8. doi: 10.2337/dc06-9910. [PubMed: 16732040].
9. Lehmann R, Kaplan V, Bingisser R, Bloch KE, Spinas GA. Impact of physical activity on cardiovascular risk factors in IDDM. *Diabetes Care.* 1997;**20**(10):1603–11. [PubMed: 9314643].
10. Riddell MC, Perkins BA. Type 1 Diabetes and Vigorous Exercise: Applications of Exercise Physiology to Patient Management. *Canadian J Diabetes.* 2006;**30**(1):63–71. doi: 10.1016/s1499-2671(06)01010-0.
11. Fuchsjager-Mayrl G, Pleiner J, Wiesinger GF, Sieder AE, Quittan M, Nuhr MJ, et al. Exercise training improves vascular endothelial function in patients with type 1 diabetes. *Diabetes Care.* 2002;**25**(10):1795–801. [PubMed: 12351480].
12. Church TS, LaMonte MJ, Barlow CE, Blair SN. Cardiorespiratory fitness and body mass index as predictors of cardiovascular disease mortality among men with diabetes. *Arch Intern Med.* 2005;**165**(18):2114–20. doi: 10.1001/archinte.165.18.2114. [PubMed: 16217001].
13. Patterson CC, Dahlquist GG, Gyurus E, Green A, Soltesz G, Eurodiab Study Group . Incidence trends for childhood type 1 diabetes in Europe during 1989-2003 and predicted new cases 2005-20: a multicentre prospective registration study. *Lancet.* 2009;**373**(9680):2027–33. doi: 10.1016/S0140-6736(09)60568-7. [PubMed: 19481249].
14. Gallen IW, Hume C, Lumb A. Fuelling the athlete with type 1 diabetes. *Diabetes Obes Metab.* 2011;**13**(2):130–6. doi: 10.1111/j.1463-1326.2010.01319.x. [PubMed: 21199264].
15. Egan B, Zierath JR. Exercise metabolism and the molecular regulation of skeletal muscle adaptation. *Cell Metab.* 2013;**17**(2):162–84. doi: 10.1016/j.cmet.2012.12.012. [PubMed: 23395166].
16. DeFronzo RA, Jacot E, Jequier E, Maeder E, Wahren J, Felber JP. The effect of insulin on the disposal of intravenous glucose. Results from indirect calorimetry and hepatic and femoral venous catheterization. *Diabetes.* 1981;**30**(12):1000–7. [PubMed: 7030826].
17. O'Neill HM. AMPK and Exercise: Glucose Uptake and Insulin Sensitivity. *Diabetes Metab J.* 2013;**37**(1):1–21. doi: 10.4093/dmj.2013.37.1.1. [PubMed: 23441028].
18. Carling D, Hardie DG. The substrate and sequence specificity of the AMP-activated protein kinase. Phosphorylation of glycogen synthase and phosphorylase kinase. *Biochim Biophys Acta.* 1989;**1012**(1):81–6. [PubMed: 2567185].
19. Bergeron R, Ren JM, Cadman KS, Moore IK, Perret P, Pypaert M, et al. Chronic activation of AMP kinase results in NRF-1 activation and mitochondrial biogenesis. *Am J Physiol Endocrinol Metab.* 2001;**281**(6):E1340–6. [PubMed: 11701451].
20. Jager S, Handschin C, St-Pierre J, Spiegelman BM. AMP-activated protein kinase (AMPK) action in skeletal muscle via direct phosphorylation of PGC-1alpha. *Proc Natl Acad Sci U S A.* 2007;**104**(29):12017–22. doi: 10.1073/pnas.0705070104. [PubMed: 17609368].
21. Kahn BB, Alquier T, Carling D, Hardie DG. AMP-activated protein kinase: ancient energy gauge provides clues to modern understanding of metabolism. *Cell Metab.* 2005;**1**(1):15–25. doi: 10.1016/j.cmet.2004.12.003. [PubMed: 16054041].
22. Wojtaszewski JF, Nielsen P, Hansen BF, Richter EA, Kiens B. Isoform-specific and exercise intensity-dependent activation of 5'-AMP-activated protein kinase in human skeletal muscle. *J Physiol.* 2000;**528 Pt 1**:221–6. [PubMed: 11018120].
