

Glucose Management for Exercise using Continuous Glucose Monitoring (CGM) and Intermittently Scanned CGM (isCGM) Systems in Type 1 Diabetes – Position Statement of the European Association for the Study of Diabetes (EASD) and of the International Society for Pediatric and Adolescent Diabetes (ISPAD) endorsed by JDRF and supported by the American Diabetes Association (ADA)

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Abstract

Physical exercise is an important component in the management of type 1 diabetes across the lifespan. Yet, acute exercise increases the risk of dysglycaemia, and the direction of glycaemic excursions depends to some extent on the intensity and duration of the type of exercise. Understandably, fear of hypoglycaemia is one of the strongest barriers to incorporate exercise in daily life. Risk of hypoglycaemia during and after exercise can be lowered when insulin dose adjustments are made and/or additional carbohydrates are consumed. Glycaemic management during exercise has been made easier with continuous (CGM) and intermittently scanned glucose monitoring (isCGM) systems; however, because of the complexity of CGM and isCGM systems, both individuals with type 1 diabetes and their health care professionals may struggle with the interpretation of given information to maximise the technological potential for effective use around exercise.

This position statement highlights the recent advancements in CGM and isCGM technology, with focus on the evidence base for their efficacy to sense glucose around exercise, adaptations in the use of these emerging tools, and updates the guidance for exercise in adults, children and adolescents with type 1 diabetes.

Abbreviations

ADL	Activities of daily living
CGM	Continuous glucose monitoring
IAH	Impaired awareness of hypoglycaemia
isCGM	Intermittently scanned continuous glucose monitoring
ISPAD	International Society for Pediatric and Adolescent Diabetes
MARD	Mean absolute relative difference
SMBG	Self-monitored blood glucose

Introduction

Regular physical activity and exercise are advocated by position and consensus statements in the management of type 1 diabetes [1–3]. As shown in a prospective observational study, dose-response relationships likely exist between the volume and the intensity of exercise and mortality in people with type 1 diabetes [4]. Predominantly based on cross-sectional analyses, the amount of exercise is inversely related to haemoglobin A1c (HbA_{1c}) levels, body mass index (BMI), the prevalence of diabetic ketoacidosis, retinopathy, microalbuminuria, hypertension, and dyslipidaemia in adults with type 1 diabetes [5]. Similar findings are seen in physically active children and adolescents with type 1 diabetes, with regard to better glycaemic control, body composition, and endothelial function as well as neurocognitive and psycho-behavioural functions [6–10]. In adults with type 1 diabetes, the recommendation for the dose of exercise is the same as for healthy adults as recommended by the *World Health Organization* (WHO)[11], at least until new evidence emerges otherwise due to the increased risk of cardiovascular disease in type 1 diabetes [12]. In general, 150 minutes per week of moderate-intensity exercise or 75 minutes per week of vigorous exercise with no more than two days of rest are suggested by position and consensus statements [1, 2], with exercise on three or more days per week typically better for glycaemic control as shown in a meta-analysis [13]. In children and adolescents aged 6–18 years, the recommendation by the *International Society for Pediatric and Adolescent Diabetes* (ISPAD) is at least 60 minutes or more of exercise each day, including moderate to intense aerobic, muscle, and bone-strengthening activities [3]. In adults, children and adolescents, different types of exercise such as endurance training (continuous exercise and high-intensity interval exercise), strength training, and sport games should be performed regularly to avoid monotony, maintain a healthy lifestyle and achieve the spectrum of exercise-associated benefits as shown in a cross-sectional study [14].

Even though the positive effects of regular physical activity and even the benefits of a single exercise session are well described in several studies and reviews [4, 5, 15–22], only 40–50% of individuals with type 1 diabetes achieve a physically active lifestyle as assessed by questionnaires and motion sensors

[23, 24]. Since exercise increases the risk of level 1 (<3.9 mmol/l) [<70 mg/dl] and level 2 hypoglycaemia (<3.0 mmol/l) [54 mg/dl]) in adults as well as in adolescents with type 1 diabetes as shown in a cross-sectional and experimental studies [5, 25, 26], questionnaire-assessed fear of hypoglycaemia is one of the strongest barriers to regular physical activity [27].

Assessment of Glucose Values around Exercise

Existing guidelines for exercise management are mainly based on self-monitoring of blood glucose (SMBG) and are consequently partly applicable for continuous (CGM) and intermittently scanned glucose monitoring (isCGM) systems [1–3]. The availability of CGM and isCGM systems is becoming a more integral component in the management of type 1 diabetes as shown by international consensus [28, 29] and allows the assessment of detailed sensor glucose profiles [29], also before, during and after exercise periods [30]. For certain devices, CGM and isCGM can now be used non-adjunctively, meaning that people with type 1 diabetes can base their therapy decisions on CGM and isCGM data [31]. A more recent review discusses how trend arrows in an isCGM system may be used to better perform therapy decisions around exercise in both people using multiple daily injection (MDI) and continuous subcutaneous insulin infusion (CSII) therapy [32]. Studies on how to use trend arrows for CGM systems are still limited; especially for exercise, recommendations from a single narrative review indicate to not perform insulin corrections for upward trend arrows during exercise [33].

CGM and isCGM systems measure glucose within the interstitial fluid, and hence a physiological lag time is present for the glucose to diffuse into or out of the blood vessels into the interstitial space as shown in an experimental study and discussed in a narrative review [34, 35]. Therefore, the concentrations of glucose measured at any time point are different between the circulating blood and interstitial fluid, and this difference is more pronounced during high rates of glucose change as shown in an experimental study [36]. Rapid increments in the rate of glucose change induced by exercise in combination with the physiological lag time between the blood and interstitial space as seen in experimental studies in adults with type 1 diabetes [37–39] challenge not only the performance of

CGM and isCGM devices but also the education on how to react best to the given information (Figure 1). For example, since these systems amalgamate the display of the directional rate of change in interstitial glucose (trend arrows) and the actual glucose values [32, 33, 40], there is a gap in the literature regarding how to guide users in CGM and isCGM particularly around exercise.

This position statement aims to highlight the recent advancements in CGM and isCGM technology, with focus on their evidence-based efficacy for sensing glucose around exercise, adaptations in the use of these emerging tools to better control glucose levels and update the guidance for exercise in adults, children and adolescents with type 1 diabetes.

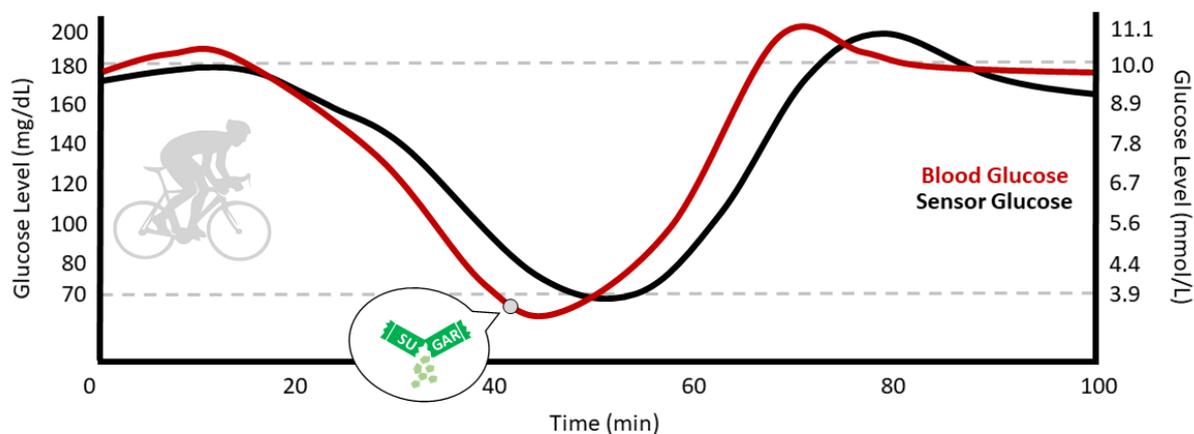


Figure 1: Schematic illustration of a potential lag time for the sensor glucose vs. blood glucose. This lag time might not be seen for all CGM and isCGM devices and in some cases sensor glucose might react earlier to glucose swifts when compared to blood glucose.

Methods Used for Group Consensus

Due to the growing popularity of CGM and isCGM technologies, this writing group produced modified and novel recommendations based on current evidence, consensus statements, and position statements for people with type 1 diabetes around exercise. This writing group consists of exercise physiologists, sports scientists, diabetologists, endocrinologists, paediatric diabetologists, bioengineers and nutritionists. After performing one-on-one meetings with all members of the writing group, a first outline was written based on the members' recommendations, including defined work packages for the authors. Subsequently, two lead authors (OM, JKM) produced a manuscript and circulated it within the writing group for further discussions. A consensus meeting was held during the

Advanced Technologies & Treatments for Diabetes (ATTD) 2020 conference in Madrid, Spain, and consensus was obtained. A final version of the position statement was then sent to the writing group for additional discussion, comments and final edits. All authors approved the final manuscript.

Data Sources, Searches and Study Selection

The consensus group accepted the position statement *Physical activity/exercise and diabetes of the American Diabetes Association (ADA)* [1], the consensus statement for *Exercise management in type 1 diabetes* [2] and the ISPAD *Clinical practice consensus guidelines for exercise in children and adolescents with diabetes* as a starting point [3]. Additionally, a systematic literature search was conducted by three independent researchers on PubMed, EMBASE, and Cochrane Library for publications on CGM and isCGM systems around exercise in people with type 1 diabetes between November to December 2019. Details on the keywords and the search strategy are available in supplemental material 1. Original data investigating the performance of CGM and isCGM systems during exercise were used to produce a forest-plot detailing the overall mean absolute relative difference (MARD) between sensor glucose and reference glucose. Systematic reviews and meta-analyses were included as additional information for the use of CGM and isCGM around exercise. In addition, reference lists from each relevant publication were screened to identify additional articles pertinent to the topic. Papers were grouped per theme and the authors reviewed the evidence. Nevertheless, though evidence-based, the recommendations presented within this position statement are the opinions of the authors.

Level of evidence was set according to the *Memorandum of Understanding* (MOU) between the *European Association for the Study of Diabetes* (EASD) and the writing group of this position statement. Level of evidence are thus expressed as: Ia) evidence from meta-analysis of randomised controlled trials, Ib) evidence from at least one randomised controlled trial, IIa) evidence from at least one controlled study without randomisation, IIb) evidence from at least one other type of quasi-experimental study, III) evidence from non-experimental descriptive studies, such as comparative

studies, correlation studies, and case-control studies, IV) evidence from expert committee reports or opinions or clinical experience of respected authorities, or both. If recommendations are given within this position statement the strength of those are expressed as: A) directly based on category I evidence, B) directly based on category II evidence or extrapolated recommendation from category I evidence, C) directly based on category III evidence or extrapolated recommendation from category I or II evidence, D) directly based on category IV evidence or extrapolated recommendation from category I, II, or III evidence date for scheduled review or expiry of the guidelines is given.

Definition of Exercise Intensity in People with Type 1 Diabetes

For the proper use of CGM and isCGM for decision-making around exercise, it is important to have knowledge of relative exercise effort and its characteristics. The writing group recommends to perform a graded incremental exercise test to determine exercise intensities during training [41](B), [42](D), [43](D), if this testing is not performed, then the BORG scale and/or the following question and answers may be used to help estimate the individual exercise intensity as given in Table 1 [44](B) [45](D). Knowledge of both the exercise intensity and the corresponding therapy adaptation ensures a better interpretation of the degree and direction of glycaemic disturbances [25, 46].

Table 1: Assessment of the exercise intensity based on questions and the BORG scale in relation to the % of the maximal heart rate. The BORG scale is a widely used scale for rate of perceived exertion (RPE). With the scale 6 to 20, a value of 6 represents rest while a value of 20 represents maximal effort.

