Working With Athletes With Diabetes

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ABSTRACT
Glycemic control can optimize participation and performance in competitive sports and strenuous physical pursuits for an exerciser with diabetes. Thus, it is crucial for athletes with diabetes to adopt strategies to improve blood-glucose control at all times. Working together, athletes who have diabetes and practitioners can help increase the athlete’s understanding of exercise factors, such as the effects of circulating insulin levels on exercise response, physiological response to different types of activities and training, and nutrition concerns. This understanding, along with frequent glucose monitoring, will enable the athlete with diabetes to perform optimally in athletic endeavors.

INTRODUCTION
Many people with type 1 diabetes and some with insulin-requiring type 2 diabetes are engaged in physically demanding exercise programs. Some participate in and excel at the top level of competitive sports, including swimming, golf, football, baseball, basketball, ice hockey, soccer, marathon running, and triathlons among others. To perform competitively, athletes with diabetes need a greater understanding of the effects of circulating levels of insulin on exercise response, the physiological response to different types of activities, and the effects of nutrition on performance. To assist these athletes in achieving optimal glycemic control and individual athletic goals, practitioners themselves need to become educated in these areas.

EFFECTS OF INSULIN ON XERCISE GLYCEMIC
Unlike individuals without diabetes whose bodies normally maintain blood-glucose levels in a tight range, athletes with type 1 diabetes must constantly adjust their insulin and food intake to balance blood-glucose levels during physical activity. Any type of physical activity promotes the uptake of glucose into active muscle cells additively with circulating insulin (1), but insulin and muscle contractions oppose each other’s effect on fuel availability from hepatic glucose output and lipid mobilization (2). The correct timing and dosage of insulin is key to effective glucose management during exercise; therefore, athletes and practitioners need to carefully consider the pharmacokinetics of injected insulin when attempting to achieve glycemic control with exercise.

Athletes who rely on exogenous insulin frequently find themselves with a relative state of hyperinsulinemia that can result in hypoglycemia during exercise (a blood-glucose level < 70 mg/dL), early fatigue, and compromised performance (3). In athletes with diabetes, the normal, physiologic decline in insulin seen in the athletes without diabetes is difficult to achieve due to sustained absorption of exogenous insulin from subcutaneous depots. The combined blood-glucose uptake by circulating insulin and muscle contractions can produce hypoglycemia, particularly when exercise occurs during the peak effects of short-acting insulin or rapid-acting insulin analogs. Under such conditions, glucose uptake into muscles is enhanced and the ability of the liver to produce glucose is suppressed, often resulting in the rapid onset of hypoglycemia. This situation can further be exacerbated by prior episodes of hypoglycemia (e.g., the previous day), which blunt the normal, glucose-raising hormonal responses to moderate exercise (about 50% of maximal aerobic capacity) in exercisers with type 1 diabetes even when blood-glucose levels are normal (4).

Not surprisingly, glycemic control is easiest to maintain when insulin levels are relatively low, such as during morning exercise before insulin is administered (5). However, it is still important when exercising in the morning to be sure that glucose level upon awakening is within appropriate range and that the person is not insulin-deficient.

When rapid-acting insulin is given prior to extended exercise, dosages must often be reduced to prevent hypoglycemia. For example, in anticipation of moderate exercise, short-acting

