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Exercise in children and adolescents with diabetes

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In the 1950s, Joslin proposed that exercise is the third essential component in blood glucose regulation for persons with type 1 diabetes after insulin and dietary management. Although most studies have shown little impact upon hemoglobin A1c (HbA1c) levels (1–3) (B), the benefits of exercise go far wider: weight control, reduced cardiovascular risk, and an improved sense of well-being (4) (B). Postmeal exercise can be a valuable way to minimize postprandial glycemic spikes (E). For some, participation in physical activity is somewhat sporadic and related to leisure, school, or work. For others, daily exercise is a part of an overall training or conditioning program.

Children and adolescents with diabetes should derive many of the same health and leisure benefits as adults and should be allowed to participate with equal opportunities and with equal safety.

Diabetes should not limit the ability to excel in a chosen sport. Many famous athletes have proved this, e.g., Sir Steve Redgrave the five times Olympic gold medal winning rower, Gary Hall the US Olympic gold medal swimmer at Athens, Wasim Akram is a Pakistani cricketer at the international level, Major League baseball player Jason Johnson, Ironman triathlete Bill Carlson, and female pro golfer Mimmi Hjorth. The topic most commonly discussed with families with regard to exercise is avoidance of hypoglycemia, but prevention of acute hyperglycemia/ketoacidosis may become a concern as well (5) (C).

While this chapter is intended to address the issue of blood glucose regulation during various forms of sports and exercise, it is important for diabetes professionals and parents to appreciate that the demands of day-to-day physical activity will also have to be considered if a young person is going to participate in any activity that for them is unusually strenuous or prolonged.

Exercise physiology

Before considering the situation in type 1 diabetes, it is useful to understand the physiological response to moderate-intensity aerobic exercise in the non-diabetic individual.

As shown in Fig. 1, non-diabetic individuals have a reduction in insulin secretion and an increase in glucose counter-regulatory hormones that facilitate an increase in liver glucose production, which matches skeletal muscle glucose uptake during exercise. As a result of this precise autonomic and endocrine regulation, blood glucose levels remain stable under most exercise conditions (4) (B).

In type 1 diabetes, the pancreas does not regulate insulin levels in response to exercise, and there may be impaired glucose counter-regulation, making normal

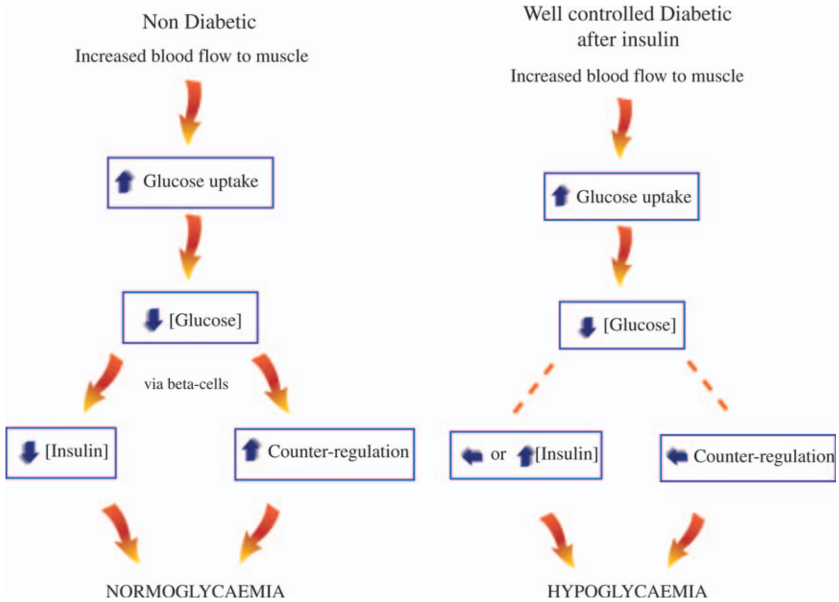

Fig. 1. Physiologic responses to exercise in the diabetic and non-diabetic individual. Square brackets denote plasma concentration.

fuel regulation nearly impossible. Hypoglycemia commonly occurs during exercise when insulin is administered prior to the start of the activity.

Response to exercise

In real life, young people with diabetes have variable blood glucose responses to exercise. The blood glucose response to 60 min of intermittent exercise is somewhat reproducible if the timing of exercise and the amount of insulin and the pre-exercise meal remain consistent (6) (B). Glucose production in healthy control subjects increases with exercise intensity and can be entirely attributed to increases in net hepatic glycogenolysis. In contrast, moderately controlled type 1 diabetic subjects exhibit increased rates of glucose production both at rest and during exercise, which can be entirely accounted for by increased gluconeogenesis (7) (B). Young people with type 1 diabetes have been found to have decreased aerobic capacity as measured by VO_2 max compared with non-diabetic control subjects (8) (B). Total body insulin-mediated glucose metabolism in adolescents correlates with the degree of glycemic control as assessed by the level of glycosylated hemoglobin (9) (B). However, even in the same individual, it is possible for the blood glucose to be increased, decreased, or unchanged by exercise dependent upon circumstances as indicated in the Table 1.