Exercise intensity	% Maximal heart rate	Question Can you speak comfortably during a prolonged (>30 minutes) aerobic exercise session?	BORG scale
Rest 	<40%	N/A	6
Mild aerobic 	40–55%	Yes, easy	7–11
Moderate aerobic 	56–70%	Yes, but it is somewhat difficult to carry on a full conversation	12–15
Intense (an)aerobic exercise 	>70%	No, too difficult	16–20

Strategies to Reduce the Risk of Exercise-Induced Hypoglycaemia

Exercise-induced hypoglycaemia is largely caused by relative hyperinsulinemia and deficient counterregulatory response to acute exercise as shown in adults with type 1 diabetes [47]. Several therapy strategies have been developed to lower the risk of exercise-induced hypoglycaemia in people living with type 1 diabetes, depending on the type of therapy and the ability to modify insulin dosages (Figure 2) [1–3]. However, all current guidelines were made for SMBG and do not contain details on how to use CGM and iscCGM systems [1–3].

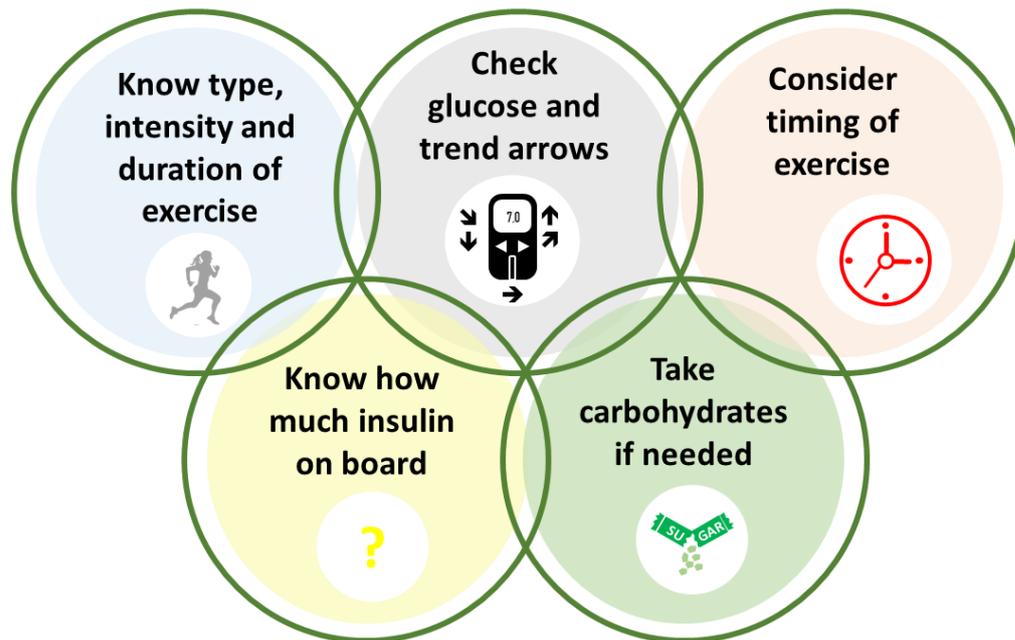


Figure 2: “The Rings to Success” to improve glycaemia for exercise in type 1 diabetes. To ameliorate glycaemia for exercise the type, intensity and duration should be defined, glucose should be monitored as of often as possible and the timing of exercise might result in different therapy adaptations; higher levels of insulin increases the carbohydrate intake during and after exercise.

Carbohydrate Consumption

An effective approach to avoid dysglycaemia is usually a small carbohydrate snack taken during or soon after exercise as shown in experimental studies and discussed in a narrative review [48–50]. The amount of ‘extra’ carbohydrates to avoid hypoglycaemia with exercise can depend on the pre-exercise glucose level and the amount of active insulin on board. It has been shown that a mean of 36g of carbohydrates per hour was successful in avoidance of hypoglycaemia during moderate aerobic exercise in adults with type 1 diabetes when a regular bolus insulin dose was injected two hours in advance [49]. The amount of consumed carbohydrates during exercise was inversely related with the pre-exercise blood glucose level, ranging from as high as 62g of carbohydrates per hour when the pre-exercise glucose level was ~ 7.3 mmol/L [131 mg/dl] to only 30g of carbohydrates per hour when the pre-exercise blood glucose level was ~ 12.4 mmol/l (223 mg/dl). Considerable inter-individual variation exists to prevent exercise-induced hypoglycaemia, with some individuals requiring less than 10g of carbohydrates per hour [49]. One retrospective controlled analysis demonstrated that carbohydrate

consumption during moderate aerobic exercise is preferable to pre-exercise bolus insulin dose reduction in avoiding hypoglycaemia [51], although the latter approach can also work [25]. The consumption of 'extra' carbohydrates with exercise can result in a loss in the caloric deficit, which may be unappealing for those wishing to lose bodyweight as discussed in a narrative review [52]. When a late-afternoon or evening exercise session is performed and a nocturnal fall in glucose is expected, an additional bedtime snack can be consumed (~0.4g carbohydrates/kg) without bolus insulin administration to counteract the potential occurrence of hypoglycaemia [53]. More information about carbohydrate supplementation around exercise is given in a previous consensus statement [2] and in the section "Therapy Decisions from Sensor Glucose Values and Trend Arrows for Exercise".

Bolus Insulin Dose Reduction

Mealtime insulin dose reduction requires planning and should be performed 1 to 3 hours prior to the start of exercise [2](**D**). The writing group recommends that the exercise intensity, duration, and type should be pre-determined, to allow for specific administrations of bolus insulin dose reductions as given in Figure 3 [25](**B**), [54](**B**), [55](**B**), [56] (**B**). Even if bolus insulin is reduced prior to the start of exercise, hyperinsulinaemia may still be present and additional carbohydrates might be required depending on the duration, intensity and type of exercise to counteract hypoglycaemia as shown in an experimental study [57]. If the first carbohydrate-rich meal is consumed within 1 to 3 hours after the exercise session and glucose level is in the euglycaemic range (3.9–10.0 mmol/l; 70–180 mg/dl), bolus insulin dose may be reduced by 25% to 75% (e.g., -25% for light activities; up to -75% for more moderate-to-intense aerobic activities), depending on characteristics of the performed exercise session and the amount of carbohydrates planned to be ingested during the exercise as shown in different experimental studies [25, 56, 58, 59](**D**). If the exercise session contains elements of very intensive aerobic and/or anaerobic work but is still of sufficient duration (>30 minutes), then some reduction in mealtime insulin dose is likely warranted [60]. The decrease in glucose levels is largely due to muscle contraction-induced increase in glucose disposal rate, likely via insulin-dependent and insulin-independent mechanisms as shown in a mice study and discussed in previous reviews [61–63].

However, significant mealtime insulin dose reduction is often associated with pre-exercise hyperglycaemia [25, 56, 58, 59], so care should be taken to monitor glucose levels carefully. If glucose levels are severely elevated prior to exercise (≥ 15.0 mmol/l [270 mg/dl]), the writing group recommends to monitor blood ketone levels [2](D) and an insulin correction may be performed based on the individual’s correction factor. If a blood ketone measurement device is not available, then urine ketone measurement can be performed; however urine ketone measurements have a decreased sensitivity and specificity to detect diabetic ketoacidosis [64](D).

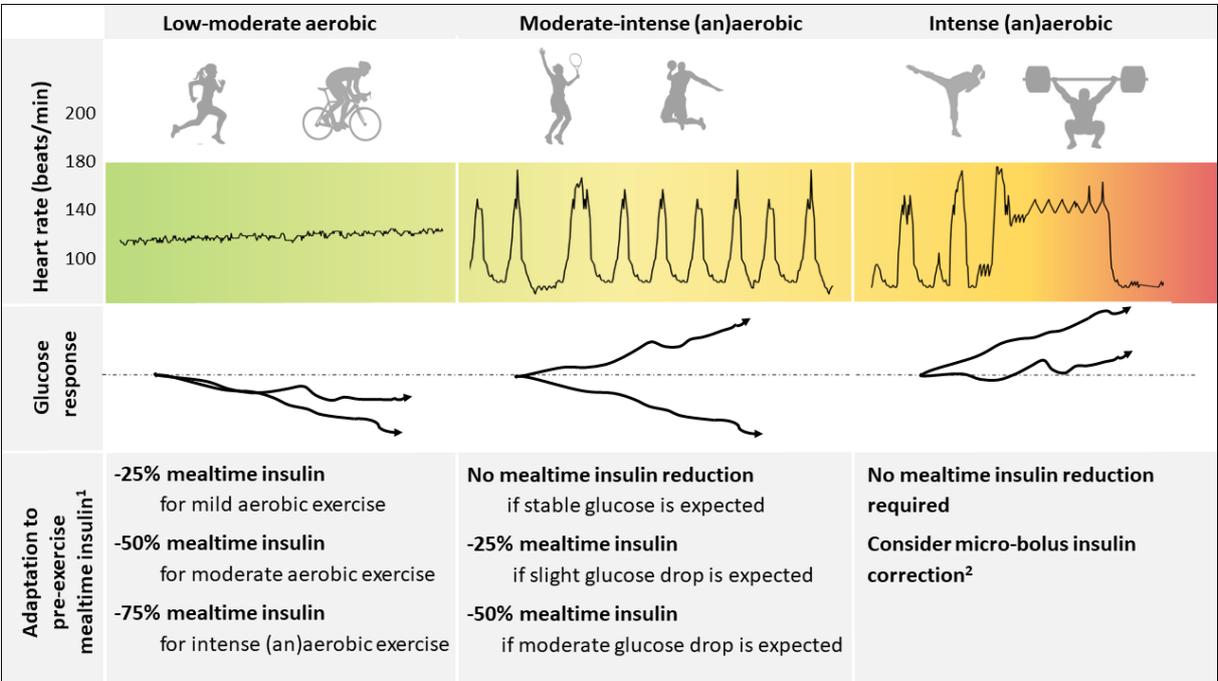


Figure 3: Expected glucose response to different workload profiles in people with type 1 diabetes and its associated action in advance to exercise to counteract hypoglycaemia. ¹ Recommendations for a duration of ~30 minutes of exercise; bolus insulin dose needs to be further reduced for longer duration exercise. ² 50% of individual correction factor. Modified from Riddell et al. [2].

Basal Insulin Dose (MDI) and Basal Rate Reductions (CSII)

Limited evidence exists on basal insulin dose reductions for exercise. As shown for insulin glargine U-100 in an experimental study, basal insulin dose reduction by 20% on the day of exercise is sufficient to reduce the risk of hypoglycaemia during and after exercise [53]. When moderate aerobic exercise is performed over consecutive days (+5 days), insulin degludec U-100 can be reduced by 25% three days

prior to the exercise event to help increase the time in range (TIR; 3.9–10 mmol/l [70–180 mg/dl]) compared to the usual degludec U-100 dose (i.e., 100% dose) as shown in an experimental study [65]. Therefore, the writing group recommends to reduce basal insulin dose for MDI by 20–25% if required, to improve glycaemia around exercise, especially for the nocturnal period [53](B), [65](B). However, reducing insulin degludec U-100 three days before a tentatively planned exercise period may not be that practical for those who are unable to plan their exercise and may promote a rise in glucose at other times of day or night.

