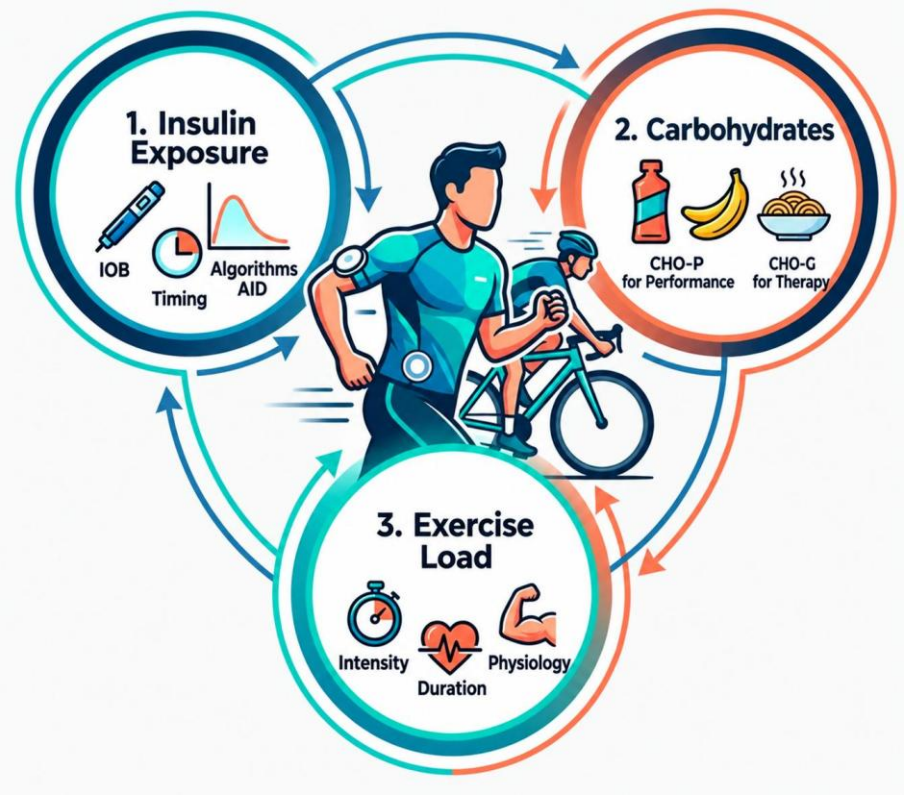
PRACTICAL ATLAS OF PATHOPHYSIOLOGY, INSULIN, NUTRITION AND SPORT IN TYPE 1 DIABETES



Understanding pathophysiology to personalize therapy, nutrition, AID and physical exercise

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Preface

The management of type 1 diabetes during physical exercise is often presented through percentages, thresholds and protocols. These tools are useful, but they become fragile when the person departs from the scenario for which they were designed. A more intense training session, a meal different from usual, a bolus that is still active, pre-competition tension, or insulin-pump algorithms characterized by different logics can turn an apparently correct strategy into an ineffective choice.

Method of the book

Each chapter starts from a clinical question, reconstructs the relevant physiology, proposes a visual representation, applies the model to a real-life situation and concludes with a few practical messages.

This volume seeks to mark the 35 years of activity of ANIAD, the Italian National Association of Athletes with Diabetes, a voluntary organization dedicated to promoting physical exercise and sport as a regular, informed and safe practice among people with diabetes. Over many years of activity, we have learned that being present in the field alongside athletes is an irreplaceable means of acquiring knowledge applicable to daily practice, through a continuous exchange of experience and expertise between diabetes care teams and the people they support.

It is nevertheless necessary to clarify, from this Preface onward, the nature of the project and the meaning of the reference to ANIAD. The Atlas is promoted, endorsed and disseminated by the Association within the scope of its aims of providing information, raising awareness and supporting people with diabetes. As a voluntary organization, ANIAD does not perform healthcare functions and, as an Association, does not itself possess the expertise required to develop or validate clinical and scientific recommendations. The reference to ANIAD therefore identifies the associative context in which the work originated and the commitment undertaken to make it accessible; it does not assign to the Association the role of scientific author or prescribing body.

ANIAD owes its existence to Prof. Andrea W. D'Agostino, a pioneer of Italian diabetology and twice President of the Association of Diabetes Specialists (AMD) between 1986 and 1990. The Association was founded to support young people with type 1 diabetes mellitus who, at a time when social and sporting stigma was still difficult to counter, were often forced to give up their aspirations or pursue them while hiding their condition.

Since then, ANIAD has promoted numerous information and training initiatives, progressively extending from Naples to neighboring areas and ultimately throughout Italy, organizing many sporting events across multiple disciplines (mountaineering, athletics, swimming, cycling, football, futsal and long-distance running), including the many official participations in the Rome Marathon. This long journey has contributed to the eventual recognition, in Italy and abroad—and at times demonstrated by sporting results at the highest level—of the role of athletes with diabetes across a wide range of disciplines.

Indeed, over its 35 years of activity, ANIAD understood from the outset that structured sporting activity, especially for people with type 1 diabetes, would be important both from a metabolic and a strictly sporting perspective. For this reason, in 2010 and subsequently in 2014, two memoranda of understanding were implemented with the Italian National Olympic Committee, with the aim of bringing sporting institutions closer to people with diabetes, helping them understand these individuals' specific needs and identifying shared pathways. The objective was to establish a common approach capable of enhancing the performance of people with diabetes, making the various Federations aware of their specific needs and facilitating, at CONI level, procedures for sports eligibility with the collaboration of the Italian Sports Medicine Federation and NADO. This

continuous exchange through meetings, sporting initiatives and editorial collaborations has led to greater understanding of the needs of people with diabetes, with significant improvements in the management of sporting activity that have also produced performances comparable to those of people without diabetes.

This achievement has also been supported by ANIAD's full integration into the International Diabetes Federation Europe (IDFE), which has provided an important international platform for the issues addressed and the possible solutions. Precisely because of this collaboration, ANIAD intends to promote and disseminate this Atlas on type 1 diabetes and sport on the occasion of World Diabetes Day on 14 November 2026, with the hope that it will be published on the IDFE website under its aegis and patronage. The choice of PDF format reflects the objective of reaching the greatest possible number of people with diabetes interested in sport, as well as professionals willing to engage with experience gained in the field.

The drafting and supervision of the clinical and scientific content are entrusted to the diabetologists who are members of ANIAD's Scientific Committee, acting on the basis of their respective professional expertise. The work also draws, within specific areas of competence, on the contribution of external professionals working in physical exercise, training, motivation and coaching. The technical assessments and guidance contained in the individual chapters are therefore attributable to the respective authors and must be read within the framework of the necessary personalization with the diabetes care team.

ANIAD's role is different, but no less important. The Association makes available the experience gained alongside people with diabetes, encourages dialogue between professionals and the people they support, helps assess the comprehensibility and practical applicability of the content, and supports its widest possible dissemination. The Atlas builds its identity on this alliance between scientific expertise, lived experience and associative responsibility.

The very composition of the group of authors reflects a conviction developed over the years: cardio-metabolic management is a necessary condition for practicing sport safely, but it does not exhaust the athlete's needs. Building performance requires specific training expertise, while continuity, autonomy, the ability to deal with uncertainty and the daily relationship with the condition inevitably also involve motivational and personal dimensions.

We chose PDF rather than a printed book in order to make the document easy to update in response to the rapid evolution of knowledge and technology, as well as downloadable and accessible to anyone interested. We would also like to broaden the ANIAD community so that many colleagues who are still isolated in their outpatient clinics can share the experience of being present in the field alongside the people they support, according to the principle of educating while at the same time learning from those who live with the condition every day, avoiding recommendations that may be theoretically valid but potentially distant from concrete reality.

For this reason, we preferred to shift the focus from rules to reasoning. The aim is not to provide a new set of therapeutic recipes, but to show how muscle, liver, insulin, glycogen, carbohydrates, training and automated systems interact in determining the athlete's response to exercise.

The guiding principle is simple: first understand the pathophysiology properly through scientifically sound concepts made accessible for educational purposes; then adapt nutrition, therapy and technology to performance and to the individual. Practical recommendations acquire meaning only when they are placed within the mechanism that justifies them.

PART I – UNDERSTANDING EXERCISE PROPERLY

Chapter 1 - From physiology to real life. The perspective of the person with type 1 diabetes

This contribution arises from the direct experience of a person with type 1 diabetes, but also from testimonies collected over many years of amateur sport, volunteering and association representation, through dialogue with other people with whom journeys, difficulties and goals have been shared. It does not intend to formulate prescriptions or turn personal experiences and collected testimonies into general rules. It starts from a question: how can sound scientific knowledge and accurate technical guidance become choices that are truly understandable, safe and sustainable in the daily lives of people with type 1 diabetes? Its aim is to bring into the shared work questions, difficulties and needs observed in real life, to be integrated with the clinical and professional expertise of the other authors.

1.1 Why the person's perspective is necessary

In recent years, knowledge about type 1 diabetes and physical activity has grown considerably. Technologies and therapeutic options have also made safer and more accessible what, until not long ago, appeared particularly difficult. An Atlas devoted to physiology, insulin, nutrition and sport therefore represents an important tool to enable people to find their way as effectively as possible within a complex and multifaceted body of knowledge.

Nevertheless, between the formulation and the practical application of a scientifically correct recommendation there is a space that cannot be ignored. Within that space lie the person's history, fears, type of therapy, available opportunities, relationship with the diabetologist of reference and, above all, the meaning that each individual attributes to physical activity. The person with diabetes cannot be regarded as the endpoint of a sequence of instructions: they must be part of the process through which recommendations are understood, adapted and made usable.