Factors affecting response to exercise

Duration and intensity.

- It is especially important to plan for long-duration or intense aerobic exercise, or else, hypoglycemia is almost inevitable. Nearly all forms of activity lasting >30 min will be likely to require some adjustment to food and/or insulin.
- Most team and field sports and also spontaneous play in children are characterized by repeated bouts of intensive activity interrupting longer periods of

Table 1. Factors that affect changes in blood glucose during exercise

Hypoglycemia	Glucose unchanged	Hyperglycemia
Hyperinsulinemia because of proximity to or excessive dose of administered insulin (both bolus and basal)	Insulin preexercise adjusted appropriately	Hypoinsulinemic state prior to and during exercise
Exercise prolonged – usually more than 30–60 min and/or no extra carbohydrate intake	Appropriate carbohydrate consumed	The emotion of competition eliciting an adrenal response
Higher-intensity aerobic exercise (50–75% maximal aerobic capacity)		Short, intermittent bouts of intense anaerobic activity eliciting an increase in adrenal response
Non-familiarity with an activity requiring greater energy expenditure than when in a trained state		Excessive carbohydrate consumed
		Postexercise when glucose production exceeds utilization

low to moderate-intensity activity or rest. This type of activity has been shown to produce a lesser fall in blood glucose levels compared with continuous moderate-intensity exercise, both during and after the physical activity in young adults (10) (B). The repeated bouts of high-intensity exercise stimulated higher levels of noradrenaline that increased blood glucose levels.

- Moderate-intensity exercise (40% of VO_2 max) followed by an intense cycling sprint at maximal intensity prevented a further decline in blood glucose for at least 2 h after the exercise (11) (B). However, typical team games may last up to 90 min, and the results may not be applicable to this length of physical activity. Furthermore, the authors were unable to explain why the short sprint countered a fall in glucose levels for so long because the rise in catecholamines following the intense exercise was very short lived (see also *Type of activity*).

Type of activity.

- Anaerobic efforts last only a short time (sometimes only seconds) but may increase the blood glucose level dramatically because of the release of the hormones adrenaline and glucagon. This rise in blood glucose is usually transient, lasting typically 30–60 min, and can be followed by hypoglycemia in the hours after finishing the exercise. Aerobic activities tend to lower blood glucose both during (usually within 20–60 min after the onset) and after the exercise (4) (B).

Metabolic control.

- Where control is poor and preexercise blood glucose level is high, circulating insulin levels may be inadequate and the effect of counter-regulatory hormones will be exaggerated leading to a higher likelihood of ketosis (E).

Blood glucose level.

- High blood glucose has been found to reduce the secretion of beta-endorphins during exercise, which has been associated with an increased rating of perceived exertion (RPE) during leg exercise (12) (B). In fact, even baseline beta-endorphin levels were reduced in the diabetic subjects irrespective of blood glucose and thus the resultant reduced tolerance of discomfort may compromise exercise performance in individuals with diabetes. Similarly, increases were found in RPE in adolescents with diabetes doing whole-body exercise (13) (B), but the authors indicate that the higher response is thought to be mainly a function of the lower peak mechanical power output often seen in these patients (14).

Type and timing of insulin injections.

- When regular (soluble) insulin has been injected prior to exercise, the most likely time for hypoglycemia will be 2–3 h after injection, and the high-risk time after rapid analogue insulin is between 40 and 90 min (15) (B).
- We have found no studies on the timing of basal insulins (NPH, glargine, or detemir) and exercise.
- When playing morning or all-day tournaments, a long-acting basal insulin given once daily in the evening can be substituted for one with shorter action (NPH) to reduce the basal insulin effect while exercising (E).

Type and timing of food.

- A meal containing carbohydrates (CHO), 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. This is especially important for longer-duration activities. 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 (16).
- If extra carbohydrate is necessary for short duration activity, then it may be useful to have 'fast-acting' carbohydrates such as glucose drinks. An isotonic beverage containing 6% simple sugar (i.e., sucrose, fructose, and glucose) provides optimal absorption compared with other more concentrated beverages with more than 8% glucose such as juice or carbonated drinks that delay gastric absorption and cause stomach upset (16). Check the glucose content of sport drinks, some contain >8% glucose. The amount of carbohydrate should be matched as closely as possible to the amount of carbohydrate utilized during exercise if a reduction in insulin is *not* performed. 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 (16) (Table 2).
- 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 (carbohydrate reloading).
- Short duration and high-intensity anaerobic activities (such as weight lifting, sprints, diving, and baseball) may not require carbohydrate prior to the activity, but may produce a delayed drop in blood sugar. For activities of these types, extra carbohydrate *after* the activity is often the best option to prevent hypoglycemia (E).
- Longer-duration, lower intensity aerobic activities such as soccer (often described as a mixture between aerobic and anaerobic exercise), cycling, jogging, and swimming will require extra carbohydrate before, possibly during, and often after the activity (E).
- Currently, no evidence-based guidelines exist on the amount and timing of increased carbohydrate to