For people using continuous subcutaneous insulin infusion (CSII), we recommend to reduce the basal rate by 50–80% of their usual rate, 90 minutes prior to the start of moderate aerobic exercise and maintain this rate throughout the duration of activity [66](B), [67](D), [68](D), [2](D). Basal rate reductions performed closer to the start of exercise may be more convenient, but may be insufficient to reduce the risk of hypoglycaemia as seen in an experimental study [69]. Insulin pump suspension at the start of exercise is likely less effective in avoiding hypoglycaemia than more proactive basal rate reductions as shown in experimental studies [66, 70]. It should be noted, however, that most CSII exercise studies were undertaken in the post-absorptive state at a time when the influence of the last mealtime insulin injection is thought to be marginal. As such, if bolus insulin is still active in circulation at the time of exercise, then some carbohydrate intake may be necessary even with proactive basal rate reductions. Especially when exercise is performed in the late afternoon or early evening, the basal rate can be reduced by 20% for six hours in the subsequent night-time to help limit post-exercise induced nocturnal hypoglycaemia as shown in an experimental study in children with type 1 diabetes [71](B). Recommendations given in the following sections are not suitable for people using hybrid closed-loop systems; guidance for hybrid closed-loop systems is shown in the section “The Use of Sensor Augmented Insulin Pumps and Hybrid Close-Loop Systems”.

Advantages and Disadvantages of CGM and isCGM for Exercise

Most common CGM systems measure glucose in the interstitial fluid, providing real-time sensor glucose data, while isCGM measures interstitial glucose levels at the time of scanning via a reader device. CGM improves the time spent in euglycaemia and reduces (severe) hypoglycaemia in people with impaired awareness of hypoglycaemia, decreases HbA_{1c} levels, and ameliorates general measures of glycaemia as shown in different randomised (cross-over) studies [72–75]. isCGM reduces the time spent in hypoglycaemia as shown by randomised controlled studies [76, 77] and decreases in HbA_{1c} levels as shown by a meta-analysis [78] of largely observational studies. Interestingly, switching from isCGM to CGM may have a beneficial impact on hypoglycaemia outcomes in people with a high risk of hypoglycaemia, perhaps because the latter displays data without the need to scan and is augmented by alerts for when the sensor glucose approaches hypoglycaemia as detailed in a randomised parallel-group study [79].

Nonetheless CGM technology is also accompanied by limitations like skin irritation and pain as assessed in children and pregnant women [80–83], sleep disruption due to discomfort associated with the position of the device [84], a constant reminder of having diabetes, overload of information and that the device is visible to others [82, 84, 85]. Furthermore, it is important to note if hypo- and hyperglycaemic symptoms are not in line with the sensor glucose value, a confirmatory SMBG should be performed.

A lag time between the point glucose value in the vasculature and interstitial fluid does exist and thus influences sensor glucose measurement accuracy against blood glucose values [35]. Moreover, other physiological changes during exercise, such as alterations in blood flow rate, body temperature and body acidity can theoretically impact interstitial glucose sensing-accuracy [35], though the degree of impact of these factors is unknown on an individual basis. Thus, when assessing the accuracy of different interstitial glucose monitoring systems versus reference glucose, which is usually assessed by a median or mean absolute relative difference (MARD), a part of the difference should be interpreted as lag time rather than inaccuracy as shown in a secondary outcome analysis

of an experimental study [86]. Additionally, other factors like local-metabolic rate, sensor site [87], exercise type [88, 89], vasoconstriction [90], potential interference with medications [91], the direction of glucose rate of change [34, 92] and baseline glucose level may influence lag time [35]. Also, the glucose concentration per se might impact the sensor accuracy as seen for isCGM, detailing a lower MARD for hyperglycaemia and higher MARD for hypoglycaemia shown by two experimental studies [57, 93]. At rest, a lag time of ~5 minutes is seen in healthy individuals [94], while in situations of rapid glucose changes, it can increase up to 12–24 minutes or even longer during exercise as seen in people with type 1 diabetes [34, 92, 95]. Depending on the CGM and isCGM device, the overall mean of all MARDs' during different types of exercise in people with type 1 diabetes is ~13.63% [11.41–15.84 as detailed in Figure 4 [34, 57, 70, 86–88, 93, 95–104]. However, more recent CGM and isCGM devices, not yet investigated for exercise, might have a lower MARD and enhanced performance.

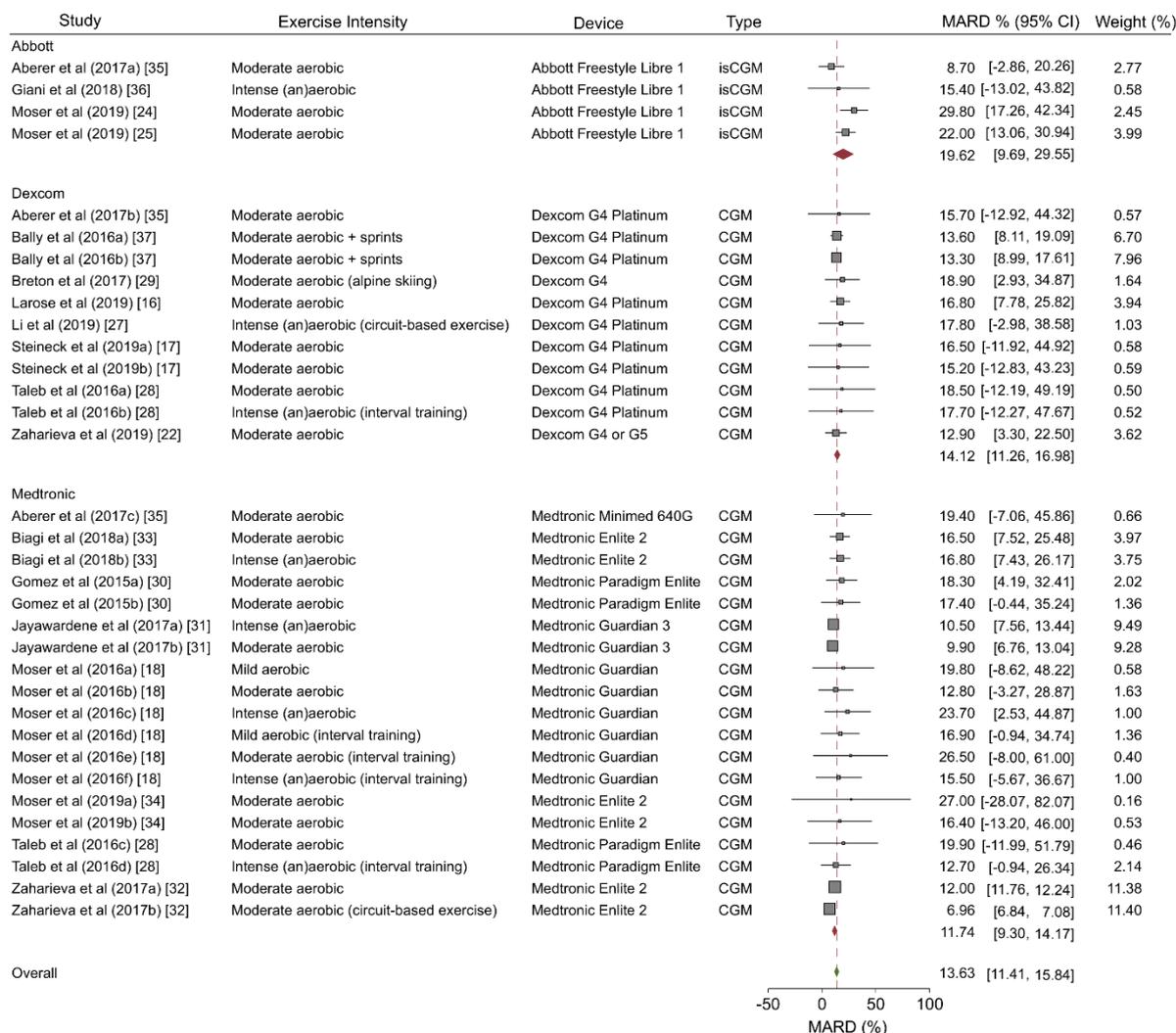


Figure 4: Weighted for number of participants and standard deviation of mean absolute relative difference (MARD) for different manufacturers over all systems. CGM = continuous glucose monitoring; isCGM = intermittently scanned glucose monitoring. All types of studies were included using CGM and/or isCGM during exercise in people with type 1 diabetes (studies Giani et al. 2018 [104] and Breton et al. 2017 [98] have been performed in children and adolescents).

Interpretation of Trend Arrows for CGM and isCGM

Trend arrows are one of the major advances of CGM and isCGM systems compared to SMBG as discussed in narrative reviews [105, 106]. Trend arrows allow the user to better understand their sensor glucose trend so that more proactive actions can be taken (e.g., intake of carbohydrates before hypoglycaemia occurs). Various CGM and isCGM systems display different trend arrows based on the expected subsequent variation of the sensor glucose concentration as shown in the respective user

manuals [107–110]. For adequate interpretation and therapy decision based on trend arrows, it is important to understand their meaning; however, recommendations given in this position statement are based on generic trend arrows as detailed in Table 2.

Table 2: Explanation of most commonly used CGM and isCGM devices with respect to trend arrows. ¹ No horizontal arrow available for this device - if Medtronic CGM system displays no trend arrow, this means that sensor glucose is stable as detailed below.

Device	Trend Arrow	Interpretation within 15 min	Conforms with generic trend arrow as used in the position statement
Abbott Devices Senseonics Devices	↑	Increase >1.7 mmol/l (30 mg/dl)	↑
	↗	Increase 0.8–1.7 mmol/l (15–30 mg/dl)	↗
	→	Increase/decrease <0.8 mmol/l (15 mg/dl)	→
	↘	Decrease 0.8–1.7 mmol/l (15–30 mg/dl)	↘
	↓	Decrease >1.7 mmol/l (30 mg/dl)	↓
Dexcom Devices	↑↑	Increase >2.5 mmol/l (45 mg/dl)	↑
	↑	Increase 1.7–2.5 mmol/l (30–45 mg/dl)	
	↗	Increase 0.8–1.7 mmol/l (15–30 mg/dl)	↗
	→	Increase/decrease <0.8 mmol/l (15 mg/dl)	→
	↘	Decrease 0.8–1.7 mmol/l (15–30 mg/dl)	↘
	↓	Decrease 1.7–2.5 mmol/l (30–45 mg/dl)	↓
	↓↓	Decrease >2.5 mmol/l (45 mg/dl)	
Medtronic Devices ¹	↑↑↑	Increase >2.5 mmol/l (45 mg/dl)	↑
	↑↑	Increase 1.7–2.5 mmol/l (30–45 mg/dl)	
	↑	Increase 0.8–1.7 mmol/l (15–30 mg/dl)	↗
		Increase/decrease <0.8 mmol/l (15 mg/dl)	→
	↓	Decrease 0.8–1.7 mmol/l (15–30 mg/dl)	↘
	↓↓	Decrease 1.7–2.5 mmol/l (30–45 mg/dl)	↓
	↓↓↓	Decrease >2.5 mmol/l (45 mg/dl)	

Therapy Decisions from Sensor Glucose Values and Trend Arrows for Exercise

Different groups of people with type 1 diabetes may require different glycaemic ranges in preparation for, during and after performing exercise when using CGM and isCGM systems based on different position and consensus statements [3, 29, 111, 112]. As discussed previously, CGM and isCGM devices may provide a different glucose reading compared to the actual SMBG, especially during exercise (Figure 4), and thus the sensor glucose value should be interpreted together with the corresponding trend arrow. Safe glycaemic ranges and specific carbohydrate consumption will be recommended below based on previous position and consensus statements [1](D), [2](D), [3](D) and modified based on experimental studies [113](D), [114](D) as well as on the experience of this writing group. Groups within the population of type 1 diabetes, based on different characteristics in this position statement are defined as children and adolescents (6 to <18 years) and adults (≥ 18 years) with type 1 diabetes. Additionally, further groups were defined based on the risk of hypoglycaemia, exercise experience and health status (older adults aged ≥ 65 years). Since structured exercise training is less common in pre-schoolers as observed in healthy individuals [115], the writing group is unable to provide specific recommendations due to the general lack of scientific evidence for this age group. Sustained hyperglycaemia (hours) and/or frequently occurring hypoglycaemia during exercise should be discussed between the individual and his/her health care professional team to develop individualised strategies that improve glycaemia and support ongoing regular participation in exercise. The recommendations below serve as starting points and should be individualised.