This transition is particularly evident in sport, an area in which decisions made by those engaging in AF are often taken far from the clinic and under changing conditions. One runs, cycles, swims, plays or simply walks and, in the meantime, must interpret a value, manage an unexpected event and make valid choices within a short time. In this sense, the educational value of the document also depends on its ability to guide the person toward greater autonomy, without promising complete predictability that cannot be guaranteed.

The central element around which the entire document revolves is the awareness that, although indispensable, knowledge becomes truly useful only when it can be translated, together with one's diabetologist, into choices suited to the life, possibilities and goals of the individual person.

1.2 From knowledge to a concrete choice

Knowing a rule is certainly necessary, but it is not yet the same as knowing how to use it. One must first understand its meaning, then interpret the concrete situation and, finally, choose a course of action within the limits agreed with one's diabetologist. These are different steps, requiring information, experience and a progressively greater ability to fully interpret what is happening.

The possibility of consulting a multiprofessional diabetes care team would certainly represent the most favorable condition. However, this opportunity still does not correspond to the healthcare reality experienced by most people with diabetes, who interact mainly with their own diabetologist.

A person may have understood the mechanism perfectly and still feel uncertain at the moment of decision. This is not necessarily a problem of inadequate education or insufficient commitment. More simply, it is necessary to acknowledge that in real life many variables change at the same time and their meaning is not always immediately recognizable. It is precisely here that education must become support toward autonomy.

The transition from knowledge to autonomy can be summarized in four stages:

1. **Understand**. What does this recommendation mean and what are its limits?

2. **Interpret**. What does it mean today, for this AF and with this amount of active insulin?

3. **Decide**. What can I safely do now, while remaining within the options agreed with the diabetologist?

4. **Review**. What can I learn from what happened, without turning the outcome into a judgment of the person?

1.3 The complexity that often remains unseen

For an outside observer, preparing for a run may simply mean putting on shoes and going out. For a person with type 1 diabetes, it often means assessing the composition of the previous meal, the amount of insulin still active, glucose both as a current value and as a trend, the expected duration of the session, the necessary supplies (supplements or rapidly absorbed sugars), and possible events expected in the following hours. Added to all this are the conditions of the setting, the possibility of stopping and the reliability of the devices.

This is largely invisible work, which can be tiring even before the activity begins. That said, the mental burden should not be regarded as secondary: a strategy that is too complex is more difficult to remember and apply precisely when exertion, haste or tension reduce the attention available. The quality of a recommendation is therefore also measured by its ease of use.

This complexity accompanies the person before, during and after the activity.

Before the activity, as already stated, it is necessary to consider what is about to be done, the expected duration and intensity, the possibility of interruptions, the meal, the bolus, the amount of insulin still active, glucose both as a current value and as a trend, as well as the products required for possible supplementation and a possible alternative plan.

During the activity, it is necessary to observe how closely what is happening corresponds to the plan, paying attention to symptoms, sensor data, trend arrows, data availability and any need to take additional carbohydrates.

After the activity, it is useful to consider recovery needs, the planned meal, residual insulin and possible delayed effects, recording only the information that may help to better understand the experience.

A good recommendation must therefore be not only correct but also fully understood, remembered and applied at the appropriate time. If it requires the simultaneous assessment of an excessive number of elements, it is useful to question the actual applicability of the proposed strategy, and not only the person who finds it difficult to follow.

1.4 Between planned physical activity and real life

Many educational pathways correctly start from an AF defined in advance: known time, predictable duration, established intensity and controlled meal. Although useful for learning and reducing variables, this model describes only part of real life.

A walk may last longer, a match may start late, a training session may be interrupted, or a climb may require greater effort than expected. Even the distinction between low, moderate or high intensity is not always

immediately clear to a beginner. The same exercise may also have a very different cost for different people. It is therefore necessary to prepare not only for the ideal scenario, but also for a change of plan.

For this reason, decision-making schemes should also provide a pathway for uncertainty: what to observe when the plan changes, when duration is no longer predictable or when it is not possible to intervene with ideal advance timing. The aim is not to provide automatic answers, but to help the person recognize when the situation no longer matches the one for which the strategy had been agreed.

A concrete example can help clarify this transition. A person plans forty minutes of walking, but the group decides to continue for another thirty. The problem is not simply that the activity lasts longer. The availability of products for possible supplementation changes, as do the timing of the next meal, the possibility of returning home and the meaning of the glucose trend. Education should also prepare the person to recognize this change of scenario.

What has been explained so far has been the guiding element of the entire Atlas. Indeed, it aims to provide the reader with useful keys for making operational decisions that are as valid as possible in full awareness and, once the outcome has been verified, to progressively refine the approach, if possible in collaboration with the diabetes care team of reference.

1.5 Fear of hypoglycemia: a real risk and a possible barrier

Fear of hypoglycemia arises from a real risk but may be intensified by previous episodes, fear of losing control, solitude or difficulty interrupting the activity and rapidly taking carbohydrates. It would therefore be wrong to dismiss it as an irrational concern or simply a lack of willpower.

Technological advances have certainly increased the information available and can reduce part of the risk. However, having a sensor or an automated system does not erase the memory of a negative episode and, by itself, does not restore the confidence needed to try again. While technology provides protection, it remains necessary to work on education, gradual progression and perceived safety.

Fear can lead a person to give up, deliberately maintain high glucose values, take more carbohydrates than necessary or check the sensor continuously. The document specifically aims to avoid two extremes: minimizing the problem or amplifying it through an endless list of dangers, in the firm belief that progressive experiences, a realistic safety plan and a clear boundary between what the person can manage and what requires support from the diabetologist should be promoted.

The way questions are asked can also facilitate or hinder this process. It is not enough for the diabetes care team to ask why a patient does not engage in physical activity. It is more useful to understand what the person fears might happen, at what point they feel least safe, and what condition might allow them to begin a new pathway with greater confidence.

1.6 Technology: greater opportunities, new skills

Continuous glucose monitoring systems, insulin pumps and automated systems have positively transformed the management of physical activity. Alarms, trend arrows and insulin modulation offer possibilities that did not exist in the past. What has just been described represents significant progress, which is now widely recognized and should increasingly be valued.

Nevertheless, every new piece of data requires interpretation and every function has its own operating conditions and limitations.

During exercise, the person may wonder whether the arrow truly describes what is happening, whether the system has already reduced delivery, how much insulin remains active, or whether the sensor is showing a delay

compared with symptoms. In water, contact sports or during a competition, access to data may also become intermittent or even impossible. Technology reduces the need to make some decisions but introduces others.

Good technological training cannot be limited to explaining where to press on the device being used; it must clarify what the system recognizes, what it cannot predict, and how to behave when data are missing or appear implausible. Device choice should also consider ease of use, tolerability, type of sport, preferences and concrete possibilities of access, not only the theoretical performance of the algorithm.

Technology can show a concentration and a trend, modulate the insulin that will be delivered, signal a possible risk and reduce some repetitive decisions. When it is understood and used appropriately by the person, it can promote greater autonomy.

Technology cannot directly measure available glycogen or energy cost, cancel insulin that has already been absorbed, or in every situation replace signals sent by the body and the person's ability to assess them. Nor can it predict with certainty how the body will respond to physical activity or prevent unexpected events related to timing, duration, intensity and the conditions in which the activity is performed.

1.7 Sport is not synonymous with elite performance

When we talk about sport, we often think of competition, structured training and results. Most people, however, exercise in pursuit of health, well-being, social interaction, autonomy or simple enjoyment. Some wish to start walking again, some attend a gym, some use a bicycle at weekends, and some practice a sport without any competitive goal.

An Atlas promoted by a voluntary association must also speak to those who do not identify with the most common Italian meaning of the word "athlete" (for English speakers, the term does not necessarily refer to a competitive sportsperson...). For such a person, the issue is not how to tackle a marathon but how to walk for twenty minutes without perceiving an uncontrollable risk: this represents a different but no less important starting point.

Different entry points into the complex world of regular physical exercise must therefore be provided. Guidance on advanced performance remains valuable, but it should be accompanied by a simple progression: begin with repeatable activities, observe the response, consult the diabetes care team, and gradually increase safety and autonomy. In this sense, simply starting is itself an achievement.

Elite sport demonstrates that many barriers can be overcome. Associations, however, must also make possible the first step for those who are not seeking a record, but health, confidence, autonomy and participation.

1.8 Turning experience into learning

General recommendations represent the starting point. Autonomy grows when the person learns to recognize recurring situations and connect what is observed with the principles learned. A morning run, a walk after lunch, an evening strength session and a competition are not equivalent experiences, even though all fall within the definition of physical activity.

Recording every detail can become unsustainable. It is preferable to collect a few useful pieces of information: type and duration of activity, perceived intensity, previous meal and insulin, carbohydrates taken, and the pattern over the following hours. The value of the diary does not depend on the amount of data, but on the ability to turn those data into useful elements for formulating more precise questions to discuss with the diabetes care team.

When an experience does not match the general scheme, it should not automatically be regarded with suspicion; if it recurs under safe conditions, it deserves to be reported and understood. Individual experience

does not demonstrate a universal rule, but it may reveal a personal variable that the general model cannot fully represent.