Table 2. Estimated number of minutes that a certain activity lasts to require 15 g of extra carbohydrate to keep your blood glucose from falling

	Body mass (kg)		
Activity	20	40	60
Basket ball (game)	30	15	10
Cross-country ski	40	20	15
Cycling			
10 km/h	65	40	25
15 km/h	45	25	15
Figure skating	25	15	10
Ice hockey (ice time)	20	10	5
Running			
8 km/h	20 25	15	10
12 km/h		15	10
Snow shoeing	30	15	10
Soccer	30	15	10
Swimming			
30 m/min Breast stroke	55	25	15
Tennis	45	25	15
Walking			
4 km/h	60	40	30
6 km/h	40	30	25

Tables of carbohydrate intake guidelines for a variety of sports are provided in a recent review (16). For example, a 40-kg child should consume 15 g of carbohydrate for every 15 min of basketball, whereas a 60-kg child should consume 15 g of carbohydrate for every 10 min of basketball. If you lower premeal or basal insulin doses, you will probably need less extra carbohydrate than shown in the table. See Perkins and Riddell (30) and Colberg (77) for more complete lists of sport-specific advice.

limit postexercise hypoglycemia. However, reductions in basal insulin, low glycemic index snacks (with no bolus), or reduced boluses at postexercise meals will usually reduce the problem (E). A snack of complex carbohydrate, fat, and protein at bedtime may limit nocturnal hypoglycemia caused by daytime exercise (17) (B).

Absorption of insulin.

- Choice of injection site: When an extremity (arm or leg) has been injected with insulin and is then exercised vigorously, the increased blood flow to the limb is likely to result in more rapid absorption and metabolic effect of the insulin (18) (B). This may be especially marked if the injection site is hypertrophied. Thus, a cyclist may achieve more consistent response by choosing to inject in an arm or the abdomen rather than a leg before an event.
- Ambient temperature: High temperature will increase insulin absorption and low temperature the converse (19) (B). The latter may be a consideration in long-distance swimming.
- Most absorption studies were done with regular insulin. The effect is less pronounced with rapid-acting analogues (20) (C). An intense 30-min period of exercise did not increase the absorption rate of glargine in adults with type 1 diabetes (21).
- Heat also places additional stress on the cardiovascular system, resulting in greater energy expenditure and potential for a faster drop in blood glucose levels.

Muscle mass/number of muscles used in the activity.

- Using more muscles produces a greater drop in blood glucose, and weight-bearing activities tend to use more energy than non-weight-bearing activities.

Conditioning.

- Patients frequently report that the drop in blood glucose may be less with regular conditioning and familiarity with the sport, although no experimental evidence exists that tests this hypothesis.

Degree of stress/competition involved in the activity.

- The adrenal response will raise the blood glucose.

Timing of the activity.

- Morning activity, done before insulin administration, may not result in hypoglycemia as circulating insulin levels are typically low and glucose counter-regulatory hormones may be high. Indeed, severe hyperglycemia may occur with vigorous exercise in these circumstances, even precipitating ketoacidosis.

Normal day-to-day exercise

- Daily physical activities should be a part of the normal routine for both health benefits and consistency in blood glucose management. Some groups of schoolchildren and teenagers with diabetes have been found to be more physically active than their non-diabetic friends (22) (C).
- Regular and accustomed exercise is easier to manage because it is part of the routine, but adjustments may also be necessary for sporadic extra physical activity.
- Whatever level of involvement in exercise and sport that a child or adolescent with diabetes adopts, it is good practice that careful notes are kept of what they do (timing and intensity of physical activity), what carbohydrate has been taken, and the blood glucose response before, during, and afterward. Advice from the diabetes team will be general in the first instance, but accurate record keeping will allow much more individualized and fruitful consultation (E).
- Where exercise is performed regularly, insulin sensitivity is generally enhanced. A positive association between glycemic control (i.e., HbA1c) and aerobic fitness or reported physical activity exists in youth with type 1 diabetes, suggesting that either increased aerobic capacity may improve glycemic control or good metabolic control maximizes exercise (8) (B). An inverse relationship was observed between HbA1c level and the maximal work load in a study in diabetic adolescents (23) (B). The lack of evidence on improving HbA1c with exercise may be related to a tendency to over-reduce insulin doses and

consume excessive carbohydrate in an effort to avoid hypoglycemia (24) (B).

Training

The management of diabetes may vary according to the phase of training so that when endurance is being built with long moderate-intensity work, the insulin regimen and additional carbohydrate may be quite different from that required when the concentration is upon power and high-intensity training. See the *Duration and intensity* section above for more detail on the possible effect of short, high-intensity work on glycemia.

