Review Article

Physical activity, sport, and pediatric diabetes


Abstract: The benefits derived from regular physical activity include improved cardiovascular fitness, increased lean mass, improved blood lipid profile, enhanced psychosocial well-being, and decreased body adiposity. The benefits for children with diabetes may also include blood glucose control and enhanced insulin sensitivity. However, for these children, engagement in vigorous physical activity and sport must be properly controlled through modifications in insulin therapy and nutritional intake so that the benefits of exercise outweigh the risks. The following review describes the various physiological and metabolic factors which occur both during exercise and during sport while describing specific recommendations to control glucose excursions by proper insulin management and diet.

MC Riddell and KE Iscoe
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Corresponding author:
Michael C. Riddell, PhD,
Kinesiology and Health Science,
York University,
Bethune College,
4700 Keele St.,
Toronto,
ON M3J 1P3,
Canada.
Tel: +1-416-736-2100x40493;
fax: +1-416-736-5774;
e-mail: mriddell@yorku.ca
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Treatment for the child with type 1 diabetes (T1DM), formally insulin-dependent or juvenile diabetes, has improved dramatically since the discovery of insulin in 1923, in both biological and technological terms. Nevertheless, a number of important clinical management issues are needed for the active child with diabetes to ensure proper health and prevention of long-term complications from the disease. Some evidence suggests that optimal metabolic control maximizes physical performance in youth with diabetes, although more studies are needed to confirm this suggestion. With the increasing prevalence of childhood obesity, the importance of physical activity to help prevent type 2 diabetes in youth is of more recent consideration. Importantly, large-scale epidemiological studies suggest that modest amounts of regular exercise (30 min/d of walking) reduce the risk of developing type 2 diabetes from a state of impaired glucose tolerance, at least in adulthood, by approximately 60% (1). Very little is known about the amount of physical activity needed to help prevent type 2 diabetes in children, although we provide some recommendations, based on Canadian and US Government bodies below.

For youth with diabetes who are engaged in sport, control must go beyond the typical regimen of diet and insulin treatment to obtain optimal performance and prevent metabolic complications that can occur both during and after physical activity. Adolescence presents additional concerns for these patients, as hormonal changes during growth and maturation create a temporary state of insulin resistance. In addition, many children maintain some endogenous insulin secretion just after diagnosis, which can make metabolic control particularly challenging. This chapter focuses on physiological and clinical aspects of diabetes management in the ‘active’ adolescent and highlights the beneficial effects of regular exercise for the child with diabetes mellitus.

Exercise benefits and guidelines

Research has improved our understanding of the various biochemical and metabolic aspects of diabetic pathology and the impact of exercise on diabetes control. Through such research, specific prescriptions of physical activity can be made to optimize health and fitness benefits. Although somewhat dependent on intensity and duration, advantages include a decline in resting heart rate and blood pressure, an increased muscle mass to fat ratio, and better weight control. Additional benefits specific to diabetes include improved insulin sensitivity, a diminished glycemic
response to a meal, and a reduction in daily insulin needs.

The Public Health Agency of Canada and the Canadian Society for Exercise Physiology propose 90 min/d of accumulated physical activity for children aged 10–14 yrs (www.phac-aspc.gc.ca/pau-uap/paguide/child_youth/index.htm), whereas the US Department of Health and Human Services recommends that children should accumulate at least 30 min of moderate-intensity physical activity on most days of the week (2).

Recent investigation showed that among Canadian adolescents aged 12–20 yrs, only 55% of males and 40% of females are sufficiently active (3). In general, for those who were previously inactive, activity patterns should be gradually increased by 5–10 min each bout. To do this, there should be a decrease in sedentary activities (such as television viewing) and an increase in recreation, play, and/or sport activities with the overall goal of accumulating at least 90 min of physical activity per day (www.phac-aspc.gc.ca/pau-uap/paguide/child_youth/index.htm).

