Pumping Insulin During Exercise
What Healthcare Providers and Diabetic Patients Need to Know

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IN BRIEF: Exercise can decrease insulin resistance in most people. Insulin pumps deliver precise insulin adjustments that improve fuel availability and provide glycemic control to help diabetic patients overcome obstacles to exercise. Diabetic patients, their physicians, and their healthcare providers should be familiar with the features and nuances of specific pump models and follow some basic guiding principles for exercise to create the most normal metabolic response possible.

People who have diabetes mellitus, whether they are athletes or not, benefit from exercise that improves the body's ability to use insulin. However, a common concern is that exercise can complicate glycemic control, particularly in patients who use insulin. In nondiabetic individuals, exercise decreases insulin release, which is a normal metabolic response when more blood glucose is transported into cells via contraction-initiated glucose transport. However, a small amount of insulin is always required during exercise to counterbalance glucosering hormones such as catecholamines, glucagon, growth hormone, and cortisol.

When diabetic patients who use insulin participate in physical activity, they must make frequent insulin adjustments to maintain glycemic control, especially during higher-intensity or longer-duration exercise. The insulin regimen that makes an exercising diabetic individual's response closest to normal is continuous subcutaneous insulin infusion (CSII) therapy, also called insulin pump therapy. Physicians and other healthcare professionals should be well versed in the physiologic effects of pump use and the features and nuances of specific insulin pump models to help their patients effectively manage glycemic control during exercise.

Essentials of Insulin Pump Use
For CSII therapy, a pager-sized pump is worn outside the body in a pouch or on a belt clip. About 10% of individuals with type 1 diabetes wear portable insulin pumps.
TABLE 1. General Benefits of Insulin Pump Use

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<tr>
<th>Benefit</th>
<th>Description</th>
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<tr>
<td>Better overall blood glucose control</td>
<td>(improved hemoglobin A1c values)</td>
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<tr>
<td>More flexibility in eating (or skipping) meals and snacks</td>
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<tr>
<td>Easier body weight management due to optional snacks and flexible meal sizes</td>
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<tr>
<td>Fewer episodes of severe hypoglycemia, especially nocturnally</td>
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<td>Teens can sleep late without risking hypoglycemia</td>
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<tr>
<td>Improvements in hypoglycemic awareness</td>
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<tr>
<td>Greater flexibility in doing spontaneous or planned exercise</td>
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<tr>
<td>Precise dosing of insulin (in 0.05- to 0.5-unit increments)</td>
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<tr>
<td>Less chance of lipodystrophy resulting from repeated injections</td>
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<tr>
<td>More flexible and instantaneous basal dose adjustments</td>
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<td>Convenience of taking insulin without the social stigma of public injections</td>
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hormonal responses to hypoglycemia, but it did improve overall blood glucose control and decreased the frequency of hypoglycemia, perhaps through a heightened hepatic sensitivity to glucagon mediated by fast-acting insulin analogues. A concern with fast-acting insulin analogue use, however, is the rapidity with which a hypoglycemic episode can occur if insulin is given and carbohydrates are not absorbed quickly enough. The glycemic index of carbohydrates should also be considered when using analogues.

Benefits of Pump Use for Exercisers

Insulin pump use provides many general benefits (Table 1). (For a review of the major benefits of exercise for individuals with diabetes, see “Type 1 Diabetes and Sports Participation: Strategies for Training and Competing Safely,” December 2000, page 49.) One of the most important benefits for active diabetic patients is that an insulin pump can produce a metabolic response to exercise that, with experience and blood sugar testing, can be similar to the response of a non-

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diabetic individual. Another advantage is the precision and speed of insulin adjustments. Other advantages include more reliable insulin action through a constant infusion of short-acting insulin, and precise dosing and timing of insulin doses with meals.

