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ISPAD CLINICAL PRACTICE CONSENSUS GUIDELINES

ISPAD Clinical Practice Consensus Guidelines 2018: Exercise in children and adolescents with diabetes

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1 | NEW INFORMATION IN RELATION TO THE PREVIOUS GUIDELINE

In the field of technology, intermittent scanning continuous glucose monitoring (isCGM) offers the opportunity to obtain glucose values more easily than with self-monitored blood glucose monitoring (SMBG). This technology also provides the user with information on the direction and the rate of glucose value changes. However, the individual must actively scan the sensor to receive a value. Alerts or alarms are not currently linked to this technology.

Real-time continuous glucose monitoring (rtCGM) is a technology also including the possibility to use individualized alerts and safety alarms besides information on glucose values on continuous basis along with information on the direction and the rate of glucose value changes.

Technology allows access to applications in smart phones to view and enable followers, for example, a legal guardian, teacher, coach, which may increase safety during and after exercise.

Recent clinical studies and clinical experience suggest that exercise itself may be a setting in which both isCGM and rtCGM could misrepresent the true dynamic changes in actual blood glucose concentrations because of apparent lag time between blood glucose levels and interstitial glucose levels.

Insulin pumps that include predictive low-glucose management (PLGM) systems may be advantageous as physical activity is associated with increased risk of hypoglycemia, not only during but also after physical activity. The step being currently evaluated is hybrid closed loop where physical activity clearly represents one of the biggest challenges for such a system.

A variety of wearable technologies offer the possibility to track glucose values (eg, smart watches) as well as level of physical activity (eg, wrist bands), heart rate, sleep quality, etc. The current trend is that the different wearables are used to an increasing extent where device connectivity and data openness might create new opportunities in the future.

2 | RECOMMENDATIONS/EXECUTIVE SUMMARY

Many recommendations provided in this guideline are based on work performed in adults, thus raising the possibility that some of these recommendations might not hold true for children and younger adolescents.

It should always be remembered that these guidelines are general recommendations, and individual responses to exercise and physical activity with type 1 diabetes (T1D) may vary. Thus, we emphasize that while exercise prescriptions and management plans (insulin and nutrition) can be based on known physiology and a limited number of clinical studies, they must often be individualized for young people in line with experience, goals, and safety in mind.

2.1 | Initial exercise management

Children, adolescents, and relevant family members should be offered ongoing education about the latest in blood glucose management in exercise. [E]

Children, adolescents, and relevant family members should be provided with a written or online copy of up-to-date and user-friendly evidence-based guidelines focusing on blood glucose management in exercise. [E]

Sedentary lifestyle behaviors should be routinely screened for and discouraged in the diabetes clinic. [E]

Practical strategies to improve engagement with an active lifestyle should be offered to all patients. [E].

An individualized blood glucose management plan should be developed for each patient as careful advice and planning on exercise and management is essential (eg, insulin dose reduction, carbohydrate intake, exercise timing). [E]

This plan should specifically include the following:

- Discuss the type and amount of carbohydrate required for specific exercise.
- Discuss the percentage reductions in insulin before exercise. [C]
- Discuss when best to exercise safely.

Written advice about exercise and sports should be included within the school management plan for carers/teachers. [E]

Care should be taken that the blood glucose meter and test strips chosen are suitable for the environment where they will be used. [C]

Where appropriate and available, patients and families should be informed that multiple daily injections or a pump may be easier to combine with exercise. [E]

Patients should be encouraged to keep detailed records of their physical activity, insulin, food, and glucose levels as these records are important for blood glucose management and clinical advice. [E]

New technologies, for example, embedded into smart phones may be of use. [E]

Although the prevalence of diabetes complications is low in children, medical clearance should be provided to inform professionals (eg, coaches) and carers of any restriction to exercise participation. [E]

Patients who have proliferative retinopathy or nephropathy should avoid resistance-based exercise or anaerobic exercise that results in high arterial blood pressure. [E]

2.2 | General precautions prior to each exercise session

2.2.1 | Elevated ketones

It is important to identify the cause of elevated ketone levels. Raised ketone levels are a safety concern before exercise. [E]

Where available, blood ketone measurement is recommended over urine ketone measurement—see ISPAD Clinical Practice Consensus Guidelines 2014 "Assessment and monitoring of glycemic control in children and adolescents with diabetes."[1]

By measuring blood ketones, changes in ketones may be detected significantly faster. Blood ketone monitors measure the dominant ketone of clinical relevance that is, beta-hydroxybutyrate (BOHB).

Elevated blood ketone between 0.6 and 1.4 mmol/L should be addressed before physical activity.

In the presence of elevated blood ketones (≥1.5 mmol/L) or urine ketones (2+ or 4.0 mmol/L) exercise in children is contraindicated.

High intensity exercise is potentially dangerous and should be avoided if preexercise blood glucose levels are high >14 mmol/L (250 mg/dL) with any evidence of elevated ketone levels (ketonuria, small or more/ketonemia (>0.5 mmol/L). In the setting of high glucose and high ketone levels, an insulin bolus using half the usual correction factor (or 0.05 U/kg) should be administered. Ideally, exercise should be postponed until evidence of ketonemia has cleared. [B]

2.2.2 | Recent hypoglycemia

Severe hypoglycemia (here defined as blood glucose ≤2.8 mmol/L [50 mg/dL]) or an event including cognitive impairment requiring external assistance for recovery within the previous 24 hours is a contraindication to physical activity.

Significant hypoglycemia (defined as blood glucose <3.0 mmol/L [<54 mg/dL]), is clinically significant and requires immediate attention. It will result in the subsequent deterioration of hormonal counterregulation during physical activity, in turn leading to an increased risk for recurrent hypoglycemia.

Non-severe hypoglycemia (defined as blood glucose 3.0-3.9 mmol/L [52-70 mg/dL]) which occurred relatively recently before planned exercise can result in the subsequent deterioration of hormonal counterregulation during physical activity, in turn leading to an increased risk for recurrent hypoglycemia.

In all situations of documented hypoglycemia prior to physical activity, we recommend vigilance regarding glucose monitoring. Physical activity should be avoided if it is associated with elevated risk for injury/accident (eg, Alpine skiing, rock climbing, swimming, scuba diving).

2.2.3 | Access to effective monitoring

Children and adolescents should be counseled that they are best prepared for exercise when blood glucose meters and test strips are readily available, particularly if they are not using glucose monitoring devices (isCGM or CGM).

Children and adolescents should be encouraged to measure their blood glucose level before, during and after exercise or, alternatively, to check sensor-based glucose values on a regular basis and have predictive alerts and low glucose alarms activated to help prevent or reduce the risk of hyperglycemia.

2.2.4 | Access to carbohydrates

High glycemic index snacks should be readily available during any form of physical activity. [E]

High glycemic index snacks and hyperglycemia remedies should always be readily available at school. [E]

2.2.5 | Communication and safety

Advice about safety should be given; children and adolescents should be encouraged to wear or carry diabetes ID when exercise is performed in the absence of a responsible adult. Counseling should include consideration of access to a mobile or alternative communication method in case urgent help is required.

2.3 | Insulin dose for blood glucose management

2.3.1 | Insulin adjustments prior to and during exercise

Insulin regimen should be tailored to activity. [B].

Most activity lasting >30 minutes is likely to require a reduction in insulin delivery, or some adjustment to carbohydrate intake to preserve euglycemia. [B]

When exercise is planned at a time of peak insulin action, typically after a meal with rapid acting bolus insulin administered, a marked reduction in insulin dose should be made (Table 6).

For Continuous Subcutaneous Insulin Infusion (CSII) users, the pump may be disconnected or suspended, or a temporary decrease in basal insulin infusion rate implemented at least 90 minutes before starting exercise to give a reduced basal effect during activity.

Insulin should not be injected in a site that will be heavily involved in muscular activity.

The rise in blood glucose level during or after intense exercise may be treated by giving a small additional dose of rapid-acting insulin—for example, 50% of the usual correction bolus when levels are >14 mmol/L (252 mg/dL), or by engaging in exercise of low to moderate intensity.

2.3.2 | Insulin adjustments for the afternoon or late evening after exercise

The risk of nocturnal hypoglycemia is increased after afternoon exercise. Similarly, morning exercise tends to lower insulin needs in the early afternoon. Two or more activity sessions in a single day (camps, tournaments, intensive training) promotes increased risk for hypoglycemia, and in particular nocturnal hypoglycemia.

In CSII treatment, a temporary basal reduction of approximately 20% at bedtime for 6 hours helps reduce the risk of nocturnal hypoglycemia.

In Multiple Daily Injections (MDI) treatment, a 20% basal analogue (eg, insulin glargine, detemir, neutral protamine Hagedorn [NPH]) dose reduction on the day of exercise together with a carbohydrate snack at bedtime, corresponding to 0.4 g carbohydrates/kg reduces the risk of hypoglycemia. In MDI treatment using a basal analogue of more stable and prolonged effect (eg, insulin degludec, glargine 300 U/mL) a dose reduction would have to be initiated before exercise based on the duration of action to achieve a lower insulin concentration during and after a physical activity. Exercise with duration <90 minutes could easier be balanced by extra carbohydrate intake.

2.4 | Carbohydrate intake for blood glucose management

2.4.1 | Carbohydrate intake prior to and during exercise

The type and amount of carbohydrates required should be tailored to specific activities. [B]

Carbohydrate intake may not be required prior to moderate intensity exercise if of short duration (<30 minutes).

When circulating insulin levels are high and preexercise insulin doses are not decreased, up to 1.5 g of carbohydrate per kilogram of body mass is recommended per hour of strenuous or longer duration exercise. [B]

If circulating insulin is at or below a basal level (defined here as the insulin level where no exogenous carbohydrate is required to maintain stable blood glucose at rest), little (ie, 0.25 g/kg/h) or no carbohydrate intake may be required, depending on exercise duration and intensity.

