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Diabetes and Exercise: The Role of the Athletic Trainer

Carolyn C. Jimenez, MS, ATC

Objective: To identify the role that exercise plays in the management of diabetes mellitus and to provide the reader with guidelines for preventing and treating exercise-related complications.

Data Sources: MEDLINE was searched from 1985 to 1996 using the key words "diabetes," "exercise," "Type I diabetes," and "athlete."

Data Synthesis: Diabetes mellitus is a chronic metabolic disorder characterized by an abnormally elevated blood glucose level. It is a disease that has long-term ramifications for the body's organ systems. The primary goal of diabetes management is to normalize the blood glucose level. Exercise,

along with dietary modifications and insulin, is an important component of the management scheme. While exercise is not consistently associated with improvements in long-term blood glucose control, it does lead to other benefits that may reduce the severity and number of diabetes-related complications.

Conclusions/Recommendations: The athletic trainer can help athletes with diabetes to compete safely by understanding their unique physiologic responses to exercise, as well as the risks and benefits of exercise.

Key Words: diabetes mellitus, blood glucose control, Type I diabetes

Whether an individual is diabetic or not, physical exercise is an important component of a healthy lifestyle. There are many benefits of regular exercise: decreased body fat, increased lean body mass, a better-functioning cardiovascular system, and an improved sense of psychological well-being. These exercise-related benefits are especially important for people with diabetes, who are at greater risk for coronary artery disease, arteriosclerosis, cerebral vascular diseases, renal diseases, ocular diseases, and other health problems.^{1,2} Therefore, along with dietary modifications and oral diabetes medications or insulin therapy, regular exercise is an important component of diabetes management.³

While there are several types of diabetes, the focus of this article will be Type 1 diabetes mellitus, previously known as insulin-dependent diabetes mellitus and previously identified as Type I.⁴ Type 1 diabetes is one of the most common chronic childhood diseases.^{5,6} The prevalence of Type 1 diabetes among children, adolescents, and young adults means that this is the form most certified athletic trainers will encounter. It is important that the athletic trainer understand the role of exercise in the management of diabetes, including the diabetic's physiologic response to exercise and how it differs from the nondiabetic's, and the risks and benefits of exercise. In this article, I will discuss these issues and how the athletic trainer can work with the diabetic to make physical exercise a safe, valuable, and enjoyable part of life.

DIABETES MELLITUS DEFINITION

Diabetes mellitus is a chronic metabolic disorder in which the body either does not produce adequate amounts of insulin or does not use it properly.³ Insulin, a hormone created in the

pancreas, is necessary for carbohydrate metabolism. Insulin allows glucose to enter the cell, where it is converted to energy. In addition, insulin plays important roles in protein synthesis and fat storage.³

Diabetes is characterized by an abnormally high blood glucose level and the inability to properly metabolize and store ingested dietary "fuels." Chronically elevated levels of blood glucose eventually damage the body's systems. As a result, diabetes is a disease with long-term negative effects on the body's renal, neurologic, ocular, cardiovascular, and musculoskeletal systems.⁵

TYPE 1 DIABETES MELLITUS

Type 1 diabetes affects approximately 10% of the diabetic population.^{5,7} It is an autoimmune disorder in which the insulin-secreting beta cells of the pancreas are destroyed over time. The immune response can be triggered by hereditary factors or environmental conditions, such as a virus.⁵ When approximately 80% of the beta cells are destroyed, the individual no longer produces sufficient insulin to facilitate the uptake of ingested fuels.⁵ Subsequently, the individual develops the signs and symptoms associated with diabetes, which may include fatigue, visual changes, excessive hunger, extreme thirst, frequent urination, and weight loss. In addition, the Type 1 diabetic is at risk for developing ketoacidosis. Ketoacidosis is caused by the buildup of ketones, acid by-products that poison the blood.³ It is commonly referred to as diabetic ketoacidosis (DKA) and occurs almost exclusively in the Type 1 diabetic.^{3,5}

IMPACT OF DIABETES

Diabetes is a disease associated with many acute and chronic complications. The acute complications include DKA and hypoglycemia (low blood sugar). Chronic complications affect the eyes, nervous system (especially the peripheral and autonomic nerves), kidneys, and cardiovascular system. It is

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important for athletic trainers to be aware that young Type 1 diabetics who have had the disease for a number of years may present with various degrees of these chronic complications.