Different glucose responses are evident depending on the type of exercise as seen in different experimental studies [38, 116–118]; mild-moderate aerobic exercise decreases glucose levels [25, 49, 119] intense aerobic-anaerobic exercise and exercises with a load-profile similar to interval exercise stabilise [120] or increase glucose levels as seen in various experimental studies [121–123]. Independent of the aforementioned groups (adults and children/adolescents), individuals who do not routinely exercise may face an increased risk of hypoglycaemia as partially shown in a prospective observational study [5](C). Additionally, impaired awareness of hypoglycaemia (IAH) [124](C),

preceding episodes of hypoglycaemia [125](B) and advanced age [5](C) potentially increase the risk of hypoglycaemia during and after exercise. Therefore, the writing group recommends that the following groups can be categorised:

- Currently minimally exercising and/or high risk of hypoglycaemia
- Currently moderately exercising and/or moderate risk of hypoglycaemia
- Currently intensively exercising and/or low risk of hypoglycaemia

Assessment of exercise routine and risk of hypoglycaemia is recommended to be performed by a decision tree modified based on a large-scale observational study and a recent consensus statement [5](C), [29](D) (Figure 5):

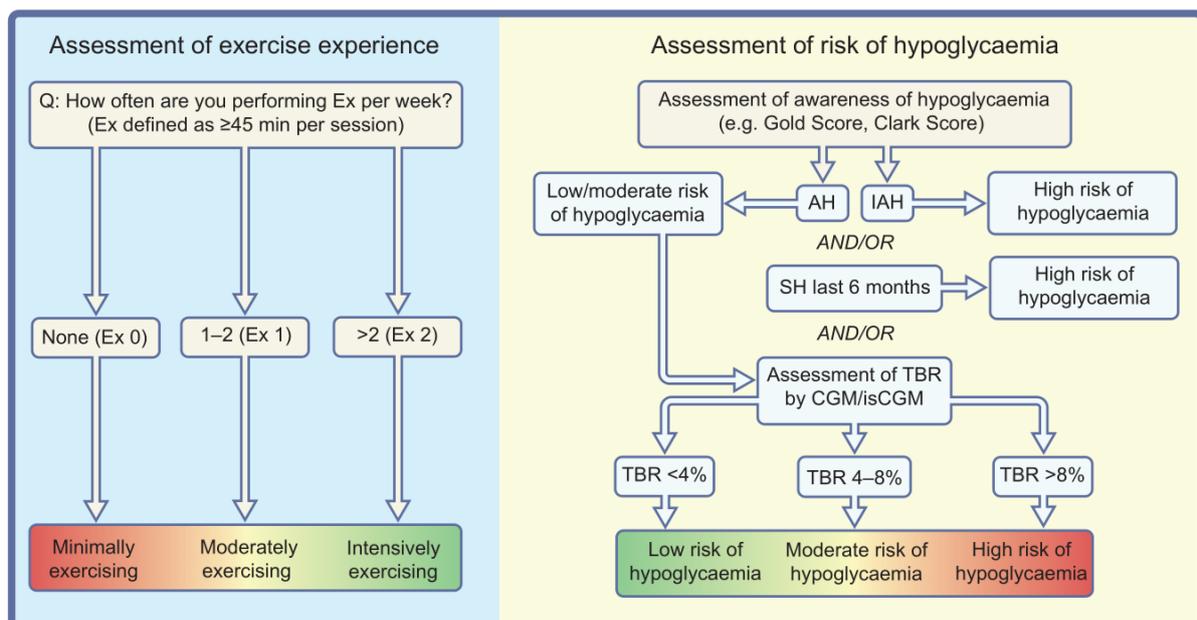


Figure 5: Assessment of exercise experience and risk of hypoglycaemia. Exercise (Ex) evaluates how often people with type 1 diabetes are exercising with a duration ≥ 45 minutes per session per week. Assessment of risk of hypoglycaemia should be based on scoring systems for being aware (AH) or showing an impaired awareness to hypoglycaemia (IAH). Additionally, if scoring system reveals AH, the time below range (TBR; <70 mg/dl, 3.9 mmol/l) over the last 3 months should be evaluated to detail the degrees of awareness. Furthermore, if an episode of severe hypoglycaemia (SH) occurred within the last 6 months then there might be a high risk of hypoglycaemia during exercise.

Older and/or frail adults with type 1 diabetes (aged ≥ 65 years) may have a different health status that is reflected by different glycaemic goals based on HbA_{1c} and TIR as discussed by recent consensus and position statements [29, 112]. In general, for this group exercise is recommended to be performed 2–

3 times per week as discussed by a position statement [1](D). However, older people with type 1 diabetes are at an increased risk of severe hypoglycaemia around physical activity and exercise [5](C). Considering this, higher glycaemic targets can be recommended for exercise based on patient characteristics and health status to lower the risk of hypoglycaemia. Therefore, exercise can also be recommended for older adults with few coexisting chronic illnesses, intact cognitive and functional status and for older adults with coexisting chronic illnesses or two or more instrumental Activities of Daily Living (ADL) impairments or mild-to-moderate cognitive impairment [126](D). For older adults with very complex and poor health status the possibility to perform exercise should be evaluated on a case-by-case basis [126](D).

Recommendations for exercise based on habitual physical activity, risk of hypoglycaemia and health status (older and/or frail people with type 1 diabetes) should follow a more conservative strategy, which enables the avoidance of exercise-induced glycaemic excursions. General therapy strategies as detailed in section “Strategies to Reduce the Risk of Exercise-Induced Hypoglycaemia” can be applied to facilitate exercise. If a person is more routinely exercising and/or has a lower risk of hypoglycaemia over a period of three months, then the glycaemic thresholds for carbohydrate consumption might be adjusted. Furthermore, in the following sections, generic trend arrows are given independently of the device used. Device-dependent interpretation of trend arrows is given in the section “Interpretation of Trend Arrows for CGM and isCGM”.

Adults with Type 1 Diabetes

CGM and isCGM systems can be used as effective tools to help indicate when carbohydrate intake should be initiated to prevent or treat hypoglycaemia during prolonged exercise as seen in experimental studies in children and adolescents with type 1 diabetes [113, 114]; however, the significant lag time in these technologies should be taken into consideration when to initiate carbohydrate intake [95]. Furthermore, the isCGM requires frequent scanning since no automatic alerts are available for the first-generation device as discussed in a narrative review [32]. The following

recommendations are given for adults with type 1 diabetes at which lower glycaemic threshold carbohydrates might be consumed [1](D), [2](D), [3](D), [113](D), [114](D). Recommendations should be further individualised:

- <7.0 mmol/l (126 mg/dl) for adults with type 1 diabetes, intensively exercising and/or low risk of hypoglycaemia
- <8.0 mmol/l (145 mg/dl) for adults with type 1 diabetes, moderately exercising and/or moderate risk of hypoglycaemia; older adults with coexisting chronic illnesses, intact cognitive and functional status
- <9.0 mmol/l (161 mg/dl) for adults with type 1 diabetes, minimally exercising and/or high risk of hypoglycaemia; older adults with coexisting chronic illnesses or two or more instrumental Activities of Daily Living (ADL) impairments or mild-to-moderate cognitive impairment

To lower the risk of hypoglycaemia during prolonged exercise, exercise should be initiated when mealtime insulin levels are low or about 90 minutes after the last carbohydrate-rich meal with a reduction in mealtime insulin [1](D), [2](D) (Figure 3). However, to achieve beneficial effects of exercise on overall glycaemic control, exaggerated bolus insulin dose reductions should be avoided as discussed in a meta-analysis [127](D).

Preparation in Advance to Exercise

If a CGM or a second-generation isCGM device is used, hypoglycaemic alerts might be set at the highest possible alarm threshold at the onset of exercise, which is currently 5.6 mmol/l (100 mg/dl) [34](D). This elevated hypoglycaemia alert setting is in line with the expected delay between interstitial glucose and blood glucose when levels are dropping during prolonged exercise [34]. Importantly, for the second generation isCGM device, an alert is only shown once and not repeated. Hyperglycaemic alert can be set to 10.0 mmol/l (180 mg/dl), or higher to avoid alarm fatigue [128](D). The rate of glucose change alerts (dropping or rising) can be used to initiate an earlier action, such as a decrease or increase in basal insulin rate for those on CSII or a change to glucose-rich or glucose-free fluids

depending on the direction of change. Thirty to sixty minutes prior to the start of prolonged aerobic exercise (>30 minutes), to reduce hypoglycaemia risk, low glycaemic index carbohydrates can be consumed in those who do not reduce insulin dose, aiming to achieve pre-exercise sensor glucose targets. A detailed description of pre-exercise sensor glucose levels, trend arrows and consumption of carbohydrates is shown in Table 3 based on position and consensus statements and experimental studies [1](D), [2](D), [3](D), [113](D), [114](D). Furthermore, the aforementioned strategies with respect to bolus and basal insulin dose, basal rate reductions, as well as insulin pump suspension, can be applied to facilitate achieving pre-exercise glycaemic ranges (see section “Strategies to Reduce the Risk of Exercise-Induced Hypoglycaemia”).

Table 3: Sensor glucose targets in advance of exercise in regard to different groups of people with type 1 diabetes.

Pre-exercise sensor glucose for different groups in T1D			Trend arrow	Action	
Ex 2 and/or low hypo risk	Ex 1 and/or moderate hypo risk ^a	Ex 0 and/or high hypo risk ^b	Direction	Increase in sensor glucose expected	Decrease in sensor glucose expected
>15.0 mmol/l (>270 mg/dl) AND >1.5 mmol/l blood ketones			↗↘↔↙↕	No Ex, Insulin correction	
>15.0 mmol/l (>270 mg/dl) AND ≤1.5 mmol/l blood ketones			↗↗	Consider insulin correction ^c , Can start AE	Consider insulin correction ^c , Can start all Ex
			→	Consider insulin correction ^c , Can start AE	Consider insulin correction ^c , Can start all Ex
			↘↘	Can start all Ex	
10.1–15.0 mmol/l (181–270 mg/dl)	11.1–15.0 mmol/l (199–270 mg/dl)	12.1–15.0 mmol/l (217–270 mg/dl)	↗↗	Can start AE	
			→	Consider insulin correction for RT, HIT ^c	
			↘↘	Can start all Ex, Consider insulin correction ^c	Can start all Ex
7.0–10.0 mmol/l (126–180 mg/dl)	8.0–11.0 mmol/l (145–198 mg/dl)	9.0–12.0 mmol/l (162–216 mg/dl)	↗↗	Can start all Ex	
			→		
			↘↘	Can start all Ex	~15 g CHO, Can start all Ex
5.0–6.9 mmol/l (90–125 mg/dl)	5.0–7.9 mmol/l (90–144 mg/dl)	5.0–8.9 mmol/l (90–161 mg/dl)	↗↗	Can start all Ex	~15 g CHO, Can start all Ex
			→	~10 g CHO, Can start all Ex	~20 g CHO, Can start all Ex
			↘	~15 g CHO, Delay all Ex ^d	~25 g CHO, Delay all Ex ^d
			↓	20 g CHO, Delay all Ex ^d	~30 g CHO, Delay all Ex ^d
3.9–4.9 mmol/l (70–89 mg/dl)			↑	~10 g CHO, Can start all Ex	~20 g CHO, Delay Ex ^d
			↗	~15 g CHO, Delay all Ex ^e	~25 g CHO, Delay all Ex ^d
			→	20 g CHO, Delay all Ex ^e	~30 g CHO, Delay all Ex ^d
			↘	~25 g CHO, Delay all Ex ^e	~35 g CHO, Delay all Ex ^d
			↓	Individual amount CHO ingestion, Delay all Ex ^e	Individual amount CHO ingestion, Delay all Ex ^d
<3.9 mmol/l (<70 mg/dl)			Individual amount CHO ingestion, Delay all Ex ^f		