1.9 Language that helps learning

A strategy may fail despite attention and commitment. The meal may be absorbed differently, intensity may change, the sensor may show a delay, or stress may modify the response. In the relationship with one's diabetes care team, the episode should not be experienced or presented as an error because, otherwise, the person unintentionally becomes less willing to report what happened and, with that, loses the opportunity to learn.

Language should describe what happened without turning glucose into a grade. Expressions such as "good" or "bad control," "good" or "non-adherent," risk shifting attention from the problem to the person. It is more useful to ask which variable changed, what worked, and what modification might be considered the next time.

Respectful communication does not mean giving up clear guidance; it means distinguishing the person from the outcome and recognizing the complexity of self-management. In this way, trust, sharing of difficulties and the possibility of truly shared decisions are strengthened.

Learning-oriented language can also be built through different questions:

- Instead of asking what was done wrong, it is more useful to ask which variable might have changed the response.
- Instead of asking why a rule was not followed, it is more useful to understand what made it difficult to apply at that moment.
- When glucose behaves differently from what was expected, it is not useful to regard the experience as simply positive or negative. It is more important to understand what happened during the activity and whether the session was safe, effective as training and sustainable.
- Instead of proposing a rigid rule to be applied on every occasion, it is preferable to agree with the diabetologist on how to adapt the strategy and which elements to observe during the next activity.

1.10 The role of ANIAD and peer learning

ANIAD performs a function different from that of the diabetologist and from that of the other healthcare professions involved in the care process. It does not prescribe therapies and does not replace those responsible for care. It can, however, create opportunities for information and discussion, help people recognize common problems and provide them with more appropriate words to describe difficulties. Above all, it can remind people that a difficulty does not necessarily represent an individual failure.

Peer experience is valuable when it remains experience and does not become a prescription. Learning how another person organizes themselves to carry out AF, talks with the coach or deals with an unexpected event can open up new possibilities. Conversely, copying doses, thresholds or carbohydrate amounts can be dangerous because the clinical and personal context that gave meaning to those choices is missing.

In this sense, through the various regional sections it could be assessed whether the materials in this Atlas speak to different audiences, whether the language is understandable and whether the guidance takes account of the opportunities actually available

in local areas. They can also collect questions and needs to be brought to the Scientific Committee. They do not assume responsibility for clinical validation, but contribute to making the document closer to people and less self-referential.

The boundary must nevertheless remain clear: a peer can describe what they observed and how they discussed it with their own diabetes care team; they should not turn that account into a prescription valid for others.

1.11 A scientifically structured Atlas that is genuinely usable

From the perspective of people with diabetes, the Atlas will prove truly useful if it enables a transition from reading to formulating better questions. In other words, it must not create the illusion that a table can replace personalization, nor leave the reader alone in the face of even greater complexity. Precisely for this reason, it aims to offer principles, examples and tools to enable the athlete, or the person approaching physical exercise, to engage in dialogue with the diabetes care team, while always keeping the boundary with clinical prescription clear.

The Atlas can offer principles for understanding physiology, insulin, nutrition and technology; questions for organizing variables; examples for recognizing different scenarios; and tools for communicating better with professionals. It can also suggest a method for learning from experience, without claiming to replace clinical assessment and the individual treatment plan, provide a universal prescription valid for every athlete, directly verify individual response, guarantee urgent support in the event of risk or malfunction, or replace professional judgment in complex cases.

1.12 Questions that should accompany the reader

- What activity am I actually about to perform and how demanding is it for me?
- With how much active insulin still in circulation, and in what nutritional state, am I starting?
- Which carbohydrates belong to performance and which might be needed for glucose stability?
- What is my AID system doing and what can it not know?
- What change would turn this activity into a different scenario from the one planned?
- Which signals require me to stop, apply the safety plan or ask for help?
- What essential information will I record to discuss it and improve next time?

1.13 Guidance for informed use

- I use the document to understand the principles and distinguish general guidance from the options agreed with my diabetes care team, without independently changing therapy.
- I always consider the type, duration and intensity of exercise, the amount of insulin still active, meal composition and glucose pattern.
- I prepare a plan for dealing with hypoglycemia, hyperglycemia, device failures or unavailable data.
- I do not copy doses or strategies from another person; when I assess a change, I observe a few useful variables and discuss the outcomes with my diabetes care team.
- If symptoms, sensor data and the situation do not agree, I follow the device instructions and my clinical plan, recognizing when professional support is necessary.

1.14 To conclude

- The person with diabetes is not a passive recipient of guidance, but part of the process of understanding and personalization. To create the best conditions for one's autonomy, time must be devoted to understanding mechanisms, interpreting context and making safe choices. Simplicity, sustainability and concrete applicability are therefore part of the quality of every educational strategy.
- Fear of hypoglycemia must be recognized and never trivialized: technology should be regarded as a valuable tool also for prevention, but it cannot identify every individual response in advance and does not eliminate unexpected events. Amateur physical activity and the first step taken in that direction deserve as much attention as competitive performance. Individual experience does not replace scientific evidence, but it can generate useful questions; ANIAD can promote information, discussion and peer learning, while keeping the boundary with clinical prescription clear.

Chapter 2 - What really happens when a muscle starts working?

Guiding question
Why can a slow run, a sprint and a football match involve the same athlete yet produce completely different metabolic responses?

Key message
The muscle does not use a single fuel, and there is no energy system that is “on” while the others are “off”. Intensity, duration and training continuously modify the combination of substrates used.

When a muscle goes from rest to contraction, energy demand increases within a fraction of a second. The visible movement - a step, a jump, a pedal stroke or a shot - is only the final outcome of a series of intracellular processes that must regenerate ATP at a rate appropriate to the power required. The first concept to acquire is therefore simple: exercise is defined not only by its duration, but above all by the rate at which the muscle must produce energy at any given moment.

This perspective is fundamental in DMT1. Insulin and nutritional strategies cannot be built solely on the duration of the activity or the number of kilometres to be covered. Continuous running, an interval-training session and a football match may have a similar duration but require very different combinations of energy substrates (glycogen, glucose and fatty acids). Understanding this dynamic properly is the first step in interpreting what we will later see on CGM and avoiding attribution to glucose of a meaning it does not have: the glucose sensor describes a concentration and a trend; it does not directly measure the energy cost of exercise.

2.1 ATP: the immediate currency of contraction

Adenosine triphosphate (ATP) is the immediately usable form of chemical energy in the muscle fibre. Its hydrolysis enables the actin-myosin cross-bridge cycle that constitutes the contractile component of the muscle fibre itself, supports the work of ion pumps that restore the sodium, potassium and calcium gradients required, and helps maintain cellular homeostasis while contraction continues.

Intramuscular ATP stores are, however, very limited compared with the amount needed to sustain even a few minutes of exercise. The physiological problem is therefore not to possess a large ATP reserve, but to continuously regenerate ATP at the same rate at which it is used. If demand suddenly increases, the rate of resynthesis must also increase almost immediately.

It is useful to distinguish two concepts that are often confused: capacity and power of the energy system. Capacity indicates how much energy a system can provide overall; power indicates how rapidly it can provide it. A sprint mainly requires high metabolic power. A marathon, by contrast, requires a great capacity to sustain over time a relatively low but continuous production of ATP.

Frequent conceptual error
Thinking that the muscle “uses ATP” only during the first few seconds and then switches to other fuels is incorrect. In reality, the muscle always uses ATP. Phosphocreatine, glycolysis and oxidative metabolism are different systems for regenerating the same energy molecule.

Application to DMT1

The requirement for insulin or carbohydrates cannot be inferred directly from the ATP consumed. ATP is the common final destination, while the substrates and pathways used to regenerate it change continuously. It is precisely this change that modifies the relationship between glycogen consumption, peripheral cellular uptake of substrates, hepatic glucose production and the glycemic response.

2.2 Three energy systems working simultaneously

For educational purposes, three major modes of ATP resynthesis are distinguished: the phosphagen system, glycolysis with substrate-level phosphorylation, and oxidative metabolism. This distinction is useful provided that it is not turned into the idea of three switches that turn on one after another.

All systems contribute from the very beginning of exercise. What varies is their predominant contribution, determined mainly by the power required, duration, substrate availability and degree of training.

Phosphagen system

Phosphocreatine allows ATP to be regenerated extremely rapidly. This system is particularly important when energy demand rises abruptly, as at a start, during a sprint, a jump or a maximal lift. Its power is extremely high, but its capacity is limited: phosphocreatine stores decline rapidly when maximal effort is maintained.

The fact that phosphocreatine is the main contributor during very brief efforts does not mean that glycolysis and oxidative metabolism are inactive. Even during a few seconds of intense work, these pathways already contribute to total ATP production.

Anaerobic glycolysis

Glycolysis makes it possible to rapidly obtain ATP from available glucose or, especially during intense exercise, from muscle glycogen converted into glucose. The rate at which it can supply energy is lower than that of the phosphagen system but higher than that permitted by substrate oxidation alone. For this reason, it becomes increasingly important when intense effort continues beyond the very first seconds or is repeated several times with incomplete recovery.

The lactate produced should not be interpreted simply as “waste”. It is an intermediate metabolic product that can be oxidized by other tissues and muscle fibres or used as a precursor for the production of new glucose. We will return to this concept later in the book because lactate is also a useful indicator for understanding the transition toward intensities at which the contribution of carbohydrates increases rapidly.

Oxidative metabolism

In the mitochondria, carbohydrates and fatty acids can be oxidized to produce large amounts of ATP. The maximum rate of this process is lower, but its capacity is much greater than that of the systems described above. It is therefore essential for prolonged exercise and becomes dominant when energy demand can be sustained mainly aerobically.