23. Egan B, Carson BP, Garcia-Roves PM, Chibalin AV, Sarsfield FM, Barron N, et al. Exercise intensity-dependent regulation of peroxisome proliferator-activated receptor coactivator-1 mRNA abundance is associated with differential activation of upstream signalling kinases in human skeletal muscle. *J Physiol.* 2010;**588**(Pt 10):1779–90. doi: 10.1113/jphysiol.2010.188011. [PubMed: 20308248].
24. Bolster DR, Crozier SJ, Kimball SR, Jefferson LS. AMP-activated protein kinase suppresses protein synthesis in rat skeletal muscle through down-regulated mammalian target of rapamycin (mTOR) signaling. *J Biol Chem.* 2002;**277**(27):23977–80. doi: 10.1074/jbc.C200171200. [PubMed: 11997383].
25. Merrill GF, Kurth EJ, Hardie DG, Winder WW. AICA riboside increases AMP-activated protein kinase, fatty acid oxidation, and glucose uptake in rat muscle. *Am J Physiol.* 1997;**273**(6 Pt 1):E1107–12. [PubMed: 9435525].
26. Winder WW, Hardie DG. Inactivation of acetyl-CoA carboxylase and activation of AMP-activated protein kinase in muscle during exercise. *Am J Physiol.* 1996;**270**(2 Pt 1):E299–304. [PubMed: 8779952].
27. Petersen KF, Price TB, Bergeron R. Regulation of net hepatic glycogenolysis and gluconeogenesis during exercise: impact of type 1 diabetes. *J Clin Endocrinol Metab.* 2004;**89**(9):4656–64. doi: 10.1210/jc.2004-0408. [PubMed: 15356077].
28. Robertson RP, Halter JB, Porte DJ. A role for alpha-adrenergic receptors in abnormal insulin secretion in diabetes mellitus. *J Clin Invest.* 1976;**57**(3):791–5. doi: 10.1172/JCI108338. [PubMed: 1249209].
29. Broadstone VL, Pfeifer MA, Bajaj V, Stagner JI, Samols E. Alpha-adrenergic blockade improves glucose-potentiated insulin secretion in non-insulin-dependent diabetes mellitus. *Diabetes.* 1987;**36**(8):932–7. [PubMed: 2885238].
30. Thorell A, Hirshman MF, Nygren J, Jorfeldt L, Wojtaszewski JF, Dufresne SD, et al. Exercise and insulin cause GLUT-4 translocation in human skeletal muscle. *Am J Physiol.* 1999;**277**(4 Pt 1):E733–41. [PubMed: 10516134].
31. Stich V, de Glisezinski I, Berlan M, Bulow J, Galitzky J, Harant I, et al. Adipose tissue lipolysis is increased during a repeated bout of aerobic exercise. *J Appl Physiol (1985).* 2000;**88**(4):1277–83. [PubMed: 10749819].
32. Kreisman SH, Ah Mew N, Halter JB, Vranic M, Marliss EB. Norepinephrine infusion during moderate-intensity exercise increases glucose production and uptake. *J Clin Endocrinol Metab.* 2001;**86**(5):2118–24. doi: 10.1210/jcem.86.5.7476. [PubMed: 11344216].
33. Marliss EB, Vranic M. Intense exercise has unique effects on both insulin release and its roles in glucoregulation: implications for diabetes. *Diabetes.* 2002;**51 Suppl 1**:S271–83. [PubMed: 11815492].
34. Burke LM, Kiens B, Ivy JL. Carbohydrates and fat for training and recovery. *J Sports Sci.* 2004;**22**(1):15–30. doi: 10.1080/0264041031000140527. [PubMed: 14971430].
35. Burke LM. Clinical Sports Nutrition. Australia: Human Kinetics; 2007.
36. Rodriguez NR, DiMarco NM, Langley S, American Dietetic A, Dietitians of C, American College of Sports Medicine N, et al. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. *J Am Diet Assoc.* 2009;**109**(3):509–27. [PubMed: 19278045].