It has recently been suggested that most US children with T1DM attain at least 30 min of exercise daily, and individuals in certain age groups even exceed the levels of sporting activity of their non-diabetic counterparts, possibly due to intensive health education and diabetic intervention (4). A high level of sports participation is surprising as exercise is the leading cause of hypoglycemia, which is both the child’s and the parent’s primary concern with exercise (5). Little is known whether a fear of hypoglycemia is a deterrent to sport or physical activity participation. In some cases, the endorsement of regular exercise may be difficult in teenagers with diabetes as hormonal changes during puberty make glucose management difficult and the risk for hypoglycemia may be increased.

A positive association between glycemic control (i.e., HbA1c) and aerobic fitness (6–8) or reported physical activity (9, 10) exists in youth with T1DM suggesting that either increased aerobic capacity (VO2max) may improve glycemic control or good metabolic control maximizes aerobic capacity. It may be that both glycemic control and aerobic fitness are influenced by physical activity. In subjects stratified according to their level of participation, metabolic control is significantly better in those who exercise frequently, regardless of the type of activity (8). Despite the positive associations between VO2max and glycemic control in cross-sectional studies, the influence of regular exercise on glycemic control is, based on a limited number of small clinical trials, unresolved. Indeed, the influence of chronic exercise on improving blood glucose control in children and adolescents with T1DM is equivocal; some studies show an improvement in blood glucose control (11–13), but others show no effect (14–17). It is likely that excess caloric intake to prevent or treat hypoglycemia may counter the beneficial effects of exercise on glycemic control in some children, because standardized carbohydrate and insulin modifications for active children are not readily available. Nonetheless, the goal of regular exercise should be to increase insulin sensitivity and to improve the overall cardiovascular and psychological profile of the child with T1DM, regardless of any putative benefits to blood glucose management.

Adolescents with T1DM who undergo aerobic training appear to improve cardio-respiratory endurance and muscle strength at least as much as their non-diabetic peers (8, 14, 18). In addition, adolescents who attend camps that feature increased regular physical activities, along with education about how to modify dietary intake or daily insulin dosage to prevent hypoglycemia, show improved metabolic control and fitness (19, 20). Very little is known about the impact of regular exercise on metabolic control in youth with type 2 diabetes, although it is likely that reductions in body mass and improvements in insulin sensitivity caused by regular exercise are beneficial. In addition, regular exercise improves high-density lipoprotein levels and endothelial function in obese insulin-resistant children (21).

Impact of diabetes on fitness and performance

Children and adolescents with T1DM may have some impaired fitness-related components and alterations in their cardiorespiratory responses to exercise. Most studies indicate that maximal aerobic power (VO2max) (14, 15, 22–27) and physical work capacity (6, 27–30) are reduced in young people with T1DM, especially if they are in fair to poor metabolic control. It is currently unclear, however, whether the observed lower aerobic performance is a function of a reduced level of habitual activity (25, 29), a smaller body stature (29, 31), or an impairment in cardio-respiratory or skeletal muscle function (see below). In some children, inactivity probably contributes to the decreased performance since, when matched for age, body size, and habitual activity, adolescents with T1DM have cardiac function and VO2max levels similar to those in control adolescents (11, 32–34).

Children with T1DM have higher systolic blood pressure (24, 35), lower O2 pulse (VO2/heart rate) (27), a thickening of capillary basal membrane in skeletal muscle (36, 37), and impairments in the regulation of skeletal muscle blood flow (38–40). Nerve conduction velocity is slower in adolescents with T1DM (41), and they may have an earlier onset of muscular fatigue (42). In addition, adolescent boys with T1DM, who exercise at a relative intensity
similar to that of controls, have elevated ratings of perceived exertion (43) and an impaired rate of carbohydrate utilization despite having elevated plasma insulin levels compared with controls (44). Thus, cardio-respiratory, metabolic, and perceptual effort may be altered in individuals with diabetes, and these factors may impair their exercise performance. Nonetheless, well-motivated youth with diabetes, who are in good metabolic control (HbA1c ≤ 7), may be able to engage in activities as effectively with as their peers. In point of fact, individuals with T1DM can achieve world-class excellence in sports, and an international organization pays tribute to these remarkable individuals (www.diabetes-exercise.org/).