Exercise causes enhanced muscle insulin sensitivity (25) and increased activation of non-insulin-sensitive glucose transporters (GLUT-4) (26) (C). Insulin sensitivity was similar directly and 15 h after exercise but decreased to near untrained levels after 5 d in non-diabetic adults (27). During and immediately after exercise and from 7–11 h in recovery, the insulin sensitivity is elevated in adolescents with type 1 diabetes (28) (B). In practical life, exercise for >1 h can lead to increased insulin sensitivity for up to 48 h. This means that adolescents who only exercise intermittently can have real difficulties in managing their basal insulins (E). It is therefore better to exercise at least every other day if possible. If not, a strategy for altering basal insulins to cope with the widely varying insulin sensitivity is needed. Younger children most often exercise rather well every day to some extent, which results in less postexercise fluctuations in blood glucose (E).

Meals with high content of carbohydrates should be consumed shortly after the exercise event to take advantage of the period of heightened insulin sensitivity to help replenish glycogen content and limit post-exercise hypoglycemia. However, the insulin dose will need to be reduced (in relation to the normal insulin-to-carbohydrate ratio for the individual) to avoid hypoglycemia. Adding protein will enhance glycogen resynthesis (29) (C).

It is well beyond the scope of this chapter to offer sport-specific training advice, but such information is readily available – see:

- Diabetes Exercise and Sports Association (www.diabetes-exercise.org), an international organization that provides guidance and networking between novices, health professionals, and experienced diabetic athletes.
- www.runsweet.com where a combination of contributions from sportsmen and sportswomen are interspersed with expert advice.

Choice of insulin regimen

For most children and adolescents, the choice of insulin regimen will not be influenced heavily by their exercise habits. However, for some who are regularly active, it is likely that either multiple daily injections or insulin pump therapy be considered to allow for manipulations in insulin delivery prior to and following the activity.

- Twice-daily injections: It may be difficult to maintain very strict blood glucose control on these regimens, especially with different levels of exercise throughout the week, but the essential requirements of taking various forms of carbohydrate before, during, and after exercise may be even more important than for more adjustable regimens.
- Three-injections insulin regimen: For example, where a mixed insulin is given before breakfast, then a split-evening insulin with rapid analogue before evening meal and a longer-acting insulin at bedtime. Again this regimen must be accompanied by appropriate carbohydrate advice for moderate exercise, e.g., dancing or swimming two or three evenings per week or at weekends.
- Multi-injection regimens or insulin pumps: This regimen affords greater flexibility for serious training and competitive events. Both preexercise bolus and basal rates can be reduced before, during, and after exercise to help increase hepatic glucose production and limit hypoglycemia (see below).

The choice of insulin regimen is always influenced by many different factors including the availability of various insulins (and pumps), professional and personal expertise, and in the ideal world should be influenced by the nature of the sport. There is no doubt that being able to reduce the training day into manageable 'chunks' of 4–6 h makes control of blood glucose much more straightforward with the potential to move training/competitive periods around in the day and being able to adjust the appropriate bolus (and perhaps basal) insulin doses (30) (C).

Hypoglycemia

In adults, the autonomic and counter-regulatory response to hypoglycemia the following day has been shown to be blunted by repeated low- or moderate-intensity exercise (31) (B). The same phenomenon is likely to be true for children. Glucose requirements to maintain stable glucose levels in adolescents with diabetes are elevated during and shortly after exercise as well as from 7–11 h after exercise (28) (B). In adults, repeated episodes of hypoglycemia in a sedentary state result in an attenuated counter-regulatory response to subsequent exercise and increase the risk for hypoglycemia. Hence, two to three times more exogenous glucose may be needed to maintain euglycemia during exercise following a previous exposure to hypoglycemia (32) (B). In laboratory studies of diabetic adolescents who received their usual insulin dose and then performed 75-min walking on a treadmill, 86% had hypoglycemia if their starting blood glucose was <6.6 mmol/L (120 mg/dL). In the same study, it was noted that 15 g CHO was frequently insufficient to restore blood glucose to normal (33) (A). In another study (34) (B), 45% of children with type 1 diabetes had blood glucose levels drop below 4.0 mmol/L (72 mg/dL) during 60 min of moderate cycling performed in the fed state. By consuming additional carbohydrate (drinking 6–8% glucose solution) at a rate that equaled carbohydrate utilization during exercise (approximately 1.0 g CHO/kg body mass/h), the drop in blood glucose during exercise could be prevented.