For low to moderate intensity/aerobic exercise of >30 minutes duration under basal insulin conditions, 0.2 to 0.5 g/kg/h may be required to maintain euglycemia, but in some circumstances, or for optimal performance, 1 g/kg/h may be required to avoid hyperglycemia. Under hyperinsulinemic conditions where preexercise bolus insulin remains active or is peaking, we recommend 1 to 1.5 g/kg/h.

2.4.2 | Carbohydrate intake after exercise

Meals with appropriate carbohydrate and protein content should be consumed within 1 to 2 hours of exercise, taking advantage of the period of heightened insulin sensitivity to help replenish glycogen stores and limit postexercise hypoglycemia risk. Bolus dose reductions after prolonged aerobic exercise may be needed if postexercise hypoglycemia typically occurs (Table 1). A 50% reduced correction bolus dose may be needed in case of postexercise hyperglycemia. [E]

Alcohol consumption inhibits gluconeogenesis and thus increases hypoglycemia risk in fasting individuals. For this reason, alcohol consumption should be avoided. After exercise if alcohol is to be consumed it should be combined with a high Glycaemic Index (GI) carbohydrate meal. [A]

Dehydration associated with exercise is a risk unless water or sugar-free fluids also are consumed during and after exercise. [E]

TABLE 1 Examples of exercise snacks/drinks comparing carbohydrate content and energy density

Snack item	Carbohydrate per serving (g)	Energy per serving (kcal)
Medium banana	15	64
250 mL isotonic sports drink	16	70
150 mL apple juice	16	62
Granola type bar	17	132
Chocolate (30 g)	17	156

2.5 | Prevention of postexercise hypoglycemia

Hypoglycemia may be anticipated during or shortly after exercise but is also possible up to 24 hours afterward due to increased insulin sensitivity. [A]

Risk of postexercise nocturnal hypoglycemia is high, and care should be taken if bedtime blood glucose level is <7.0 mmol/L (125 mg/dL). However, no specific bedtime glucose value guarantees that nocturnal hypoglycemia will be avoided. [E]

Extra carbohydrate after the activity may be the best option to prevent postexercise hypoglycemia when short duration and high intensity anaerobic activities are performed under hyperinsulinemic conditions but is less likely to prevent delayed nocturnal hypoglycemia without appropriate insulin adjustment. [E]

Short sprints added to aerobic exercise can reduce the risk of hypoglycemia early after exercise if the person is mildly hyperinsulinemic (<2 hours). [E]

2.6 | The use of advanced technology for blood glucose management

RtCGM may have a role in helping to avoid hypoglycemia during and after exercise. Evidence is still lacking regarding beneficial effects of using isCGM. [C]

New pump technologies such as low-glucose suspend, predictive low glucose suspend (LGS), and hybrid closed loop automated insulin delivery are likely useful [E] though exercise remains a challenge even for these technologies.

All users of current technology and their family members or carers must be informed that this technology may tend to overestimate blood glucose level under conditions where blood glucose is falling rapidly such as in response to exercise performed under hyperinsulinemic conditions. Measurements using blood glucose meters can still be recommended for guidance during rapid changes of sensor glucose values or when current values do not match symptoms. [E]

2.7 | The need for ongoing training of professionals

Professionals should take opportunity to attend camps for children with diabetes to understand better the challenges they face. [E]

Several barriers appear to be related to regular discussion of exercise in youth with diabetes. These include insufficient knowledge and education on the part of both patients and providers. [E]

Methods to improve the frequency and quality of exercise education in the diabetes clinic should be encouraged. [E]

It is important to ensure that all professionals (eg, nurses, diabetes educators, dietitians, physicians) are kept up-to-date with the latest evidence-based guidelines in blood glucose management. [E]

3 | INTRODUCTION

All children and adolescents between 6 and 18 years should do 60 minutes or more of physical activity each day,[2] which should include (1) moderate to vigorous aerobic activity, (2) muscle strengthening, and (3) bone strengthening activities. The aerobic activity should constitute the main portion of the 60 minutes. Higher intensity (vigorous) exercise is recommended at least three times during a week. Muscle and bone strengthening exercise should be included at least three times a week.

Activity recommendations for children and adolescents with diabetes are the same as the general population. Following physical activity recommendations helps to mitigate increased cardiovascular risk, and physical activity has an important role to play in prevention of type 2 diabetes. However, achieving recommended levels of physical activity may be difficult due to disease complexity. T1D may be associated with specific barriers which can nonetheless usually be overcome with appropriate education and training. 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. This is a defining goal of modern diabetes care.

Diabetes should not limit the ability to excel in a chosen sport. Many famous athletes have proved this, for example, Sir Steve Redgrave five times Olympic Gold Medal winning rower, Kris Freeman—Olympic cross-country skier (four winter Olympics), Gary Hall—five times Olympic Gold Medal swimmer, Zippora Karz—ballerina, Wasim Akram—Pakistani cricketer at international level, Jordan Morris—US soccer player, Brandon Morrow—Major League baseball player, Cliff Scherb and Andreas Petz—Ironman Triathletes, Scott Verplank—PGA Tour golfer, female professional golfer Mimmi Hjorth, and Emil Molin—NHL ice-hockey player. A professional cycling team with all riders having T1D (Team Novo Nordisk) holds the record for the Race Across America and aspires to compete at the Tour de France.

In the 1950s, Joslin proposed that exercise, after insulin and dietary management, is the third essential component in blood glucose regulation for those with T1D. Evidence for exercise improving glycemic control has been evaluated in several studies. In a meta-analysis of 12 studies in youth and adults, no benefit overall on HbA1c was found for exercise, though the studies in youth approached statistical significance for improved glycemia.[3] Yardley et al, however, showed that in adults with T1D, regular exercise performed at least two times a week for at least 8 weeks was associated with a significant absolute reduction in HbA1c.[4] A cross-sectional analysis of data on a larger cohort showed that the frequency of regular physical activity was associated with lower HbA1c without increasing the risk of severe hypoglycemia.[5] Finally, a recent meta-analysis of physical activity intervention studies in youth showed an overall effect on HbA1c of −0.85%.[6] When studies of young adults were included in another meta-analysis, the overall effect on HbA1c was −0.52%.[7] Thus, the total sum of evidence suggests a beneficial effect of exercise on HbA1c, especially in youth.

The benefits of exercise likely extend beyond HbA1c, however, and include weight control, reduced cardiovascular risk,[8] and improved sense of wellbeing.[9] There is growing evidence that the antecedents of cardiovascular risk begin early in diabetes[10] and studies have shown that exercise has a beneficial effect on various markers of vascular health including skin microvascular reactivity[11] and endothelial function.[12] A systematic review of adult studies concluded that physical activity is associated with a marked decrease in cardiovascular and all-cause mortality in both men and women, even after adjusting for other relevant risk factors.[8] Even if glucose targets, as measured by HbA1c are not achieved, regular physical activity is associated with reduced early mortality in the adult population.[13]

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, particularly in under-insulinized patients and for those who do intensive and competitive activities.[14] This emphasizes the need for education and individualized feedback.

Recent data from large cohorts of adolescents (youth) with T1D show that rates of overweight and obesity are as high or higher than the general population. Furthermore, the Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) study demonstrated, in a large multicenter cohort of European adolescents without diabetes, that muscular fitness and cardiorespiratory fitness are independently associated with metabolic risk of insulin resistance[15] and therefore of type 2 diabetes. Part of this study showed that self-reported physical activity correlates negatively with insulin resistance (after adjusting for confounders such as waist-hip ratio) but that higher cardiorespiratory fitness reduces the impact—insulin sensitivity was higher in those with higher fitness.[16] These findings have been supported by the Tracking Adolescents´ Individual Lives Survey (TRAILS) which also showed that increased fat mass in childhood is associated with increased cardiometabolic risk but that this is, to some extent, mitigated by fitness.[17] Finally, Nadeau et al have shown that adolescents with T1D have insulin resistance on par with obese non-diabetic peers, and that markers of exercise function correlate with insulin sensitivity.[18]

The relationship between physical activity, sedentary behavior, fitness, and glycemic control is complex, as suggested above, but several studies have found that children and adolescents with T1D are less fit than their non-diabetic peers, particularly if they are in poor glycemic control.[19,20] Young adults living with T1D may have altered muscle ultrastructure and mitochondrial dysfunction, both of which may impair the muscles capacity for endurance or force generation.[21] Youth with T1D have alterations in the inflammatory, oxidative metabolic responses, particularly if they are overweight or obese.[22] Nonetheless, young patients living with the disease can still aspire to reach their activity and competitive goals, as have been seen with numerous individuals competing at all levels of sport.

Huge efforts are being made around the world to get children and adolescents to engage more in physical activity and to reduce sedentary behavior. The need for education and training is clear, and the Juvenile Diabetes Research Foundation (JDRF) organization has in recent years formed an international group which has compiled two training programs for health care professionals/diabetes team members as well as patients and their relatives. Part of the group behind this program also published a consensus statement describing exercise management in adult T1D.[23] Similar educational and training efforts continue nationally and locally, which is of great importance.

4 | EXERCISE PHYSIOLOGY

Before considering the exercise perturbations unique to T1D, it is useful to understand the "normal" physiological responses to moderate intensity aerobic exercise in the non-diabetic individual.

As shown in Figure 1, non-diabetic individuals have a reduction in insulin secretion and an increase in glucose counterregulatory hormones facilitating an increase in liver glucose production that 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.[9]

Exercise increases non-insulin dependent glucose uptake into muscle by the translocation of the glucose transporter type 4 (GLUT-4) proteins to the cell surface. Thus, glucose uptake during exercise increases even when insulin levels are low.[24] The translocation activity of the GLUT-4 proteins remains high during recovery of exercise via unclear mechanisms likely to replenish muscle glycogen levels.[25]

In T1D, the pancreas does not regulate insulin levels in response to exercise and there may be impaired glucose counterregulation, making normal fuel regulation nearly impossible. As a result, hypoglycemia or hyperglycemia commonly occurs during or soon after exercise.