Sensor glucose targets are detailed for the following groups in type 1 diabetes (T1D): intensively exercising and/or low risk of hypoglycaemia (Ex 2); moderately exercising and/or moderate risk of hypoglycaemia (Ex 1); minimally exercising and/or high risk of hypoglycaemia (Ex 0)

^a Recommendation for older adults with coexisting chronic illnesses and intact cognitive and functional status

^b Recommendation for older adults with coexisting chronic illnesses or two or more instrumental ADL impairments or mild-to-moderate cognitive impairment

^c 50% of regular insulin correction factor when sensor glucose is close to the upper threshold

^d Delay exercise until reaching at least 5.0 mmol/l (90 mg/dl) and →, ↗, or ↑

^e Delay exercise until reaching at least 3.9–4.9 mmol/l (70–89 mg/dl) and ↑

^f Delay exercise until reaching a sensor glucose of 3.9–4.9 mmol/l (70–89 mg/dl) with an ↑ arrow if an increase in sensor glucose is expected during exercise, or delay exercise until reaching at least 5.0 mmol/l (90 mg/dl) and →, ↗, or ↑ if a decrease in sensor glucose during exercise is expected

When reaching the required sensor glucose level to start exercise, only consume carbohydrates again when trend arrow is starting to decrease

These recommendations are not applicable to hybrid closed-loop systems

Green shading, no/minimal action required; light-yellow shading, minimal/moderate action required; dark-yellow shading, moderate/intense action required; red shading, no/delay exercise

AE, mild-to-moderate intensity aerobic exercise; CHO, carbohydrate; Ex, exercise; HIT, high-intensity training; hypo, hypoglycaemia; RT, resistance training

During Exercise

Independent of the type of exercise, the target sensor glucose ranges should be between 5.0–10.0 mmol/l (90–180 mg/dl) and ideally between 7.0–10.0 mmol/l (126–180 mg/dl) for prolonged aerobic exercise for the majority of adults with type 1 diabetes and slightly higher for those with an increased risk of hypoglycaemia (Table 4) [1](D), [2] (D). If sensor glucose is expected to increase as often seen in people performing fasted high-intensity interval training [121, 129], resistance training [117, 130, 131] and also in training above the anaerobic threshold [132], then an insulin correction can be administered at the onset as well as during exercise (50% of typical correction factor) [133](D), [134](D).

For safety reasons, the exercise should be suspended, at least temporarily, if the sensor glucose level reaches <3.9 mmol/l (70 mg/dl) and oral carbohydrates should be consumed [28](D). Furthermore, at this threshold, a confirmatory SMBG might be performed to confirm the sensor glucose level. After

reaching a sensor glucose level close to 4.4 mmol/l (80 mg/dl), accompanied by horizontal/upward trend arrow, exercise can be restarted. Many CGM systems provide a hypoglycaemia prediction alert. If the sensor glucose level is predicted to reach <3.0 mmol/l (54 mg/dl), then fast-acting oral carbohydrates should be consumed immediately. If sensor glucose drops below 3.0 mmol/l (54 mg/dl) then exercise should not be restarted. During exercise, fast-acting liquid carbohydrates should be consumed consisting primarily of glucose (dextrose) or a mixture of glucose/fructose as discussed in narrative reviews [135](D), [136](D). A read or scan from the CGM or isCGM system might be performed every 15–30 minutes if feasible during exercise to ensure early and appropriate treatment against hypo- or hyperglycaemia, and to assess the appropriateness of strategies to prevent dysglycaemia. With CGM, alerts could also be activated regarding the rate of change in glucose, providing the user with valuable information. For the majority of adults with type 1 diabetes who are at a low risk of hypoglycaemia, at a glycaemic threshold of 7.0 mmol/l (126 mg/dl), accompanied by a horizontal trend arrow, 10–15g of carbohydrates should be consumed; 15–25g carbohydrates should be consumed immediately if accompanied by a (slight) downward trend arrow; 20–35g of carbohydrates should be consumed if accompanied with a downward trending arrow (Table 4) [1](D), [2](D), [3](D), [113](D), [114](D). Carbohydrates should be consumed regularly (e.g., every 15 to 20 minutes) when reaching the lower glycaemic threshold, and carbohydrate supplementation should be repeated if sensor glucose is not rising according to the trend arrows within 30 minutes. These carbohydrate recommendations should be used as a guidance and personalized based on individual glucose responses to exercise and the amount of carbohydrate supplementation, if necessary. Carbohydrate consumption during exercise in individuals with type 1 diabetes for endurance performance is similar to the carbohydrate needs in healthy individuals (30–80g carbohydrates per hour), typically reflecting the physiological and/or performance demands of exercise [137](A). A lower carbohydrate intake rate can be achieved during prolonged exercise if desired, but aggressive insulin dose adjustments will likely need to be made [25](B), [54](B), [138](D).

Table 4: Sensor glucose targets during exercise in regard to different groups of people with type 1 diabetes.

During exercise sensor glucose for different groups in T1D			Trend arrow	Action	
Ex 2 and/or low hypo risk	Ex 1 and/or moderate hypo risk ^a	Ex 0 and/or high hypo risk ^b	Direction	Increase in sensor glucose expected	Decrease in sensor glucose expected
>15.0 mmol/l (>270 mg/dl) AND >1.5 mmol/l blood ketones			↗↘↙↚	Stop Ex, Consider insulin correction, No restart of Ex	
>15.0 mmol/l (>270 mg/dl) AND ≤1.5 mmol/l blood ketones			↗↗	Consider insulin correction ^c , Proceed all Ex	Proceed all Ex, Consider AE
			→	Consider insulin correction ^c , Proceed all Ex	Proceed all Ex
			↘↘	Proceed all Ex	
10.1–15.0 mmol/l (181–270 mg/dl)	11.1–15.0 mmol/l (199–270 mg/dl)	12.1–15.0 mmol/l (217–270 mg/dl)	↗↗	Proceed all Ex, Consider insulin correction ^c	Proceed all Ex
			→		
			↘↘	Proceed all Ex	
7.0–10.0 mmol/l (126–180 mg/dl)	8.0–11.0 mmol/l (145–198 mg/dl)	9.0–12.0 mmol/l (162–216 mg/dl)	↗↗	Proceed all Ex	
			→		
			↘↘		
<7.0 mmol/l (<126 mg/dl)	<8.0 mmol/l (<145 mg/dl)	<9.0 mmol/l (<162 mg/dl)	↗↗	Proceed all Ex	
			→	~10 g CHO, Proceed all Ex ^d	~15 g CHO, Proceed all Ex ^d
			↘	~15 g CHO, Proceed all Ex ^d	~25 g CHO, Proceed all Ex ^d
			↓	~20 g CHO, Proceed all Ex ^d	~35 g CHO, Proceed all Ex ^d
<3.9 mmol/l (<70 mg/dl)			↑	Stop all Ex, Consider confirmatory SMBG, Individual amount CHO ingestion, Restart of all Ex possible ^e	
			↗		
			→		
			↘		
			↓		
<3.0 mmol/l (<54 mg/dl)			Stop all Ex, Confirmatory SMBG, Individual amount CHO ingestion, No restart of Ex		

Sensor glucose targets are detailed for the following groups in type 1 diabetes (T1D): intensively exercising and/or low risk of hypoglycaemia (Ex 2); moderately exercising and/or moderate risk of hypoglycaemia (Ex 1); minimally exercising and/or high risk of hypoglycaemia (Ex 0)

^a Recommendation for older adults with coexisting chronic illnesses and intact cognitive and functional status

^b Recommendation for older adults with coexisting chronic illnesses or two or more instrumental ADL impairments or mild-to-moderate cognitive impairment

^c 50% of the regular insulin correction factor

^d Check sensor glucose at least 30 min after carbohydrate consumption and repeat treatment if required

^e Restart exercise when reaching sensor glucose levels of at least 4.4 mmol/l (80 mg/dl) and →, ↗, or ↑

When reaching the required sensor glucose level during exercise, only consume carbohydrates again when trend arrow is starting to decrease

These recommendations are not applicable to hybrid closed-loop systems

Green shading, no/minimal action required; light-yellow shading, minimal/ moderate action required; dark-yellow shading, moderate/intense action required; red shading, stop exercise

AE, mild-to-moderate intensity aerobic exercise; CHO, carbohydrate; Ex, exercise; hypo, hypoglycaemia

Post-Exercise Period

During the first 90 minutes following exercise, an interstitial glycaemic range of 4.4–10.0 mmol/l (80–180 mg/dl) might be targeted in the majority of people with type 1 diabetes who are at a low risk of hypoglycaemia, reflecting the clinical targets for CGM and isCGM [29](D) with a slight increased lower glycaemic limit, as recently recommended [139](D). People with an elevated risk of hypoglycaemia are recommended to increase the lower limit in sensor glucose to 5.0 mmol/l (90 mg/dl) or 5.6 mmol/l (100 mg/dl) during the post-exercise period [5](D). Sensor glucose may be monitored regularly via CGM, or every 15-30 minutes in the case of isCGM, during the 90-minute post-exercise period and hypoglycaemia alert can be set at 4.4 mmol/l (80 mg/dl), 5.0 mmol/l (90 mg/dl) or 5.6 mmol/l (100 mg/dl) based on the risk of hypoglycaemia. If sensor glucose is rapidly increasing in the post-exercise phase (detected by CGM when using the rate of change alert), then an insulin correction can be considered (50% of typical correction dose) [133](D), [134](D). If exercise was performed at a moderate-to-high intensity and/or for a long duration, then glucose may decrease during the acute post-exercise period as seen in experimental studies [58, 140]. At a glycaemic threshold of 4.4 mmol/l (80 mg/dl), or slightly higher based on the risk of hypoglycaemia [139] and accompanied with a

horizontal trend arrow, ~10g of carbohydrates are recommended to be consumed, 15g of carbohydrates accompanied by a (slight) downward trend arrow, and an individual amount of carbohydrates if accompanied by rapidly falling downward trend arrows (Table 5) [1](D), [2](D), [3](D), [113](D), [114](D). Carbohydrates should be consumed and the amount of carbohydrates individualised based on the individual's experience if required whenever reaching this threshold in consideration of trend arrows, and treatment should be repeated if sensor glucose is not rising within 30 minutes as reflected by trend arrows. If an interstitial level <3.0 mmol/l (54 mg/dl) is displayed, rapidly acting carbohydrates should be given and a confirmatory SMBG may be performed. Exogenous glucagon is recommended if the person is unable to self-treat [141](B).

Table 5: Sensor glucose targets for carbohydrates consumption during the post-exercise phase including the nocturnal post-exercise phase if exercise was performed in the late afternoon/evening.

