In Brief

An effective management plan for an athlete with type 1 diabetes must consider the energy demands of intense competition and training, the athlete's goals, factors related to competitive sports that may affect glucose homeostasis, and strategies that may be employed to allow safe, effective sports participation. Athletes should be appropriately screened, counseled to avoid risky behaviors, and provided with specific recommendations for glucose monitoring and insulin and diet adjustments so that they may anticipate and compensate for glucose responses during sports competition.

Management of Competitive Athletes With Diabetes

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Exercise has been recommended as an important therapeutic tool for most patients with diabetes and for those at risk for diabetes.[1,2] The American Diabetes Association (ADA) Council on Exercise has released two valuable handbooks to assist health care professionals in exercise management.[3,4] The most recent of these publications acknowledges "remarkable progress" in the scientific understanding of diabetes and exercise, especially in the areas of biochemical events that regulate muscle metabolism, diabetes prevention, exercise maintenance, and exercise prescription.[4] It is now easier to make appropriate decisions regarding who should exercise, what types of physical activity are appropriate, and how often, how long, and how intense physical activity should be.

One area of scientific understanding that remains extremely limited is management of competitive athletes with diabetes. While there are a number of anecdotal descriptions of management strategies used by these athletes and several published case reports, there are very few well-controlled studies that add to our knowledge of formulating effective treatment plans. It is encouraging to find that athletes with diabetes have been able to achieve outstanding success at all levels of competition from schoolyard playing fields to the Olympic games. Management of competitive athletes with diabetes presents far different challenges than those typically encountered in routine patient care. An effective management plan must consider the typical demands of training and competition, the goals of the athlete, factors related to sports participation that may affect glucose homeostasis, safety of athletic participation, adequate monitoring of blood glucose, and possible adjustments to diet and insulin to allow safe and effective athletic performance.

Energy Demands of Sports Competition

Exercise has been defined as any form of body movement that results in an increase in metabolic demand.[5] In general, it is common to describe the metabolic processes that supply energy for muscular contractions to move the body as being either aerobic (with oxygen) or anaerobic (without oxygen).[6] In reality, most physical activity is some combination of both aerobic and anaerobic exercise, but the activity is typically classified based on which energy system predominates. We usually prescribe aerobic exercise for development of cardiorespiratory fitness and anaerobic exercise, such as resistance training, for development of muscular fitness and strength.

Physical activity recommendations for healthy adults and for patients with type 2 diabetes are quite similar.

The American College of Sports Medicine (ACSM) recommends aerobic exercise at 50–85% of the maximal volume of oxygen that can be consumed ($\dot{V}O_{2max}$) for promoting cardiorespiratory fitness and one set of eight to twelve repetitions using eight to ten resistance exercises for developing muscular fitness and strength in healthy adults.[7] ACSM and ADA recommend aerobic exercise at an intensity of 40–70% of $\dot{V}O_{2max}$ and anaerobic exercise for a minimum of one set of ten to fifteen repetitions using eight to ten resistance exercises for most patients with type 2 diabetes.[8] Modifications may be necessary depending on comorbid conditions.

It is important to recognize that the metabolic demands of the recommended aerobic activity for healthy adults and for the management of patients with type 2 diabetes are a percentage of the $\dot{V}O_{2max}$ and are intended to minimize contributions of the anaerobic energy systems. These exercise prescriptions are intentionally designed to be moderate in intensity so that individuals can be active for extended periods of time (20–60 minutes) to allow for an adequate stimulus to increase or maintain aerobic capacity and to expend sufficient caloric energy to assist with weight control. The vast majority of research in diabetes and exercise has utilized exercise intensities from 40 to 85% $\dot{V}O_{2max}$, and this research forms the basis for clinical decisions regarding exercise management.

Type 2 diabetes is extremely rare in competitive athletes. This discussion will be limited to considering the management of type 1 diabetes in school-aged children and adolescents participating in school and community sport activities, college athletes, and young adults participating in highly competitive amateur and professional sports. Many of these individuals will be without any significant long-term complications. General benefits of physical activity for those with type 1 diabetes include enhancement of physical fitness, reduction in cardiovascular disease risk, and improved social and emotional well-being. The primary risks of physical activity in type 1 patients who do not have complications are exercise-induced hypoglycemia and aggravation of hyperglycemia and ketosis.