Under conditions of intense exercise, catecholamines and other counterregulatory hormones (eg, growth hormone, cortisol) rise, as does circulating lactate, all of which are associated with increases in glucose production by the liver relative to muscle glucose uptake.[26] This can result in a transient rise in glucose levels even in non-diabetic children.[27] The rise in blood glucose can be protracted in youth with T1D unless insulin is administered.

4.1 | Cardiometabolic responses to exercise in T1D/impact of chronic glycemia

Young people with T1D, overall, may have decreased aerobic capacity as measured by VO_2 max, compared to non-diabetic control subjects.[28] However, Adolfsson et al performed a detailed study of VO_2 max and endocrine responses to different intensities of exercise (bicycle ergometer) in 12 reasonably well-controlled adolescents with T1D (6 boys and 6 girls) and 12 controls matched for age, gender, and level of physical activity. They found no significant differences except for higher growth hormone levels in those with diabetes.[29] All

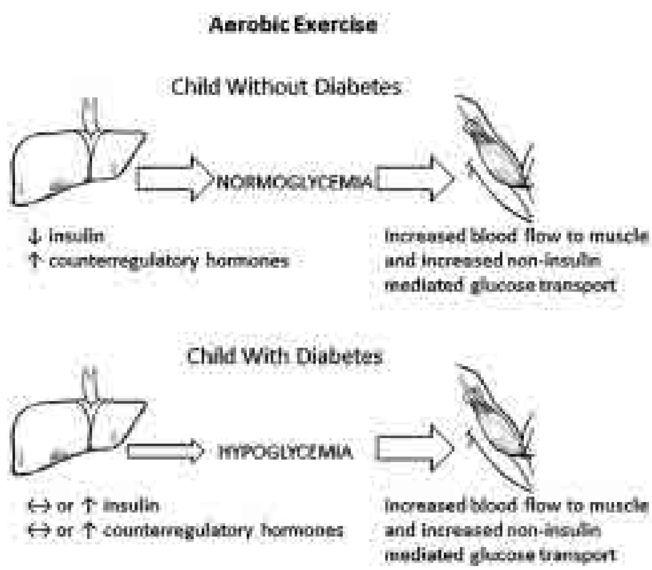

FIGURE 1 Physiologic responses to aerobic exercise in children with or without type 1 diabetes

participants in the latter study reported that they participated regularly in physical activity; thus, it might be that T1D per se is associated with less physical activity and that the overall lower fitness in adolescents with T1D may be driven by this difference in activity level. Cuenca García et al. compared 60 children and adolescents aged 8 to 16 with T1D with 37 sibling controls and found no difference in fitness or physical activity, but that moderate to vigorous physical activity was associated with better metabolic control and accounted for approximately 1/3 of the variance in HbA1c.[30]

In triathletes with T1D, those with near normal HbA1c had performance equivalent to non-diabetic controls,[31] while aerobic capacity was lower and fatigue rate higher in with T1D when glycemic control was suboptimal.[28] Similarly, children with T1D appear to have normal aerobic and endurance capacity if target glycemic control is achieved HbA1c <53 mmol/mmol (<7.0%), even when mildly hyperglycemic at the time of exercise. In another study, physical working capacity in well-controlled prepubertal boys was not different from non-diabetic boys matched for age, weight, and physical activity patterns, even though the boys with diabetes exercised with considerably higher blood glucose concentrations (mean blood glucose 15 mmol/L at onset of exercise).[32]

4.2 | Acute glucose levels—effect on exercise performance

Limited evidence exists to support the notion that hyperglycemia may be detrimental to exercise performance. Hyperglycemia 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.[33] In fact, even baseline beta-endorphin levels were reduced in the diabetic participants involved in that study, irrespective of blood glucose levels, thus suggesting that the resultant reduced tolerance to discomfort may compromise exercise performance in individuals with diabetes.

However, some evidence suggests that acute hyperglycemia may not be overtly detrimental to exercise performance. Indirect but weak evidence to this effect is provided by a study reporting that physical working capacity does not to differ between well-controlled prepubertal boys and non-diabetic boys matched for age, weight, and physical activity patterns, even though the boys with diabetes exercised with considerably higher blood glucose concentrations (mean blood glucose 15 mmol/L at the onset of exercise).[32] More compelling evidence against the notion that hyperglycemia may be detrimental to exercise performance is the observation that cycling performance in adult males with T1D does not differ between glucose clamped at euglycemic vs hyperglycemic level (12 mmol/L, 220 mg/dL).[34] Nonetheless, sustained hyperglycemia (days, weeks) likely impacts several metabolic and circulatory processes that would impact work capacity (ie, loss in lean mass, dehydration, impaired mitochondrial bioenergetics, and alterations in the micro circulation).[35] For children and adolescents doing regular physical activity, prolonged periods of hyperglycemia may have a negative influence on achieving overall glycemic management targets.

Hypoglycemia clearly compromises both exercise performance and cognitive function in youth with T1D.[36] Thus, a near normal glucose concentration may be optimal for overall exercise performance, though whether there is an "ideal" range of blood glucose level remains unclear.

5 | THE IMPACT OF EXERCISE ON BLOOD GLUCOSE LEVELS

5.1 | Type and classifications of physical activity and exercise

The duration, intensity, and type of exercise are all known to affect blood glucose response to exercise. Figure 2 summarizes the impact of exercise type and duration on glucose levels.

In general, aerobic exercise is associated with decreasing glucose values[37] while brief very high intensity or anaerobic exercise, particularly if performed under basal insulin conditions, is associated with increasing glucose values.[9] However, if plasma insulin levels are elevated, all forms of exercise are likely to cause a fall in blood glucose levels, and most activity lasting >30 minutes is likely to require a reduction in insulin delivery, or some adjustment to carbohydrate intake to preserve euglycemia.

Importantly, real-world physical activity for many children and adolescents consists of spontaneous play, and/or team and field sports, all of which may be characterized by repeated bouts of relatively intense activity interspersed with low to moderate intensity activity or rest. This type of "interval" or intermittent activity has been shown to result in a lesser rate of fall in Blood Glucose Level (BGL) compared to continuous moderate intensity exercise, both during and after exercise.[38]

Purely aerobic physical activities tend to lower blood glucose both during (usually within 20-60 minutes after the onset) and after the exercise.[9] However, when plasma insulin is at near basal levels, blood glucose level often remains stable or fall at a low rate in response to exercise of moderate intensity, but not if aerobic exercise is intense since intense aerobic exercise under basal or near basal insulinemic conditions is associated with a rise in blood glucose level.[26] Overall, their appears to be an inverted U-shape in the relationship between aerobic exercise intensity and muscle glucose disposal, with the highest risk for hypoglycemia likely occurring at about 50% of the individuals' maximal aerobic capacity.[39]

Intense efforts, such as cycling or running sprints performed after moderate-intensity exercise (~40% of VO_2 max) prevents a further decline in blood glucose for at least 2 hours after exercise[40] when exercise is performed under mildly hyperinsulinemic conditions. Team games may last up to 90 minutes and typically these kinds of sports include repeated bouts of sprints, blood glucose responses therefore may be as described above (see Figure 2).

Anaerobic efforts lasting only a short time (seconds to minutes) may increase blood glucose levels. In general, the rise in blood glucose is transient, lasting typically 30 to 60 minutes during and after a sprint performed in a basal insulinemic state.[26] Importantly, it may be followed by hypoglycemia in the hours after finishing the exercise, especially where over-aggressive postexercise correction boluses are given.

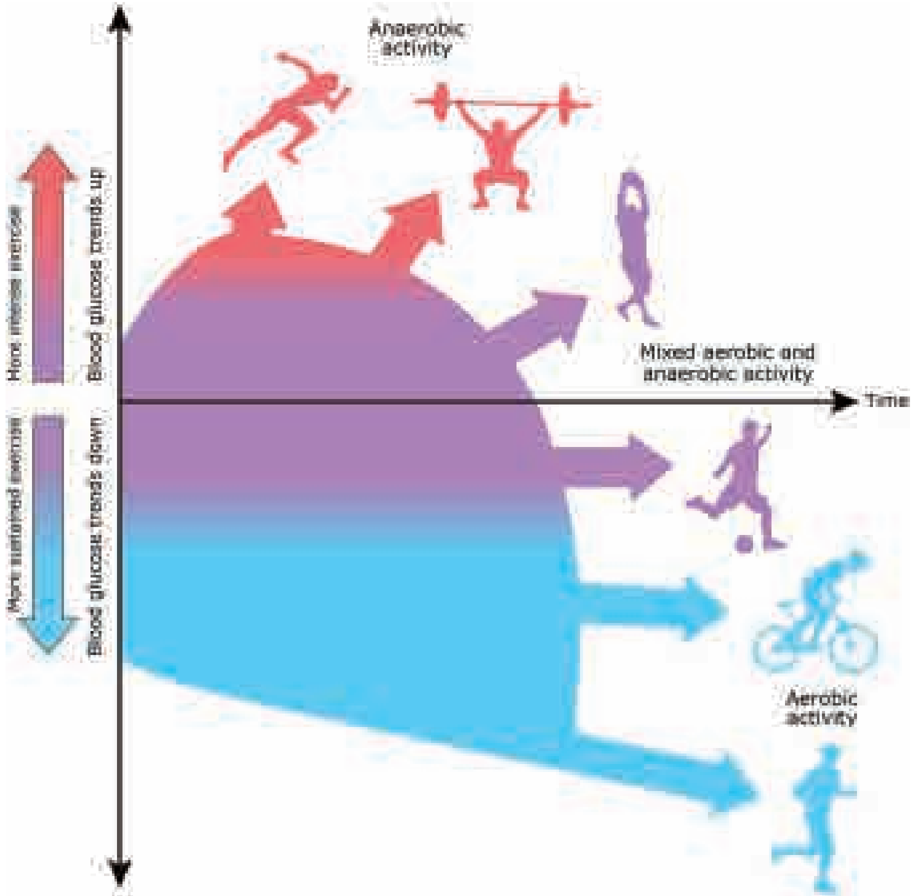

FIGURE 2 Illustration of different types of exercise including mutual differences in intensities and the way this affects glucose levels. Illustration by Anne Greene, Senior Medical Illustrator, reproduced with permission from UpToDate, Inc. Copyright © 2017 Duration and intensity

Although not yet well studied in the pediatric population, resistance-based exercise (ie, weight training) produces less of a drop in glycemia compared to aerobic exercise,[37] at least acutely.