Post-exercise sensor glucose including nocturnal phase for different groups in T1D			Trend arrow	Action
Ex 2 and/or low hypo risk	Ex 1 and/or moderate hypo risk ^a	Ex 0 and/or high hypo risk ^b	Direction	CHO (g)
<4.4 mmol/l (<80 mg/dl)	<5.0 mmol/l (<90 mg/dl)	<5.6 mmol/l <100 mg/dl	↑	No CHO
			↗	
			→	~10g CHO
			↘	~15g CHO
			↓	Individual amount CHO ingestion

Sensor glucose thresholds for treatments are detailed for the following groups in type 1 diabetes (T1D): intensively exercising and/or low risk of hypoglycaemia (Ex 2); moderately exercising and/or moderate risk of hypoglycaemia (Ex 1); minimally exercising and/or high risk of hypoglycaemia (Ex 0)

^a Recommendation for older adults with coexisting chronic illnesses and intact cognitive and functional status

^b Recommendation for older adults with coexisting chronic illnesses or two or more instrumental ADL impairments or mild-to-moderate cognitive impairment

If an insulin correction is applied due to high sensor glucose levels, then the regular correction factor might be reduced by up to 50%

Check sensor glucose at least 30min after carbohydrate consumption and repeat treatment if required

These recommendations are not applicable to hybrid closed-loop systems

The intensity of yellow shading indicates the level of action required: lighter yellow shading indicates that minimal/moderate action is required, while darker yellow shading indicates that moderate/intense action is required

CHO, carbohydrate; Ex, exercise; hypo, hypoglycaemia

Nocturnal Post-Exercise Period

Following an evening or late afternoon exercise session, or an exercise session high intensity and long duration, people with type 1 diabetes are at an elevated risk of nocturnal hypoglycaemia as shown in experimental and observational studies [142, 143]. Hypoglycaemia typically occurs within 6–15 hours after exercise, although the risk may remain longer as seen in children and adolescents as well as adults [144, 145]. People using a CGM system should therefore set the hypoglycaemia alert at 4.4 mmol/l (80 mg/dl) during the night-time period, or higher for groups with an elevated risk of hypoglycaemia to allow for earlier proactive treatments [139](D). When reaching 4.4 mmol/l (80 mg/dl) or higher if deemed necessary, the following carbohydrate guidance can be applied [1](D), [2](D), [3](D), [113](D), [114](D): with a horizontal trend arrow ~10g of carbohydrates are recommended to be consumed, 15g of carbohydrates accompanied by a (slight) downward trend arrow, and an individual amount of carbohydrates accompanied by downward trend arrows. These recommendations might also be applied for the second generation of isCGM systems where a real-time alert is given when reaching hypo- and hyperglycaemia threshold.

People using an isCGM system should perform at least one scan during the night-time period, preferably between midnight and 3 AM, since this is typically the nocturnal nadir after exercise [146](D). Carbohydrates should be given at 4.4 mmol/l (80 mg/dl) or earlier in people with an elevated risk of hypoglycaemia, following the same strategy as given for CGM [139](D) (Table 5). When carbohydrates were consumed after reaching this threshold, a scan should be performed not later than 2 hours afterwards. If considered necessary, this procedure should be repeated frequently based on the glycaemic threshold and trend arrow. Recommendations to minimize the risk of nocturnal hypoglycaemia may be followed as shown in section “Strategies to Reduce the Risk of Exercise-Induced Hypoglycaemia”.

Children and Adolescents with Type 1 Diabetes

Exercise may improve glycaemic control, blood lipid profiles, physical fitness and quality of life and can decrease the total daily dose of insulin in children and adolescents with type 1 diabetes as shown in randomised-controlled trials and in a systematic review [147–150]. Despite the positive effects of exercise, deterioration of diabetes control, fear of hypoglycaemia and other exercise-related fears similar to the ones experienced by children without diabetes are major barriers to an active lifestyle in children and adolescents with type 1 diabetes as assessed via questionnaire [151]. Furthermore, parents of children and adolescents with type 1 diabetes reported to have a conflict between planned and spontaneous activity and struggle to control glucose levels [152]. Therefore, children and adolescents, as well as their parents, should actively participate in consultations with the health care professional team, as parental support appears to be the key to an active lifestyle [151](C).

Hypo- and hyperglycaemic alerts should be set at 5.6 mmol/l (100 mg/dl) and 10.0 mmol/l (180 mg/dl) or individualised if required [3](D),[113](D),[114](D). The rate of glucose change alerts should be used to initiate an earlier action [3](D),[113](D),[114](D). The use of remote monitors (e.g., via a mobile phone app to follow sensor glucose in real-time from remote) should be used to assess and react to glycaemic excursions during exercise [3](D). Both parents and most caregivers report a decreased overall worry and stress when using remote monitoring [153, 154]. Carbohydrate supplementation might be performed in relation to the individual bodyweight or as an absolute amount [3](D); however, it was shown that weight-adjusted carbohydrate supplementation is more effective to treat hypoglycaemia in children with type 1 diabetes in a randomised-crossover study [155]. The guidelines in Table 6 can be followed for exercise, which are in alignment with *ISPAD Clinical Practice Consensus Guidelines 2018: Exercise in children and adolescents with diabetes* and other consensus and position statements [1](D), [2](D), [3](D).

Table 6: General insulin therapy and carbohydrate recommendations for exercise in children and adolescents with type 1 diabetes.

Type of therapy	Type/intensity of exercise Duration 30–45 min	Type/intensity of exercise Duration >45 min
MDI/CSII: mealtime bolus insulin dose reduction	–25% for mild aerobic –50% for moderate aerobic –50% for intense aerobic –25% for mixed aerobic/anaerobic Up to –50% post exercise	–50% for mild aerobic –75% for moderate aerobic –75% for intense aerobic –50% for mixed aerobic/anaerobic Up to –50% post exercise
MDI: basal insulin ^a	–20% for evening/late afternoon exercise	–20% for evening/late afternoon exercise –30 to –50% for all-day/unusual activities ^a
CSII: basal insulin rate	Up to –50% 90 min pre exercise Insulin pump suspension (<60 min) –20% for post-exercise night time ^b	Up to –80% 90 min pre exercise Insulin pump suspension (<60 min) –20% for post-exercise night time ^b
General CHO intake ^c	10–15 g CHO depending on IOB and sensor glucose level 1.5 g CHO per kg BW/h for intense exercise (regular IOB) 0.25 g CHO per kg BW/h for intense exercise (less IOB) 0.4 g CHO/kg BW pre-bed snack for evening/late afternoon exercise	10–15 g CHO depending on IOB and sensor glucose level 1.5 g CHO per kg BW/h for intense and/or long-lasting exercise (regular IOB) 0.25 g CHO per kg BW/h for intense exercise (less IOB) 0.4 g CHO/kg BW pre-bed snack for evening/late afternoon exercise

^a Basal insulin dose might be reduced the day prior and on the day of all-day exercise

^b Basal insulin rate might be reduced by 20% before bedtime if late afternoon/evening exercise was performed, depending on the duration and intensity of exercise

^c Regular IOB, no/little insulin reduction has been performed; less IOB, moderate/high insulin reduction has been performed

BW, body weight; CHO, carbohydrate; CSII, continuous subcutaneous insulin infusion; IOB, insulin on board; MDI, multiple daily injections

Preparation in Advance to Exercise

For the immediate pre-exercise phase, the target sensor glucose range should be between 7.0–10.0 mmol/l (126–180 mg/dl), 8.0–11 mmol/l (145–198 mg/dl) for children and adolescents with a moderate risk of hypoglycaemia and/or moderately exercising and 9.0–12.0 mmol/l (162–216 mg/dl) for children and adolescents with a high risk of hypoglycaemia and/or minimally exercising (Table 7)

[3](D), [26](D). These glucose targets can be achieved by mealtime insulin dose reduction ranging from 25–75% (Table 6) [1](D), [2](D), [3](D). Bolus insulin dose reduction can be based on the individual glucose response to the type, intensity and duration of exercise [156] (D). If sensor glucose concentration is below these glycaemic targets, then small amounts of oral carbohydrates should be consumed (e.g. 10–15g of carbohydrate) [3](D), [113](D), [114](D). Exercise may be started when reaching 5.0 mmol/l (90 mg/dl) and ideally from 7.0–10.0 mmol/l (126–180 mg/dl) or higher in those with an increased risk of hypoglycaemia (Table 7) [3](D). Depending on the trend arrows on the CGM or isCGM, 5g, 10g, 15g or more carbohydrates may be consumed when reaching the predefined glycaemic thresholds [3](D), [113](D), [114](D). At an upper limit of >15.0 mmol/l (270 mg/dl) and blood ketones >1.5 mmol/l exercise is contraindicated and blood ketones of 0.6–1.4 mmol/l should be addressed before exercise [3](D), [157](D), [158](D). In the case of extreme hyperglycaemia, an insulin correction might be applied (50% of a typical correction dose) [159](D). When using a CGM or a second-generation isCGM, the hypoglycaemia alert threshold should be set at 5.6 mmol/l (100 mg/dl) and the hyperglycaemia alert threshold should be set at 10.0 mmol/l (180 mg/dl) or individually higher [3](D), [113](D), [114](D). Predictive hypoglycaemia threshold, as well as rate of change in glucose alerts, should be switched on for CGM [3](D), [113](D), [114](D). Remote devices can be used by parents and caregivers to facilitate supportive action during exercise in children and adolescents with type 1 diabetes [153](D). The strategies given in Table 7 should be applied to achieve the recommended glycaemic targets [3](D), [113](D), [114](D).

Table 7: Sensor glucose targets in advance to exercise in regard to different groups of children and adolescents with type 1 diabetes.

Pre-exercise sensor glucose for different groups in T1D			Trend arrow	Action	
Ex 2 and/or low hypo risk	Ex 1 and/or moderate hypo risk	Ex 0 and/or high hypo risk	Direction	Increase in sensor glucose expected	Decrease in sensor glucose expected
>15.0 mmol/l (>270 mg/dl) AND >1.5 mmol/l blood ketones			↗↘↙↚	No Ex, Insulin correction	
>15.0 mmol/l (>270 mg/dl) AND ≤1.5 mmol/l blood ketones			↗↗	Consider insulin correction ^a , Can start AE	Consider insulin correction ^a , Can start all Ex
			→	Consider insulin correction ^a , Can start AE	Can start all Ex
			↘↘	Can start all Ex	
10.1–15.0 mmol/l (181–270 mg/dl)	11.1–15.0 mmol/l (199–270 mg/dl)	12.1–15.0 mmol/l (217–270 mg/dl)	↗↗	Can start AE	Can start all Ex
			→	Can start all Ex	
			↘↘		
7.0–10.0 mmol/l (126–180 mg/dl)	8.0–11.0 mmol/l (145–198 mg/dl)	9.0–12.0 mmol/l (162–216 mg/dl)	↗↗	Can start all Ex	
			→		
			↘↘	~5 g CHO (0.2 g/kg), Can start all Ex	~10 g CHO (0.3 g/kg), Can start all Ex
5.0–6.9 mmol/l (90–125 mg/dl)	5.0–7.9 mmol/l (90–144 mg/dl)	5.0–8.9 mmol/l (90–161 mg/dl)	↗↗	Can start all Ex	~5 g CHO (0.2 g/kg), Can start all Ex
			→	~5 g CHO (0.2 g/kg), Can start all Ex	~10 g CHO (0.3 g/kg), Can start all Ex
			↘	~10 g CHO (0.3 g/kg), Delay all Ex ^b	~15 g CHO (0.4 g/kg), Delay all Ex ^b
			↓	Individual amount CHO ingestion, Delay all Ex ^b	
<5.0 mmol/l (<90 mg/dl)			Individual amount CHO ingestion, Delay all Ex ^b		

Sensor glucose targets are detailed for the following groups in type 1 diabetes (T1D): intensively exercising and/or low risk of hypoglycaemia (Ex 2); moderately exercising and/or moderate risk of hypoglycaemia (Ex1), minimally exercising and/or high risk of hypoglycaemia (Ex 0)

^a 50% of regular insulin correction factor when sensor glucose is close to the upper glycaemic threshold

^b Delay exercise until reaching at least 5.0 mmol/l (90 mg/dl) and, ideally, from 7.0 mmol/l to 10.0 mmol/l (126 mg/dl to 180 mg/dl) or higher in those with an increased risk of hypoglycaemia accompanied by →, ↗, or ↘

When reaching the required sensor glucose level to start exercise, only consume carbohydrates again when the trend arrow is starting to decrease