- If a child with diabetes is feeling unwell during exercise with signs and symptoms of hypoglycemia, glucose tablets or other form of quick-acting carbohydrate should be given as for treatment of hypoglycemia, even if blood glucose cannot be measured to confirm hypoglycemia (E).
- On outward-bound or activity holidays, all the responsible adults (and also peers) should be alert to the possibility of hypoglycemia. Strict guidance should be given that no person with diabetes should exercise or go off alone or 'decide' not to have regular snacks when they are provided.
- A sensible rule is that if young people with diabetes are together on holiday, they should stay in groups of at least four, so that two can accompany each other if they need to alert adult helpers to the occurrence of an accident or hypoglycemia.
- Glucose tablets, glucose gel, or some form of rapidly absorbed sugar should always be carried by young people who exercise or, at a minimum, kept within a reasonable distance of the activity.

Late hypoglycemia

Hypoglycemia can occur several hours after exercise especially when this has been prolonged and of moderate or high intensity (35) (C). This is because of the late effect of increased insulin sensitivity and delay in replenishing liver and muscle glycogen stores. A single bout of exercise can increase glucose transport into skeletal muscle tissue for at least 16 h postexercise in non-diabetic and diabetic subjects (25) (B). In a controlled study, twice as many youngsters aged 11–17 yr had a hypoglycemic event on the night after an exercise day compared with the night after a sedentary day (when the basal overnight insulin was not altered) (36) (A). Continuous glucose monitoring (CGM) may be a valuable tool for determining the blood glucose response and hypoglycemia risk during and after exercise (37).

Insulin adjustments

Competitive athletes may be tempted to reduce their insulin doses too much to avoid hypoglycemia, and their metabolic control may suffer as a result (24) (B). Careful monitoring and experiential adjustments are essential. In a group of young people aged 10–18 yr, those attending a competitive sport of at least 6 h of exercise per week had a lower HbA1c (22) (C).

In one study, cross-country skiers with type 1 diabetes were able to carry on for several hours without hypoglycemia when reducing the premeal dose by 80% compared with only 90 min if the dose was reduced by 50% (38) (C). Some people find that lowering their premeal insulin dose may cause an initial rise in their blood glucose, which impairs their performance (E). In such a case, it is probably better to rely on extra carbohydrate intake rather than dose reduction for best performance.

- See Table 3 for recommendations on adjustments of preexercise bolus doses. There is a greater need for reduction of rapid-acting insulin when the dose is given within 1 h of the exercise, while the need of reduction is greater for later exercise (3 h postmeal) when using regular insulin. (15) (B).
- For evening exercise, it may be sensible to reduce the rapid analogue before the evening meal by 25–75% as well as taking 10–15 g of fast-acting carbohydrate before the activity.
- Advice about reducing insulin (e.g., a reduction in overnight long-acting/basal insulin or basal rate in pump or reductions in subsequent mealtime boluses) and/or extra low-glycemic index snacks following the activity is prudent.
- With daylong or unusual activities such as camps, long-distance walking, skiing, water sports, etc., consider a 30–50% reduction of long-acting insulin the night before and on the day of the activity or a 30–50% reduction in the pump's basal insulin throughout the day and the night following the activity. High

Table 3. Recommendations for percent reduction in premeal insulin bolus (either pump or multiple daily injections) for low-, moderate-, and heavy-intensity exercise lasting 30 or 60 min in duration

	Duration of exercise and recommended reduction in insulin (%)	
Intensity of exercise	30 min	60 min
Low (~25% VO_2 max)	25	50
Moderate (~50% VO_2 max)	50	75
Heavy (~75% VO_2 max)	75	100

Note, however, that this study was in adults and did not consider the effect of additional carbohydrate before or during the exercise (78) (A). Note that % VO_2 max indicates percentage of maximal aerobic capacity.

excitement amusement parks and fairs may be more likely to raise BG because of adrenalin surges (E).

Insulin pumps

- For certain types of exercise (like contact sports), it may be appropriate to disconnect prior to the start of the activity and remain disconnected for up to 1–2 h during an event. In these situations, patients may require a 50% bolus correction afterward (i.e., 50% of the missed basal insulin while disconnected), if needed, to reduce any resulting postexercise hyperglycemia. To get a significant lowering of the basal insulin effect during the exercise, the pump needs to be disconnected at least 90 min before starting the exercise (39) (C), but many centers advise that the pump should not be disconnected for more than 2 h. The safer option may be to move to a 50% temporary basal rate 90 min before the activity until the end of exercise.
- Even if the pump is removed during exercise, hypoglycemia can still occur for several hours after the end of the activity (40) (C).
- After a short period of intense exercise (80% VO_2 max), marked catecholamine responses lead to hyperglycemia, which lasts for approximately 2 h postexercise in adults with type 1 diabetes (41) (B). Even when pre-exercise plasma glucose was normal, there ensued a post-exercise hyperglycemia, which lasted for 2 h post-exhaustion in pump patients (42) (C). This reaction may be exaggerated if the pump has been disconnected during exercise. The rise in blood glucose may be prevented by giving a small additional dose of rapid-acting insulin at halftime or immediately after the exercise is finished (E).