5.2 | Timing of the exercise

Many children and adolescents with diabetes are active during the school day and the afternoon/after school period. This presents challenges in minimizing their exposure to a relatively hyperinsulinemic state during exercise due to previously delivered bolus insulin, for example, at lunch or an afternoon snack. Management of daytime physical activity in children and adolescents must allow for relative hyperinsulinemia or planning around meal times which is a greater challenge especially in the youngest children given that physical activity then more often is conducted as bursts.

Morning activity before breakfast and bolus insulin administration reduces the risk of acute hypoglycemia as circulating insulin levels are typically low.[41] Furthermore, timing exercise earlier in the day may be an adequate strategy to avoid nocturnal hypoglycemia. For example, in a study of adolescents cycling in the aerobic zone at noon, insulin sensitivity was increased for the next 11 hours, but not thereafter.[42] Thus, while the total duration of lower insulin requirements was similar to studies of afternoon exercise, the risk of hypoglycemia after midnight was attenuated.

5.3 | Physical fitness and conditioning

Individuals new to a fitness program, starting at a lower baseline level of fitness, are likely to oxidize a greater proportion of carbohydrate stores during exercise compared to fitter individuals exercising at the same absolute intensity, which require replenishment during and after exercise. Interestingly, however, patients with good fitness level, including adolescents with T1D, tend to have a greater drop during exercise, perhaps because they can exercise at a higher absolute workload.[43]

5.4 | Degree of stress/competition involved in the activity

It is commonly reported that patients experience a rise in glucose responses to exercise while competing but not during practice and training. For a young athlete who has spent many months or years preparing for competition, and who aims to manage his or her blood glucose level tightly, this rise in glucose levels during competition may be very frustrating and may occur even in highly trained and experienced athletes. The rise in catecholamine levels during high intensity exercise may be due, in part, to the "fight or flight" response of psychologically stressful situations such as a competition situation or race. This rise can contribute to moderate hyperglycemia during aerobic exercise,[44] and may require corrective insulin administration.[26] Also, precompetition rise in blood glucose levels may be due to patients being in a hypoinsulinemic state as a result of reducing their basal insulin dose prior to competition, a common practice that can cause hyperglycemia particularly if preexercise insulin levels are below basal level. Patients should therefore be educated by their diabetes care team on the differences between training and competition days and informed about the importance of documenting their glycemic responses to each setting so that an individualized plan can be implemented.

5.5 | Antecedent Glycemia

Hypoglycemia in the 24 to 48 hours prior to exercise in young athletes has been shown to blunt counterregulatory hormone responses during exercise, and thus increase the risk of acute hypoglycemia.[35] Obesity and exercising in the cold, blunts the growth hormone response to exercise, which may increase hypoglycemia risk, although this has not been explicitly studied in children and adolescents with diabetes.[35] Exercise itself also reduces subsequent counterregulatory responses to hypoglycemia in adolescents with T1D, an effect that appears to be worsened during sleep, particularly for those on a fixed basal dose regimen.[42,45] Glucagon, catecholamines and growth hormone responses to hypoglycemia have all been shown to be blunted if preceded by a prior bout of exercise, increasing the risk of delayed nocturnal hypoglycemia.[35]

5.6 | Type and timing of insulin delivery

Acute and chronic insulinopenia is an area of concern in diabetes management, particularly in children and adolescents with T1D who may accidentally or voluntarily interrupt their insulin therapy or omit insulin doses. Severe hypoinsulinemia is associated with a marked rise in plasma glucagon/insulin ratio, a potent activator of hepatic ketogenesis and gluconeogenesis. The resulting severe hyperglycemia and ketoacidosis can be further aggravated by exercise[46] thus increasing the risk ketoacidosis-mediated complications and even death. Practical suggestions for insulin dosing and the management of exercise at times of ketosis are provided elsewhere in this chapter.

All patients should receive specific education regarding time of active insulin, time of peak insulin effect, and total duration as this is important information regarding exercise-related glucose fluctuations. When regular (soluble) insulin has been injected prior to exercise, the most likely time for hypoglycemia will be 2 to 3 hours after injection, when insulin levels peak. However, rapid-acting insulin analogues peak earlier, at around 60 to 90 minutes, and thus hypoglycemia risk is earlier when this peak effect coincides with an exercise-mediated glucose reduction.[47] This is particularly so regarding early postprandial exercise, which is common in children and adolescents who by nature exercise mostly later in the day or after school.

Critically, it should also be noted, that exercise increases skin and systemic blood flow, along with insulin and glucose delivery to skeletal muscle.[48] Exercise increases the rate of rapid-acting insulin absorption,[49] thereby likely hastening the peak insulin action. Basal insulin absorption, on the other hand, is not significantly increased by exercise.[50]

Thus, hypoglycemia prevention during prolonged aerobic or mixed type exercise typically requires reductions in bolus and basal insulin. These recommendations are discussed in detail later in this chapter, but usual recommendations include to reduce rapid-acting analogue exposure prior to exercise lasting longer than 30 minutes; reassuringly this appears unlikely to increase risk of postexercise ketosis.[51] This is a reassuring message and is helpful when encouraging young people to experiment to find what scale of reduction works for them; we again emphasize that every patient is unique and that an individualized plan that accounts for variability in exercise responses is key.

We have found no studies on the timing of basal insulins (NPH, glargine, or detemir) and exercise in children but it has been reported that insulin detemir was associated with less hypoglycemia during and postexercise than insulin glargine.[52]

5.7 | Absorption of insulin

5.7.1 | Choice of injection site

As mentioned previously, 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.[53] This effect likely occurs in other locations like the abdomen and buttock.[54] This may be especially marked if the injection site is hypertrophied. Nevertheless, a cyclist may achieve more consistent response by choosing to inject in an arm or the abdomen rather than a leg before an event.

5.7.2 | Ambient temperature

High temperature will increase insulin absorption and low temperature the converse.[55] The latter may be a consideration in long distance swimming. Heat also places additional stress on the cardiovascular system, resulting in greater energy expenditure and potential for a more rapid decrease in blood glucose levels.

5.7.3 | Altitude

The physiological effects of high altitude and T1D have recently been reviewed.[56] High altitude tends to increase the risk for exercise-associated hyperglycemia possibly because of increased stress hormone release, despite the increased activity demands. However, there is likely to be no altitude effect on insulin during recreational activities such as piste (backcountry) skiing, but de Mol et al[57] studied eight complication-free young people with diabetes, climbing above 5000 m and found that despite high energy expenditure, insulin requirement increased. This may be related to the very high intensity of even continuous efforts at altitude where oxygen availability is low, creating a relatively anaerobic environment. Further, they found that glucose levels (and insulin requirement) correlated directly with the symptoms of acute mountain sickness,[57] further suggesting a stress response was responsible. These environmental effects on insulin absorption may be less pronounced with rapid-acting analogues.[58]

5.8 | Type and timing of food

The need for food intake prior to exercise depends on the timing of activity in relation to insulin delivery and the type and purpose of activity. A meal or snack is not required in all situations for routine physical activity, particularly if the activity is limited to less than 30 minutes. In most cases, however, good nutrition and timely snacks support more prolonged activities that may or may not be competitive in nature. Advice on sports nutrition with the aim to maximize performance will include information about type and amount of food/carbohydrates as well as timing of the intake. Detailed information about this can be found in the nutrition chapter.

For children and adolescents undertaking daily activities associated with health (ie, 60 minutes of Moderate and Vigorous Physical Activity (MVPA) daily), daily food intake should be sufficient to meet the demands of the activity provided meals are distributed regularly across the day and an age appropriate amount of carbohydrate and energy are consumed. Country-specific guidelines on energy and macronutrient intake exist in many parts of the world and, in general, increased energy requirements are linked to increased activity levels. Children and adolescents should be advised to consume regular meals based on healthy food choices with additional snacks prior to exercise if indicated by blood glucose level. Advice on hypoglycemia prevention should not increase total energy intake above expenditure and the use of snacks should not decrease dietary quality. (See Table 1 for a comparison of common exercise snack items).

Whilst it is recommended that a preactivity meal is consumed 3 to 4 hours prior to prolonged exercise to maximize muscle and liver glycogen stores, this is impractical for many and timing of meals and snacks will often depend on the school routine. It is more likely that meals will be consumed 1 to 3 hours before most activity in a typical day, though additional snacks may be needed prior to exercise at the end of the school day.

Additional carbohydrate may be needed just prior to and during exercise as dictated by blood glucose levels and insulin adjustment as well as type and duration of exercise/activity. This is more likely to be needed when exercise is unplanned, and insulin has not been adjusted as advised previously.

Carbohydrate type and hypoglycemia prevention has not been well studied in children and adolescents with T1D. However, it is sensible to suggest that carbohydrate with a high glycemic index value and low-fat content is consumed just prior to (or perhaps during once the glucose reaches a targeted range) exercise. Acceptability and tolerance of carbohydrate sources is as important as the type of carbohydrate. Attention should be paid to the health value of the foods suggested to offset hypoglycemia. Advice about the prevention of dental caries should also be given to children and adolescents. An isotonic beverage containing 6% simple sugar (ie, sucrose, fructose, dextrose) provides optimal absorption compared with other more concentrated beverages with more than 8% to 10% glucose, such as juice or carbonated drinks that delay gastric absorption and cause stomach upset.[59] One study, however, found that both an 8% and a 10% isotonic beverage were well tolerated and helped to prevent the drop in blood glucose level during exercise in adolescents with T1D.[60]

For activities that last 60 minutes or longer, additional carbohydrate may be needed during exercise dependent on blood glucose responses but also on the goal of the exercise. Up to 1.5 g of carbohydrate per kilogram of body mass per hour of exercise can be tolerated.[59] Total carbohydrate and energy intake should match the daily requirements of the individual; the need for additional carbohydrate for hypoglycemia prevention is balanced by insulin adjustment. In Table 1, examples of snacks/drinks are shown along with carbohydrate and energy content.