These recommendations are not applicable to hybrid closed-loop systems

Green shading, no/minimal action required; light-yellow shading, minimal/ moderate action required; dark-yellow shading, moderate/intense action required; red shading, no/delay exercise

AE, mild-to-moderate intensity aerobic exercise; CHO, carbohydrate; Ex, exercise; hypo, hypoglycaemia

During Exercise

Sensor glucose ranges of 5.0–10.0 mmol/l (90–180 mg/dl) and ideally of 7.0–10.0 mmol/l (126–180 mg/dl) should be targeted for exercise [3](D), [113](D), [114](D). These ranges should be higher for children and adolescents who are minimally exercising and/or with a higher risk of hypoglycaemia (Table 8) [3](D), [113](D), [114](D). Carbohydrate consumption at a threshold of 7.0 mmol/l (126 mg/dl), 8.0 mmol/l (145 mg/dl) or 9.0 mmol/l (162 mg/dl) based on the risk of hypoglycaemia with respect to trend arrows has been shown to avoid significant hypoglycaemia in children with type 1 diabetes [3](D), [113](D), [114](D). If sensor glucose is >15.0 mmol/l (270 mg/dl) blood ketones should be measured [3](D), [157](D), [158](D). If blood ketones are >1.5 mmol/l, exercise should be stopped, source of hyperglycaemia should be assessed and an insulin correction might be applied (50% of typical correction dose) [159](D). Elevated blood ketone levels should lead to repeated controls after exercise to ensure that ketosis (>1.5 mmol/l) or diabetic ketoacidosis is not developed. If sensor glucose is >15.0 mmol/l (270 mg/dl) and blood ketones are ≤1.5 mmol/l then only mild aerobic exercise may be performed to avoid a further increase in glucose levels by sympathoadrenal responses to intense (an)aerobic exercise [9](D). Exercise may be stopped at a sensor glucose level of 5.0 mmol/l (90 mg/dl), SMBG may be performed and carbohydrates should be consumed [3](D), [157](D), [158](D). Exercise may be restarted when reaching a sensor glucose level of 5.0 mmol/l (90 mg/dl) accompanied by horizontal or upward trend arrows. Exercise should not be restarted when reaching a sensor glucose level of <3.0 mmol/l (54 mg/dl). Sensor glucose may be checked every 15 minutes during exercise and parents/caregivers are recommended to observe sensor glucose levels via a remote device [160](D). With respect to the specific trend arrow a certain amount of carbohydrates may be consumed at a glycaemic threshold of 7.0 mmol/l (126 mg/dl) or higher (Table 8) that should be further personalized in line with individual characteristics [3](D), [113](D), [114](D).

Table 8: Sensor glucose targets during exercise in regard to different groups of children and adolescents with type 1 diabetes.

During exercise sensor glucose for different groups in T1D			Trend arrow	Action	
Ex 2 and/or low hypo risk	Ex 1 and/or moderate hypo risk	Ex 0 and/or high hypo risk	Direction	Increase in sensor glucose expected	Decrease in sensor glucose expected
>15.0 mmol/l (>270 mg/dl) AND >1.5 mmol/l blood ketones			↗↘↔↙↕	Stop Ex, Consider insulin correction, No restart of Ex	
>15.0 mmol/l (>270 mg/dl) AND ≤1.5 mmol/l blood ketones			↗↗	Consider insulin correction ^a , Proceed all Ex	Proceed all Ex, Consider AE
			→	Consider insulin correction ^a , Proceed all Ex	Proceed all Ex
			↘↘	Proceed all Ex	
10.1–15.0 mmol/l (181–270 mg/dl)	11.1–15.0 mmol/l (199–270 mg/dl)	12.1–15.0 mmol/l (217–270 mg/dl)	↗↗	Proceed all Ex, Consider insulin correction ^a	Proceed all Ex
			→		
			↘↘	Proceed all Ex	
7.0–10.0 mmol/l (126–180 mg/dl)	8.0–11.0 mmol/l (145–198 mg/dl)	9.0–12.0 mmol/l (162–216 mg/dl)	↗↗	Proceed all Ex	
			→		
			↘↘		
<7.0 mmol/l (<126 mg/dl)	<8.0 mmol/l (<145 mg/dl)	<9.0 mmol/l (<162 mg/dl)	↗↗	Proceed all Ex	
			→	~5 g CHO (~0.2 g/kg), Proceed all Ex ^b	~10 g CHO (~0.3 g/kg), Proceed all Ex ^b
			↘	~10 g CHO (~0.3 g/kg), Proceed all Ex ^b	~15 g CHO (~0.4 g/kg), Proceed all Ex ^b
			↓	~15 g CHO (~0.4 g/kg), Proceed all Ex ^b	~20 g CHO (~0.4–0.5 g/kg), Proceed all Ex ^b
<5.0 mmol/l (<90 mg/dl)			↑	Stop all Ex, Consider confirmatory SMBG, Individual amount CHO ingestion, Restart of all Ex possible ^{c,d}	
			↗		
			→		
			↘		
			↓		
<3.0 mmol/l (<54 mg/dl)			Stop all Ex, Confirmatory SMBG, Individual amount CHO ingestion, No restart of Ex		

Sensor glucose targets are detailed for the following groups in type 1 diabetes (T1D): intensively exercising and/or low risk of hypoglycaemia (Ex 2); moderately exercising and/or moderate risk of hypoglycaemia (Ex1); minimally exercising and/or high risk of hypoglycaemia (Ex 0)

^a Elevated blood ketone levels should lead to repeated controls after exercise to ensure that ketosis (blood ketones >1.5 mmol/l) or diabetic ketoacidosis is not developed. If sensor glucose is >15.0 mmol/l (>270 mg/dl) and blood ketones are ≤1.5 mmol/l, then only mild aerobic exercise may be performed

^b 50% of regular insulin correction factor when sensor glucose is close to the upper glycaemic threshold

^c Check sensor glucose at least 30 min after carbohydrate consumption and repeat treatment if required

^d Restart exercise when reaching at least a sensor glucose levels of 5.0 mmol/l (90 mg/dl) and or ↗, or ↑

When reaching the required sensor glucose level during exercise, only consume carbohydrates again when the trend arrow is starting to decrease

These recommendations are not applicable to hybrid closed-loop systems

Green shading, no/minimal action required; light-yellow shading, minimal/ moderate action required; dark-yellow shading, moderate/intense action required; red shading, stop exercise

AE, mild-to-moderate intensity aerobic exercise; CHO, carbohydrate; Ex, exercise; hypo, hypoglycaemia

Post-Exercise Period

Up to two hours after exercise, children and adolescents may refill the intramuscular and hepatic glycogen storages via carbohydrates and protein similar to recommendations children and adolescents without diabetes[161]. After finishing exercise, the sensor glucose target should be between 4.4–10.0 mmol/l (80–180 mg/dl) or higher based on the risk of hypoglycaemia, in the 90-minute post-exercise period [3](D), [139](D) (Table 9). If sensor glucose levels increase rapidly post-exercise, then an insulin correction can be considered (50% of typical correction dose), based on the individual's insulin sensitivity factor and sensor glucose level [159](D). However, correctional insulin dose close to bedtime should be avoided since it may increase the risk of post-exercise nocturnal hypoglycaemia. Importantly, frequently checking sensor glucose values should be stressed to help to reduce the likelihood of developing post-exercise late-onset hypoglycaemia following bolus insulin correction.

If the sensor glucose level falls below 4.4 mmol/l (80 mg/dl) for children and adolescents of typical hypoglycaemia risk, then oral carbohydrates should be given; carbohydrates should be given at a

higher glycaemic threshold for individuals at higher risk of hypoglycaemia (Table 9) [1](D), [2](D), [3](D). Oral carbohydrate consumption should be repeated as required to stabilise glucose levels. There will be a time delay of up to 20 minutes following oral carbohydrate consumption before a change in the trend arrow should be expected to be observed.

Table 9: Sensor glucose targets for carbohydrates consumption during the post-exercise phase including the nocturnal post-exercise phase if exercise was performed in the late afternoon/evening in children and adolescents with type 1 diabetes.

Post-exercise sensor glucose, including nocturnal phase, for different groups in T1D			Trend arrow	Action
Ex 2 and/or low hypo risk	Ex 1 and/or moderate hypo risk	Ex 0 and/or high hypo risk	Direction	CHO (g)
<4.4 mmol/l (<80 mg/dl)	<5.0 mmol/l (<90 mg/dl)	<5.6 mmol/l (<100 mg/dl)	↑	No CHO
			↗	No CHO
			→	~5 g CHO (~0.2 g/kg)
			↘	~10 g CHO (~0.3 g/kg)
			↓	Individual amount CHO ingestion

Sensor glucose threshold for treatments is detailed for the following groups with type 1 diabetes (T1D): intensively exercising and/or low risk of hypoglycaemia (Ex 2); moderately exercising and/or moderate risk of hypoglycaemia (Ex 1); minimally exercising and/or high risk of hypoglycaemia (Ex 0)

If an insulin correction is applied due to high sensor glucose levels, then the regular correction factor might be reduced by up to 50%

These recommendations are not applicable to hybrid closed-loop systems

The intensity of yellow shading indicates the level of action required: lighter yellow shading indicates that minimal/moderate action is required, while darker yellow shading indicates that moderate/intense action is required

CHO, carbohydrate; Ex, exercise; hypo, hypoglycaemia

Nocturnal Post-Exercise Period

Children and adolescents may set the hypoglycaemia alert threshold at 4.4 mmol/l (80 mg/dl) or even higher in those with a higher risk of hypoglycaemia to be able to prospectively counteract impending hypoglycaemia [139](D). When reaching this threshold, the guidance as shown in Table 9 can be followed and further individualised if required. Children and adolescents using an isCGM should perform a scan at least twice during the nocturnal period (e.g. at 01.00 AM and 04.00 AM) due to the

increased risk of nocturnal hypoglycaemia [163–166](D) especially after exercise [71, 144, 166, 167](D). Parents or other care providers can be alerted using the remote monitoring function within CGM, which can support parents in their effort to avoid nocturnal hypoglycaemia in children [154](D). In addition to the intake of carbohydrates, the insulin strategies mentioned in Table 6 should also be applied to lower the risk of nocturnal hypoglycaemia [1](D), [2](D), [3](D).

The Use of Sensor Augmented Insulin Pumps and Hybrid Closed-Loop Systems

People can use different CGM systems in combination with insulin pumps and a control algorithm to automatically adjust insulin delivery in response to sensor glucose data [168–170]. Most advanced are hybrid closed-loop systems, which are devices where the basal insulin is automatically adjusted based on the current CGM value and trend arrows. Other devices work by suspending the basal insulin rate for a period when a low sensor glucose value is predicted to occur. However, research is presently emerging how these systems interact under exercise conditions. Recommendations for sensor-augmented pumps with predictive low glucose insulin suspend and hybrid closed-loop systems are different than the recommendations provided earlier in this manuscript.