Oxidative metabolism does not mean “fat metabolism”. Carbohydrates are also oxidized in the mitochondria. A moderate-intensity aerobic run can therefore simultaneously use a significant proportion of both glucose and glycogen and fatty acids, i.e. energy fuels with great availability. This explains why some Olympic disciplines such as long-distance running may be repeated only after long intervals, allowing the body time to restore the glycogen stores consumed, whereas explosive disciplines that rely predominantly on the phosphagen system (which recycles rapidly) can be repeated several times within a few minutes, as in the high jump.

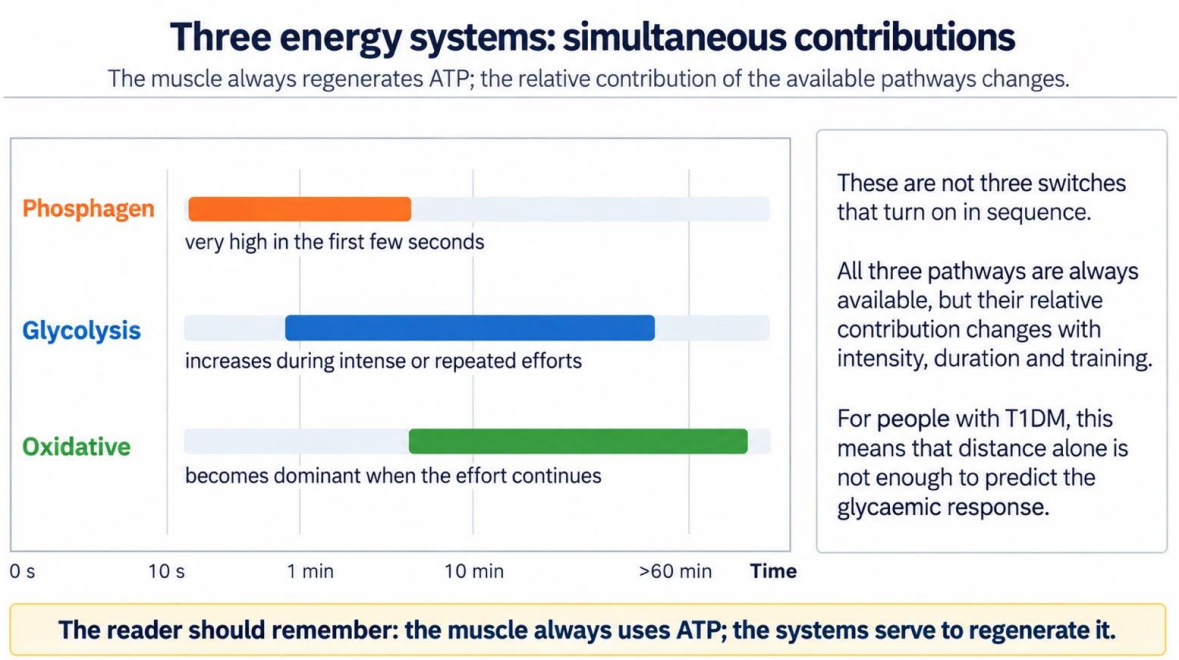


Figure 2.1. Contribution of the energy system: the system are active simultaneously, while their relative contribution varies.

2.3 Intensity: the variable that changes the rate of energy demand

Exercise intensity largely determines the rate at which the muscle must regenerate ATP. As the required power increases, so does the need to use pathways capable of supplying energy rapidly. From this principle derives the progressive increase in the contribution of carbohydrates at higher intensities.

Fatty acids represent a very abundant energy reserve and are fundamental during low- and moderate-intensity activities. However, their oxidation cannot increase indefinitely as power rises. When muscular work becomes more demanding, reliance on muscle glycogen and circulating glucose increases, because these substrates can sustain higher rates of ATP production.

The so-called “crossover” between the relative predominance of fats and increasing dependence on carbohydrates is a useful model, not a universal threshold. The position of this transition varies with training status, glycogen availability, nutritional status, relative intensity compared with individual aerobic capacity, and numerous biological characteristics.

Absolute intensity and relative intensity

Saying that two people both run at 10 km/h describes the same absolute intensity, but not necessarily the same relative intensity. For a trained athlete, this speed may represent easy exercise; for a poorly trained person, it may require a much larger fraction of maximal aerobic capacity. Consequently, substrate contribution and hormonal response may differ even when the work appears identical from the outside.

This distinction is particularly important when comparing athletes with DMT1. Speed or distance alone is not enough to estimate the glycemic response: it is necessary to know how much that specific effort “costs” the body of that specific person.

Why does carbohydrate oxidation increase with intensity?

The phenomenon depends on several factors acting simultaneously: recruitment of fast-twitch fibres increases, muscle glycogenolysis rises, sympathetic activation increases, and priority is given to the availability

of a substrate capable of rapidly sustaining ATP production. In this situation, glycogen represents a strategic resource.

However, it would be incorrect to turn this concept into the equation “high intensity = falling glucose”. During intense efforts, the rise in catecholamines may simultaneously stimulate substantial hepatic glucose production through glycogenolysis. It must also be considered that glycogen is a macromolecule made up of hundreds to thousands of glucose molecules; therefore, during glycogenolysis in intense exercise accompanied by sympathetic activation, the circulation may receive amounts of glucose that are sometimes greater than the increased muscular uptake, creating the possibility of hyperglycemia. Muscular carbohydrate consumption may therefore be high while glucose remains stable or even rises. This apparent paradox, which depends essentially on the level (high-normal-low) of hepatic insulinization, will be explored in the chapters devoted to the liver and insulin.

2.4 Duration: metabolism evolves as exercise continues

Duration is not simply elapsed time. As exercise continues, substrate availability, hormonal response, body temperature, hydration and degree of fatigue change. Consequently, even if speed remains constant, the physiological cost of the same movement can change over the course of the session.

During the first minutes of moderate exercise, glycogen availability is generally high and the cardiovascular system is still reaching steady state. As activity continues, the contribution of oxidative processes increases, glycogen availability may decline, and metabolism tends to adapt to the need to preserve the substrates that can be used most rapidly.

When duration becomes prolonged, carbohydrate availability may become a limiting factor for performance. This phenomenon does not necessarily coincide with hypoglycemia: the muscle may have difficulty sustaining the required power even when circulating glucose remains within the desired range. This distinction between “adequate glucose” and “adequate muscle substrate” will be central to the chapter devoted to glycogen.

Practical example

Running for 30 minutes at a moderate pace and running for two hours at the same pace do not simply represent performing the same exercise multiplied by four. In the second situation, the progressive reduction in glycogen stores, exogenous carbohydrate intake, hydration and insulin modulation over time become much more relevant.

2.5 Carbohydrates and fats: cooperation, not an alternative

In practice, people often speak of “burning fat” or “burning sugar” as though the muscle selected only one fuel. In reality, energy production almost always derives from a mixture of substrates. The proportion changes with intensity, duration and metabolic availability.

At low or moderate intensities, fatty acids can contribute substantially to ATP production. As intensity increases, dependence on carbohydrates progressively rises. This transition is functional: carbohydrates can sustain high energy fluxes and muscle glycogen can be mobilized very rapidly close to the contractile apparatus.

Substrate availability also influences the choice. A reduction in glycogen stores may increase relative reliance on lipids at intensities compatible with this adaptation, but at the same time may reduce the ability to maintain high power. Conversely, high availability favours carbohydrate use.

Frequent conceptual error

It is not justified to confuse the percentage of energy derived from fats with the absolute amount of fat oxidized. Light exercise may use a high percentage of fat but have modest energy expenditure. At moderate intensity, the percentage may decrease while the absolute amount of lipid oxidized per unit of time increases.

Application to DMT1

The fact that an exercise uses a high proportion of carbohydrates does not automatically imply the need to introduce the same amount of CHO from outside. Part of the carbohydrates used comes from muscle glycogen and hepatic production. The amount that must be ingested will also depend on insulin exposure and the liver's ability to support circulating glucose.

2.6 External load and internal load

It is important to distinguish what the body does to enable the athlete to perform an exercise.

External load

Includes the variables that describe the work performed:

- speed and distance covered,
- mechanical power developed,
- number and duration of sprints,
- accelerations and decelerations,
- elevation gain, jumps, changes of direction and loads lifted.

Internal load

Describes the body's response to that work and may include:

- heart rate and oxygen consumption,
- perceived exertion,
- ventilatory response and lactate,
- glycogen and substrate availability,
- sympathetic activation and hormonal response,
- in DMT1, insulin exposure, glucose and trend direction.

The distinction is essential because the same external load can produce different internal loads. A trained athlete and a poorly trained person may run at the same speed but at very different percentages of their aerobic capacity. Similarly, the same session may be metabolically different in the same athlete depending on sleep quality, heat, recovery, glycogen availability or insulin still active.

With regard to active insulin, in DMT1 the internal load acquires an additional dimension. Insulin is a metabolic signal that does not adapt instantaneously to exercise as it does in a person without diabetes. For this reason, two sessions that are identical on the stopwatch may require different strategies if they are started with different amounts of active insulin. Indeed, this depends on the amount reaching the portal circulation which, if excessive, inhibits and, if below a critical threshold, enhances glucose production by the liver. The circulating insulin level in turn depends not only on the doses injected but also on the time interval between injection and the start of exercise (timing), correct choice of injection site, temperature, degree of humidity and any lipodystrophy of the subcutaneous tissue. Furthermore, the subcutaneous route of administration, unlike native insulin which is delivered directly into the portal circulation, by definition produces hyperinsulinization of the peripheral circulation with increased glucose extraction, especially at muscle level.