Postexercise ingestion of both carbohydrate and protein maybe beneficial for both hypoglycemia prevention and muscle recovery. Insulin sensitivity remains elevated for hours postactivity and early replenishment of glycogen stores helps to reduce the risk of late onset hypoglycemia. The use of nutrition strategies for hypoglycemia prevention should be linked to insulin adjustment. If the usual routine is a meal or snack consumed within 1 to 2 hours of completing the exercise, then supplemental nutrition postexercise may not be required. This is entirely dependent on blood glucose responses to activity.[61] Ensuring that total energy, carbohydrate, and protein intake meet requirements will contribute to the prevention of hypoglycemia through adequate repletion of glycogen stores[62] taking into account the fact that the amount of insulin can also affect the outcome. Balanced against this is the need to ensure that advice on hypoglycemia prevention does not increase consumption of less healthful foods as a result of being more active.

Currently, no evidence-based guidelines exist on the amount and timing of increased carbohydrate intake to 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. Adding protein to the postexercise meal increases the glucose uptake and enhances glycogen synthesis in healthy individuals.[63,64] Added protein will also stimulate muscle-recovery postexercise. A carbohydrate, fat, and protein snack at bedtime may limit nocturnal hypoglycemia caused by daytime exercise.[65] However, attention should be paid to the nutritional quality of the bedtime snack, avoiding high saturated, high sugar items. Table 2 provides a summary of nutrition strategies that may be considered before, during, and after exercise. The amount of carbohydrate and protein consumed at meals will vary with age, sex, activity levels. More detail on carbohydrate and protein requirements can be found in the nutrition chapter. Additional protein requirements to prevent overnight hypoglycemia have not been well studied but 25 g protein consumed with 30 g carbohydrate has been shown to impact on postprandial glycemia in nutrition studies. When protein quantity was increased in a low-fat meal with consistent amount of carbohydrates glucose excursions in the early (0-60 minutes) postprandial period was decreased. However, in the later postprandial period glucose excursions was increased in a dose-dependent manner, which meant that the more protein that was added in addition to carbohydrates, the more glucose excursions 150 to 300 minutes postexercise.[66] Sports nutrition recommendations for adults suggest a requirement of 20 to 30 g protein postexercise. The effects of various amounts of protein postexercise on net protein balance has also been evaluated in children without diabetes and showed that net protein balance was increased in a dose-dependent manner within the protein range

TABLE 2 Summary of suggested distribution of nutrients before, during and after exercise

	Three to four hours prior to exercise	Immediately prior to exercise	During exercise	Immediately postexercise	One to two hours postexercise
Carbohydrate	Low fat whole grain low glycemic index carbohydrate as part of mixed meal	10-15 g carbohydrate snack if indicated by blood glucose levels and activity type	10-15 g per 30 minutes for aerobic/longer duration activity adjusted according to insulin on board and blood glucose levels. Not usually needed for anaerobic/ competitive/short duration exercise unless indicated by blood glucose levels	If meal to be eaten within an hour not needed unless indicated by BGL. If meal >1 hour postexercise 10-15 g snack, for example, fruit, low fat cereal bar, 150-200 mL milk	Low fat wholegrain low glycemic index carbohydrate as part of mixed meal. For exercise activity before sleep consume additional bedtime snack
Protein	As part of mixed meal	Not needed	Not needed	Not needed	As part of mixed meal or bedtime snack
Fluid (water for activities lasting less than 60 minutes)	Consume fluid with meal at least 100-150 mL	Consume fluid	Consume fluid	Consume fluid	Consume fluid with meal

BGl

studied (0-15 g). Thus, children with diabetes should consider consuming a source of dietary protein after physical activity to enhance whole-body anabolism.[67]

Numerous charts indicating carbohydrate replacement for specific exercises based on duration of activity and body size are found in *Think Like a Pancreas, published 2012 by Da Capo Lifelong Books*, by Gary Scheiner, *Pumping Insulin (fifth ed.), published 2016 by Torrey Pines Press*, by John Walsh and Ruth Roberts and for children and adolescents specifically in a review by Riddell and Iscoe.[59] Care should be taken when estimating carbohydrate requirements during activity as children and adolescents may over-report the actual duration of activity. A 1-hour activity session, for example, may include some non-active time. Increasing carbohydrate intake may have an adverse impact on weight when activity time is over estimated. Table 3 provides suggested carbohydrate and energy requirements related to the aim of the physical activity.

The growing use of CGM may offer opportunities for better tailoring of food intake before, during, and after exercise using more precise algorithms.[68,69]

Adolescents and young adults of drinking age need to understand the effect of alcohol on the ability to respond to exercise and falling blood glucose (see chapters on Nutrition and Adolescence). Some sports are associated with a "drinking" culture and counseling particularly for sports trips and moving to university settings should include advice on alcohol, but not endorsing its consumption. Alcohol impairs the glucose counterregulation in subjects with diabetes by inhibiting gluconeogenesis (but not glycogenolysis).[70–72,73] Accordingly, hypoglycemia (especially night time) becomes more likely and is best avoided when participating in exercise, especially as alcohol may also impair performance.

Adequate fluid intake is essential to reduce the risk of dehydration.[74] Fluid requirements are discussed in the nutrition chapter in detail. Higher blood glucose levels are an indication that more attention should be paid to fluid intake. In most situations water or sugar-free fluids are most suitable for maintain hydration.

5.8.1 | Supplements

Evidence from child/adolescent sports competitors demonstrates a high use of sports supplements.[75,76] In most cases, supplements are unnecessary. A recent paper from Australia described protein supplement use in 60% of the adolescents who participated.[77] Counseling on how to use food to maximize training adaptions is essential. Advice on the risks of supplement use, which include contamination with banned performance-enhancing substances should be provided along with guidance on anti-doping according to the sport and level of competition, as some sports begin anti-doping procedures below the age of 18 years. Educational programs on anti-doping in sport are

TABLE 3 Suggested carbohydrate and energy requirements for children and adolescents engaged in regular physical activity

	Carbohydrate and energy availability	Insulin
Normal daily activity	45%-50% total energy intake distributed across Exercise snacks according to Blood Glucose (BG) responses	Insulin adjustment for blood glucose management
Weight loss	Meet daily energy needs for growth. No increase in total carbohydrate intake across day	Insulin adjustment essential for hypoglycemia prevention and reduced weight
Training	50%-55% energy as carbohydrate. Meet energy demand for growth and training. Carbohydrate during exercise for performance	Insulin adjustment to manage blood glucose levels including fuel utilization during competition

BG

available through many national sporting organizations. Information about therapeutic use exemption for insulin is available on the world anti-doping authority website (https://www.wada-ama.org).

6 | PRACTICAL ADVICE—GETTING STARTED WITH EXERCISE IN YOUTH WITH T1D

On average, at least 60 minutes of cumulative activity is recommended by most organizations with at least 20 minutes daily of vigorous activity. Guidelines also state that for health benefits, children (aged 5-11 years) and adolescents (aged 12-17 years) should minimize the time that they spend being sedentary each day.[78] Sedentary time (ie, screen time) is linked to elevated HbA1c levels in children and adolescents with T1D.[79]

However, many adolescents with T1D, and especially type 2 diabetes, are sedentary at baseline and require thoughtful planning about how to get started safely and sustain an active lifestyle. While there is a dearth of evidence on how to successfully and safely initiate an exercise program in sedentary children and adolescents with T1D, a general structured approach is suggested in the accompanying Table 4.

7 | PRACTICAL ADVICE—NORMAL DAY-TO-DAY EXERCISE

Habitual physical activity in youth encompasses activities performed during leisure time as well as more structured activities in the framework of regular exercise, sports, and some specific school-related activities such as physical education lessons. Spontaneous activity of children is by nature sporadic and intermittent, with bouts (95% of the time) of very intense activity not exceeding 15 seconds, and only 0.1% of active periods for more than 1 minute.[80] These activity periods are interspersed by rest periods that are shorter than 4 minutes. This particular form of spontaneous physical activity is consistent with the biological needs of children[81] and necessary for their appropriate growth and development.[80]

TABLE 4 A practical approach to planning the initiation of exercise in sedentary children and adolescents with type 1 diabetes

Identify barriers that might reduce chances of success (eg, fear of hypoglycemia, knowledge gaps, parental barriers, personal fears of embarrassment, body image concerns)
Set a specific goal (eg, improved fitness, better glucose control, weight loss, safety vs performance)
Plan the schedule of exercise where possible (eg, every day, 3 days per week)
Discuss the type of exercise and how this affects glucose levels differently
Discuss time of day, especially if exercise will be close to meals or in the evening
Discuss a specific glucose monitoring plan (eg, BG only, CGM, and when to check glucose before, during and after exercise
Plan preexercise meal and insulin dose (timing and any dose adjustment)
Plan basal injected insulin dose adjustment, or pump basal rate adjustment so that it is active during the desired period
Plan the postexercise meal and insulin dose (timing and any dose adjustment)
Discuss risks of delayed glycemic excursions and plan to avoid postexercise nocturnal hypoglycemia
Plan the time to review glucose data around exercise with care team such that modifications can be made
Plan review of overall insulin doses after 1-2 weeks as insulin sensitivity changes (note—3 months later at the next clinic visit is not soon enough)

Abbreviation: BG, CGM, continuous glucose monitoring.

