

Type 1 Diabetes and Aerobic Exercise: Strategies for Optimal Glycemic Control

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Importance of optimal glycemic control for exercise

The long-term benefits of regular exercise include improved body composition, enhanced cardiovascular (CV) health and reduced risk of several chronic diseases. While exercise is clearly beneficial for those with type 1 diabetes, it can make blood glucose (BG) control more challenging. Although there are no conclusive studies of dysglycemia and exercise performance, the symptoms (shakiness, fatigue, disorientation) that accompany low BG (<4.0 mmol/L) can impair performance and place individuals at risk of injury. On the other hand, significantly elevated BG (≥ 12 mmol/L) may cause dehydration and can be associated with inefficient muscle and liver glycogen stores, leading to impaired performance.

Several factors contribute to the BG changes associated with exercise, including exercise intensity and duration, circulating insulin and glucose counterregulatory hormones (glucagon, catecholamines, cortisol, growth hormone), the participant's level of fitness, and even gender and age. As a result, it is difficult to develop specific strategies to prevent exercise-associated changes in glycemia, although general recommendations have been found to be useful (1,2). Here we attempt to summarize the insulin and carbohydrate strategies that can be tested and implemented for predominantly aerobic activities.

Forms of exercise

Anaerobic activities, such as hockey or sprinting, are typified by brief periods (5 to 30 seconds) of high-intensity muscular contraction followed by longer periods of rest or recovery. This type of exercise often elicits a dramatic increase in plasma adrenaline that can markedly increase BG, both during and immediately after the exercise (3). Surprisingly, no clinical studies exist to offer strategies for preventing the often dramatic rise in BG seen with anaerobic exercise!

Experimental evidence suggests that

basal insulin may need to double to maintain BG levels during and after anaerobic exercise (4). Intuitively, then, changes in such basal insulin can be considered for those on insulin pump therapy, e.g. if hyperglycemia is consistently seen after such exercise, gradual increases in the basal rate can be made before the activity is started. Alternatively, an insulin bolus correction may be needed following the activity.

Aerobic exercise, a more common form of cardiovascular exercise, typically includes activities at intensities between 40 and 85% of VO_2max (maximal oxygen consumption) or 55 to 90% of maximal heart rate (5). These 'endurance' activities, which include running and cycling, are often characterized by longer duration and lower-intensity muscular contractions. Aerobic activities usually cause reductions in BG. It should be noted that many sports include periods of anaerobic activity that help limit the drop in BG levels due to increased secretion of counterregulatory hormones (6-8).

Adjustments for aerobic exercise

In general, there are 4 options for preventing hypoglycemia during and after exercise:

1. Consume extra carbohydrates for the exercise to match the utilization of glucose by active muscle.
2. Decrease the amount of bolus insulin for the meal preceding the exercise (food bolus approach).
3. Decrease the basal insulin that is active during exercise (basal insulin approach).
4. A combination of the 3 strategies above.

Extra carbohydrate for aerobic exercise ("ExCarbs")

For many, especially children and adolescents, carbohydrate supplementation may be more appropriate, as activities are often unplanned, not allowing sufficient time to adjust insulin dosage. Furthermore, individuals are often reluctant to reduce their insulin dose due to fear of high BG during the hours prior to exercise.

Although there is good evidence to support the general concept of ExCarbs (9), the specific approaches for estimating the quantity needed are based primarily on consensus opinions and ideas popularized in the lay-literature (10). The simplest method recommends 15 to 30 grams of carbohydrate for each 30 to 60 minutes of mild to moderate activity. This dose, however, does not take into consideration the wide range of energy expenditure during the activity, which is based on a variety of factors including the individual's age, body mass, gender and exercise intensity. The second and more quantitative strategy takes into account the participant's body weight in addition to the duration of exercise, suggesting 1 gram of carbohydrate for every kg of body weight per hour of exercise ($1\text{g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$). The third and most quantitative method also accounts for the intensity of a specific exercise. The ExCarbs estimates are based on determinants of carbohydrate oxidation during various types and intensities of common activities and sports (1,11). As an example of this last strategy, Jeremy, who weighs ~70 kg, is planning on playing a moderate intensity volleyball game for 1 hour. Jeremy estimates he will use 34 g of carbohydrate and decides to drink 250 mL of a sports drink containing 15 grams of carbohydrate/250 mL at the start, and again midway through the game (15 grams $\times 2 = 45$ grams, which closely approximates the 34 g of ExCarbs needed).

Insulin adjustments for aerobic exercise

If done effectively, adjusting insulin for exercise is not only an optimal choice because it emulates the normal physiological response to exercise but also because it may prevent weight gain that usually arises from the need for excess carbohydrate intake to prevent hypoglycemia.