Sports selection

Recommended sporting activities for children with diabetes have traditionally been those with stable energy expenditures that are spread out over long periods (45–47), and these may be relevant for those attempting to determine caloric expenditures and carbohydrate and insulin adjustments for exercise. Most sports, however, have unpredictable energy demands similar to children’s activities, which are often spontaneous and of an unpredictable duration.

With adequate education and insulin therapy, the child with diabetes should be encouraged to participate in any sport using self-blood glucose monitoring (SBGM) prior to, during, and after the activity. He or she should feel confident and understand how to control glucose fluctuations by changing their carbohydrate and insulin intake (see below for recommendations).

Aerobic vs. anaerobic exercise

Exercise can be classified into two forms (i.e., anaerobic and aerobic) based on the dominant metabolic energy sources used during the activity. Anaerobic activities are characterized by higher intensities of muscular contraction. Contractions are sustained by the phosphagen and anaerobic glycolytic systems to produce lactic acid and energy in the form of adenosine triphosphate (i.e., ATP). Anaerobic activities include sprinting, power lifting, hockey, and some motions during basketball and racquet sports. Anaerobic fitness refers to the ability to work at a very high level during these activities for relatively short periods (5–30 s).

Aerobic activities are characterized by lower rates of muscular contraction. These contractions are usually more prolonged in duration and use carbohydrates, fats, and some protein for oxidation by mitochondria within the muscle. Aerobic metabolism is the primary method of energy production during endurance activities such as running, cycling, rowing, swimming, soccer, and ultraendurance events. Aerobic fitness (VO2max) indicates the endurance capacity of the individual’s heart, lungs, and muscles that allows him/her the ability to offset fatigue over the course of an activity. It is crucial to note that these and similar activities often include short bursts of anaerobic metabolism. The distinction between the two types of exercise is important because of their different effects on blood glucose concentration. For example, many individuals find that aerobic-type exercise causes blood glucose to decrease both during and post activity. On the contrary, anaerobic activities, which may only last for seconds, tend to cause dramatic increases in blood glucose levels.

Fuel metabolism and mechanisms of glucose regulation during exercise

To understand the possible metabolic responses to exercise in children with diabetes, it is useful to first briefly describe the mechanisms of glucose regulation in non-diabetic youth.

Non-diabetic children and adolescents

In healthy children, precise autonomic and endocrine regulation allows blood glucose levels to remain relatively stable, except for a transient decrease in blood glucose at the start of exercise (48, 49). At rest, the body uses primarily free fatty acids (FFAs) as fuel which are delivered from adipose tissue. During the transition to exercise, muscles draw upon a complex mixture of circulating FFAs, muscle triglycerides, muscle glycogen, and blood glucose derived from liver glycogen. Although there are no studies specifically conducted in children, under most circumstances, protein oxidation represents <5% of the overall energy utilization and thus has a negligible effect on performance. Fuel metabolism during exercise is under complex neuroendocrine control and includes the hormones insulin, glucagon, catecholamines, growth hormone, and cortisol (50). The proportions of substrate depend on the intensity and duration of the activity. In general, at low-to-moderate intensities, plasma-derived FFAs predominate, while both plasma glucose and muscle glycogen make up the majority of fuel as the exercise intensifies. During heavy exercise, total carbohydrate utilization may be as great as 1.0–1.5 g/kg body mass per hour in healthy adolescents and in adolescents with diabetes (44). As the exercise duration increases, there is a greater reliance on fuels from outside of the muscle, including plasma FFAs and blood glucose.
This greater dependence on fuels from outside the muscle, as the duration of exercise increases, can have dramatic effects on blood glucose levels, particularly for the child with T1DM. Compared with adults, children and adolescents utilize less carbohydrate and more fat during exercise performed at the same relative intensity (51), possibly because they have less endogenous carbohydrate stores. Hypo- and hyperglycemia are rare in healthy children who do not have diabetes because insulin secretion is lowered and counterregulatory hormones are elevated, thereby causing glucose production by the liver to match utilization by the working muscles (Fig. 1A).