**Effects of Exercise**

Aerobic exercise in nondiabetic individuals usually decreases insulin release by the pancreas and increases glucagon release. In nondiabetic subjects who have fasted overnight, exercise can stimulate whole-body glucose uptake even when insulin levels are relatively deficient. Some circulating insulin is required to maintain glycemic control during exercise, and pumps can help diabetic patients control circulating insulin levels.

**Pump vs syringe.** Viberti et al. studied the hormonal and glycemic responses to moderately severe exercise performed 2 hours after breakfast by eight patients who had type 1 diabetes. Conventional insulin therapy (CIT), involving two to three daily injections of short- and intermediate-acting insulin, produced large decreases in glucose levels during activity (from 220 mg/dL to 80 mg/dL or 12.1 mM to 4.4 mM) with a large increase in free insulin levels. When patients repeated this exercise using CSII therapy, glucose levels fell (from 129.1 mg/dL to 55.4 mg/dL or 7.1 mM to 3.6 mM) but stabilized, and users experienced no increase in free insulin levels. Furthermore, the exaggerated rise in growth hormone during CIT was normalized by 3 weeks of CSII therapy. The authors concluded that good metabolic control attained with insulin pump therapy was accompanied by nearly normal hormonal and metabolic responses to exercise.

**Time of day.** Circulating insulin levels can be affected by the time of day that pump users exercise. Suspending regular insulin delivery via CSII therapy, 30 minutes before and during exercise, lowered free insulin levels during the activity but still produced hypoglycemia during fasting exercise, when a relative state of hyperinsulinemia existed. The exercise consisted of 45 minutes of moderately intense cycling at 60% VO_{2}max. When subjects repeated this exercise in the afternoon at least 4 hours after the last premeal bolus of insulin, they experienced a more pronounced decline in blood glucose levels compared with the morning’s fasting bout. Even with today’s fast-acting insulin analogues, these results suggest that to reduce circulating insulin levels at the start of prolonged exercise, basal insulin delivery may need to be reduced for a longer period (perhaps 60 to 90 minutes) before some moderate or strenuous activities that last longer than 30 to 45 minutes.

Schiffrin et al. demonstrated that moderate cycling performed in the fasting state can produce hypoglycemia during CSII therapy. The subjects’ normal fasting, basal insulin infusion rates were maintained during a bout of cycling (45 minutes at 50% VO_{2}max), but subjects experienced a sharp decrease in glycemia after exercise.

Trovati et al. showed that, when using insulin pumps, type 1 diabetic patients who are tightly controlled can perform 30 minutes of mild and moderate exercise 2 or 3 hours after breakfast without a high risk of hypoglycemia, despite mild hyperinsulinemia. To achieve optimal control, it is clear that appropriate insulin reductions should be made for planned exercise that closely follows an insulin bolus. This precaution will minimize circulating free insulin and the risk of hypoglycemia during and after the activity.

**Intense activity.** Exercise intensity and elevated starting blood glucose levels are other factors that appear to affect the metabolic response, often resulting in hyperglycemia instead of the more usual hypoglycemia. Mitchell et al. investigated eight type 1 diabetic subjects on CSII therapy to determine their response to a short period of exercise performed in the fasting state at 80% VO_{2}max. When these individuals began exercise with normal blood glucose levels (86.9 mg/dL ± 4 mg/dL or 4.8 mM ± 0.22 mM), they experienced mild hyperglycemia (128.4 mg/dL ± 7.1 mg/dL or 7.06 mM ± 0.39 mM) for 2 hours postexercise. Furthermore, elevated mean preexercise blood glucose levels (150.5 mg/dL ± 9.1 or 8.28 mM ± 0.50 mM) rose progressively during the same 2 hours. (231.3 mg/dL ± 28.4 mg/dL or 12.72 mM ± 1.56 mM). The authors concluded that metabolic control can deteriorate with intense exercise. These glycemic effects, demonstrated in both nondiabetic and euglycemic diabetic subjects, were attributed to exaggerated epinephrine and norepinephrine responses. Apparently, a relative state of hypoinsulinemia during fasting exercise can also alter the normal metabolic response to exercise.