MANAGEMENT OF TYPE 1 DIABETES

Effective management of Type 1 diabetes is composed of three elements: insulin, dietary modifications, and exercise. The primary goal of diabetes management is to maintain blood glucose levels as close to normal (80–120 mg/dL) as possible.^{8,9} The importance of a consistent, near-normal blood glucose level has recently been brought to light by the Diabetes Control and Complications Trial.¹⁰ This study evaluated the effects of intensive blood glucose management on the prevention and progression of diabetes-related complications. Following more than 1400 Type 1 diabetics for an average of 6.5 years, the trial demonstrated that maintaining near-normal blood glucose levels reduces the risk of developing chronic complications and slows the progress of these conditions. Specifically, the risk of developing retinopathy was reduced by 76%, and the progression of existing retinopathy was slowed by 54%. In the Diabetes Control and Complications Trial, the risk of developing nephropathy was reduced by 34%, and disease progression was slowed by 43%. Similarly, the risk of developing neuropathy was reduced by 69%, and progression was slowed by 57%.¹⁰

THE ROLE OF EXERCISE IN THE MANAGEMENT OF TYPE 1 DIABETES

Exercise is an important component of diabetes management. Various authors^{1,2,11} have reported that regular exercise has improved the cardiovascular system, decreased some of the risk factors leading to cardiovascular disease, promoted fat loss, increased muscle mass, increased glucose uptake by cells, improved insulin sensitivity, and enhanced the psychological well-being of the diabetic. In other research,^{2,11} regular exercise was noted to improve cardiovascular fitness and work capacity, while decreasing resting and exercise blood pressures, as well as peripheral vascular resistance. Finally, exercise has been shown to decrease the risk of cardiovascular disease and improve total cholesterol and high-density lipoprotein levels.^{2,12} These benefits are especially important since a Type 1 diabetic is two to four times more likely to develop heart disease and five times more likely to have a stroke than a nondiabetic.³

Exercise also increases total caloric expenditure, promotes fat loss, and increases lean body mass.^{2,11} Excessive amounts of fat are associated with insulin resistance, a phenomenon in which the body may have an adequate amount of insulin available but cannot use it.^{3,7} A loss of body fat has been shown to decrease insulin resistance in diabetics.² Along with decreasing body fat, exercise can increase muscle mass. Increases in muscle mass are important because muscles are a major disposal site for excess blood glucose.¹³

Finally, exercise can lower blood glucose levels by increasing insulin's binding activity to insulin receptors, enhancing the cell membrane permeability to glucose and increasing

peripheral glucose uptake.^{1,5,7} Increases in the rate of glucose uptake are due in part to an increase in expression of a cellular glucose transporter (GLUT 4), which assists in the transport of glucose during exercise.¹³ It should be noted, however, that although blood glucose levels decrease with exercise, most studies have demonstrated that exercise alone has not improved long-term blood glucose control in Type 1 diabetics.^{1,12,14,15} Long-term blood glucose control is measured through a glycosylated hemoglobin test (Hgb A1c), which reflects the average blood glucose control over the past 3 or 4 months.³

Landry and Allen¹² demonstrated that, despite exercise-induced improvements, such as an increase in insulin sensitivity, long-term blood glucose control did not improve. A possible explanation may be the necessity for concurrent dietary and insulin adjustments.^{2,11,15} Schneider et al¹⁵ reported an improvement in blood glucose control in Type 1 diabetics who were enrolled in an exercise program. However, they noted that these individuals were highly motivated to maintain appropriate diets, adjusted insulin doses in anticipation of exercise, and demonstrated above-average monitoring of their blood glucose levels.

Based on all these observations, the American Diabetes Association currently recommends that Type 1 diabetics should exercise to improve their cardiovascular fitness, to derive the benefits in insulin sensitivity and glucose uptake, and to enhance their psychological well-being.³

PHYSIOLOGIC RESPONSE TO EXERCISE

The athletic trainer should have an understanding of the Type 1 diabetic's physiologic response to exercise. Exercise requires rapid mobilization and utilization of fuels, particularly glucose and free fatty acids,⁵ which are accomplished through the release of hormones such as epinephrine, norepinephrine, insulin, and glucagon.^{1,7} In the nondiabetic, the end result is a coordinated and balanced response, so that fuel supply is adequate to meet demand.

In the nondiabetic, the onset of exercise brings about a complex neural and hormonal response. The primary goal of this response is to maintain the supply of metabolic fuels for the muscles. Exercise results in an increase in epinephrine and glucagon levels and a decrease in insulin levels.^{5,7} Each of these hormones plays an important role in providing adequate fuel for working muscles. The release of epinephrine stimulates the release of free fatty acids from lipocytes and signals the liver to produce glucose. Similarly, a decrease in insulin stimulates the release of free fatty acids and increases hepatic glucose production. Hormonal increases in glucagon further increase hepatic glucose output.^{1,5,7}