Children and adolescents with type 1 diabetes
The mix of fuel utilization during exercise in youth with T1DM appears to be similar to that of non-diabetics, except that those with diabetes may rely even more on fat and less on carbohydrates (44, 52). In individuals with T1DM, the pancreas does not regulate insulin levels in response to exercise, making normal fuel regulation nearly impossible. Moreover, there can be deficiencies in the release of epinephrine and glucagon that would normally help facilitate glucose production and release by the liver (50). As patients soon discover, they may have either increases (hyperglycemia) or decreases (hypoglycemia) in blood glucose levels during exercise. The following sections outline the typical problems of over- and under-insulization during exercise that can contribute to the development of acute metabolic complications (Fig. 1B–D).

Intensive insulin therapy, over-insulization, and hypoglycemia. Many find that intensive insulin therapy helps with glucose management during exercise, because it allows for frequent changes in insulin dosages, particularly if they use an insulin pump. Intensive insulin therapy (i.e., ‘tight’ control) attempts to mimic the natural pattern of insulin secretion. Although most believe it to include higher insulin dosages, it simply requires closer blood monitoring and more frequent insulin injections or an insulin infusion pump to prevent extreme glucose excursions. The move toward more aggressive insulin therapy to prevent long-term complications from diabetes increases the risk of exercise-associated hypoglycemia for some active people with diabetes (53). It has recently been stated that hypoglycemia is the most severe acute complication of intensive insulin treatment, with exercise being a frequent cause (54). For example, in a small cohort of youth with diabetes, 45 min of moderate exercise performed 2 h after breakfast caused asymptomatic nocturnal hypoglycemia in nine of 10 patients who maintained their usual basal and bolus insulin pump infusion rates. Even when basal insulin rates were omitted during exercise, six of 10 patients had nocturnal hypoglycemia (55). Nonetheless, such aggressive insulin therapy should be considered because it helps to prevent long-term complications from the disease (56) and because physical performance and aerobic

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**Fig. 1.** (A–D) Schematic illustration of the blood glucose response to exercise in non-diabetic or ideally controlled youth with diabetes (panel A), over-insulized youth (panel B), under-insulized youth (panel C), and youth under competition and/or heat stress (panel D). Blood glucose balance is primarily a function of circulating insulin levels, counterregulatory hormone levels, parameters related to the exercise itself (mode, duration, and intensity) and characteristics of the individual. In this schema, the thickness of the block arrows represents glucose flux. In panel A, glucose production by liver matches glucose utilization by muscle, and blood glucose concentration does not change. In panel B, a relatively high insulin concentration lowers hepatic glucose production and may further enhance muscle glucose uptake, which results in a decrease in blood glucose concentration. In panel C, a relatively low insulin concentration, or an elevation in glucose counterregulatory hormone levels, increases hepatic glucose production and lowers muscle glucose uptake, thereby resulting in an increase in blood glucose concentration. In panel D, high-intensity exercise, competition stress, and heat stress can all act to dramatically increase counterregulatory hormones that increase hepatic glucose production and limit muscle glucose uptake, thereby causing hyperglycemia.

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capacity are related to the degree of metabolic control (see above).

Most children and adolescents with type 1 diabetes who exercise for prolonged periods (i.e., >30 min) experience a significant drop in blood glucose levels (24, 57–60). Hypoglycemia is not restricted to those individuals who begin exercise with lower glycemic levels, as there appears to be a strong positive correlation between the drop in glycemia and the pre-exercise value (60). In addition, severe postexercise late-onset hypoglycemia (i.e., up to 36 h after exercise) may be particularly prevalent in active children with T1DM (61–65), possibly because proper insulin and nutritional strategies are not adopted while muscle and liver glycogen stores are being replaced. Patients and parents should be particularly cautious therefore if exercise is performed before bedtime. Strategies to limit the possibility of hypoglycemia caused by exercise are provided under the Practical considerations section below.