37. Below PR, Mora-Rodriguez R, Gonzalez-Alonso J, Coyle EF. Fluid and carbohydrate ingestion independently improve performance during 1 h of intense exercise. *Med Sci Sports Exerc.* 1995;**27**(2):200–10. [PubMed: 7723643].
38. Fisher BM, Cleland JG, Dargie HJ, Frier BM. Non-invasive evaluation of cardiac function in young patients with type 1 diabetes. *Diabet Med.* 1989;**6**(8):677–81. [PubMed: 2532100].
39. Wanke T, Formanek D, Auinger M, Zwick H, Irsigler K. Pulmonary gas exchange and oxygen uptake during exercise in patients with type 1 diabetes mellitus. *Diabet Med.* 1992;**9**(3):252–7. [PubMed: 1576807].

40. Nugent AM, Steele IC, al-Modaris F, Vallely S, Moore A, Campbell NP, et al. Exercise responses in patients with IDDM. *Diabetes Care.* 1997;**20**(12):1814–21. [PubMed: 9405899].
41. Veves A, Saouaf R, Donaghue VM, Mullooly CA, Kistler JA, Giurini JM, et al. Aerobic exercise capacity remains normal despite impaired endothelial function in the micro- and macrocirculation of physically active IDDM patients. *Diabetes.* 1997;**46**(11):1846–52. [PubMed: 9356035].
42. Koivisto VA, Felig P. Effects of leg exercise on insulin absorption in diabetic patients. *N Engl J Med.* 1978;**298**(2):79–83. doi: 10.1056/NEJM197801122980205. [PubMed: 619237].
43. Goodyear LJ, Kahn BB. Exercise, glucose transport, and insulin sensitivity. *Annu Rev Med.* 1998;**49**:235–61. doi: 10.1146/annurev.med.49.1.235. [PubMed: 9509261].
44. Galassetti P, Tate D, Neill RA, Morrey S, Wasserman DH, Davis SN. Effect of antecedent hypoglycemia on counterregulatory responses to subsequent euglycemic exercise in type 1 diabetes. *Diabetes.* 2003;**52**(7):1761–9. [PubMed: 12829644].
45. Ratjen I, Weber KS, Roden M, Herrmann ME, Mussig K. Type 1 diabetes mellitus and exercise in competitive athletes. *Exp Clin Endocrinol Diabetes.* 2015;**123**(7):419–22. doi: 10.1055/s-0035-1545344. [PubMed: 25853705].
46. MacDonald MJ. Postexercise late-onset hypoglycemia in insulin-dependent diabetic patients. *Diabetes Care.* 1987;**10**(5):584–8. [PubMed: 3677976].
47. McMahon SK, Ferreira LD, Ratnam N, Davey RJ, Youngs LM, Davis EA, et al. Glucose requirements to maintain euglycemia after moderate-intensity afternoon exercise in adolescents with type 1 diabetes are increased in a biphasic manner. *J Clin Endocrinol Metab.* 2007;**92**(3):963–8. doi: 10.1210/jc.2006-2263. [PubMed: 17118993].
48. Kraniou GN, Cameron-Smith D, Hargreaves M. Acute exercise and GLUT4 expression in human skeletal muscle: influence of exercise intensity. *J Appl Physiol (1985).* 2006;**101**(3):934–7. doi: 10.1152/japplphysiol.01489.2005. [PubMed: 16763099].
49. Kraniou GN, Cameron-Smith D, Hargreaves M. Effect of short-term training on GLUT-4 mRNA and protein expression in human skeletal muscle. *Exp Physiol.* 2004;**89**(5):559–63. doi: 10.1113/expphysiol.2004.027409. [PubMed: 15184360].
50. Sigal RJ, Fisher SJ, Manzon A, Morais JA, Halter JB, Vranic M, et al. Glucoregulation during and after intense exercise: effects of alpha-adrenergic blockade. *Metabolism.* 2000;**49**(3):386–94. [PubMed: 10726919].