Regular and accustomed exercise is easier to manage because it is part of the daily routine. However, adjustments to insulin and fueling strategies may still 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 a good practice to keep careful notes of what they do (ie, timing and intensity of physical activity), what carbohydrate has been taken and the blood glucose response before, during, and afterwards. Much of the above structured approach to the sedentary patient is applicable to a regular review cycle in those who are more active but who may still be struggling with glycemic excursions and overall frustration. Advice from the diabetes care team will be general in the first instance, but accurate record keeping will allow much more individualized and fruitful consultation.

8 | PRACTICAL ADVICE—TRAINING

The management of diabetes may vary according to the phase of training so 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 on power and high intensity training.[82]

Exercise causes enhanced muscle insulin sensitivity[83] and increased activation of non-insulin sensitive glucose transporters (GLUT-4).[24,84] Insulin sensitivity was similar directly and 15 hours after exercise but decreased to near untrained levels after 5 days in non-diabetic adults.[85] During and immediately after exercise performed in the late afternoon and from 7 to 11 hours in recovery, the insulin sensitivity is elevated in adolescents with T1D.[86] In contrast, exercise performed earlier in the day results in heightened insulin sensitivity throughout 11 hours of recovery in adolescents with T1D, without an obvious biphasic response in sensitivity.[87]

In practical life, exercise for >1 hour appears to lead to increased insulin sensitivity in recovery and therefore an increased risk for hypoglycemia for the next 12 to 24 hours,[86] often occurring during evening after exercise.[88] This may be because of several factors including the change in insulin sensitivity, a reduction in glucose counterregulation and the problem of a fixed basal regimen.[45] This means that adolescents who only exercise on occasion can have difficulty in managing their basal insulin. If hypoglycemia is frequent, then it may be better to limit vigorous exercise to every other day rather than daily, if possible. If not, a strategy for altering basal insulins to cope with the widely varying insulin sensitivity is needed. Younger children more often exercise every day to some extent, which results in less postexercise fluctuations in blood glucose.

Meals with high carbohydrate content 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 postexercise 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.

9 | PRACTICAL ADVICE—RECOMMENDED GLUCOSE LEVELS AT START OF EXERCISE AND STRATEGIES FOR GLUCOSE MANAGEMENT

Before starting physical activity, it is important to consider several factors that can affect glucose control. Examples of such are insulin concentration (time since most recently given bolus dose/insulin on board, and possible adjustments of basal/long-acting dose), previous and more recent trends in glucose concentration, to what extent safety need to be considered and the experience the individual has from previous occasions of the same kind of physical activity. Consideration must be given specifically to the insulin concentration as the carbohydrate intake will need to be higher if the insulin concentration is higher at the start of exercise.

Recommendations and strategies related to different glucose levels at start of physical activity are provided in Figure 3.

10 | CHOICE OF INSULIN REGIMEN

In developed health care environments, it is now the norm to commence insulin therapy with a multi-injection regimen or an insulin pump. While for most children and adolescents, the choice of insulin regimen will not be influenced heavily by their exercise habits, for those who are regularly active either multiple daily injections or insulin pump therapy should be considered to allow for manipulations in insulin delivery prior to and following the activity.

10.1 | 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. In these situations, tables of Exercise Carbohydrate equivalents may be a useful starting point.[89]

10.2 | Three injections insulin regimen

In these situations, normally mixed insulin is given before breakfast, then a split-evening insulin regimen with rapid analogue before the evening meal, and a longer acting insulin at bedtime. In some cases, regular insulin may be used along with the evening meal instead of a rapid analogue. Again, this regimen must be accompanied by appropriate carbohydrate advice for moderate exercise, for example, dancing or swimming two or three evenings per week or at weekends.

10.3 | Multi-injection regimens or insulin pumps

These regimens afford 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 little doubt that being able to reduce the training day into manageable "chunks" of 4 to 6 hours makes management 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.[90] In general, if basal rates are to be reduced for exercise, then the reduction should occur approximately 90 minutes

B-Glucose	Carbohydrates and glucose management strategies
<5 mmol/L (<90 mg/dL)	Ingest 10-20g of carbohydrates before starting any exercise Delay exercise until blood glucose is above 5 mmol/l and rising
5-6.9 mmol/L (90-124 mg/dL)	Ingest 10-20g of carbohydrates before starting aerobic exercise
7-10 mmol/L (126-180 mg/dL)	No carbohydrates needed before start but soon afterwards Aerobic and anaerobic exercise can be started
10.1- 14 mmol/L (182-252 mg/dL)	Aerobic and anaerobic exercise can be started
>14 mmol/L (>252 mg/dL)	If the hyperglycaemia is unexplained, blood ketones should be checked If B-Ketones >0.6 mmol/ actions are required before starting any exercise

The suggested carbohydrate intake above is only intended to stabilize glycaemia at the start of exercise. More carbohydrates will be needed with continuous exercise.

Anaerobic exercise can result in an increased glucose concentration.

Always monitor closely to detect risk of hypoglycaemia and in case this is detected in sensor use, blood glucose should be checked by capillary sampling.

FIGURE 3 Blood glucose concentrations before start of exercise and recommended glucose management strategies before the onset of the activity to allow the circulating insulin levels to drop sufficiently before the exercise starts.[89]

With current insulin pump technology, LGS function was first added followed by PLGM with the goal of basal insulin suspension at predicted hypoglycemia.[91] The level at which PLGM is activated can be individually set allowing adjustment of threshold levels, for example, during competitions and subsequent nights to prevent or reduce time spent in the hypoglycemic range.

11 | HYPOGLYCEMIA

Hypoglycemia is an important consideration when planning exercise with diabetes. Hypoglycemia can occur during, immediately after, or with prolonged delay after exercise. Furthermore, an episode of hypoglycemia prior to exercise can alter hormonal responses to exercise. Parental fear of hypoglycemia is a factor that can limit the encouragement of their children with T1D to exercise.

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.

To treat hypoglycemia with a rise in BG of approximately 3 to 4 mmol/L (55-70 mg/dL), approximately 9 g of glucose is needed for a 30 kg child (0.3 g/kg) and 15 g for a 50-kg child. See the hypoglycemia chapter for further advice and references.

The risk of hypoglycemia during exercise varies with both the duration and intensity of exercise. It is more likely to occur with mod intensity exercise compared with intermittent high intensity exercise. Perhaps counterintuitively, hypoglycemia is less likely with high intensity exercise than with moderate intensity effort.[39]

There is minimal data to support an increased risk of hypoglycemia with less than 30 minutes of activity and so glucose monitoring is recommended at 30 minute intervals to detect risk of alternatively existing hypoglycemia. Using CGM increases the chances of preventing hypoglycemia. Scenarios which increase the risk of hypoglycemia during exercise include exercise in a high insulin state, for example, postprandial, and in this situation Carbohydrates (CHO) supplementation may be needed to reduce hypo risk.

In adults, the autonomic and counterregulatory response to hypoglycemia the following day has been shown to be blunted by repeated episodes of low or moderate intensity exercise.[92,93] The same phenomenon is likely to be true for children. Glucose requirements for maintaining stable glucose levels in adolescents with diabetes are elevated during and shortly after exercise, as well as from 7 to 11 hours after exercise.[42] In adults, repeated episodes of hypoglycemia in a sedentary state result in an attenuated counterregulatory response to subsequent exercise and increases 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.[94] In laboratory studies of diabetic adolescents who received their usual insulin dose and then performed 75 minutes walking on a treadmill, 86% had hypoglycemia if their starting blood glucose was less than 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.[95] In another study,[96] 45% of children with T1D had blood glucose levels drop below 4.0 mmol/L (72 mg/dL) during 60 minutes of moderate cycling performed in the fed state when insulin was unadjusted for the activity. By consuming additional carbohydrate (drinking 6%-8% glucose solution) at a rate that equaled carbohydrate utilization during exercise (approximately 1 g of carbohydrate per kilogram body mass per hour), the drop in blood glucose during exercise could be prevented.[96]

The use of continuous glucose monitoring and appropriate response to falling glucose may help to attenuate or avoid hypoglycemia during and after exercise.[92] Sensor augmented pump therapy used in conjunction with two consecutive bouts of 30 minutes of moderate intensity exercise has been shown to reduce the number of hypoglycemic events.[97] Recently, the same authors showed that PLGM compared with sensor augmented pump therapy further reduced hypoglycemia without deterioration of glycemic control in a 6-month, multicenter, randomized controlled trial.[98]

When active outdoors, in the backcountry, or on activity holidays, all responsible adults (and peers) should be alert to the possibility of hypoglycemia. Strict guidance should be given that no person with diabetes should exercise alone, or "decide" not to have regular snacks when they are needed. 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.

See Table 5 for further advice on how to avoid hypoglycemia when exercising.