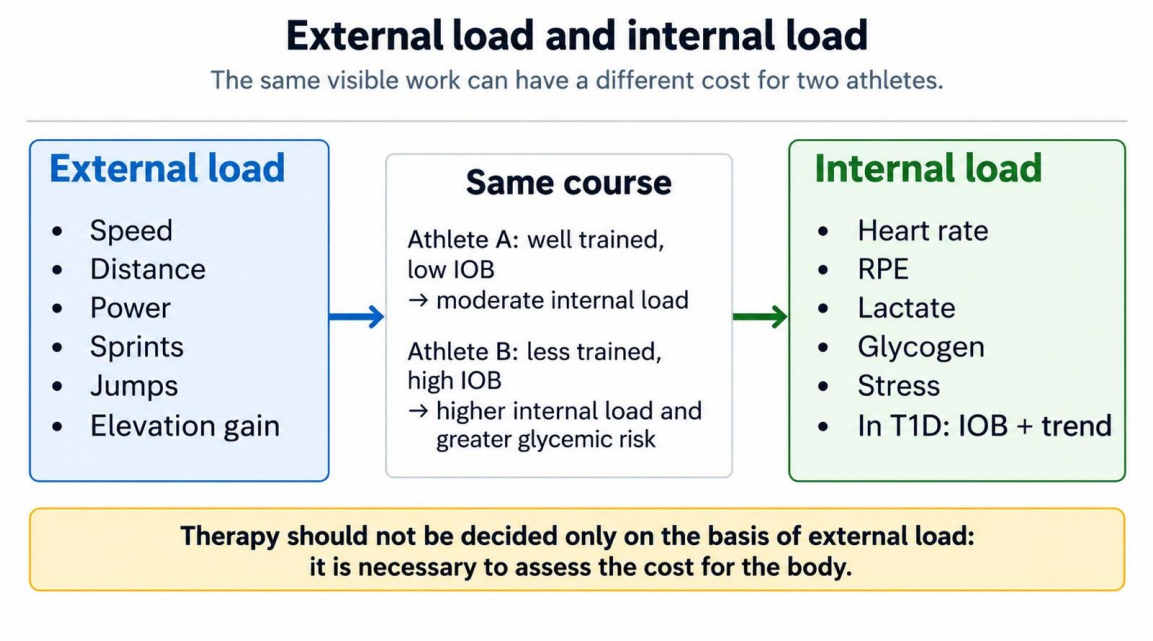


Figure 2.2. The same external load can result in very different internal loads and metabolic contexts

Two athletes on the same course: identical external load but different internal load. Integrating heart rate, relative intensity, glycogen and IOB helps explain why therapeutic requirements may diverge.

2.7 Training: the same external work can have a different cost

Endurance training induces adaptations that profoundly modify the way the muscle produces energy. Mitochondrial density and function, oxidative capacity, capillarization and efficiency of lipid use at submaximal intensities increase. At the same absolute speed, the trained athlete also works at a lower percentage of their maximal capacity than a novice or poorly conditioned person.

This adaptation may allow glycogen to be spared during moderate activities and exercise to be sustained for longer before carbohydrate availability becomes limiting. However, it does not mean that the trained athlete does not use carbohydrates. When intensity is sufficiently high, even a very well-trained person must markedly increase reliance on glycogen and glucose.

Metabolic flexibility can be understood as the ability to effectively modify substrate contribution according to demand. It is a more useful concept than the simple label “fat burner”, because it describes the ability to shift from a mixture relatively rich in lipids to one richer in carbohydrates when power requires it.

Why is this concept important in DMT1?

Two people performing the same course may have different substrate consumption and, above all, different glycemic responses. Training status modifies relative metabolic demand, but in DMT1 this variability is compounded by active insulin, starting glucose, hepatic glucose production and nutritional strategy. Therapeutic requirements therefore cannot be inferred solely from external work.

2.8 Muscle fibres and recruitment: why a sprint changes everything

Skeletal muscle is not metabolically uniform. Fibres differ in contractile characteristics and oxidative capacity. During light activity, motor units suited to sustaining prolonged contractions are recruited predominantly; as the force required increases, units capable of developing greater power are progressively recruited, with greater dependence on glycolysis and glycogen.

Recruitment does not occur as a clean replacement of one fibre type by another. Motor units already active continue working while others are added. Consequently, an acceleration inserted into a moderate run, even if it lasts only a few seconds, suddenly increases ATP demand and glycogen consumption.

This principle explains why intermittent sports are difficult to describe with a single metabolic label. A football match includes periods of low intensity, moderate running, accelerations-decelerations, sprints, jumps and static phases. Average metabolism may appear aerobic, but many decisive moments depend on high rates of glycogenolysis and a substantial adrenergic response.

2.9 From metabolism to glucose: what CGM sees and what it does not see

One of the most important consequences of the preceding concepts is that the energy requirement of exercise arises before the glucose observation. Intensity, duration, required power and muscle recruitment determine the need for ATP and therefore substrate use. CGM does not measure these processes.

The sensor instead describes the pattern of interstitial glucose, which represents the net result of the interaction between glucose entering and leaving the circulating compartment. During exercise, this balance depends, among other things, on muscle uptake, hepatic production, insulin present and carbohydrates ingested.

For this reason, stable glucose does not demonstrate that the muscle is consuming few carbohydrates. During an intense run, glycogen consumption may be high while the liver maintains circulating glucose. Likewise, falling glucose does not necessarily mean that the muscle has suddenly increased its energy requirement: it may reflect excessive insulin exposure relative to the liver's ability to compensate for peripheral uptake.

Frequent conceptual error

Using CGM as though it were a gauge of muscle fuel is incorrect. CGM is indispensable for safety and therapeutic management, but it does not directly provide information on the amount of glycogen remaining or on the proportion of fats and carbohydrates oxidized.

Application to DMT1

The correct logical sequence is therefore: first define the metabolic demand of the activity, then assess how that demand interacts with insulin exposure, hepatic production, glucose and trend. This conceptual order will be revisited in the following chapters devoted to glycogen, liver, IOB and carbohydrate requirements.

2.10 Three exercises, three metabolic problems

A brief comparison brings together the concepts developed in the chapter.

Slow continuous running

ATP demand is relatively stable. Oxidative metabolism can sustain much of the work, with a combined contribution of fats and carbohydrates. In the presence of relatively high insulin, glucose uptake may exceed hepatic production and promote a progressive fall in glucose.

20-30-second sprint

Power demand is very high. Phosphocreatine and glycolysis become very important, glycogen consumption rises rapidly, and reactive adrenaline release may stimulate hepatic glucose production through glycogenolysis. Glucose may therefore not fall despite the high muscular use of carbohydrates.

Football match

The load is intermittent. Periods of recovery and moderate running alternate with accelerations, sprints, jumps and changes of direction. There is no single intensity capable of describing the entire match. Glycogen consumption may be substantial, while the glycemic response depends on the sequence of phases, the adrenergic response, active insulin and CHO intake, and the role played.

This comparison anticipates a principle that will accompany the entire volume: classifying a sport as simply "aerobic" or "anaerobic" is often insufficient for planning diabetes management. It is necessary to understand the real structure of the activity and its interaction with individual pathophysiology.

2.11 What important message should the reader take away?

Before discussing insulin doses, targets or amounts of carbohydrates, it is necessary to know what metabolic problem the activity is imposing. The initial question should not be "how much should I eat?" or "how much should I reduce insulin?", but "what energy demand will this exercise create and which substrates are likely to be most important?".

Only after this first definition will it be possible to integrate the diabetes-specific variables: amount of active insulin, glucose and trend, ability to modulate basal insulin, availability of CHO and the individual response previously observed.

Take-home messages

- the muscle always uses ATP and must regenerate it continuously at the rate required by the work,
- phosphagen, glycolysis and oxidative metabolism operate simultaneously, while their relative contribution changes,
- as intensity increases, dependence on carbohydrates and muscle glycogen generally increases,
- duration and training modify the substrate mixture and the internal cost of the same external work,
- external load and internal load are not equivalent, especially in DMT1,
- CGM describes the behaviour of interstitial glucose, not energy requirements or glycogen stores,
- therapeutic management must therefore start from exercise physiology and only subsequently integrate insulin, glucose and carbohydrates.

Guiding question
During a competition, 100 g of carbohydrates are oxidized: does this mean that the athlete needs to consume 100 g of carbohydrates?

Key message
Glycogen is a fuel for performance; blood glucose is a systemic variable. The two interact, but they are not interchangeable.

Guiding question
Why can blood glucose remain stable while the muscles consume large amounts of glucose?

Key message
Blood glucose is not the athlete's "energy reservoir." It is the moment-to-moment result of the balance between glucose entering and leaving the circulation.

Guiding question
Why can aerobic exercise cause blood glucose to fall rapidly even when the insulin dose was appropriate before starting?

Key message
During exercise, it is not only the administered dose that matters: what matters is the actual insulin exposure at the time when muscle physiology changes.

Essential references for further reading

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Chapter 3 – Glycogen: the Strategic Fuel

Guiding question
If 100 g of carbohydrates are oxidized during a competition, must the athlete necessarily ingest 100 g?