> Key points
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> - Tailor insulin regimen to activity.
> - Discuss the percentage reductions in insulin before exercise.
> - Discuss type and amount of carbohydrate required for specific activities.
> - Advise about risk of late hypoglycemia and reduction in long-acting/basal insulin.

Ketones

- In situations of under-insulinization, whether through systematically poor control or intercurrent illness, intense exercise is likely to be dangerous because of the effect of uninhibited action of the counter-regulatory hormones. In one study in adults, patients with a blood glucose of >20 mmol/L (260 mg/dL) and ketonuria experienced a further rise in blood glucose during 40 min of exercise (43) (B).
- The rapid production of ketone bodies coupled with impaired muscle glucose uptake will not only lead to under-performance but also may precipitate keto-acidotic abdominal pain and vomiting. Thus, it is important for families to be warned about not participating in strenuous exercise if blood glucose is high and ketones (small or more) are present in the urine (4, 17, 43) (A) or >0.5 mmol/L of beta-hydroxybutyrate (blood ketones, BOHB) in blood.
- It is a relatively common misconception that no insulin is needed when prolonged exercise is to be undertaken. This could be a dangerous error unless insulin cover is being provided by a long-acting product and under carefully monitored conditions.
- Blood ketone testing (measuring BOHB) provides additional information to urine ketone testing (44) (E). This method is excellent for rapid detection and exact measurement of ketone levels and is preferable when available (E). During resolution of ketosis, blood BOHB normalizes sooner than urine ketones (45). Blood BOHB >0.5 mmol/L is abnormal in children with diabetes (46, 47) (C and B).

> Key point
>
> - Strenuous exercise is dangerous and should be avoided if preexercise blood glucose levels are high (>14 mmol/L or 250 mg/dL) with ketonuria/ketonemia. Give approximately 0.05 U/kg or 5% of total daily dose (TDD; including all meal bolus doses and basal insulin/basal rate in pump) and postpone exercise until ketones have cleared (E).

What to eat and drink

When insulin is not reduced to accommodate for exercise, it is usually necessary to consume extra carbohydrate in order to avoid hypoglycemia. This is dependent upon type and duration of activity.

- The amount of carbohydrate needed depends largely on the mass of the child and the activity performed as well as the level of circulating insulin (15) (B). Up to 1.5 g CHO/kg body mass/h of strenuous exercise may be needed.
- Numerous charts indicating carbohydrate replacement for specific exercises based on duration of activity and body size are found in *Think Like a Pancreas* by Gary Scheiner, *Pumping Insulin* (3rd edition) by John Walsh and Ruth Roberts, and for youth specifically in a recent review by Riddell and Iscoe (16).
- It is worth reminding adolescents and young adults about the effect of alcohol upon the ability to respond to exercise and falling blood glucose. Alcohol impairs the glucose counter-regulation in subjects with diabetes by inhibiting gluconeogenesis

(but not glycogenolysis) (48–51) (B, B, C, and B). Accordingly, hypoglycemia (especially night time) becomes more likely and is best avoided when participating in exercise, especially as alcohol may also impair performance.
- While not confined to people with diabetes, the risk of dehydration should be borne in mind lest too much focus be kept upon glucose control. Even a 1% decrease in body mass because of dehydration may impair performance (52) (C). In practice, both needs can often be met by using specially formulated drinks, but if dehydration is a risk, sugar-free fluids should also be taken. Fluid intake should match sweat and hyperventilation losses such that there is no change in body weight preexercise vs. postexercise. Fluid intake may need to be as great as 1.3 L/h in adolescents exercising in hot and humid environments (53) (B).

> Key points
>
> - Consume up to 1.5 g CHO/kg body mass/h of strenuous or longer-duration exercise when circulating insulin levels are high.
> - Alcohol inhibits gluconeogenesis, so hypoglycemia is more likely.
> - Dehydration is a risk unless sugar-free fluids also are consumed.

Monitoring

- Blood glucose monitoring is key for the active child with diabetes so that trends in glycemic responses can be identified. Records should include notes of their blood glucose, the timing, duration and intensity of exercise as well as the strategies used to maintain glucose concentrations in the normal range. Measurements of glucose should be taken before, during, and after the end of exercise with particular attention paid to the direction of change in glycemia.
- Monitoring several hours after exercise and before bed is particularly critical on days where strenuous activities occur as nocturnal hypoglycemia is common. It remains controversial whether certain bedtime BG levels predict nocturnal hypoglycemia, and predictions are particularly difficult after exercise. In one hospital-based study, a bedtime blood glucose of <7 mmol/L (125 mg/dL) suggested particular risk for nocturnal hypoglycemia (54) (C), while another study found no threshold for nocturnal hypoglycemia risk after exercise in the afternoon (36) (A).
- It remains to be seen what the practical impact of continuous glucose monitoring (CGM) systems will be.
- Caution should be taken when using BG meters in extreme temperatures (55) (B). Meters using glucose dehydrogenase may give more accurate readings at high altitude. In circumstances where control solution is used to check the meter, e.g., on a long hike, further criteria apply with the solution only being accurate between 15–30°C. In cold environments such as skiing, keeping a meter and strips inside several layers of clothes close to the body will usually prevent inaccurate readings.
- Special care should be taken at high altitude where the symptoms of hypoglycemia may be confused with those of hypoxia/altitude sickness.