Most competitive sports are not aerobic in terms of the major energy systems involved. Team sports such as football, baseball, softball, basketball, and soccer rely primarily on relatively brief bursts of explosive, high-power output and primarily rely on the adenosine triphosphate-phosphocreatine (ATP-PC) energy system for muscular contractions. These energy stores are extremely limited and can provide maximal power output for only 8–10 seconds.[9]

Muscles can continue to contract for longer periods by utilizing anaerobic glycolysis. This system is only about half as fast as the ATP-PC system but allows activity to continue at fairly high power outputs for an additional 1.5–2 minutes. The anaerobic glycolysis energy system can allow an individual to perform all-out exercise for longer than a few seconds, but large amounts of lactic acid accumulate within the contracting muscles and ultimately in the blood. As activity continues much beyond 2 minutes, the intensity of activity must be reduced, muscles must be provided with oxygen, and there is a gradual shift to aerobic metabolism.

Figure 1 describes the relative involvement of energy systems for many competitive sports.[10] Obviously, the energy requirements may differ depending on the level of competition and may also vary from position to position for team sports, but should serve to illustrate the importance of the ATP-PC system and anaerobic glycolysis for athletic competition.

The energy demands of training for a particular sport can be quite different depending on the age of the athlete, the level of competition, and the specific metabolic goals of training. Exercise training for an athlete with diabetes is usually determined by a coach rather than by any member of the health care team. Health care professionals should attempt to gather information about the specific training practices and be able to provide recommendations for blood glucose monitoring and reasonable adjustments to diet and insulin therapy so that athletes may be able to achieve peak performance in their chosen sport activities.

Goals of the Athlete

Motivation to become involved in sport activities typically has little to do with benefits of health. One group, observing that children and adolescents with diabetes are more likely to spend time in sport activities than those without diabetes, has proposed this may be a result of diabetes education encouraging active lifestyles or may be a "compensating social behavior" that allows young people with diabetes to feel more accepted by their peers.[11] Studies that have examined motives for sport participation have identified factors related to excitement and competition, appearance, fun, team atmosphere, friendship, achievement, and skill development.[12,13] Athletes in high school, college, and professional sports may be motivated by these factors as well but may have the additional incentive of potential or actual financial rewards. College scholarships can be worth as much as \$200,000, and professional sports contracts and endorsements may bring from hundreds of thousands to millions of dollars. Whether the moti-

Figure 1. Relative energy system involvement for competitive sports. Adapted from Ref. 10.

vating factor is the desire for an Olympic gold medal or simply to be "part of the team," it should be remembered that the specific goals of the athlete may be far more important than blood glucose control or avoidance of complications.

One common goal in competitive sports is to improve performance. Unfortunately, athletes may resort to a number of practices that can compromise blood glucose control and health in general in an attempt to gain a competitive advantage. These may include unsafe dietary patterns, use of nutritional supplements and other ergogenic aids, and the use of illegal drugs.

Common dietary problems seen in athletes include the female athlete triad (described below), rapid weight loss to "make weight," and excessive consumption of a single macronutrient, such as protein. It is important to be familiar with these practices and to counsel athletes appropriately.

Minimizing Risky Behaviors

The female athlete triad of disordered eating, amenorrhea, and osteoporosis was first identified in 1997 and is often found in women's endurance sports that emphasize low body weight, such as distance running, or aesthetic sports, such as gymnastics, figure skating, cheering, and ballet.[14,15] A study of weight control practices in type 1 diabetes reported unhealthy weight control in 37.9% of adolescent females and found that methods used included skipping insulin or taking less insulin in an effort to control body weight.[16] The topic of eating disorders in adolescent girls and young women with type 1 diabetes has been explored in depth, and it is clear that the problem is fairly common and is associated with poor metabolic control.[17] Anyone managing female athletes with diabetes, especially those involved in sports having a high prevalence of the female athlete triad, should be sensitive to prevention and early identification and treatment of this problem.

Omission of insulin is a common practice for athletes with diabetes who compete in sports having weight categories, such as wrestling, boxing, and weightlifting. Practices frequently used by athletes without diabetes to "make weight" include dehydration through perspiration, use of laxatives, diet pills, and diuretics, as well as vomiting.[18] Even though the National Collegiate Athletic Association and most state high school leagues have implemented programs to reduce unhealthy weight loss in the sport of wrestling, the practice of significantly reducing weight before competition with subsequent weight gain after the event still persists.[19] Athletes with diabetes quickly discover they can rapidly lose weight by withholding insulin until after weighing in. Metabolic control is obviously poor during the time that insulin is omitted, and there is always the serious risk of ketoacidosis. This is a difficult problem because the practice obviously works, and athletes with type 1 diabetes are often willing to take the associated risks.