In addition to intensive insulin therapy, there are other factors that contribute to over-insulinization and hypoglycemia during exercise:

(i) The absorption of injected insulin increases with exercise. The increase in subcutaneous tissue and skeletal muscle blood flow and rise in body temperature is associated with a concurrent increase in insulin absorption and accelerated hypoglycemia (66).

(ii) Plasma insulin levels do not decrease and may even increase during exercise [see (i) above]. A failure in the ability to lower insulin levels during exercise, as would normally occur in a non-diabetic individual, causes a relative hyperinsulinemia that impairs hepatic glucose production and initiates hypoglycemia, usually within 20–60 min after the onset of exercise (59, 60).

(iii) Exercise causes enhanced muscle insulin sensitivity via increased activation of non-insulin sensitive glucose transporters (54). During exercise, the dramatic increase in non-insulin-mediated glucose disposal considerably reduces the need for circulating insulin levels. Because the increase in insulin action persists after the end of exercise in children with diabetes (67), probably to help replenish muscle and liver glycogen stores, patients are at increased risk of hypoglycemia after the completion of exercise.

Counterregulatory failure. Hypoglycemia during exercise may also result from an impaired release of counterregulatory hormones caused by previous exposure to either exercise or hypoglycemia (54). The mechanisms for impaired counterregulation are unclear, but repeated episodes of either hypoglycemia or exercise appear to degrade the body’s ability to mount a counterregulatory response to either stressor (68, 69). This finding of a blunted counterregulatory response to exercise is similar to the scenario that occurs in intensively treated patients with diabetes who develop defects in counterregulatory responses to hypoglycemia (70).

Under-insulinization and hyperglycemia. Not all forms of exercise are associated with hypoglycemia, and some patients frequently report hyperglycemia immediately after heavy exercise, probably because of an inability to secrete insulin to compensate for elevations in catecholamine levels (71). Indeed, intermittent high-intensity exercise, which reflects field and team sports, does not appear to increase the risk of hypoglycemia in patients with T1DM, probably because of increases in catecholamine levels (72).

In children with poor metabolic control, exercise can cause an additional increase in blood glucose and ketoacidosis. The rise in blood glucose is caused by exaggerated hepatic glucose production and impairment in exercise-induced glucose utilization by muscle (Fig. 1C). Increased ketone body production results from elevated FFA release from adipocytes (i.e., lipolysis) and possibly from an increase in intrahepatic ketogenic efficiency (73). Hyperglycemia and ketosis during exercise is particularly undesirable because it causes dehydration and may decrease blood pH, both of which impair exercise performance. Heavy exercise (i.e., >60–70% VO_2max or >75–85% of maximal heart rate) may particularly aggravate this condition, because increases in catecholamines and glucocorticoids will further exaggerate the elevations in glucose concentrations and ketone production (74).

High-intensity exercise and hyperglycemia

High-intensity exercise may be defined as activities above the ‘lactate threshold’. This occurs when there is an exponential increase in lactate production caused by a greater reliance on anaerobic metabolism, occurring at approximately 60–70% of VO_2max or 85–90% maximal heart rate. This threshold coincides with dramatic elevation in catecholamines that increase hepatic glucose release, FFA, and ketone levels, and impair glucose utilization by skeletal muscle (Fig. 1C). Even those individuals treated with intensive insulin therapy may have increases in blood glucose levels during and after high-intensity exercise (71, 75), probably due to a failure in insulin release to offset the increases in counterregulatory hormones. This rise in glucose concentration is usually transient and tends to last only as long as there are elevations in counterregulatory hormones (i.e., 30–60 min). Although some individuals can easily correct the elevations with an insulin bolus, particularly if they take rapid acting insulin analogs, others may be reluctant
to take additional insulin after exercise, because there will be greater risk of late-onset postexercise hypoglycemia.