Key message
The answer is no. Glycogen represents one of the main energy stores available during exercise and allows the muscle to use carbohydrates already stored before the start. To understand nutrition in the athlete with DMT1, it is therefore essential to distinguish three quantities that are often confused: carbohydrates oxidized, carbohydrates present in stores, and carbohydrates introduced from outside.

This distinction becomes even more important in DMT1, because a portion of the carbohydrates consumed during activity may have a predominantly energetic purpose, while another portion may serve mainly to compensate for relatively high insulin exposure. The amount ingested is therefore not a direct measure of muscle carbohydrate consumption.

3.1 What Glycogen Is and Why It Is So Important

Glycogen is a branched polymer of glucose that allows carbohydrates to be stored in a form that can be rapidly mobilized. A fully oxidized glycogen molecule can provide the body with 200,000–300,000 molecules of active glucose. The quantitatively and functionally most relevant sites are skeletal muscle and the liver, but their roles are not interchangeable.

Muscle glycogen is a local store: the fibre containing it can use it to support contraction, but it cannot directly release significant quantities of free glucose into the blood. Liver glycogen, by contrast, can use its glycogen stores for this purpose and, in practice, contributes to stabilizing blood glucose by drawing on glycogen to make glucose available to the entire body.

This difference explains an apparent paradox: an athlete may have normal blood glucose and, at the same time, partially depleted muscle glycogen stores. Blood glucose describes what is happening in the circulating compartment; it does not measure the muscle's energy stores.

3.2 How Much Glycogen Do We Have?

The absolute amount of glycogen varies and depends on muscle mass, nutrition, training status and activity performed in the preceding days. Muscle stores are generally much greater than liver stores, but they are distributed across a large tissue mass and are intended mainly for local work. The liver contains a smaller amount, but one that is metabolically strategic because it contributes to maintaining blood glucose.

It is therefore not useful to imagine glycogen as a single "tank". It is more accurate to think of many muscle stores, used in relation to the fibres recruited, and a liver store with a systemic function.

Frequent conceptual error
High blood glucose does not demonstrate that muscle glycogen stores are adequate. Conversely, low blood glucose does not necessarily imply depletion of muscle glycogen. The two pieces of information describe different conditions.

3.3 Intensity, Muscle Recruitment and Glycogen Consumption

The rate of glycogen use increases as intensity rises. When the muscle must produce ATP rapidly, carbohydrates allow a higher rate of energy production than fatty acids. For this reason, sprints, accelerations, climbs, changes of direction and phases of high power require particularly substantial use of glycogen.

Consumption, however, is not uniform across all fibres. The motor units most heavily recruited during a given movement use their own stores more intensively. In an intermittent sport, therefore, the glycogen cost depends not only on the overall duration of the session but also on the number and intensity of high-power actions.

This clarifies why a football match and a continuous 90-minute run are not metabolically equivalent, even if total energy expenditure were similar. In the match, repeated accelerations require frequent increases in muscle glycogenolysis.

3.4 Glycogen and Training Status

Training modifies both the capacity to store glycogen and the way in which it is used. An aerobically trained athlete can sustain a given relative speed using a greater proportion of energy from fatty acids than a less trained individual. This allows a relative "sparing" of glycogen at submaximal intensities.

This adaptation does not mean that the trained athlete does not use carbohydrates. When intensity increases, especially near higher thresholds or during sprints and changes of pace, glycogen remains a fundamental substrate even in the highly trained individual.

For this reason, the same external activity may produce different glycogen consumption depending on training level. Absolute speed alone does not describe the internal metabolic cost.

3.5 Oxidized Carbohydrates, Glycogen and Ingested Carbohydrates

During exercise, oxidized carbohydrates may come from muscle glycogen, glucose derived from hepatic production, and carbohydrates introduced from outside. These sources converge in energy production but are not interchangeable from a physiological and clinical standpoint.

If an athlete oxidizes a total of 80 g of glucose during an event, it cannot simply be inferred that 80 g of carbohydrates must be ingested. A portion may come from stores accumulated in the preceding hours and days and a portion from hepatic production. Intake during the event becomes necessary when duration and intensity make it appropriate to support substrate availability, when performance must be preserved or, in DMT1, when blood glucose requires preventive or therapeutic correction.

Application to DMT1

The amount of CHO ingested during exercise should not be used retrospectively as an estimate of energy consumption. An athlete with more active insulin may be forced to consume more carbohydrates while performing the same activity and oxidizing similar amounts of substrate.

3.6 Glycogen Depletion and Performance

When glycogen stores are substantially reduced, it becomes more difficult to maintain high rates of ATP production. The practical consequence is a reduced ability to sustain high intensities, accelerations and power.

The phenomenon is particularly evident in long-duration events, but it may also be important in intermittent sports when the athlete accumulates numerous intense actions. The subjective perception may be that of "still having energy" but no longer being able to produce the same pace or power.

In DMT1 it is important not to confuse this condition with hypoglycaemia. Glycogen depletion is a problem of intramuscular availability; hypoglycaemia is a reduction in the concentration of glucose in the blood. They may coexist, but they are not synonymous.

3.7 Recovery: Glycogen Resynthesis and Insulin Sensitivity

The recovery phase is not metabolically neutral. After exercise, the muscle increases glucose uptake and glycogen synthesis. In the first hours, resynthesis is promoted both by greater activity of glucose transporters and by increased insulin sensitivity.

In the individual with DMT1, this phenomenon has two opposite but complementary consequences. On the one hand, it promotes energy recovery; on the other, it may increase the risk of hypoglycaemia if insulin exposure remains high relative to the needs of the post-exercise period.

For this reason, the recovery meal should not be considered only as caloric replenishment. It must be placed in the context of an assessment of the amount of glycogen used, the level of insulin still active, the timing of the session and the likelihood of a subsequent fall in blood glucose.

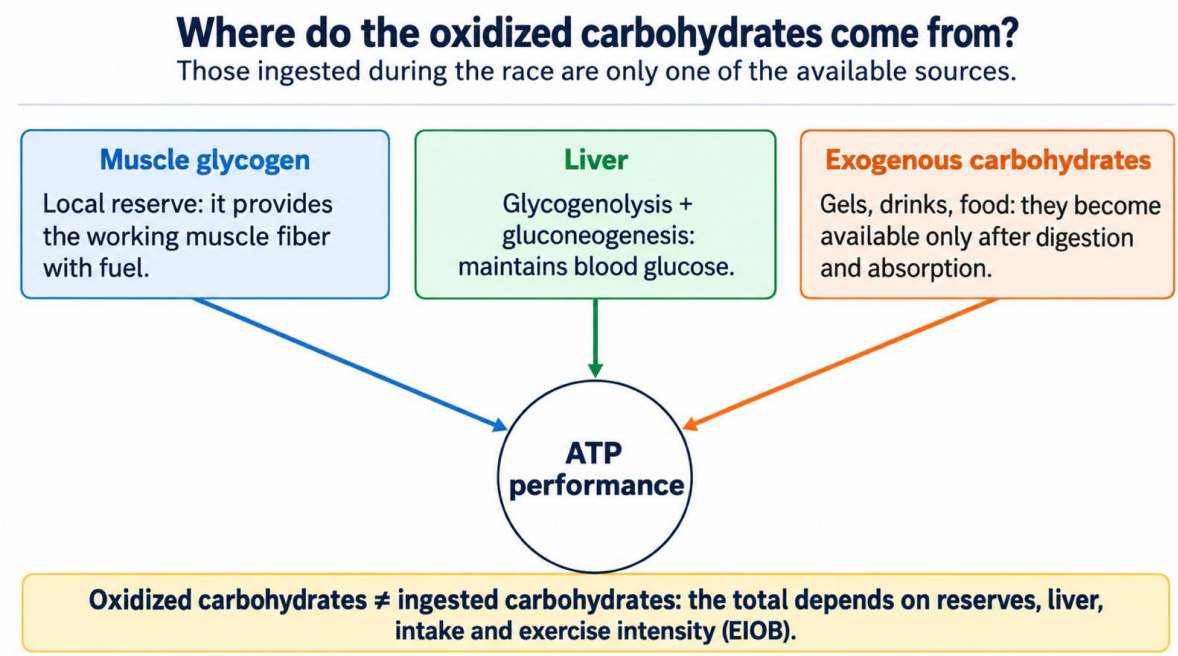


Figure 3.1. main sources of carbohydrates oxidized during exercise: muscle glycogen, hepatic glucose production, and exogenous carbohydrates

3.8 Supercompensation: What It Really Means

After a significant reduction in stores, adequate carbohydrate availability may allow resynthesis that leads the muscle to store quantities of glycogen above the previous level. This phenomenon, known as supercompensation, underlies some nutritional strategies used in endurance sports.

In DMT1 the pathophysiological logic remains the same, but the strategy must be compatible with safe insulin management. A high carbohydrate intake without consistent insulin management does not automatically improve energy availability and may produce marked hyperglycaemia.