Athletes with or without diabetes require adequate amounts of macronutrients to support their training and sustain performance during competition. A joint position statement issued by the ACSM, the American Dietetic Association, and the Dietitians of Canada summarized general nutrient requirements for competitive athletes.[20] These included:

- Carbohydrate consumption ranging from 6 to 10 g/kg of body weight/day to maintain blood glucose and replace muscle glycogen during activity. It was stated that a specified amount was dependent on the individual's daily total energy expenditure, sport type, sex, and environmental circumstances.
- Protein consumption ranging from 1.2 to 1.4 g/kg of body weight/day for endurance-trained athletes to maintain nitrogen balance and 1.6 to 1.7 g/kg of body weight/day for strength-trained athletes to permit the accretion and maintenance of muscle mass. If total energy intake is adequate to maintain body weight, adequate protein can be obtained solely through the diet, without fortification from protein supplements.
- Fat consumption should range from 20 to 25% of total daily calories, the majority of which should be in unsaturated form. Fat is critically important in athletic diets because it provides energy, fat-soluble vitamins, and essential fatty acids for daily activity and health. Some investigators have quantified this amount from 5 to 10 g/kg of body weight/day, depending on training intensity.[21,22] There is no scientific evidence indicating that high-fat diets enhance athletic performance.
- Total energy consumption ranging from 37 to 41 kcal/kg of body weight/ day for endurance athletes training at moderate intensity to 44 to 50+ kcal/kg of body weight/day for resistance-trained athletes. Strength and power athletes attempting to increase lean mass should consume sufficient amounts of energy to support muscle growth. Numeric estimations of energy intake, the authors noted, are somewhat crude in approximating the energy requirements of individual athletes. However, any athlete must consume enough energy to maintain desirable weight and body composition while training for and competing in specific sports.
- Though some diets have become popular in weight-loss circles (e.g., Atkins, South Beach, Pritikin, Zone), there is no scientific data that suggests that any of these approaches will improve performance. Some of these strategies, in fact, promote low or very low consumption of carbohydrates, with the stated intent of producing ketoacidosis, the mobilization of ketone bodies for metabolism. Ketoacidosis, however, is a serious metabolic disturbance, and its detrimental effects in people with diabetes have been well established. It is, therefore, recommended that athletes with type 1 diabetes avoid carbohydrate-restricted diets. A "balanced" diet composed of 55–60% of energy from carbohydrate, 12–18% of energy from protein, and 25–30% of energy from fat is recommended for competitive athletes.

These recommendations for nutrition were developed for athletes without special consideration for type 1 diabetes. They should be used only within the guidelines set forth in the ADA position statement "Nutrition Principles and Recommendations in Diabetes."[23]

Strength-trained athletes with diabetes require adequate amounts of protein just like all other individuals engaged in resistance exercise. While the needs of resistance-trained athletes and individuals engaged in chronic intense exercise are higher than those of sedentary individuals, this need is usually met by eating a balanced diet that is higher in energy intake. There is evidence that indicates that large amounts of protein (i.e., > 2.4 g/kg/day), including that provided through supplementation, may place additional stress on the kidneys.[24] Individuals with preexisting renal conditions may be particularly susceptible to impaired kidney function during heightened protein consumption.

Athletes often turn to nutritional supplements in the belief that performance will be improved. Competitive athletes with type 1 diabetes should recognize which products may result in harmful effects as well as those that are likely to be a waste of money. Some of the popular nutritional supplements include fat burners, thermogenic enhancers, boosters, ephedra, chitin, medium-chain triglycerides, creatine monohydrate, and androstenedione. These supplements and their use in diabetes management have been previously described in detail.[25]

Anabolic steroids are synthetic derivatives of testosterone. Though access to anabolic steroids is restricted to specific medical interventions, their use in sports remains widespread in the United States, perhaps involving as many as 3 million athletes.[26] Recent media coverage has heightened publicity surrounding anabolic steroids. Available studies have used untrained men taking both pharmacological and suprapharmacological doses of the drug. Whereas most investigations examining pharmacological administration have shown little if any improvement in body composition or strength, some studies employing suprapharmacological doses have indeed shown beneficial changes in lean mass, strength, and performance.[27,28] Studies involving the high doses believed to improve performance in athletes are nonexistent, largely because of the ethical considerations of administering large amounts of dangerous drugs to nonclinical populations. Anecdotal evidence indicates that suprapharmacological administration of anabolic steroids in competitive athletes definitively improves performance.