> Key points
>
> - Use of detailed records of activity, insulin, food, and glucose results is important for good diabetes control during exercise.
> - Risk of postexercise nocturnal hypoglycemia is high, and particular care should be taken if bedtime blood glucose <7.0 mM.
> - Care should be taken that the meter and test strips chosen are suitable for the environment where they will be used.

School activity and diabetes camps

While this chapter is aimed principally at the practicalities of managing intense and/or prolonged physical activity, it is clear that the advice can be tailored for more moderate exercise. In the normal school week, most young people will have at least one period of physical education, and how they deal with avoiding hypoglycemia will be dependent upon all of the factors mentioned above.

- For many, all that will be required is a small snack of 10–15 g carbohydrate, for example a fruit or fruit juice, dried fruit, a cereal, fruit or granola bar, or sports bar. This may also be a convenient opportunity to allow a treat such as chocolate or few sweets. Chocolate contains fat that will cause the sugar to be absorbed more slowly (56). This can make it more suitable for low-grade, longer-lasting activity, for example hiking, swimming, or long walks. However, the extra calories will not benefit a child with weight problems.
- Where a multi-injection regimen or a pump is being used, a reduction in the preexercise bolus or setting a temporary basal rate may be appropriate (Table 3).
- For pump patients, a short period of disconnection may be best to allow free activity.
- For longer periods of physical activity (>60 min), a reduction in basal insulin by 30–50% should be considered along with carbohydrate snacks being provided.
- Activity weeks are now a common part of the school curriculum, and many young people with diabetes also have the opportunity to attend dedicated diabetes camps. These two situations differ mainly in the expertise available, with the latter usually being

managed and monitored by diabetes professionals with advice about adjustments of insulin and food on-site.
- Clinical professionals can gain much more insight into the day-to-day management of diabetes by participating in diabetes camps, and in some countries, this is now a training requirement.
- The benefits of spending a week being active in the open air are obvious, but self-esteem is often improved, and where the activity is shared with others with diabetes, there are real opportunities to learn better ways of coping. Camps for children with diabetes that include counseling on nutrition and insulin adjustments for exercise can result in improved glycemic control (57–59) (C, C, and C).
- Insulin doses may have to be reduced substantially to prevent hypoglycemia, especially in children not accustomed to physical activity, and it is wise to begin with a 20–25% reduction in TDD (60) (C).
- When being physically active for a prolonged period, on a skiing trip or an outward-bound camp for example, insulin sensitivity will increase after 1–2 d, which will probably call for substantially lowered insulin doses (decreased by 20% or sometimes even 50% especially if not used to hard physical exercise). The increased insulin sensitivity will continue for at least a couple of days after returning home (25).
- Where young people will be cared for by non-clinical professionals (e.g., teachers), it is vital that both the adults and the child/adolescent are provided with appropriate verbal and written information as well as emergency contact telephone numbers.
- Special mention should be made of the need to plan ahead – activities often last longer than anticipated, so extra snacks and hypoglycemia remedies should always be carried.
- While very rare, it may occasionally be advisable for a diabetes team to recommend to a school that a young person should not go on a school activity week. For example, safety might be compromised if the person with diabetes had exhibited dangerous behavior such as frequent omission of insulin or episodes of disabling hypoglycemia. The negative experience from handling a difficult child and the impact upon the others in the group might prejudice the prospects for future children with diabetes.

> Key points
>
> - Snacks and hypoglycemia remedies should always be readily available at school.
> - Careful advice on and planning of travel, exercise, and management is essential.
> - Written advice should be provided for carers/teachers.
> - Professionals should take opportunity to attend camps for children with diabetes.

Miscellaneous advice

Everything possible should be done to support a young person with diabetes who has serious sporting aspirations or simply wants to understand how best to manage their control while participating. However, diabetes teams have a duty of care, and there are occasions when medical 'certification' is required before participation is allowed. Examples include diving and boxing. It would be negligent to provide such certification without careful consideration of the overall control and knowledge of the participant as well as the possible impact of any other health factors such as diabetes complications. It may be possible to use a little leverage here to persuade the young person that it is in their interest to work with the team to improve their self-management.