12 | LATE HYPOGLYCEMIA

As mentioned above, hypoglycemia may occur several hours after exercise, especially when this has been prolonged and of moderate or high intensity.[99] This is due to the late effect of increased insulin sensitivity, delay in replenishing liver and muscle glycogen stores and attenuated glucose counterregulatory hormone responses, especially during the night.[45] A single bout of exercise can increase glucose transport into skeletal muscle tissue for at least 16 hours postexercise in non-diabetic and diabetic subjects.[30] In a controlled study, twice as many youth aged 11 to 17 years had a hypoglycemic event on the night after an exercise day compared to the night after a sedentary day (when the basal overnight insulin was not altered).[88] RtCGM is a valuable tool for determining the blood glucose response and hypoglycemia risk during and after exercise.[100,101] Data from adults suggests[102] that late hypoglycemia is still common after intermittent high intensity exercise, even when hypoglycemia occurs during exercise, perhaps due to the greater need for glycogen replenishment for the next 24 hours. Indeed, the likelihood of late hypoglycemia may be greater after intermittent high intensity than lower/moderate intensity exercise.[102] Again in adults, use of Continuous Glucose Monitoring System (CGMS) in conjunction with a LGS (ie, threshold suspend

TABLE 5 Summary recommendations for avoiding hypoglycemia in physically active young people with type 1 diabetes

Arrive in target metabolic control neither with hyperglycemia nor elevated ketone levels, and measure glucose before start of exercise
Always bring carbohydrates
Increase the intensity and/or the duration of the exercise progressively
In the few hours preceding the exercise, ingest slowly absorbing carbohydrates
In the case of unforeseen physical activity decrease the insulin dose during and after intense muscular activity
Do not inject insulin at a site that will be heavily involved in muscular activity
When physical activity is planned at a time of peak insulin action, a marked reduction of the insulin dose should be made
If the activity is prolonged, add glucose sweetened water or carbohydrates before, during and after the exercise
Measure the blood glucose value before bedtime on the evening after major physical activity and make sure to add extra carbohydrates and/or reduce long-acting/basal dose to reduce the risk of nocturnal hypoglycemia
Evaluate the effect after every modification in insulin dose and every change regarding carbohydrate supplementation or change in nutritional status
Make the people accompanying you aware of the procedures and treatment of severe hypoglycemia
If CGM: Check alert levels of decreasing values or low glucose limit and add a follower to increase safety

Abbreviation: CGM, continuous glucose monitoring.

or predictive LGS) function on insulin pumps may reduce the duration and severity of hypoglycemia with exercise in laboratory conditions.[103] It should be noted, however, that if a recent episode of exercise associated with hypoglycemia occurred, LGS technology may not be as effective in ameliorating hypoglycemia risk.[104]

Taplin et al attempted to prevent nocturnal hypoglycemia after a 60-minute bout of afternoon exercise in 16 youth with T1D on insulin pumps by either reducing their overnight basal insulin by 20% for 6 hours or by giving 2.5 mg of oral terbutaline as a means to enhance counterregulation.[105] Although the latter did reduce overnight hypoglycemia, it was associated with overnight hyperglycemia. Reducing insulin in this way is not possible for patients on MDI treatment; however, in studies of adults using multiple daily injections, a similar 20% reduction in basal analogues is similarly effective in reducing the risk of delayed postexercise nocturnal hypoglycemia. And, finally, in studies of closed loop insulin delivery, automatically delivered nocturnal basal insulin to maintain euglycemia was approximately 20% lower after an exercise session compared with a sedentary day.[106]

13 | HYPERGLYCEMIA

Hyperglycemia might occur during exercise of high intensity due to release of catecholamines, but generally also after excessive carbohydrate intake or too large insulin dose reductions. During competitions, stress release of catecholamines may also result in hyperglycemia. If this situation occurs a conservative approach is to use a 50% correction dose.[107]

14 | INSULIN ADJUSTMENTS

Before adjustments of insulin doses are made by the individual, it is of utmost importance that information is provided about the specific insulins used by the patient (eg, duration until peak max effect and total time of duration). The individual can be provided with instructions regarding recommended adjustments step by step.

Competitive athletes may be tempted to reduce their insulin doses too much to avoid hypoglycemia and metabolic control may suffer as a result.[108] Careful monitoring and experiential adjustments are essential.

In one study, cross-country skiers with T1D were able to exercise for several hours without hypoglycemia when reducing the premeal dose by 80%, compared to only 90 minutes if the dose was reduced by 50%.[109] Some people find that lowering their premeal insulin dose may cause an initial rise in their blood glucose which impairs their performance. In such a case, it is probably better to rely on extra carbohydrate intake just before the onset of exercise rather than dose reduction for best performance.

See Table 6, for examples, on adjustments of preexercise bolus doses in order to avoid hypoglycemia.[23,110] There is a greater need for reduction of rapid-acting insulin when the dose is given within 1 hour of the exercise, while the need of reduction is greater for later exercise (3 hours postmeal) when using regular insulin.[47]

For evening exercise, it may be sensible to reduce the rapid analogue before the evening meal by 25% to 75%, as well as taking 10 to 15 g of fast acting carbohydrate before the activity.

Advice should be given about reducing basal insulin by approximately 20% (eg, 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 all-day or unusual activities such as camps, long-distance walking, skiing, water sports, etc. consider a 30% to 50% reduction of long-acting insulin the night before and on the day of the activity, or a 30% to 50% reduction in the pump's basal insulin throughout the day

TABLE 6 Prandial (bolus) insulin adjustments for postprandial exercise when exercise is conducted in hyperinsulinemic state

	Meal before exercise		
	Activities lasting 30-45 minutes	Activities lasting >45 minutes	Meal after exercise
Continuous, moderate to vigorous intensity aerobic activities (eg, jogging/running, moderate intensity swimming, bicycling, cross country, aerobic play)	25%-50% bolus reduction	50%-75% bolus reduction	Up to 50% bolus reduction
Mixed aerobic and anaerobic burst activities (eg, hopping, skipping, dance, gymnastics, tag, dodgeball, field and team sports, individual racquet sports, etc.)	~25% bolus reduction	~50% bolus reduction	Up to 50% bolus reduction

and the night following the activity. High excitement amusement parks and fairs may be more likely to raise BG because of adrenalin surges.

It should be obvious from the above that individuals vary in their response to different types of exercise, so the most important thing is for patients and families to be aware of the broad themes and to use this knowledge coupled with good record keeping finding what works for them.

15 | 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 to 2 hours during an event. In these situations, patients may require a 50% bolus correction afterwards (ie, 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 60 minutes before starting the exercise,[111] but many centers advise that the pump should not be disconnected for more than 2 hours due to risks of ketosis. The safer option may be to set a temporary basal rate 90 minutes before the activity (50%-80% reduction depending upon the intensity and duration of the activity), lasting until the end of exercise.

Even if the pump is removed during exercise, hyperglycemia can still occur for several hours after the end of the activity.[112]

After a short period of intense exercise (≥80% VO_2 max), marked catecholamine responses lead to hyperglycemia which lasts for approximately 2 hours postexercise in adults with T1D.[26] Even when preexercise plasma glucose was normal, postexercise hyperglycemia lasted for 2 hours postexhaustion in pump patients.[113] 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 half-time or immediately after the exercise is finished.

New insulin pump technology may offer better opportunities to avoid hypoglycemia associated with exercise. The Automation to Simulate Pancreatic Insulin Response (ASPIRE) study, considered the use of LGS technology to turn off an insulin pump for 2 hours once a CGM sensor detected a blood glucose value less than 3.9 mmol/L (70 mg/dL). Subjects, including adolescents, were randomized to sensor augmented pump therapy with or without LGS turned on in a crossover study. After overnight fasting, subjects exercised until hypoglycemia occurred/LGS was activated. The LGS group duration of hypoglycemia was less.[103]

With the later added PLGM function the possibilities of further improvements are even more promising.[98]

During the last year promising closed-loop automated insulin delivery studies have been conducted. One study evaluated glucose control in young people with T1D during and after unannounced physical activity. In this study, glucose values were mostly maintained within the target range, without an increased risk of hypoglycemia.[114]

16 | GLUCOSE MONITORING

Blood glucose monitoring is the 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 attention paid to the direction of change in glycemia.

It can be especially useful, where a young person is involved in multiple sports or different types of training/competition for them to keep records in a structure that allows similar elements (eg, all the gym sessions or competition days) to be looked at together.

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 blood glucose levels predict nocturnal hypoglycemia and predictions are particularly difficult after exercise. In one hospital-based study where 34% had night-time hypoglycemia using a twice daily regimen NPH as basal insulin, a bedtime blood glucose of less than 7 mmol/L (125 mg/dL) suggested particular risk for nocturnal hypoglycemia,[115] while another study using long-acting basal analogues or pumps found a lower frequency of 13% but no threshold for nocturnal hypoglycemia risk after exercise in the afternoon.[88]

RtCGM has proven to be a valuable adjunct to blood glucose monitoring in both the prevention and early detection of exercise-induced hypoglycemia[100,101] and during a sports camp detected significantly more episodes of hypo- and hyperglycemia than frequent blood glucose testing.[116] With CGM it was also shown that exercise-induced hypoglycemia could be reduced by using value and trend information along with a new carbohydrate intake program.[69] Structured education can be implemented using downloads of SMBG, CGM, and insulin pumps.[117] CGM now offers the possibility to add followers who could assist the athlete. The use of isCGM during physical activity remains to be evaluated.

17 | EXERCISE MONITORING

Most smartphones can include pedometers, accelerometers, and Global Positioning System (GPS) receivers but the quality of the registered data as well as the impact on health has been questioned.[118] However, recently a study concluded that wearables have acceptable accuracy regarding monitoring of heart rate and energy expenditures. Thus, wearables may be important in the future as exercise then could be evaluated along with carbohydrate intake, insulin doses and glucose values.[119]

18 | KETONES

In situations of under-insulinization, any exercise is likely to be dangerous because of the effect of uninhibited action of the counterregulatory hormones. In one study in adults, patients exercising with a blood glucose of >20 mmol/L (360 mg/dL) and ketonuria experienced a rise in blood glucose over 40 minutes.[120]

The rapid production of ketone bodies coupled with impaired muscle glucose uptake will lead not only to under-performance but also may precipitate ketoacidotic abdominal pain and vomiting. Thus, it is important for families to be warned about participating in exercise if blood glucose is high and significant ketosis is present in the urine,[9,90,120] or when the level of BOHB (blood ketones) in blood is >0.5 mmol/L.

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 long-acting/basal insulin coverage is being provided, and under carefully monitored conditions.

Blood ketone testing provides additional information to urine ketone testing.[121] This method is excellent for rapid detection and exact measurement of ketone levels and is preferable, when available. During resolution of ketosis, blood ketones normalize before urine ketones.[122] Blood ketone levels >0.5 mmol/L are abnormal in children with diabetes.[123,124]

Patients can be reassured that reducing insulin down to 25% of preexercise doses does not make later ketosis more likely.[51]

See Figure 4 for overview on the recommended actions in the presence of elevated blood ketone values before the start of physical activity.

19 | SCHOOL ACTIVITIES AND DIABETES CAMPS

While this chapter is aimed principally at the practicalities of managing intense and/or prolonged physical activity, 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 the factors mentioned above. The subject is also described in 2018 ISPAD Clinical Practice Consensus Guidelines: Management and support of children and adolescents with T1D in school.