Reports of adverse side effects associated with anabolic steroid use have been documented and included cardiovascular disease, hypertension, hepatic disease, hormonal dysfunction, abnormal lipoprotein changes (increased LDL cholesterol, decreased HDL cholesterol), and personality disorders. No evidence, even anecdotal reports, of the effects of anabolic steroid use in athletes with type 1 diabetes is available. However, because of the known systemic disturbances associated with anabolic steroid use, it is clear that athletes with type 1 diabetes should not experiment with this class of drugs.

Competitive sports are generally safe for anyone with type 1 diabetes who is in good metabolic control and without long-term complications.[2] A careful medical history and physical examination can minimize risk. The examination should attempt to identify whether the athlete is at increased risk of orthopedic injuries, back or neck injuries, and dental trauma and should also include visual acuity and hearing screening. For long-term complications of diabetes, the exam should focus on signs and symptoms of disease affecting the heart and blood vessels, eyes, kidneys, feet, and nervous system. A formal graded exercise test is usually not necessary but may be helpful if the athlete has one of the following:

- Age > 35 years
- Age > 25 years and type 1 diabetes of duration > 15 years
- Presence of any additional risk factor for coronary artery disease
- Presence of proliferative retinopathy or nephropathy including microalbuminuria
- Peripheral vascular disease
- Autonomic neuropathy[2]

The most common acute risks for competitive athletes with diabetes are exercise-induced hypoglycemia and deterioration of hyperglycemia and ketosis brought on by physical activity during periods of hypoinsulinemia. Blood glucose is relatively unchanged during exercise in individuals without diabetes because glucose uptake by skeletal muscles is precisely matched by glucose released from the liver. One important control over this mobilization of fuel is a reduction in circulating insulin. People with type 1 diabetes must rely on exogenous insulin and are unable to reduce circulating insulin at the onset of exercise. This frequently results in hypoglycemia because there is an imbalance of increased glucose uptake by skeletal muscles with inadequate hepatic glucose release.

When insulin is not available to assist in the transport of glucose into skeletal muscles during exercise, glucose uptake is decreased, glucose release from the liver is increased, and there is a rise in blood glucose. Without adequate insulin, skeletal muscles will be forced to rely on fat as fuel, and eventually this can lead to an increase in ketone bodies. Individuals with diabetes should not exercise if insulin is inadequate. Athletes with diabetes should not exercise when blood glucose is > 250 mg/dl and ketosis is present. If glucose is > 300 mg/dl, it is probably inadvisable to exercise even without ketosis.[2]

The Management Plan

There are a number of recommendations for strategies that may be useful in the management of competitive athletes with type 1 diabetes, but they are not well supported by the scientific literature.[29–32] Most competitive athletes learn by trial and error and by sharing personal experiences with other athletes.[33] The Diabetes Exercise and Sports Association (http://www.diabetes-exercise.org) may be a valuable resource for any athlete with diabetes who is interested in sports competition.

Of those investigations that have examined athletes with diabetes, one study reported blood glucose responses for two consecutive years in athletes using different diet and insulin adjustments while competing in a 75-km cross-country ski race,[34] and another reported fuel homeostasis and insulin sensitivity in 11 athletes with diabetes from a variety of endurance and power sports.[35] Subjects in the cross-country skiing study began the consecutive annual races with blood glucose levels at 365 ± 32.4 mg/dl and 232 ± 28.8 mg/dl.[34] Athletes in the second study were found to have lower total insulin doses but did not have improved insulin sensitivity and had higher hemoglobin A_{1c} (A1C) levels when compared to sedentary subjects with type 1 diabetes.[35] One additional observation reported that children and adolescents with type 1 diabetes involved in competitive sports had a lower daily insulin dose, but these activities were not associated with improved A1C.[11]

These findings suggest that athletes with type 1 diabetes are not achieving good blood glucose control. This may be because athletes are intentionally competing with high blood glucose levels to prevent exercise-induced hypoglycemia, or diet and insulin strategies are simply not yet good enough to achieve tight control. A case study providing guidelines for the management of a collegiate football player describes setting target blood glucose levels between 150 and 250 mg/dl.[36] Using a very detailed management plan, the authors were able to limit hypoglycemia during football games to only two episodes, and these were reported as 55 and 65 mg/dl.