Table 1. Variables Affecting Exercise Glycemic Control

<table>
<thead>
<tr>
<th>Acute exercise</th>
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<tbody>
<tr>
<td>Starting blood-glucose level</td>
</tr>
<tr>
<td>Circulating insulin level, determined by:</td>
</tr>
<tr>
<td>- Types of insulin(s) used</td>
</tr>
<tr>
<td>- Timing of prior insulin injection or bolus</td>
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<tr>
<td>- Insulin dosages</td>
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<tr>
<td>Type, intensity and duration of activity</td>
</tr>
<tr>
<td>Carbohydrate ingestion before and during activity</td>
</tr>
<tr>
<td>Activity status (new or usual)</td>
</tr>
<tr>
<td>Time of day of exercise</td>
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<tr>
<td>Prior exercise</td>
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<table>
<thead>
<tr>
<th>Chronic exercise training</th>
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</thead>
<tbody>
<tr>
<td>Type of training (aerobic vs. anaerobic)</td>
</tr>
<tr>
<td>Fitness level (specific to the activity)</td>
</tr>
<tr>
<td>Enhancements in insulin sensitivity</td>
</tr>
<tr>
<td>Reductions in overall insulin doses</td>
</tr>
<tr>
<td>Change in fuel utilization (greater fat use)</td>
</tr>
<tr>
<td>Dietary status (energy balance, fuel intake)</td>
</tr>
<tr>
<td>Body composition (e.g., increased muscle mass)</td>
</tr>
<tr>
<td>Frequency of glycogen-depleting exercise</td>
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<tr>
<td>Attenuated hormonal response</td>
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insulin doses may need to be reduced by 33% to 50%, with greater reductions required for longer-duration activities (6). In addition to reducing bolus (meal time) insulin, insulin pump users can also more closely replicate a normal physiological decline in insulin levels by reducing or suspending basal insulin prior to the start of exercise.

In contrast, initiating vigorous exercise without sufficient circulating insulin can aggravate hyperglycemia. When insulin levels are too low, the rise in catecholamines elicited by exercise can trigger hyperglycemia, or if ketones are being produced, diabetic ketoacidosis (7). Skipping usual insulin doses for mealtime food intake prior to exercise seldom works effectively for these reasons (6). Blood-glucose levels should be monitored closely when the plan is to suspend basal insulin administration for more than 60 to 90 minutes. Doing so, in combination with ketone testing, will help to determine if sufficient circulating insulin continues to be available for exercise.

Short-term hyperglycemia may or may not be limiting to athletes with diabetes, if ketones are absent. However, athletes have reported that they feel less sluggish and perform better when their starting blood glucose falls in a more normal range, such as 80 to 180 mg/dL. (6). Longer-term elevations in glycemia can negatively impact performance. In a study of younger individuals with long-standing type 1 diabetes, the maximal workload and oxygen uptake were markedly impaired in chronically hyperglycemic subjects compared with those with normal or near-normal glycated hemoglobin levels. Those with near-normal levels experienced lesser restrictions of lung volume, lung diffusing capacity, and cardiac performance (stroke index and membrane diffusing capacity) during exercise (8).

In addition to circulating insulin levels, myriad other variables (listed in Table 1) can impact the glycemic response to exercise. For instance, morning exercise lowers blood-glucose levels less than the same exercise done later in the day due to increased insulin resistance caused by early-morning elevations in cortisol and growth hormone (7). Thus, undertaking morning exercise usually requires a smaller reduction in insulin doses and, in some cases, a supplemental dose of insulin to lower blood-glucose levels following the activity (6). Late evening exercise is most likely to result in nocturnal hypoglycemia, but exercise earlier in the day can also result in late-onset hypoglycemia unless precautionary measures are taken, such as a bedtime snack or lower bedtime insulin doses (9). In addition, prior strenuous exercise can impair the normal glucoregulatory response to subsequent hypoglycemia or to another bout of exercise. Thus, athletes with diabetes may be at higher risk for developing hypoglycemia when engaging in successive days of exercise training (10).

**Table 2. Guidelines For Fluid And Carbohydrate Ingestion For Physical Activity**

**Fluids**
- Consume adequate fluids before, during and following exercise to help prevent dehydration during exercise, particularly when hyperglycemic.
- During exercise, 6–8 ounces of water should be consumed for every 10 to 15 minutes of activity. Sports drinks or diluted fruit juices (50% dilution) can be useful because they supply fluid as well as fuel for activities longer than 60 minutes in duration.

**Carbohydrate before exercise**
- Carbohydrate intake a few hours before exercise generally benefits endurance capacity and should be covered with adequate insulin.
- Extra carbohydrate prior to exercise is recommended if blood glucose levels are <100 mg/dL, especially if insulin cannot be lowered.
- Avoid food with a high fiber or fat content before (and during) exercise.