Some earlier studies have shown that school time may be one of the highest providers of activity to youth.[125] This is particularly relevant because the school environment has the potential to encourage physical activity in youth through physical education lessons, extracurricular activities (structured physical activity), and during recess or lunchtime (discretionary physical activity).

For many, all that will be required for a 30-minute recess break is a small snack of 10 to 15 g carbohydrate, for example, a fruit or fruit juice, dried fruit, a cereal, fruit or granola bar, or sports bar. Chocolate contains fat which will cause the sugar to be absorbed more slowly.[126] This can make it more suitable for low-grade longer-lasting activity, for example, hiking, swimming, or long walks. However, the extra calories are ideally avoided in those who are overweight or obese.

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.

For pump patients, a short period of disconnection may be best to allow free activity.

For longer periods of physical activity (>60 minutes), a reduction in basal insulin by 30% to 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 can also 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 and broad, but self-esteem is often improved, and where the activity is shared with others with diabetes, there are opportunities to learn better ways of coping and camaraderie shared with peers. Camps for children with diabetes that include counseling on nutrition and insulin adjustments for exercise can result in improved glycemic control.[127–129]

B-Ketones	B-Glucose ≤14 mmol/l (≤252 mg/dl)	B-Glucose >14 mmol/l (>252 mg/dl)	B-Glucose
B-Ketones ≥ 1.5 mmol/l	Add carbohydrates + insulin and give ½ correction dose of insulin with pen or syringe Act according to plan	Give ½ correction dose of insulin with pen or syringe Act according to plan	Avoid Exercise
B-Ketones1.1 – 1.4 mmol/l	Add carbohydrates + insulin and give ½ correction dose of insulin with pen or syringe	Give ½ correction dose of insulin with pen or syringe	Wait 60 min after correction and ensure decreasing glucose value Then OK to Exercise
B-Ketones 0.6 –1.0 mmol/l	Add carbohydrates + insulin and give ½ correction dose of insulin with pen or syringe	Give ½ correction dose of insulin with pen or syringe	Wait 15 min after correction Then OK to Exercise
B-Ketones < 0.6 mmol/l	No signs of DKA	No signs of DKA	Exercise is OK

FIGURE 4 Overview on the recommended actions in the presence of elevated blood ketone values before the start of physical activity

Insulin doses may have to be reduced substantially to prevent hypoglycemia in a camp setting, especially in children not accustomed to physical activity, and it is wise to begin with a 20% to 25% reduction in total daily dose.[130] A more recent study by Miller et al was conducted on 256 children aged 7 to 15 years attending a week long summer camp.[131] They reduced all children's insulin by 10% (55% were on pumps). Sixty percent of them had at least one episode of hypoglycemia on the first day. While, overall, insulin doses did not decrease further during the camp, the number of hypoglycemic episodes decreased. There was a difference between pumps and injections with children using injections requiring, approximately, an extra 8% insulin reduction. They also noted that the older children were more likely to have hypoglycemic episodes. Consideration of these factors may be wise before recommending the scale of insulin reduction.

When being physically active for a prolonged period, on a skiing trip or an outdoor camp, for example, insulin sensitivity will increase after 1 to 2 days 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.[83]

Where young people will be cared for by non-clinical professionals (eg, 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.

The emergence of "cloud technology" will afford even better opportunities to support children and young people participating in camps and activities away from home but care will be required not to overstep and impinge upon the development of independence.

Special mention should be made of the need to plan. Activities often last longer than anticipated so extra snacks and hyperglycemia remedies should always be carried. Diabetes educators may meet with parents, school and support staff to ensure that a child's participation can be planned properly.

20 | MISCELLANEOUS ADVICE FOR UNUSUAL ACTIVITIES

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 blood glucose while participating. However, diabetes care 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 a "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, for example, 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.

Diving clubs in the United Kingdom, as well as in many other countries, have allowed individuals with diabetes to scuba dive under certain carefully controlled circumstances.[132] In recent years, diving with T1D has been permitted in Australia and New Zealand, for example. The suggested age limit in the United Kingdom is ≥18 years (≥16 years if taking part in a special training program).[133] In the United States, the same age limits apply, and teenagers are only allowed to dive after counseling by a physician and with a letter stating they understand how to care for their diabetes during a dive. This letter is usually only provided to teenagers diving with their parents and after completing diving certification[133] (http://www.diversalertnetwork.org/news/download/SummaryGuidelines.pdf). In all countries where recreational scuba diving is allowed when diagnosed with T1D, the individual has to be declared as "fit-to-dive" by a physician and this should also be continuously reevaluated.[133] Specifically, the individual should have had no severe hypoglycemic episodes in the last 12 months.

A large number of dives performed by individuals with diabetes has been reported where no deaths, episodes of decompression illness, or hypoglycemia occurred,[134] even in 16- to 17-year old adolescents.[135] In another report, hypoglycemic events were present in very small numbers, with no adverse outcome.[136] Divers Alert Network (DAN) found 1.5% of participants having diabetes in a group of 1180 divers in Project Dive Exploration.[137] In this report, 4 of 101 accidents involved diabetes that could indicate that individuals with diabetes are exposed to a higher risk than healthy individuals.

Repetitive episodes of hypoglycemia should be avoided during days before diving, because this could blunt the hormonal response during subsequent exercise or hypoglycemia.[94]

The use of downloaded data from 2 weeks of home glucose measurements made it possible to identify those who are suitable for diving.

In order to prevent episodes of hypoglycemia during the dive, a monitoring schedule is recommended with assessment of capillary glucose levels 60, 30, and 10 minutes predive and immediately postdive.[138] This recommendation was later confirmed by analyzing data from a continuous glucose monitor before, during, and after dive.[139]

Those individuals with T1D who are permitted to dive should be trained to signal "L" (low) for hypoglycemia (signal performed with the hand while diving). For safety reasons they should also be trained to use a fructose/glucose gel for oral ingestion below the surface, if signs of hypoglycemia are present during dive.[139]

21 | TYPE 2 DIABETES

Without question, exercise has a direct and important role to play 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, reduces blood pressure and Low-Density Lipoprotein (LDL) cholesterol, and increases HDL, reducing the risk of cardiovascular morbidity and mortality.[140] Most 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.

Affected individuals and family members of adolescents in whom type 2 diabetes has been diagnosed have lifestyles characterized by minimal physical activity[141] and fitness.[142]

A twice-per-week 16-week resistance training program significantly increased insulin sensitivity in overweight adolescents independent of changes in body composition.[143]

Large clinical trials in adults with impaired glucose tolerance demonstrate that lifestyle interventions including exercise can reduce the incidence of type 2 diabetes.[144]

In a meta-analysis, it was found that exercise training reduced HbA1c by an amount that should decrease the risk of diabetes complications. This effect was not mediated primarily by weight loss.[145]

The incidence of hypoglycemia in type 2 diabetes is lower than in T1D, partly because counterregulatory mechanisms are less affected, but patients taking insulin or sulfonylurea medication (especially long acting preparations) may still require reduction in doses.[146,147]

22 | DIABETES COMPLICATIONS

Competitive sports are generally safe for anyone with T1D who is in good metabolic control and without long-term complications.[148] However, patients who have proliferative retinopathy or nephropathy should avoid exercise conditions that can result in high arterial blood pressures (systolic pressure >180 mm Hg), such as lifting heavy weights (or any tasks in which a Valsalva maneuver is involved) or performing high-intensity sprints[149] or a cold bath after a sauna. Patients with complications should be monitored with ambulatory blood pressure measurement during exercise. 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.[149] See Reference 148 for more detailed advice on diabetes complications and exercise, and Reference 150 for a more complete list of sport-specific advice.

23 | DIABETES AND BONE

The relationship between diabetes and osteopenia has been known since the 1950s but there has been much conflicting evidence. More recent studies have confirmed that children and adolescents with T1D do appear to have reduced bone mineral density compared to their peers without diabetes (inversely correlated with HbA1c).[151] Whether or not this is, in turn, influenced by physical activity is interesting given the widespread evidence that children generally are not meeting the published targets for activity. Salvatoni et al[152] studied 57 children and adolescents with diabetes and 57 controls and followed them with accelerometers to assess activity. Like others, they found that bone mineral density was less in diabetes, but they also found a direct correlation between the average time per week spent doing physical activity and bone mineral content. Their findings were confirmed by Heilman et al,[153] who found the most significant reductions in bone mineral content and bone mineral density in boys with diabetes and that the boys were also the least active.

Contrary evidence was presented in Maggio et al[154] who found that bone mineral density was normal during growth in 32 children with diabetes but that markers of bone turnover were decreased. Further support for abnormal bone metabolism in diabetes was demonstrated by Hamed et al when they studied 36 children and adolescents with diabetes and 15 controls and found that the group with diabetes had higher phosphate and parathyroid hormone levels with significantly lower levels of calcium, IGF-1 and 25(OH)D. They also showed total body osteopenia-osteoporosis in 94.4% (total body).[155]

A prospective study by Maggio et al[156] looked at the impact of two 90 minutes sessions per week of weight bearing exercise for 9 months (ball games, jumping, rope-skipping, and gymnastics) upon bone mineral density in 27 children with diabetes and 32 children without diabetes. After the intervention, both diabetes and non-diabetes cohort randomized to exercise had similar measures of bone mineral density and these were significantly different from the non-intervention group.

24 | SUMMARY

The management of exercise and physical activity physical activity presents challenges to the child/adolescent and their family members/carers in addition to the diabetes care team. Advice based on an understanding of the physiology of the activities and therefore the likely blood glucose responses is needed to enable increased levels of engagement in physical activity. Barriers to increasing levels of physical activity need to be tackled through education of both the health care provider and child/adolescent with diabetes. Counseling and advice should include safety advice and be individual to each child/adolescent and their situation. Promotion of regular physical activity is an integral part of diabetes care delivery and health care providers should promote this message at every available opportunity.

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