Food bolus approach

For prolonged exercise (lasting 30 to 60 minutes) performed during times of peak insulin activity, a reduction in pre-meal

insulin bolus by 25% (mild exercise) to 75% (heavy exercise) is recommended (Table 1) (12). Another more individualized method to adjust insulin dosage for postprandial exercise (i.e. within 90 minutes) is based on the estimated ExCarbs required of the exercise. Using this table, the ExCarb amount is subtracted from the carbohydrate intake of the meal prior to the exercise. For example, if Jeremy's same volleyball game described earlier were to be played after his lunch he could subtract the ExCarbs required by his muscles from the insulin dose calculation for that meal. For example, if he were to eat a lunch containing 75 grams of carbohydrate, he could subtract from this the 34 grams required by exercise. Thus, he would bolus for 41 grams (75 grams carbohydrate – 34 grams ExCarbs). In essence, this leaves 34 grams of carbs free for muscles to take up during the exercise. This method is a simple strategy appropriate for those using multiple daily injections (MDI) as well as for those using continuous subcutaneous insulin infusion (pump therapy).

Basal insulin approach for pump users

For high-intensity and longer-duration activity, an approach that also involves adjustment of the basal rate is favoured. Specifically, this avoids the situation in which the peaking activity of insulin from a food bolus overlaps with exercise, thus increasing the risk of hypoglycemia. Furthermore, meals preceding some high-intensity sports can cause nausea and abdominal pain. In these situations, it may be preferable to exercise at a time that does not coincide with a meal. Specifically because the rapid-acting analogue insulin peaks at 1 to 1.5 hours, it is advisable to make basal rate changes at least 90 minutes before the onset of exercise. Furthermore, following exercise it is often advantageous to continue reduced basal rates for at least

90 minutes after exercise in order to prevent post-exercise hypoglycemia. It is generally recommended that patients not reduce their basal rate by more than 50% as an initial strategy for exercise. Further reductions should be based on experience from monitoring of BG during previous activity.

As an example, let's consider a situation in which Jeremy will play the same volleyball game on a Saturday morning before he eats breakfast. Jeremy receives 0.7 units per hour throughout the morning hours. A 50% reduction in basal insulin beginning 90 minutes prior to and ending 90 minutes after a one-hour volleyball game represents a reduction in insulin of 1.4 units (0.7 units per hour x 50% x 4 hours). Given his carbohydrate-to-insulin Ratio of 15 grams per unit of insulin, this represents the equivalent of 21 grams of ExCarbs (1.4 units of insulin x 15 grams of carbohydrate per unit of insulin). Given that his volleyball game demands 34 grams of Excarbs, he need only consume 13 grams of additional carbohydrates for his game (34 grams minus 21 grams ExCarb), which he takes in the form of 250 mL of a commercially-available sports drink (containing 15 grams of carbohydrate) at the beginning of his game. If Jeremy learns that he maintains good levels of BG after this game, on a subsequent game he could try a 75% basal reduction and thus need to consume even fewer ExCarbs for this activity.

After very intense (60 to 80% of $VO_2\text{max}$) or prolonged activity (>60 minutes), it is wise to reduce basal dosages during night-time hours to avoid late-onset hypoglycemia (see below). These strategies using the concept of ExCarbs are intended to offer patients a starting point for engaging in exercise. Close monitoring of capillary blood glucose—described below—is necessary to evaluate the need for adjusting doses.

Blood glucose monitoring

As seen with the case of Jeremy and his participation in volleyball games, frequent BG monitoring is a critical component to help optimize BG both during and after exercise and to test the efficacy of insulin and carbohydrate adjustments. Individuals often base exercise modifications on a single measurement that does not indicate the glycemic direction nor the rate of change. As such, a minimum of 2 to 3 measurements should be made within two hours prior to, every 30 minutes during, and 2 to 3 times over the ~3 hours after exercise (2). These strategies, especially if recorded in activity logs, will help identify recurring trends and assist in later adjustments. This is especially important for those engaging in a new activity or just beginning a fitness program.

Intense aerobic activities or those lasting >90 minutes may require additional monitoring during night-time hours to protect against late-onset hypoglycemia. This is defined as an episode of hypoglycemia occurring up to 31 hours after exercise has ended (13-15) as insulin sensitivity remains enhanced, increasing carbohydrate uptake, in addition to possible deficits in the release of glucose counter-regulatory hormones. As repeated and/or night-time tests of capillary glucose are rarely performed, continuous glucose monitoring systems (CGMS) can facilitate detection of episodes of hypoglycemia, especially during night-time sleep, that may otherwise pass unnoticed (16).

Conclusion

This brief report summarizes current strategies that help to minimize BG changes commonly resulting from exercise. As these are just recommendations, individuals should plan to reduce insulin dosages by no more than 50% when first trying these strategies—close BG monitoring will reveal whether further reductions can safely be made. In addition, ExCarb values may overestimate energy requirements for those who are more physically fit, and underestimate energy needs for those who are less fit or just learning an activity. Finally, individuals should always take along additional carbohydrates and test strips, especially if the activities are in remote areas (e.g. hiking, mountain biking). The concepts summarized in this short report are fundamental—a clear understanding of 'ExCarbs'

Table 1. Percent reduction in pre-meal insulin bolus in anticipation of subsequent exercise of various duration and intensity (modified from reference 12)

Duration of exercise (minutes)	30	60
Intensity of exercise (%)		
Mild (25% $VO_2\text{max}$)	25	50
Moderate (50% $VO_2\text{max}$)	50	75
Heavy (75% $VO_2\text{max}$)	75	–

% $VO_2\text{max}$ = percentage of maximal aerobic capacity

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will likely give your patients with diabetes a strong foundation for improving confidence, performance, and the enjoyment of an active lifestyle.

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