Predictive Low Glucose Insulin Suspension

Predictive low glucose insulin suspension systems are lacking in their efficacy at preventing aerobic exercise-induced hypoglycaemia as shown in randomised studies [171, 172]. The reason for this is likely because the kinetics of subcutaneously delivered insulin are generally too slow to drop effectively enough during an exercise session when glucose uptake is increased [173]. Insulin suspension systems rely on abrupt changes in sensor glucose to predict hypoglycaemia and to shut off insulin when hypoglycaemia is predicted. However, by the time the sensor glucose is dropping rapidly, there is insufficient time to reduce insulin in a way that would result in absolute avoidance of hypoglycaemia. Some in silico studies and experimental studies have shown for resting conditions and during exercise that if insulin was reduced 60–90 minutes prior to the start of exercise, hypoglycaemia during and shortly after exercise could be reduced [174–176]. Sensor glucose targets including treatment

suggestions with regard to trend arrows and its carbohydrate consumption as given in the previous sections can be applied for sensor augmented pumps with predictive low glucose insulin suspend. For some systems, we recommend setting the threshold for predictive low glucose insulin suspend at a glucose level of 4.4 mmol/l (80 mg/dl) for exercise [139](D). In the acute post-exercise condition (<90 minutes), this threshold should remain at 4.4 mmol/l (80 mg/dl). During the nocturnal post-exercise period, the glucose suspend threshold can be lowered to 3.9 mmol/l (70 mg/dl) based on the individual hypoglycaemia risk. In these systems, a restart of insulin administration is activated when the threshold level is reached again. For other devices, the predictive low glucose insulin suspension function is not based on a fixed glucose level but induces a pause and a suspension of insulin administration 30 min before predicted 4.4 mmol/l (80 mg/dl) and a restart of insulin administration at the first increasing 5-minute glucose value thereafter, leading to a shorter suspension of the insulin administration. The recommendations given above are based on the experience of the writing group – more research is required.

Hybrid Closed-Loop Systems

When using a hybrid closed-loop system, people might follow the standard recommendations as provided by the manufacturers and also establish management strategies in close collaboration with their health care professional team [108](D), [177](D). If the automated mode of the hybrid closed-loop system increases the risk of glycaemic excursions, then usual pump therapy settings can be used (i.e. manual mode). Recommendations, as given in the previous sections concerning the preparation in advance to, during and potentially after exercise can be followed when using the manual mode, but not when using the auto mode. Current hybrid closed-loop systems enable the user to adjust their target threshold to be higher or lower, or to use three different target intervals. Some systems enable an exercise mode whereby the device-dependent target is increased to 8.3 mmol/l (150 mg/dl) [108](D) or 7.8–8.9 mmol/l (140–160 mg/dl) [177](D). While increasing the target during exercise is in most cases a good idea, it will not prevent exercise-induced hypoglycaemia caused by moderate-intensity aerobic exercise as shown in various experimental studies whereby insulin was completely

shut off at the start of exercise and reduced by 50% during the 1-hour post-exercise period [171, 172]. As discussed above for predictive low glucose insulin suspension systems, insulin needs to be reduced about 90 minutes in advance of exercise to prevent exercise-induced hypoglycaemia. In the automated mode, the sensor glucose target value should be set at a higher temporary target of around 90 minutes in advance to exercise. If drastic decreases in sensor glucose levels occur, then people should switch into temporary basal rate or manual mode and carbohydrates can be consumed as discussed in the previous sections. Advanced hybrid closed-loop systems were not extensively tested during intense/prolonged exercise and in the auto-mode, the “automated correction bolus” feature may add excess bolus insulin potentially triggering hypoglycaemia. During the post-exercise period, the sensor glucose target may be kept at 8.3 mmol/l (150 mg/dl) [108](D) or 7.8–8.9 mmol/l (140–160 mg/dl) [177](D) for ~90 minutes, or if stable sensor glucose levels are expected, then the threshold can be lowered to the regular range of 6.7 mmol/l (120 mg/dl) or 6.1 mmol/l (110 mg/dl). During the nocturnal post-exercise period, we recommend the regular sensor glucose target of 6.7 mmol/l (120 mg/dl), however, in people with high-risk of post-exercise hypoglycaemia glycaemic targets might be set at a higher level of 8.3 mmol/l (150 mg/dl) [108](D) or 7.8–8.9 mmol/l (140–160 mg/dl) [177](D) over the entire or half of the night [71](D).

Other systems use a variety of target range settings like “regular”, “exercise” and “sleep activity”. The “regular” target range is 6.2–8.9 mmol/l (112–160 mg/dl), where the system maintains pre-programmed basal rates. If the CGM predicts a rise above 8.9 mmol/l (160 mg/dl) in the next 30 min, the basal rate will automatically be increased. If the glucose value is predicted to go above 10.0 mmol/l (180 mg/dl) in the next 30 min, a correction bolus will be delivered automatically, corresponding to 60% of a correction related to current pump settings, with a target of 6.1 mmol/l (110 mg/dl). The optional “exercise” mode allows for a target of 7.8–8.9 mmol/l (140–160 mg/dl), which then could be activated 90 minutes prior to exercise and used throughout the exercise session. It continues to give automatic bolus doses to bring glucose levels down to the target range. The third optional target range

setting is the “sleep activity” mode, which allows a more aggressive range of 6.1–6.7 mmol/l (110–120 mg/dl). However, this optional setting does not allow any auto insulin correction [177].

For children aged between 7–12 years using hybrid closed-loop systems, the sensor glucose target should be set at a device-dependent temporary target of 8.3 mmol/l (150 mg/dl) [108](D) or 7.8–8.9 mmol/l (140–160 mg/dl) [177](D) approximately 60–120 minutes in advance to exercise and a slight reduction of individual mealtime insulin doses 60–120 minutes prior to the exercise should be considered. Another approach using the system with different target range settings would be to activate the “exercise” mode 60–120 minutes before exercise. Some children with very well-regulated diabetes might also use the “sleep activity” mode for longer duration [177](D)

Older children and adolescents might apply recommendations as for adults with type 1 diabetes when using a hybrid closed-loop system. In the future, exogenous glucagon may be included as a secondary hormone to insulin within closed-loop systems. Earlier work has shown that if aerobic moderate-intensity exercise is detected or announced to the system, exogenous glucagon may be delivered to the person to help reduce the risk of hypoglycaemia during exercise [172, 178].

For adults as well as children and adolescents with type 1 diabetes, carbohydrates should not be consumed when using a hybrid closed-loop system on auto mode, since the subsequent rise in sensor glucose in response to the carbohydrates may trigger correction insulin, creating a cycle of hypo- and hyperglycaemia. If prolonged exercise is performed then it might be recommended to consume very small amounts of carbohydrates that potentially decrease the risk of hypoglycaemia, or switch into manual mode and consume carbohydrates as recommended for regular open-loop therapy. Furthermore, for post-exercise meals insulin dose might be slightly reduced to lower the risk of post-exercise hypoglycaemia, practically done by entering less carbohydrates into the system as actually consumed. The recommendations given above are based on the experience of the writing group – more research is required.

The Use CGM and isCGM under Special Exercise Conditions

The following section is mainly based on the experience of the writing group – more research is required, e.g. for exercise during extreme heat, heavy cold or under hypoxia. Different circumstances around exercise may require special considerations to ensure the safety of CGM and isCGM. Especially in situations where SMBG is inconvenient or cannot be performed (e.g. skydiving, swimming, contact sports), CGM and isCGM systems are advantageous. When the advantages and disadvantages regarding different CGM and isCGM systems are considered, the motivation and possibility to scan frequently before, during and after exercise should be weighed against the need to use different types of alerts and alarms as well as the need of using the remote function.

One area that often receives little attention but should not be ignored are the adhesive tapes and location of wear for different CGM and isCGM devices, particularly around exercise. It is important to consider the type and level of exercise being performed in order to determine the appropriate sensor location and additional adhesive protection required [179]. Commonly used regions for sensor placement include the abdomen, upper arm, upper buttock, and upper thigh regions [179]; however, people with type 1 diabetes should choose regions based on manufacturer's recommendations in order to avoid potential issues with the accuracy of CGM and isCGM. Adhesive products for CGM and isCGM can vary from liquid adhesive wipes to transparent dressings, to external wraps and protective sleeves [179]. A primary concern of covering the entire sensor and transmitter unit with one piece of dressing is the increased likelihood of moisture build-up underneath the device. Therefore, it might be important to create a cut or opening in the dressing and avoid covering the whole transmitter with tape. All people with type 1 diabetes should be educated on appropriate skincare techniques and potential issues that may arise regarding skin irritations from adhesives for CGM and isCGM devices [180](D).

Swimming

For swimming, several manufacturers produce small waterproof bags that can be used for CGM/isCGM reader/scanner to measure the sensor glucose while swimming. This might be of interest when swimming sessions are performed in an open-water setting. In case of a prolonged or extended swimming session, carbohydrates can be carried alongside the CGM/isCGM device. We recommend liquid glucose gels or tablets since these can be stored in swimwear or under the swim cap without the risk of water ingress. Sensor glucose might be measured as explained in the previous sections and oral carbohydrates should be consumed based on the actual sensor glucose values accompanied with trend arrows. If swimming is performed in a swimming pool, then the reader/scanner and oral glucose can be placed at the edge of the pool. For some CGM devices, a smart watch might be used on which sensor glucose data are displayed if the mobile phone (=receiver) is close enough to the transmitter. Furthermore, if swimming is performed regularly, we recommend using an adhesive tape to ensure that the glucose sensor is not getting lost during the swim sessions.

Scuba diving

Using CGM/isCGM in relation to scuba diving adds beneficial effects as this means that the sensor glucose level and trend arrows could be used before scuba diving in order to prevent hypoglycaemia. The only possibility to actually follow sensor glucose data underwater would require a pressure- and waterproof “house” as this has been used in studies [181]. A more common option is that glucose data could be reviewed after scuba dives where new knowledge could be brought from this. As scuba dives sometimes are conducted repeatedly in a day, the use of CGM/isCGM may also have beneficial effects in nocturnal hypoglycaemia prevention - either used as a standalone system including alerts or as part of a predictive low glucose insulin suspension system before hypoglycaemia [181].

Sports at High-Altitude

CGM systems reliably measure sensor glucose compared to SMBG up to altitudes of ~3600 m (~11,800 ft) [182]. In people with type 1 diabetes, it is difficult to provide general recommendations with regard to insulin administration strategies since variable glucose responses have been observed, depending on the speed of ascent and altitude attained [183, 184]. Alternating glucose and insulin requirements might be tested in advance to the expedition to tailor strategies to overcome glycaemic disturbances. For safety reasons and to incorporate potential sensor inaccuracy, a sensor glucose level of ~10.0 mmol/l (180 mg/dl) might be targeted. Sensor glucose should be checked as often as possible and if required insulin correction can be given (50% of regular correction dose). Since high altitude is associated with cold temperature the sensor might be worn at a site not too far in the periphery.

Contact sports

To the best of our knowledge, there is currently no research that investigated the use of CGM and isCGM systems around contact sports (e.g. boxing, kickboxing, Brazilian jiu-jitsu, mixed martial arts, etc.) in people with type 1 diabetes. Therefore, this section is based on the authors' experience and expertise. For contact sports, the glucose sensor can be placed at a site with the lowest risk of strikes. However, in contact sports with groundwork/grappling (e.g. Brazilian jiu-jitsu), this is generally based on the individual's preference, including the back of the arm (triceps) and abdomen. With grappling, the clothing that is generally worn is a rash guard and tighter material providing additional protection and stability over the CGM and isCGM sensor site. Available implantable sensors might be beneficial for individuals with type 1 diabetes if contact sports are being performed on a regular basis. Reading/scanning may be performed as recommended for other types of exercise and oral glucose can be consumed as in response to sensor glucose thresholds and trend arrows described earlier. Glucose sensors should be covered by adhesive tape to reduce the risk of injury or losing the sensor during exercise.

Discussion

In this position statement, we detailed the use of sensor glucose values accompanied by trend arrows for CGM and isCGM systems, for different groups of people with type 1 diabetes and for different sensor glucose responses to exercise. Of note, in this position statement, recommendations for carbohydrate consumption were stratified with respect to the rate of change in glucose for the pre-exercise, during exercise, post-exercise and nocturnal post-exercise phase. Taking the lag time of CGM and isCGM systems against SBMG around exercise into account, safe sensor glucose thresholds are recommended for people with type 1 diabetes. In general, these recommendations can be used as a first guidance tool that also needs to be tailored individually. The recommendations in this position statement will need to be updated in future years to provide the best and most evidence-based recommendations for people with type 1 diabetes using CGM and isCGM for exercise.

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