In contrast to the well-coordinated response described above, the exercise response for the Type 1 diabetic is complicated by the fact that exogenously administered insulin cannot match the precise control of natural endogenous insulin during activity.¹⁶ During exercise, Type 1 diabetics may experience problems with both excessive and inadequate amounts of insulin. If the diabetic athlete begins exercise with an excessive amount of insulin in the blood, which can occur if an insulin injection is taken shortly before exercise, hypo-

glycemia will result. This happens for two reasons. First, insulin and exercise facilitate cellular glucose uptake. Working together, they have an additive effect that rapidly lowers blood glucose.¹³ Second, insulin suppresses glucose production in the liver. Thus, excess levels of insulin both inhibit glucose production and increase glucose uptake, with the end result of hypoglycemia in the exercising diabetic.⁵

RISKS OF EXERCISE FOR TYPE 1 DIABETICS

In addition to the benefits of regular exercise, the Type 1 diabetic and the athletic trainer should be aware of the potential risks. These include the previously mentioned hypoglycemia, as well as, occasionally, hyperglycemia (high blood sugar) leading to DKA.

Hypoglycemia is the most frequently encountered risk.^{12,17-19} It can occur either during exercise or hours later. Maynard² noted that the factors that affect blood glucose levels during exercise include the time and content of the last meal; time, dosage, and type of diabetic medications; and type of activity being performed. If all factors are considered equal, then the duration and intensity of the exercise affect blood glucose levels the most.²

Hypoglycemia is a problem for Type 1 diabetics because their ability to recover from it is limited.²⁰ Recovery is mediated via the release of epinephrine, norepinephrine, and glucagon. Schneider et al²⁰ compared recovery rates after an exercise bout involving hypoglycemic Type 1 diabetics and involving controls in whom hypoglycemia was induced. Increases in glucagon, epinephrine, and norepinephrine were lower in the Type 1 diabetic group. Therefore, the ability to recover endogenously from a hypoglycemic event is clearly impaired in Type 1 diabetics and may require the special management strategies that are described later.²⁰

Another problem Type 1 diabetics may encounter is an increase in blood glucose levels during exercise. If blood glucose control is poor or blood glucose levels are excessively high prior to activity, which may occur when the diabetic is sick or forgets an insulin dose, exercise can cause a further rise in the blood glucose level. Superimposing exercise may lead to the production of ketones, causing DKA.^{5,7} This occurs because, when insulin is not available to facilitate glucose uptake, the body assumes that blood glucose levels are low. It responds by releasing hormones that cause a further rise in the blood glucose level. Also, if the body cannot use glucose as a fuel, it will begin to metabolize fats. Ketones are by-products of fat metabolism. Excessive levels of ketones in the blood lead to DKA, a potentially life-threatening condition.^{5,21}

GUIDELINES FOR SAFE EXERCISE

Epidemiologic evidence suggests that Type 1 diabetics who engage in a lifetime of regular physical activity may live longer and suffer fewer and less severe diabetes-related complications.²² As part of the routine medical clearance procedure, the athletic trainer will want to ensure that the Type 1 diabetic athlete has had a thorough medical examination conducted by a physician. The examination should establish that the athlete

is in good metabolic control, as measured by the Hgb A1c test, and does not have any existing medical conditions that may be exacerbated by exercise.^{1,5,7}

Several authors^{2,5} recommend that all exercising diabetics should

1. wear identification indicating that they are diabetic;
2. avoid exercising at the peak of insulin action;
3. adjust carbohydrate intake or insulin dosage before exercise;
4. check blood sugar before, after, and, if possible, during exercise;
5. prevent dehydration by consuming adequate fluids before, during, and after exercise;
6. have access to a fast-acting carbohydrate during exercise in the event of hypoglycemia;
7. have blood glucose testing equipment and supplies available.

The athletic trainer should be ready and able to handle exercise-related emergencies. As stated earlier, the most frequently encountered exercise risk is hypoglycemia. Although each athlete responds differently, hypoglycemia is defined as a blood glucose level less than 70 mg/dL. The signs and symptoms of a hypoglycemic reaction include shakiness, sweating, a rapid heartbeat, trouble concentrating, headache, dizziness, mood changes, and tingling in the face, tongue, and lips.³ Most cases of hypoglycemia can be reversed by giving the athlete 10 to 15 g of a fast-acting carbohydrate source, such as half a can of nondiet soda, 118 ml (4 oz) of orange juice, four packets of table sugar, or five to seven Life Savers.^{3,5} Foods that contain high levels of fat, such as chocolate, should not be used for treating a hypoglycemic reaction because the fat interferes with the absorption of the sugar.⁵ After eating, the athlete should wait 15 minutes and check the blood sugar level. If the blood glucose level remains below 70 mg/dL, another 10 to 15 g of carbohydrates are given. Repeat blood testing and treating until the blood glucose level is normalized.⁵

In cases of severe hypoglycemia, where the athlete is unconscious or unable to swallow, glucagon must be administered. While diabetics are instructed to teach friends and relatives how to mix, draw up, and inject glucagon, the role of the athletic trainer in this circumstance is less clear.^{5,21} To clarify responsibility, the athletic trainer should meet with the athlete, the parents, the physician, and appropriate school officials to discuss how to handle a severe hypoglycemic reaction. Specifically, the athletic trainer needs to know whether, and under what circumstances, a glucagon injection should be administered and the time line for activating emergency medical services. The agreed-upon policy should then be put in writing. If the athletic trainer is to administer the injection, he or she must be trained to do so. This training can be easily provided by the athlete's physician or appointee.