**Microalbuminuria.** Exercise can also exaggerate albumin excretion (a critical marker for diabetic renal dis...
Choosing the Best Insulin Pump for Exercise

Insulin pumps differ in delivery options and features, so physicians need to know the nuances of current models to help their patients select the best model for safe and effective use during exercise.

Current insulin pumps provide a variety of features, such as different basal increments and duration, basal profiles, frequency of basal insulin delivery, temporary basal rate settings, bolus increments, bolus delivery, size, cost, and use in water during swimming or bathing. For exercise, the most important model features are basal rate and bolus increments, basal profiles, and temporary basal settings.

Certain pump models, such as the ones listed below, are clearly superior in their ability to adjust for extended exercise, either planned or spontaneous, through refinements in basal rate reduction.

**Animas R-1000** (Animas Corp., Frazer, Pennsylvania) has four basal profiles that are designed to accommodate varying workouts on subsequent days. It has smaller basal increments (0.05 U/hr) that allow insulin-sensitive individuals, such as those on total daily insulin doses of 30 units or less, the flexibility of making minute changes. It also has a temporary basal setting (±10% for 0.5 to 12 hours) that allows slightly more fine-tuning than, but is similar to, the D-TRON discussed below. It is waterproof for surface water activities.

**D-TRON** (Disetronic Medical Systems, St. Paul) has a second basal rate profile that can be set for exercise days. The D-TRON can also deliver meal boluses over an extended period from 15 minutes to 4 hours. This feature could be used to delay or reduce meal boluses for exercise after meals. This pump can also combine extended and normal boluses. The D-TRON offers flexibility in setting a temporary basal rate in 10% increments or decrements over 1 to 24 hours. This model is waterproof during surface water activities.

**Model 508** (Medtronic Minimed, Northridge, California) has three separate basal profiles that can be programmed for regular activity, and small basal (0.1 U/hr) and bolus increments (0.1 unit) similar to the D-TRON. The 508 also offers extended boluses or a combination of extended and normal boluses. One mild drawback of the 508 is that it is only water resistant, not waterproof, and cannot be worn during extended water surface activities. For shorter water workouts, most infusion sets can be disconnected near the infusion site. A bolus (0.5 to 1 unit) may be needed when the unit is reconnected.

Medtronic also makes the Paradigm pump, a newer, smaller model that features a simplified menu system. The Paradigm is watertight up to 8 feet for 30 minutes, so users can shower or swim.

For a detailed comparison chart of common models, go to www.diabetes.net/diabetes_technology/insulin_pump_models.php. More specific information is available online at http://childrenwithdiabetes.com.
threatening condition that may require emergency treatment in a hospital, can begin as quickly as 5 hours after the displacement of an infusion set, especially when it contains a rapid-acting insulin analogue. When a patient becomes hypoinsulinemic from any interruption of insulin delivery, exercise can exacerbate the situation and speed the development of DKA. Because of the severity of DKA, insulin pump users must be especially vigilant about maintaining the integrity of their infusion sites during exercise.

Sweating. Excessive sweating may dislodge the subcutaneous infusion set, producing elevated blood sugar levels or DKA if the displacement remains unnoticed for some time. To prevent sweat-related displacement, patients can use liquid skin preparations (e.g., Skin-Tac, Torbot Group, Cranston, Rhode Island) and stronger adhesives to anchor the set more firmly. Applying antiperspirant to the skin at the infusion site can minimize sweating beneath the set. Users should check the integrity of the infusion site following vigorous exercise, sweating, or water contact.

Irritation. For those using metal needles, movement or contact may irritate the infusion site. This problem, however, is greatly reduced with pumps that use flexible Teflon infusion sets. Patients, especially those who exercise vigorously, must adhere to the recommendation to replace their insulin infusion sets every 2 to 3 days to prevent skin irritation.