51. Francescato MP, Geat M, Fusi S, Stupar G, Noacco C, Cattin L. Carbohydrate requirement and insulin concentration during moderate exercise in type 1 diabetic patients. *Metabolism.* 2004;**53**(9):1126–30. [PubMed: 15334372].
52. Francescato MP, Stel G, Stenner E, Geat M. Prolonged exercise in type 1 diabetes: performance of a customizable algorithm to estimate the carbohydrate supplements to minimize glycemic imbalances. *PLoS One.* 2015;**10**(4):e0125220. doi: 10.1371/journal.pone.0125220. [PubMed: 25918842].
53. Davis SN, Galassetti P, Wasserman DH, Tate D. Effects of antecedent hypoglycemia on subsequent counterregulatory responses to exercise. *Diabetes.* 2000;**49**(1):73–81. [PubMed: 10615952].
54. American Diabetes Association . Diabetes Mellitus and Exercise. *Diabetes Care.* 2002;**25**(Supplement 1):S64. doi: 10.2337/diacare.25.2007.S64.
55. Klingensmith G, Kaufman F, Schatz D, Clarke W, American Diabetes A. Care of children with diabetes in the school and day care setting. *Diabetes Care.* 2003;**26 Suppl 1**:S131–5. [PubMed: 12502641].
56. Lisle DK, Trojian TH. Managing the athlete with type 1 diabetes. *Curr Sports Med Rep.* 2006;**5**(2):93–8. [PubMed: 16529680].
57. Riddell MC, Milliken J. Preventing exercise-induced hypoglycemia in type 1 diabetes using real-time continuous glucose monitoring and a new carbohydrate intake algorithm: an observational field study. *Diabetes Technol Ther.* 2011;**13**(8):819–25. doi: 10.1089/dia.2011.0052. [PubMed: 21599515].
58. Marcason W. Is there a recommended target range for blood glucose for the type 1 diabetic endurance athlete?. *J Acad Nutr Diet.* 2012;**112**(12):2092. doi: 10.1016/j.jand.2012.10.003. [PubMed: 23174691].
59. Horton ES. Role and management of exercise in diabetes mellitus. *Diabetes Care.* 1988;**11**(2):201–11. [PubMed: 3289869].
60. Jensen J, Leighton B. The diabetic athlete. In: Maughan RJ, editor. Nutrition in sport. Oxford (UK): Blackwell Science; 2000. pp. 457–66.
61. Tamis-Jortberg B, Downs DJ, Colten ME. Effects of a glucose polymer sports drink on blood glucose, insulin, and performance in subjects with diabetes. *Diabetes Educ.* 1996;**22**(5):471–87. [PubMed: 8936126].
62. Ludwig DS. The glycemic index: physiological mechanisms relating to obesity, diabetes, and cardiovascular disease. *JAMA.* 2002;**287**(18):2414–23. [PubMed: 11988062].
63. Foster-Powell K, Miller JB. International tables of glycemic index. *Am J Clin Nutr.* 1995;**62**(4):871S–90S. [PubMed: 7572722].
64. Bogardus C, LaGrange BM, Horton ES, Sims EA. Comparison of carbohydrate-containing and carbohydrate-restricted hypocaloric diets in the treatment of obesity. Endurance and metabolic fuel homeostasis during strenuous exercise. *J Clin Invest.* 1981;**68**(2):399–404. [PubMed: 7263859].
65. Flood L, Constance A. Diabetes and exercise safety. *Am J Nurs.* 2002;**102**(6):47–55. [PubMed: 12394077] quiz 56.
66. Mauvais-Jarvis F, Sobngwi E, Porcher R, Garnier JP, Vexiau P, Duvallet A, et al. Glucose response to intense aerobic exercise in type 1 diabetes: maintenance of near euglycemia despite a drastic decrease in insulin dose. *Diabetes Care.* 2003;**26**(4):1316–7. [PubMed: 12663620].
67. The health professionals guide to diabetes and exercise. Alexandria (VA): American Diabetes Association; 1995.
68. Frid A, Ostman J, Linde B. Hypoglycemia risk during exercise after intramuscular injection of insulin in thigh in IDDM. *Diabetes Care.* 1990;**13**(5):473–7. [PubMed: 2190773].