**Carbohydrate during exercise**
- For activities lasting longer than 30 to 45 minutes, or if pre-exercise blood glucose is <100 mg/dL, consume 10–15 g. of carbohydrate every 15–30 minutes during activity (6). This recommendation should be modified for each athlete based on insulin regimen and exercise type.
- During exercise lasting more than 45 minutes, use of a carbohydrate drink may help avoid low blood glucose and to improve exercise performance.

**Carbohydrate after exercise**
- Following exercise, modest amounts of additional carbohydrate should be ingested to minimize the risk of late-onset hypoglycemia.
- Post-exercise carbohydrate needs will vary depending upon blood-glucose levels, how much carbohydrate was consumed during the activity, and total energy expenditure.

**Physiological Responses to Different Types of Activities**

During physical activity, increased energy expenditure by skeletal muscle is supported by enhanced mobilization of plasma glucose and free fatty acids, as well as utilization of glycogen and triglyceride stores within skeletal muscle. The intensity and duration of exercise are the primary determinants of the relative use of
Box 1. Resources For Working With Athletes Who Have Diabetes

Books:

Other:
- Diabetes Station. Biweekly online chat, "Exercise & Diabetes" that has varying topics. Accessible at www.diabetesstation.org (previous chats archived at same Web site).

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these metabolic fuels (11). For low intensity exercise such as slow walking, particularly if sustained for long intervals, the predominant fuel is circulating plasma-free fatty acids, with relatively slow depletion of muscle glycogen (12). During prolonged lower-intensity activities, blood-glucose utilization can still be quite significant as muscle glycogen stores become depleted over time, increasing the risk of hypoglycemia.

During moderate intensity exercise, blood glucose utilization is usually increased three- to four-fold above rest (13). Lipid mobilization and oxidation are also enhanced. Both the duration of exercise and the training state of the athlete are determinants of the relative use of lipids. Longer-duration exercise and higher levels of fitness favor increased reliance on fat as a fuel source, although the greatest utilization of triglyceride stores in muscle occurs during recovery from moderate-intensity activities (14).

For short-duration activity, carbohydrate intake alone can effectively control blood-glucose levels. However, for prolonged exercise sessions, most athletes with diabetes will need to reduce insulin doses as well (6). Although aerobic activities use a fuel mix of muscle glycogen, blood glucose and lipids during high-intensity, prolonged activities like running, carbohydrate is the body’s fuel of choice. If the activity is sustained, near-depletion of both muscle glycogen and blood glucose is inevitable (15). High-intensity, repeated interval training also results in significant depletion of muscle glycogen and an elevated risk of hypoglycemia.

At the other extreme, during brief high-intensity exercise, the muscles rely primarily on their glycogen stores and to a lesser extent on plasma glucose and lipids (15). Short-duration intense activities such as sprinting or power lifting are mostly anaerobic. Muscles rapidly use high-energy phosphate compounds, and, if lasting longer than 10 seconds, intramuscular stores of glycogen to support short, intense bursts of exercise. High-intensity exercise causes a strong sympathetic nervous system response, which can be exacerbated by the mental stress of competition, resulting in the release of epinephrine and other hormones that raise blood-glucose levels. Such activities generally cause transient hyperglycemia that may require additional insulin to correct (16). Uncorrected, blood-glucose levels may remain elevated for two to three hours post exercise, even if blood-glucose levels were normal prior to exercise. Athletes must guard against hypoglycemia resulting from ongoing muscle glycogen replacement in muscles post-exercise, which is largely insulin-independent (17).

Athletes with diabetes who train regularly typically exhibit a heightened sensitivity to insulin, which allows blood glucose to enter muscle cells more efficiently both acutely and chronically with exercise (1). Acute changes likely result from heightened muscle glycogen repletion following physical exertion. However, Tuominen et al. reported that the morning following a competitive marathon, normoglycemic athletes with type 1 diabetes had unchanged insulin sensitivity despite significant glycogen depletion (18). Under such conditions, it is likely that enhanced lipid oxidation following exhaustive exercise, which typically occurs in all athletes, combined with some degree of muscular damage, creates a transient state of insulin resistance.