- Participation in almost any sport or exercise is likely to be safer in company, but for the person with diabetes, this is even more important. At very least, one companion should know something about diabetes and how to recognize and manage hypoglycemia. Every participant in a sports team should be aware of a person with diabetes and know where to find the person's hypoglycemia remedies.
- It is good practice to have 'Diabetes ID' somewhere on the body – preferably in the form of a durable bracelet or necklace.
- Taking account of diabetes in other extreme situations may be lifesaving, e.g., the signs and symptoms of exhaustion and hypothermia could easily be confused with hypoglycemia. It is always safer to assume that the latter is making some contribution and to check blood glucose or treat expectantly.
- Taking acetazolamide to prevent or treat altitude sickness may contribute to an increased risk of ketoacidosis in a person with diabetes (61) (C).
- UK diving clubs have allowed individuals with diabetes to dive under certain carefully controlled circumstances (62), while in Australia and New Zealand, only people with diet-controlled diabetes are allowed to dive (63). The suggested age limit in the UK is >18 yr (>16 yr if taking part in a special training program) (64).
- A large number of dives performed by individuals with diabetes has been reported where no deaths, episodes of decompression illness, or hypoglycemia occurred (65), even in 16- to 17-yr-old adolescents (66). In another report, hypoglycemic events were present in very small numbers, with no adverse outcome (67).
- Repetitive episodes of hypoglycemia should be avoided during days before diving because this could blunt the hormonal response during subsequent exercise or hypoglycemia (32) (B).

Type 2 diabetes

As opposed to the situation in type 1 diabetes, there is no question that exercise has a direct and important part in the treatment of type 2 diabetes. Exercise results in changes in body composition, reducing the amount of fat and increasing the amount of lean tissue: muscle, fibers, and bone. This increases the metabolic rate and reduces blood pressure and LDL cholesterol, and increases HDL, reducing the risk of cardiovascular morbidity and mortality (68). The vast majority of studies on type 2 diabetes and exercise have been done in adults, but there is every reason to believe that the results are applicable to adolescents as well (E).

- Probands and other family members of adolescents in whom type 2 diabetes has been diagnosed have lifestyles characterized by minimal physical activity (69).
- A twice-per-week 16-wk resistance training program significantly increased insulin sensitivity in overweight adolescents independent of changes in body composition (70).
- Large clinical trials in adults with impaired glucose tolerance demonstrate that lifestyle interventions including exercise can reduce the incidence of type 2 diabetes (71).
- In a meta-analysis, it was found that exercise training reduced HbA1c by an amount that should decrease the risk of diabetic complications. This effect was not mediated primarily by weight loss (72).
- The incidence of hypoglycemia in type 2 diabetes is less than in type 1 partly because counter-regulatory mechanisms are much less affected, but patients taking insulin or sulphonylurea medication (especially long-acting preparations) may require reduction in doses (73, 74).

Diabetes complications

Competitive sports are generally safe for anyone with type 1 diabetes who is in good metabolic control and without long-term complications (75) (E). However, patients who have proliferative nephropathy or nephropathy should avoid exercise conditions that can result in high arterial blood pressures (systolic pressures >180 mmHg), such as lifting heavy weights (or any tasks in which a Valsalva maneuver is involved) or performing high-intensity sprints (76) (E). Ambulatory blood pressure measurement during exercise can be helpful in patients with complications. Patients with peripheral neuropathy should be careful to avoid blisters and cuts and should avoid running and other sports that involve excessive wear of legs and feet (76). See American Diabetes Association (75) for more detailed advice on diabetes complications and exercise (Table 4).

Table 4. Summary recommendations for physical activity in young people with diabetes (79)

Arrive at a good level of metabolic control: neither hyperglycemia nor ketonuria. Eventually measure blood glucose concentration before the activity
Always carry some sugar
Increase the intensity and duration of the activity in a progressive fashion
In the few hours preceding the exercise, ingest slowly absorbing carbohydrates in order to replete the liver and muscle glycogen reserves
In the case of unforeseen physical activity, increase glucose consumption immediately before, during, and after the activity
In the case of foreseen activity, decrease the insulin dose during and after intense muscular activity
Do not inject the insulin at a site that will be heavily involved in the muscular activity
Avoid physical exercise at the time of the peak action of insulin
If the activity is of the prolonged endurance type, be certain to ingest glucose-sweetened water or carbohydrates just before, during, and after the exercise
Measure the blood glucose before retiring on the evening after major physical activity in order to avoid hypoglycemia during the night
Evaluate the effect after every modification in insulin dose and every change in nutritional status
Make the people accompanying you aware of the procedures and treatment of severe hypoglycemia (glucagon injection)

This article is a chapter in the ISPAD Clinical Practice Consensus Guidelines 2006–2007 of the International Society for Pediatric and Adolescent Diabetes (ISPAD; www.ispad.org). The complete set of these Guidelines will later be published as a compendium. Additional comments, clarifications, or corrections should be directed to the corresponding author.

The evidence grading system used in the ISPAD Guidelines is the same as that used by the American Diabetes Association. See the Introduction of the ISPAD Clinical Practice Consensus Guidelines in Pediatric Diabetes 2006: 7: 341–342.

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Appendix

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