69. Yardley JE, Iscoe KE, Sigal RJ, Kenny GP, Perkins BA, Riddell MC. Insulin pump therapy is associated with less post-exercise hyperglycemia than multiple daily injections: an observational study of physically active type 1 diabetes patients. *Diabetes Technol Ther.* 2013;**15**(1):84–8. doi: 10.1089/dia.2012.0168. [PubMed: 23216304].
70. Sonnenberg GE, Kemmer FW, Berger M. Exercise in type 1 (insulin-dependent) diabetic patients treated with continuous subcutaneous insulin infusion. Prevention of exercise induced hypoglycaemia. *Diabetologia.* 1990;**33**(11):696–703. [PubMed: 2076801].
71. Schiffrin A, Parikh S. Accommodating planned exercise in type I diabetic patients on intensive treatment. *Diabetes Care.* 1985;**8**(4):337–42. [PubMed: 3899554].
72. Coyle EF. Substrate utilization during exercise in active people. *Am J Clin Nutr.* 1995;**61**(4 Suppl):968S–79S. [PubMed: 7900696].
73. Galassetti P, Mann S, Tate D, Neill RA, Wasserman DH, Davis SN. Effect of morning exercise on counterregulatory responses to subsequent, afternoon exercise. *J Appl Physiol (1985).* 2001;**91**(1):91–9. [PubMed: 11408418].
74. Camacho RC, Galassetti P, Davis SN, Wasserman DH. Glucoregulation during and after exercise in health and insulin-dependent diabetes. *Exerc Sport Sci Rev.* 2005;**33**(1):17–23. [PubMed: 15640716].
75. Hilsted J, Galbo H, Christensen NJ. Impaired responses of catecholamines, growth hormone, and cortisol to graded exercise in diabetic autonomic neuropathy. *Diabetes.* 1980;**29**(4):257–62. [PubMed: 7358226].
76. Grimm JJ, Ybarra J, Berne C, Muchnick S, Golay A. A new table for prevention of hypoglycaemia during physical activity in type 1 diabetic patients. *Diabetes Metab.* 2004;**30**(5):465–70. [PubMed: 15671916].
77. Hernandez JM, Moccia T, Fluckey JD, Ulbrecht JS, Farrell PA. Fluid snacks to help persons with type 1 diabetes avoid late onset postexercise hypoglycemia. *Med Sci Sports Exerc.* 2000;**32**(5):904–10. [PubMed: 10795779].
78. A core curriculum for diabetes education. 3rd ed. Chicago: American

Association of Diabetes Educators; 1998. p. 32.
79. Peirce NS. Diabetes and exercise. *Br J Sports Med.* 1999;**33**(3):161–72. [PubMed: 10378067] quiz 172-3, 222.
80. Grunberger G, Bailey T, Camacho PM, Einhorn D, Garber AJ, Handelsman Y, et al. Proceedings from the american association of clinical endocrinologists and american college of endocrinology consensus conference on glucose monitoring. *Endocr Pract.* 2015;**21**(5):522–33. doi: 10.4158/EP15653.CS. [PubMed: 25962091].
81. Kropff J, DeVries JH. Continuous Glucose Monitoring, Future Products, and Update on Worldwide Artificial Pancreas Projects. *Diabetes Technol Ther.* 2016;**18 Suppl 2**:S253–63. doi: 10.1089/dia.2015.0345. [PubMed: 26784131].
82. Khodaee M, Riederer M, VanBaak K, Hill JC. Ultraendurance athletes with type 1 diabetes: Leadville 100 experience. *Wilderness Environ Med.* 2015;**26**(2):273–5. doi: 10.1016/j.wem.2014.10.002. [PubMed: 25676658].

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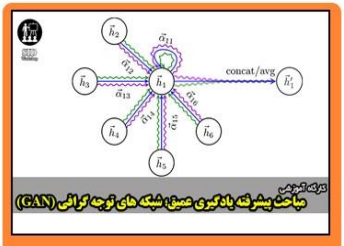

مباحث پیشرفته یادگیری عمیق؛
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