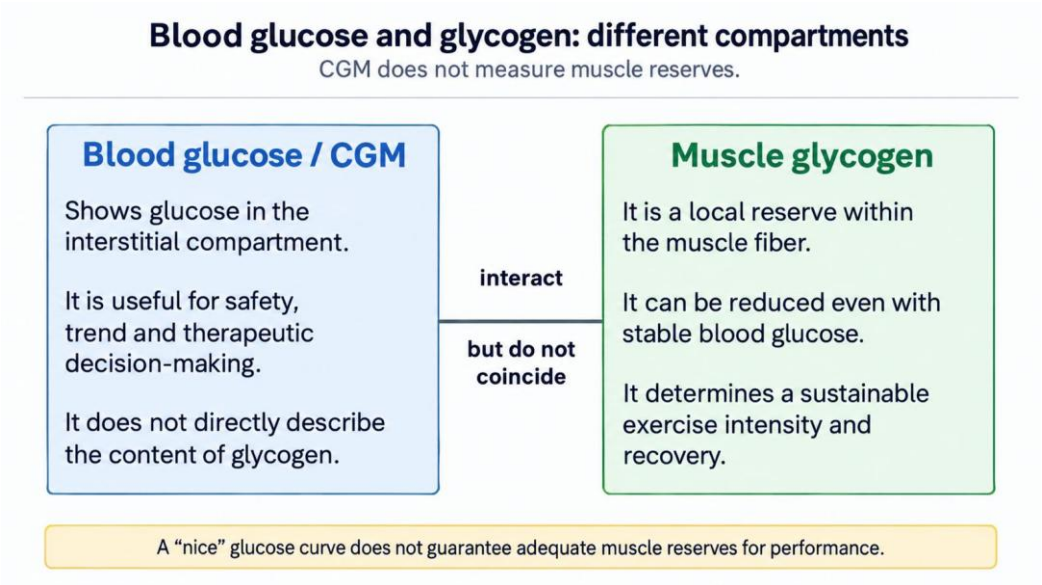


Figure 3.2. Blood glucose and glycogen describe different compartments: CGM does not measure muscle glycogen stores.

Take-home messages

- muscle and liver glycogen have different functions,
- intensity and fibre recruitment profoundly modify the rate of glycogen use,
- oxidized and ingested carbohydrates are not equivalent quantities,
- blood glucose does not measure muscle glycogen stores,
- in DMT1, part of the CHO consumed during exercise activity may have a therapeutic as well as an energetic function,
- glycogen recovery increases glucose uptake and must be considered together with post-exercise insulin exposure as a possible cause of late hypoglycaemia (post-exercise late onset hypoglicaemia), especially at night.

Essential references for further reading

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Chapter 4 – The Liver During Exercise: the Muscle's Invisible Partner

Guiding question
Why can blood glucose remain stable while the muscle consumes large amounts of glucose?

Key message
The answer requires shifting our attention from the muscle to the liver. During exercise, blood glucose is the result of a dynamic balance: on one side, tissues, especially muscle, remove glucose from the circulation; on the other, the liver releases it through glycogenolysis and gluconeogenesis. Glycaemic stability therefore does not indicate an absence of consumption, but rather a balance between opposing flows.

In DMT1 this balance is particularly delicate because exogenous insulin can limit hepatic production precisely when the muscle increases its demand.

4.1 Hepatic Glucose Production

The liver maintains the systemic availability of glucose through two main processes: glycogenolysis and gluconeogenesis. Glycogenolysis releases glucose from hepatic stores; gluconeogenesis produces new glucose using precursors such as lactate, glycerol and certain amino acids.

In the initial phases of moderate-intensity exercise, hepatic glycogenolysis can make a substantial contribution. As exercise continues and stores are progressively reduced, the relative importance of gluconeogenesis increases.

The liver's ability to rapidly adapt its production is one of the main reasons why a person without diabetes can markedly increase muscular glucose utilization without necessarily developing hypoglycaemia.

4.2 The Insulin–Glucagon Ratio

In a person without diabetes, the onset of aerobic exercise is accompanied by a reduction in insulin secretion and a relative increase in glucagon. This hormone, which in people with diabetes already appears "hypertrophic" and poorly responsive to inhibition, is a powerful stimulator first of glycogenolysis and subsequently of gluconeogenesis. The result is a hormonal environment favourable to the mobilization of stores and hepatic glucose production and therefore to hyperglycaemia.

In DMT1, insulin administered subcutaneously cannot decrease with the same rapidity because, once injected, it is inexorably released for a predetermined period in relation to the amount administered. If the insulin concentration remains relatively high, the liver receives a signal that tends to limit glucose production, while the muscle simultaneously increases glucose utilization. The condition just described is one of those most favourable to a fall in blood glucose during aerobic exercise.

Why does this happen?

Insulin acts on both sides of the balance: it promotes peripheral uptake and simultaneously inhibits hepatic glucose production. During exercise, this dual effect can become much more relevant than at rest.

4.3 Catecholamines, Intensity and Hepatic Production

When intensity increases, adrenaline and noradrenaline (another very similar “catecholamine”), as typical expressions of stress in the body, promote hepatic and muscle glycogenolysis and can thus rapidly increase glucose availability and then, if the stimulus persists, stimulate gluconeogenesis in the same way as glucagon. During very intense activities, hepatic production can temporarily exceed peripheral uptake, resulting in stable or increased blood glucose.

This response is particularly evident during sprints, HIIT, strength exercises, decisive phases of a competition and situations in which physical effort is associated with strong emotional activation. Blood glucose can therefore increase despite very high muscular carbohydrate consumption.

This explains why there is no single rule such as “exercise lowers blood glucose”. The effect depends on the balance among intensity, hormonal response, hepatic production and available insulin.

4.4 Lactate Is Not Merely an End Product

During intense exercise, lactate produced by the muscles can be used by other tissues or reach the liver, where it contributes to gluconeogenesis through the specific metabolic pathway known as the “Cori cycle”. Lactate therefore also represents a substrate for metabolic exchange, not simply a waste product to be eliminated.

This concept helps us understand how integrated metabolism is during exercise: muscle and liver do not work as isolated compartments but continuously exchange substrates and signals.

4.5 The Dynamic Balance of Blood Glucose

From a practical standpoint, we can imagine three scenarios. If peripheral uptake exceeds hepatic production, blood glucose tends to fall. If the two flows are equivalent, blood glucose remains relatively stable. If hepatic production exceeds uptake, blood glucose can rise.

This scheme is deliberately simple, but it is very useful for interpreting apparently contradictory CGM curves. An athlete can consume enormous amounts of carbohydrates during a final sprint and simultaneously show an increase in blood glucose because the catecholamine response has stimulated the liver to an even greater extent.

The Dawn Phenomenon

The dawn phenomenon is an evolutionary and ancestral adaptation that developed millions of years ago with the purpose of supplying the body with glucose, in the pre-agricultural era when obtaining foods containing carbohydrates was extremely difficult. Glucose was necessary for the muscular activity involved in hunting, which at that time consisted of running rapidly at dawn to hunt and therefore capture prey, as well as escaping large predators; this supply was therefore essential for feeding, survival and perpetuation of the species. It is produced by a cortisol peak that begins to occur precisely at dawn and, as is known, activates gluconeogenesis (the production of new glucose from non-carbohydrate substrates). This adaptation, which is now written into our chromosomes, is clearly useless and harmful in the person with diabetes.

4.6 Fasting Exercise and Time of Day

The hepatic response also varies with context. During morning exercise in the fasting state, circulating insulin is often relatively low and the counter-regulatory environment may favour greater hepatic production. Some individuals therefore show stable or increasing blood glucose, whereas the same type of exercise performed after a meal with a still-active prandial bolus may produce a marked fall in blood glucose.

Time of day is therefore not merely an organizational variable but changes the hormonal and insulin context in which the same activity is performed.

4.7 Why CGM Does Not Describe Energy Requirements

CGM measures the concentration of glucose in the interstitial compartment and its change over time. It does not, however, measure energy expenditure, the rate of carbohydrate oxidation, muscle glycogen availability or hepatic production.

Energy demand originates from muscular activity and logically precedes interpretation of the sensor. CGM enters the clinical reasoning subsequently, showing the result of the interaction among hepatic production, peripheral uptake, insulin and ingested carbohydrates.

Frequent conceptual error

Using stable blood glucose as evidence of low carbohydrate consumption leads to errors of assessment. Stability may simply indicate that hepatic production is effectively compensating for peripheral utilization.

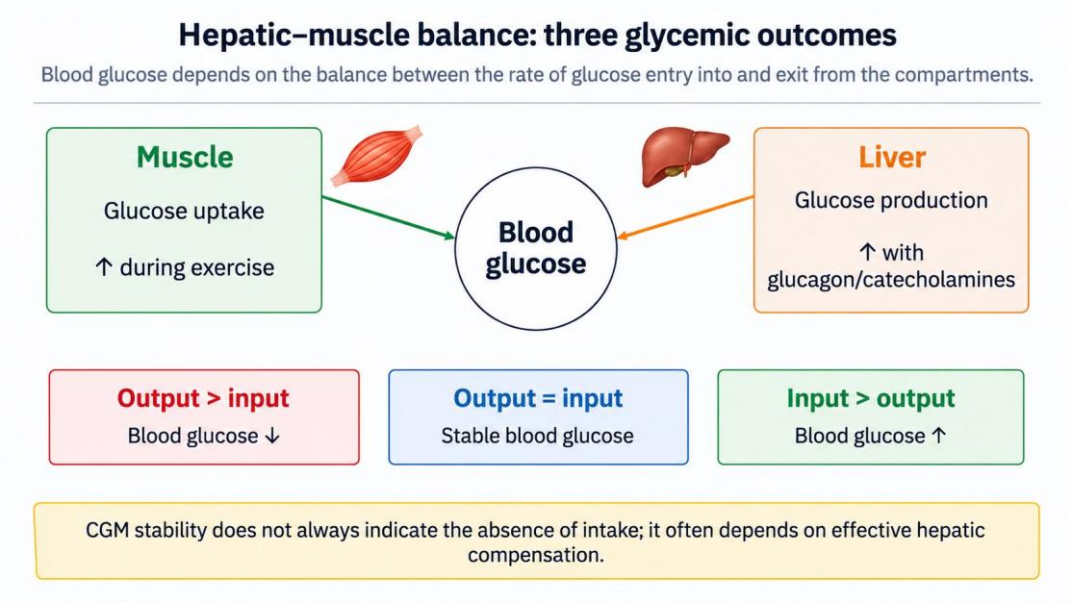


Figure 4.1. Dynamic balance between hepatic production and peripheral uptake: three possible directions of blood glucose.