Chronic changes in insulin sensitivity are attributed to adaptive changes in muscle tissue, which enhance insulin-mediated glucose transport by insulin-sensitive glucose transporter (GLUT4) proteins (19) and reduce hepatic glucose output. Aerobic training also increases the proportion of lipids used during low- or moderate-intensity activity (20). Enhanced lipid utilization effectively spares some muscle glycogen and blood glucose and allows for better glycemic control during activities. These changes in fuel utilization in response to training result in a need for smaller compensatory adjustments in insulin dosages or carbohydrate intake to maintain glycemic control compared to prior to training. Therefore, training adaptations lower overall insulin needs, regardless of the insulin regimen (6,20). Exercise must be consistent since this heightened state of insulin sensitivity begins to decline after only one to two days of inactivity (21).

Similar to aerobic activities, resistance training also enhances insulin sensitivity and blood-glucose utilization. Skeletal muscle is a metabolically active tissue that takes up more blood glucose (through non-oxidative disposal, or glycogen synthesis) than other body tissues. Therefore, athletes with diabetes who gain muscle mass from resistance work also have lower overall insulin requirements and must lower their insulin doses both acutely and chronically (6).
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**NUTRITIONAL CONCERNS IN ATHLETES WITH DIABETES**

Exercise can cause hypoglycemia, which requires additional carbohydrate intake for its treatment. Ingestion of supplemental carbohydrates before, during, and/or after exercise can contribute to excess caloric intake. To replace enough carbohydrate to support optimal performance without causing excessive weight gain, combining a small increase in carbohydrate intake with concomitant reductions in insulin dose is often desirable.

Adequate hydration is also important to support optimal performance. As a rule of thumb, to prevent dehydration, 6 to 8 ounces of cool, dilute fluids (e.g., water or sports drinks) should be consumed every 10 to 15 minutes during prolonged activities, particularly in warm or hot environments. Additional practical guidelines for carbohydrate and fluid ingestion for athletes with diabetes are given in Table 2.

Athletes are known for taking various ergogenic supplements to potentially enhance their performance. Some of these nutritional supplements, however, could cause harm to an athlete with diabetes. For example, protein and amino acid supplements add stress to the kidneys due to the necessary excretion of excess amounts of nitrogen released when these supplements are metabolized. Such excretions can especially strain kidneys with any pre-existing damage from long-term diabetes.

In clinical studies, creatine monophosphate supplementation has been shown to harm already damaged kidneys (22), particularly during an initial creatine loading period, although the actual effect has not been tested in humans.

Athletes with and without diabetes also frequently use caffeine to enhance their performance. Care must be taken with its use prior to exercise, as it may cause excessive water loss and dehydration in a hot environment if adequate fluids are not consumed. However, when taken during exercise, its diuretic effect is not evident (23).

Athletes with diabetes, like their non-diabetic counterparts, frequently utilize the practice of carbohydrate loading prior to competition. However, with insulin users it can cause hyperglycemia before, during, and/or after exercise if adequate insulin is not taken. Moreover, carbohydrate loading has been shown to reduce the body’s formation of GLUT4 and lower insulin sensitivity (24).

Conversely, hypoglycemia can occur if carbohydrate is consumed before exercise and excessive compensatory insulin is given. As prevention for, and treatment of hypoglycemia, athletes should always carry a supply of rapidly absorbable carbohydrate (e.g., glucose tablets, glucose polymers, sports drinks, juice, regular soda and hard candy) that can be easily consumed before, during and after physical activities.

Consuming carbohydrate within 30 minutes of exhaustive, glycogen-depleting exercise allows for rapid restoration of muscle glycogen and may prevent late-onset hypoglycemia that can occur up to 24 hours after exercise (9). Insulin sensitivity is generally heightened immediately post-exercise, and during this time, glucose uptake into muscle to restore glycogen can be accomplished with minimal circulating insulin. Good glycemic control during the post-exercise recovery period is essential to subsequent exercise performance, since reduced rates of net muscle glycogen repletion are experienced by individuals with poorly controlled type 1 diabetes (25). To maintain glycemic control, some additional insulin may be needed to cover carbohydrate intake post-exercise, though generally less than usual is needed (6).

**REFERENCES**

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