**Competition stress, heat stress, and hyperglycemia.** The psychological stress of competition is frequently associated with increases in blood glucose levels even though the pre-exercise glucose concentrations may be normal. Those pursuing vigorous aerobic exercise may find that on regular training or practice days they become hypoglycemic, but on the day of competition they develop hyperglycemia. Although empiric data do not exist for children with T1DM, excessive increases in glucose counterregulatory hormones probably occur just before exercise when anticipatory stress is high. It is also probable that the stress during competition can further increase blood glucose levels. Individuals may find that play or sporting activities in warm and humid environments also elevates blood glucose levels, probably because of excessive increases in circulating plasma catecholamines, glucagon, cortisol, and growth hormone (Fig. 1D) (76).

**Practical considerations for the clinical management of type 1 diabetes in athletic youth**

The major challenge for active youth with T1DM is to balance food, insulin, and exercise to limit blood glucose excursions. Some of the factors affecting blood glucose levels during exercise are circulating plasma insulin levels, the intensity and duration of the exercise, the type of exercise performed (aerobic vs. anaerobic), and the prevailing concentrations of the glucose counterregulatory hormones. To a lesser extent, age, gender, level of metabolic control, and the level of aerobic fitness also contribute. Although the glycemic response varies greatly between children (57, 60), blood glucose changes during exercise have some degree of reproducibility, as long as the exercise conditions and pre-exercise insulin and diet are consistent (57). Whereas no precise guidelines exist to limit fluctuations in glucose levels during exercise, some general strategies do exist (Table 1). Importantly, a well-organized plan should be developed and conveyed to the child’s coaches, teachers, friends, guardians, and siblings. Children and adolescents should delay participation in physical activity if blood glucose levels are below 60 mg/dL (<3.5 mmol/L) or above 270 mg/dL (15.0 mmol/L) with detectable urine or blood ketones. Practical recommendations to help prevent hypo- and hyperglycemia are provided below and are summarised in Table 1.

**Blood glucose monitoring**

Regular blood glucose monitoring, coupled with activity and nutritional logs, is essential for developing insulin strategies to prevent hypo- and hyperglycemia. Prior to and during activity, measurements should be taken every 30 min to map glucose trends, as a single assessment will not determine the direction of change. Post-exercise monitoring can be less frequent (every 2 h) but is imperative to avoid late-onset hypoglycemia.

Patients and parents should be told that ‘body awareness’ and symptoms of hypo- or hyperglycemia do not translate to quantitative estimation of a child’s blood glucose levels. Indeed, a poor correlation exists between estimated and measured blood glucose in exercising youth with diabetes (77). Because frequent monitoring may be impractical in some sports, the convenience of continuous glucose-monitoring devices (e.g., Guardian RT, Medtronic) and insulin pump therapy may be ideal for youth (78).

**Insulin**

Whether therapy is by continuous subcutaneous insulin infusion (CSII) or multiple daily injections (MDI), any adjustments made to an insulin regimen must be preceded by a history of self-monitoring and a log of blood glucose measurements. Specific modifications to insulin management depend on a combination of factors, including the type, duration, and intensity of exercise, as well as the child’s nutrient intake and level of fitness. Because it is impossible to predict the exact insulin reduction needed, individuals should use records of previous experiences as a guideline and always have additional carbohydrates available. The need for insulin is less during exercise, and reductions in basal/bolus needs may be as low as 10% for light activities (e.g., brisk walking) and as high as 90% for prolonged vigorous activities (e.g., marathon). Indeed, several elite athletes with diabetes will remove their insulin pump altogether for sport and competition to dramatically reduce circulating insulin levels (79).