Ambient temperature. Insulin is temperature-sensitive. Exercising in hot or cold environments may cause insulin to degrade and lose its effectiveness. If an insulin pump is placed close to the skin during exercise in the heat, the insulin may become overheated as well. Patients should be cautioned to replace the entire insulin-filled cartridge and infusion catheter at the first sign of any unanticipated hyperglycemia.

Guiding Principles

Knowledgeable healthcare providers can instruct active diabetic patients to follow some basic principles for exercise to achieve the most normal metabolic response possible.

Understand metabolism and activity. Some activities, such as resistance or high-intensity interval training, stress mainly anaerobic energy sources and can have a markedly different effect on glycemia compared with prolonged or mild aerobic exercise.

Predict glycemic response. The glycemic effect of the exercise can often be predicted based on the type of activity, time of day, and circulating insulin levels. Paramount are the length and intensity of the exercise and the training level of the participant. Regimen changes may be needed to prevent hypoglycemia during the activity and for up to 24 hours afterward.

Establish glycemic patterns. Each time they do a new activity, exercisers should check blood glucose levels before, during, and after the activity to establish usual response patterns and watch for future variations.

Make appropriate changes. Regimen changes (increased carbohydrate consumption or decreased insulin) should be made according to previous glycemic responses to the activity. Additional alterations can be made depending on whether physical fitness or weight loss is the exercise goal.

Expect a training response. Finally, active patients should expect a glycemic training response to occur after they have consistently done an activity for 2 to 3 weeks. Training increases fat utilization and potentially spares blood glucose. This response may reduce the need for regimen changes during prolonged aerobic activities. In addition, as muscle mass increases in response to training, an individual’s overall insulin sensitivity may increase, which may allow for lower basal and bolus insulin doses.

General Recommendations for Regimen Changes

The American College of Sports Medicine and the American Diabetes Association have established general clinical practice recommendations for exercise and diabetes that apply to patients who use insulin pumps. The problem with these recommendations lies in their generality. The wide variety of sports and recreational activities makes it difficult to make all-encompassing recommendations, but a rule of thumb is for pump users to first consider preexercise blood glucose levels.

The main change from previous recommendations is that patients who have preexercise blood glucose levels less than 100 mg/dL (5.5 mM) may not require a carbohydrate snack; pump users can simply reduce or suspend basal insulin during an activity. The insulin reductions and the carbohydrate intake necessary for aerobic activity will depend on its intensity and duration. A change in either insulin (basal or bolus dose...
es) or carbohydrate intake can often compensate for shorter, less intense activities.

Exercise is advised if blood glucose levels are less than 250 mg/dL (13.75 mM) and no ketones are detected. If blood glucose is more than 250 mg/dL, exercise is still advised if ketones are not present; however, a small insulin bolus may be needed. If ketones are found and the preexercise blood glucose exceeds 250 mg/dL, exercise is not advised. Exercise may be possible if blood glucose is more than 300 mg/dL (16.5 mM) and ketones are not present, but extra caution is advised, and an insulin bolus may be necessary.

Short, intense activities, such as weight training, may not require any immediate regimen changes, but delayed-onset hypoglycemia should be anticipated. Longer, more intense exercise generally requires a combination of carbohydrate intake and insulin reduction to maintain normal glycemia. For sport- and activity-specific recommendations, more information about initiating pump use, and guidance about insulin dose adjustments, please consult recent texts.21

Pumping Up Exercise Benefits

Active people who have diabetes and use insulin pumps can benefit from more normal physiologic responses to exercise and blood glucose levels that remain more stable during and following exercise. Choosing an insulin pump is mainly a matter of patient preference.

Normal exercise concerns for diabetic individuals apply to pump users, but some of these concerns are abated by pump use. To counsel patients on safe and effective insulin pump use during exercise, physicians should be aware of current insulin pump features, basic guiding principles for exercise, and general recommendations for insulin regimen changes.22

REFERENCES