The Diabetes Control and Complications Trial conclusively demonstrated that the risk of development or progression of long-term complications can be reduced by intensive treatment resulting in a reduction in A1C.[37] The risk of hypoglycemia was increased threefold with intensive management. It is likely that many athletes with type 1 diabetes are chronically hyperglycemic to avoid exercise-induced hypoglycemia. Questions remaining to be answered include the following:

- Does hyperglycemia interfere with athletic performance?
- Does improved glucose control translate into improved performance?
- What blood glucose targets are appropriate for competitive athletes with type 1 diabetes?

It is likely that poor control of blood glucose increases susceptibility to infection.[38] Sport activities are frequently associated with cuts, scrapes, and blisters, which must be treated appropriately. It is important for athletic training personnel to be aware of athletes with type 1 diabetes and to pay special attention to any injury that is susceptible to infection. It is also important for athletic training staff to be aware of treatment modalities that may alter absorption of injected insulin. These may include massage therapy, ice therapy, or heat and whirlpool therapy.

The management plan for athletes with type 1 diabetes must attempt to anticipate blood glucose responses to sports training and competition. Ideally, blood glucose will be monitored and recorded before and after each meal, as well as before, during, and after each training session and athletic contest. It is also helpful to have descriptions of the exercise performed with the type, duration, and intensity of exercise, as well as any significant environmental conditions. If sports training is just beginning, or if training is dramatically increased, blood glucose should also be monitored at 2:00 a.m.

Appropriate blood glucose targets can be established based on the pattern of blood glucose responses and the ability of the individual athlete to make appropriate adjustments to keep glucose in the target range. At the beginning of sports training, it is often necessary to adjust insulin therapy by decreasing the total insulin dose by 20–50%. Reductions may be needed in both short- or rapid-acting insulin and intermediate- or long-acting insulin. Athletes on pump therapy may need to decrease bolus doses by 20–50% and may choose to discontinue basal insulin during exercise and decrease the basal insulin by 25% after exercise is completed.

The site and timing of insulin injection can affect the glucose response to exercise. If subcutaneous insulin is injected over muscles that will be actively contracting, insulin absorption will be accelerated. Insulin may be also be absorbed at a faster rate if exercise begins < 30 minutes after injection. It is recommended that insulin should be injected > 60 minutes before the start of activity. Changing the region of the injection site (thigh vs. abdomen, for example) is generally not recommended because this may also alter the time course of insulin absorption. The general recommendation is to rotate the injection sites within the same region rather than to alter the region that is used.

Once the athlete is accustomed to training, most adjustments to prevent exercise-induced hypoglycemia will be made by dietary supplementation with carbohydrate. Typically, this will involve a specified amount of carbohydrate at an appropriate time to match the anticipated reduction in blood glucose. The amount of carbohydrate required is usually 15–60 g. Drinks containing 5–10% carbohydrate may be good choices to assist with fluid loss during exercise. Most commercial sports drinks have approximately 6–7% carbohydrate. Actual amounts are easily determined from the labels. Drinks containing > 10% carbohydrate may cause gastrointestinal distress and should probably be diluted.

Sport activities by their nature are unpredictable. A tennis match that is expected to take 40 minutes may turn into a 2-hour contest. The glucose response to exercise is affected by factors such as exercise intensity, exercise duration, time of day, environmental conditions, emotional stress or excitement, and absorption of insulin and dietary supplements. When the management plan does not adequately adjust for the glucose response, there should be a plan for appropriate compensation. Rapidly absorbable carbohydrate should be readily available. Coaches, athletic trainers, team physicians, teammates, and parents should be familiar with signs of hypoglycemia, be trained to monitor blood glucose, and be able to assist athletes in case of hypoglycemia.

A successful early experience in competitive sports can be an important foundation for a lifetime of active living. Sports can improve health, fitness, psychological well-being, and social interaction. Safe participation is possible for the large majority of athletes with diabetes. Most of these individuals have a strong drive to make the most of their abilities, and a properly devised management plan can be an important tool to help them reach their competitive performance goals.

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