**CSII reductions**

Quantitative adjustments for active children and adolescents wearing insulin pumps have yet to be established. A recent study demonstrated that when children maintain their usual basal insulin infusion rates during unplanned activity, performed several hours after a meal, they typically develop late-onset postexercise hypoglycemia during sleep, even though hypoglycemia does not typically occur during exercise (55). Furthermore, after complete removal of insulin delivery during exercise, 60% of children still had nocturnal hypoglycemia, as measured by a continuous glucose-monitoring system. The importance of reductions in bedtime basal rates and proper bedtime...
Carbohydrate intake is important during prolonged exercise to maintain glycemia and is also needed after exercise to replace depleted liver and muscle glycogen stores. Endogenous (i.e., muscle and liver glycogen) and exogenous (i.e., ingested) carbohydrates are oxidized at high rates during exercise in healthy and diabetic children (52) and are the sole energy source for cognitive functioning. It is generally recommended that carbohydrate should be 60% of the total daily caloric intake, with the majority in the complex form (e.g., whole grains, beans). These low-glycemic foods limit postmeal hyperglycemia and elevated needs for insulin. Although recommendations are not readily available for active children with diabetes, endurance athletes should consume approximately 8–10 g CHO/kg body weight/d (88, 89). The amount of additional carbohydrate needed for exercise will vary according to body size and the intensity of the activity (see Table 2). A healthy daily diet should also include 12–15% derived from protein (preferably from lean meats and vegetable sources) and approximately 25–30% from fat, with no more than 10% obtained from saturated sources (e.g., animal fat) (88, 89).

The total amount of carbohydrate needed for exercise should be as close as possible to the estimated carbohydrate expenditure for the given activity and body mass (Table 2) However, these tables are only guidelines, and individual blood glucose responses to exercise and carbohydrate intake vary considerably among children and adolescents (60). In addition, less carbohydrate may be consumed if individuals wish to lower blood glucose toward euglycemic levels. It is important that a low glycemic bedtime snack be provided to help limit nocturnal hypoglycemia.

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**Table 1. Practical guidelines to limit glucose excursions before, during, and after exercise**

<table>
<thead>
<tr>
<th>Before exercise</th>
</tr>
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<tbody>
<tr>
<td>1. Determine the timing, mode, duration, and intensity of exercise.</td>
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<tr>
<td>2. Eat a carbohydrate meal 1–3 h prior to exercise.</td>
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<tr>
<td>3. Assess metabolic control.</td>
</tr>
<tr>
<td>A) If blood glucose is &lt;5.0 mm/L and levels are decreasing, extra calories may be needed.</td>
</tr>
<tr>
<td>B) If blood glucose is 5–15 mm, extra calories may not be needed, depending on the duration of exercise and the individual responses to exercise.</td>
</tr>
<tr>
<td>C) If blood glucose is &gt;15 mm and urine or blood ketones are present, delay exercise until levels are normalized with insulin administration.</td>
</tr>
<tr>
<td>4. If the activity is aerobic, estimate the energy expenditure (Table 2), and determine whether insulin or additional carbohydrate will be needed based on the peak insulin activity.</td>
</tr>
<tr>
<td>A) If insulin dose is to be changed for long duration – moderate-to-high intensity activities; try a 50% premeal reduction 1 h prior to exercise. Dosages can be altered on subsequent exercise days based on the measured individual responses. Insulin should be injected to a site distal to the exercising muscles and should be into subcutaneous tissue.</td>
</tr>
<tr>
<td>B) If carbohydrate intake is to be increased, try 1.0 g/kg body mass/h of moderate-to-high intensity exercise performed during peak insulin activity and less carbohydrate, as the duration since insulin injection increases. Refer to tables of exercise exchanges for sport-specific recommendations and children ranging from 20 to 60 kg. The amount of carbohydrate can be altered on subsequent exercise days based on the measured individual responses. The total dose of carbohydrate should be divided equally and consumed at 20-min intervals.</td>
</tr>
<tr>
<td>5. If the exercise is anaerobic or during heat or competition stress, then an increase in insulin may be needed.</td>
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<tr>
<td>6. Consider fluid intake to maintain hydration (approximately 250 mL 20 min prior to exercise).</td>
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</tbody>
</table>