Although there is some variation, a glucagon injection kit typically contains a syringe that is prefilled with a diluting solution and a vial of glucagon powder. Once the solution and powder are thoroughly mixed, they are injected into the upper arm, thigh, or buttock. The athlete should be placed on his or

Recommended Food Intake Based on Type of Exercise and Blood Glucose Level*

Exercise	Blood Glucose Level	Food Exchanges to Add†
Short-duration, low- to moderate-intensity exercise walking (1/2 mile) or leisurely cycling (less than 30 minutes)	under 80 mg/dL	2 fruit
	over 80 mg/dL	1 fruit
Moderate-intensity exercise tennis, swimming, jogging, golfing, or leisurely cycling (1 hour)	under 80 mg/dL	1/2 meat and 2 bread
	80–180 mg/dL	1 fruit or 1 bread
	180–300 mg/dL	no extra food
	over 300 mg/dL	DO NOT EXERCISE
Strenuous exercise football, hockey, racquetball, basketball, strenuous cycling or swimming, or shoveling	under 80 mg/dL	1 meat, 2 bread, 1 fruit, and 1 milk
	80–180 mg/dL	1 meat and 2 bread
	180–300 mg/dL	1 fruit or 1 bread
	over 300 mg/dL	DO NOT EXERCISE

* Adapted with permission from Lundstrom and Rossini.²¹

† 1 fruit = 118 ml (4 oz) orange juice. 1 meat = 15 ml (1T) peanut butter. 1 bread = 14 g (1/2 oz) bagel. 1 milk = 237 ml (8 oz) 2% or skim milk.

her side because the glucagon may cause vomiting. Given available glycogen stores in the liver, an individual will typically respond within 15 minutes. When the athlete is able to chew and swallow, a fast-acting source of carbohydrate should be provided, followed by a longer-acting source of carbohydrate, such as cheese and crackers.⁵

If the diabetic's pre-exercise blood glucose is excessively high, signs and symptoms may include headache, blurry vision, sleepiness, and increased thirst and urination. In this situation, the athlete should conduct a blood glucose test. If the reading is 250 mg/dL or higher, then the athlete should check the urine for ketones. Ketones suggest a loss of metabolic control, in which case exercise should be delayed until the ketone test is negative and until the athlete's physician is contacted for further instructions.² In order to prevent dehydration as a result of the high blood glucose level, the athlete should drink plenty of water.

STRATEGIES TO PREVENT HYPOGLYCEMIA AND HYPERGLYCEMIA DURING EXERCISE

The diabetic athlete and the athletic trainer should know how to prevent both hypoglycemia and conditions that may lead to DKA. Two strategies to prevent hypoglycemia include decreasing the amount of insulin injected before exercise and supplementing carbohydrates before and during exercise. The diabetic should discuss specific insulin adjustments with the physician, particularly when the exercise bout is longer than 45 minutes.⁵ The Table provides general guidelines for carbohydrate supplementation prior to different types of exercise and when such exercise should be delayed.²¹ In addition to supplementing carbohydrates before exercise, it is generally recommended that 10 to 15 g of carbohydrates be ingested during activity for every 30 minutes of exercise.⁵

Occasionally exercise will cause blood glucose levels to rise, particularly when the pre-exercise blood glucose level is at or above 250 mg/dL. If ketones are present, exercise should be delayed. However, Maynard² believes that, if the pre-exercise blood glucose is 250 mg/dL without ketones in the urine,

insulin levels are adequate for exercise to cause a decrease in blood glucose levels. As noted in the Table, when the pre-exercise blood glucose reading is over 300 mg/dL, regardless of the ketone status, exercise should be delayed until blood glucose levels are less than 250 mg/dL.^{2,5,21}

CONCLUSIONS

As athletic trainers, we must recognize that we are key players on the diabetic's management team. We are likely to have more contact with the diabetic athlete than the athlete's physician does. As such, we can help the athlete learn how to appropriately monitor and regulate blood glucose levels before and during exercise, allowing physical activity to become an integral and enjoyable component of life, which may significantly reduce the risk of many of the serious complications of this disease.

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