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MDI reductions

On the basis of limited published studies with children, patients who are on MDI therapy often become hypoglycemic within 45 min of starting strenuous exercise when the activity is performed 2 h after a typical meal and their usual insulin (59, 60). This reduction in blood glucose can be prevented by a 30–50% reduction in premeal bolus insulin (59). Exercise performed just after a meal may cause a greater risk of hypoglycemia because plasma insulin levels are elevated 2–3-fold (60). For more prolonged activities, a 50–90% reduction in insulin may be needed (80). Higher aerobic exercise intensities that are prolonged elicit a greater drop in blood glucose and a greater need for reduced insulin dosage (81–84). In contrast, exercise performed in the fasted or post-absorptive state (i.e., >3 h after insulin analog administration and meal) may be performed with no reduction in bolus insulin (85, 86). Because muscular contractions accelerate insulin absorption, the site of injection should be distal from working muscles to minimize risk of hypoglycemia (87), and fast-acting carbohydrates should be made available to treat hypoglycemia.
A meal containing carbohydrates, fats, and protein should be consumed roughly 3–4 h prior to competition to allow for digestion and for a maximizing of endogenous energy stores. Glycogen stores can be enhanced with a carbohydrate beverage (1–2 g CHO/kg) approximately 1 h prior; this also helps to supplement energy stores and provide adequate fluids for hydration. A beverage containing 6% simple sugar (i.e., sucrose, fructose, glucose) provides optimal absorption compared with other more concentrated beverages such as juice or carbonated drinks that delay gastric absorption and cause stomach upset. Nutritionally complete snacks that contain fat and protein may be effective in preventing late-onset post-exercise hypoglycemia if they are consumed immediately after the activity (90).

In general, approximately 1.0–1.5 g CHO/kg body weight/h should be consumed during exercise performed during peak insulin action in young adults with diabetes (54). As mentioned above, tables of exercise exchanges that estimate carbohydrate utilization may be helpful in determining the carbohydrate intake regime for younger individuals (77). To treat hypoglycemia, 15 g is recommended and a retest of blood glucose level is needed prior to resuming exercise.

Carbohydrates are not only required for energy during activity but also to replace the energy derived from liver and muscle glycogen stores. Because insulin sensitivity remains elevated for hours postexercise, carbohydrate stores must be replenished quickly to lower the risk of hypoglycemia during the first few hours postactivity. For patients who tend to experience postexercise, late-onset hypoglycemia during the night, a complex carbohydrate (e.g., uncooked corn starch), or a mixed snack containing fat and protein may be particularly beneficial at bedtime (91).

Fluid requirements have been extrapolated from adult needs (92) and are estimated to be approximately 1.6 L/d for basic requirements and an additional 0.5–1 L/h of vigorous physical activity (88). In warmer environments, fluid requirements are higher for youth as they experience greater heat accumulation and they perspire less than adults do (88). Those with diabetes may be at particular risk because a prior bout of hyperglycemia reduces body fluid levels.

### Future research

Advances in technology have facilitated research methods to help understand the diverse aspects of diabetes. Continuous glucose-monitoring systems (e.g., Guardian) will be especially important to identify precursors for re-occurring hypoglycemia in children with diabetes in addition to determining appropriate basal insulin adjustments and quantification of nutritional snacks for bedtime to help prevent glucose excursions. Further research is needed in this area, as few prediction models exist based on exercise duration and intensity, insulin dose, and carbohydrate intake.

Insulin pump therapy has become the method of choice for many adults. However, its use for children and adolescents has been accepted with some reluctance from fear of hypoglycemia. Although improvements have been made to reduce glucose excursions, research is still needed to evaluate its efficacy in both children and adolescents both before, during, and after exercise. If proven beneficial, or at least dampening blood glucose instability, insulin pumps may instill the confidence needed in children to become more physically active by dissipating concerns of hypoglycemia.

### Summary

Regular physical activity should be considered an important component in the clinical management of youth with diabetes. Research has provided some...
understanding of the physiological responses to exercise in the child with diabetes, and as a result, there are some general guidelines for the modification of insulin and diet to limit excursions in blood glucose levels. The goal for all children with diabetes should be to learn their individual glycemic responses to exercise and sport and to control glucose fluctuations by modifying insulin dosage and diet appropriately. Few limitations should be placed on active youth with diabetes so that they may compete on equal ground with their peers and so that they can derive the social, psychological, and physiological benefits of a physically active lifestyle.

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