4.8 Application to DMT1: Reading the Curve as a Balance

To interpret a glucose curve recorded during sporting activity, it is useful to ask not only “how much is the sensor value falling or rising?” but also “which flows are probably producing this pattern?”. A progressive decline during aerobic exercise may suggest a predominance of peripheral uptake, favoured by significant IOB. A sudden rise during a sprint may indicate an increase in catecholamine-dependent hepatic production.

This interpretation does not allow the individual flows to be quantified precisely, but it avoids simplistic interpretations and prepares the ground for therapeutic personalization.

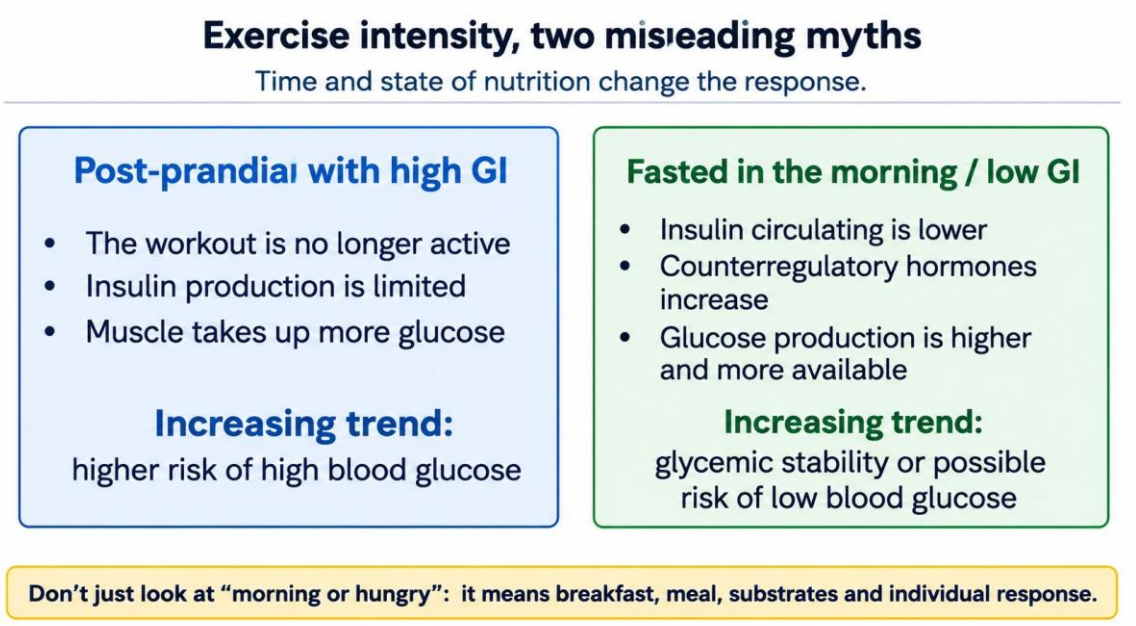


Figure 4.2. The same exercise can produce different responses if the nutritional state and insulin exposure change.

Take-home messages

- blood glucose during exercise is the result of opposing flows, not a direct measure of energy consumption,
- the liver supports blood glucose through glycogenolysis and gluconeogenesis,
- relatively high insulin can limit hepatic production precisely when the muscle increases uptake,
- catecholamines and high intensity can increase hepatic production to the point of causing hyperglycaemia,
- CGM describes the outcome of the balance, not the individual mechanisms that determine it.

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PART II – INSULIN, NUTRITION AND DECISION-MAKING

Chapter 5 — Insulin during exercise: when a dose that is appropriate at rest becomes excessive

Guiding question
Why can an amount of insulin that is appropriate before activity become excessive only a few minutes after exercise begins?

Key message
Exercise changes the context in which insulin acts. The muscle increases glucose uptake through mechanisms related to contraction and capillarisation and simultaneously becomes more sensitive to insulin. For this reason, the same insulin concentration can have very different metabolic consequences at rest and during activity.

In people without diabetes, the body responds by rapidly reducing insulin secretion. In T1D, this adaptation cannot occur in the same way, because exogenous insulin that has already been administered continues to be absorbed into the peripheral circulation and therefore acts predominantly at the muscular level.

5.1 The physiological response in people without diabetes

At the onset of aerobic exercise, pancreatic insulin secretion decreases. This reduction does not represent a "lack" of insulin, but a necessary adaptation: it promotes hepatic glucose production and limits excessive insulin-dependent uptake while the muscle is already increasing its uptake as a result of contraction.

At the same time, glucagon and catecholamines increase to a degree that varies with intensity and duration. The result is a dynamic system capable of supplying energy to the muscle while, in most circumstances, maintaining blood glucose within a narrow range.

5.2 The limitation of exogenous insulin

In T1D, insulin is administered into subcutaneous tissue and reaches the circulation with kinetics that cannot be modified instantaneously. Future delivery can be reduced or suspended, but insulin that has already been absorbed cannot be removed, nor can insulin still present in the subcutaneous depot be cancelled.

This temporal asymmetry is one of the central problems of exercise: an effective therapeutic decision often has to be made before exercise begins. Intervening when the CGM already shows a rapid decline may mean acting when an important part of the problem has already been determined by previously administered insulin.

5.3 Muscle contraction and insulin sensitivity

Contraction promotes the translocation of intracellular GLUT4 transporters to the outer membrane through pathways that are partly independent of insulin. After exercise, moreover, increased insulin sensitivity may remain significant for several hours. The muscle therefore becomes able to take up glucose more efficiently both during and after the session.

In T1D, this physiological advantage can turn into a risk of hypoglycaemia if the insulin available remains excessive relative to the tissue's new sensitivity.

5.4 Aerobic exercise: the context most favourable to a fall in blood glucose

During continuous moderate-intensity aerobic exercise, muscle glucose uptake progressively increases, while hepatic production must adapt to maintain blood glucose. If circulating insulin is relatively high, the muscle receives an additional stimulus for uptake and the liver is simultaneously inhibited from producing glucose.

The combination of these two effects explains why running, cycling or a long walk can produce a much more marked fall in blood glucose when started in the hours following a mealtime bolus.

Practical application

Reducing the carbohydrates to be consumed during exercise does not necessarily mean "eating less": it often means starting the activity with a more appropriate insulin exposure.

5.5 Intense exercise, strength exercise and intermittent sports

In very intense exercise, the response is different. The rise in catecholamines can rapidly stimulate hepatic glucose production and reduce or reverse the downward trend. For this reason, sprints, HIIT (the acronym stands for High Intensity Interval Training and refers to an activity in which maximal anaerobic phases, mostly alactic, alternate with medium-to-low intensity aerobic phases), weight training and high-intensity competitive phases may result in stable blood glucose or hyperglycaemia even when muscular carbohydrate consumption is high.

In intermittent sports such as football, tennis or basketball, aerobic phases and high-intensity actions alternate. The overall glycaemic effect therefore depends on the combination of IOB, duration, sprint frequency, catecholamine response and training status.

5.6 The pre-exercise window

The period preceding exercise is often more important than the first minutes of the session. The bolus for the previous meal, a recent correction, the basal insulin already absorbed and the timing of any exercise target determine the insulin exposure with which the athlete will enter the session.

Effective prevention of hypoglycaemia therefore usually begins 90–120 minutes before planned activity, especially with AID systems, and even earlier when considering meals and boluses. The principle is not to achieve a complete absence of insulin, but an amount appropriate to the new metabolic context.

5.7 Basal and bolus insulin do not carry the same weight in every situation

In the period immediately following a meal, the mealtime bolus may represent the dominant component of insulin exposure. During exercise performed away from meals, the basal component becomes more important. The strategy must therefore identify which component of insulin is actually driving the risk at that moment.

This distinction also helps explain why a simple reduction in basal insulin started only a few minutes before exercise may be insufficient when a significant residual bolus is still present.

5.8 Post-exercise: when the insulin effect changes again

After the session, the muscle continues to replenish glycogen stores and remains more insulin-sensitive. Consequently, usual doses of mealtime or basal insulin may have a greater effect than on a relatively sedentary day.

The risk is not uniform. It depends on exercise duration and intensity, the amount of glycogen used, time of day, post-exercise nutrition and residual insulin. Evening activities deserve particular attention because part of the period of increased sensitivity may coincide with sleep.

5.9 Insulin, performance and safety

An effective insulin strategy should not be assessed solely by its ability to prevent hypoglycaemia. Excessive reduction may promote hyperglycaemia, increased hepatic glucose production, ketogenesis and impaired performance. The goal is to maintain a minimum but sufficient availability of insulin to ensure metabolic balance without producing excessive exposure relative to the demands of exercise because, while in the complete absence of insulin the channels that allow glucose to enter cells do not open, once the mechanism has been initiated, glucose influx is maintained by the high blood flow and by all that we have already described as the extra-insulin effect of physical exercise itself in enhancing muscular uptake of energy substrates.

From this perspective, the “right dose” is not a fixed amount but a relationship between available insulin and the physiological context.

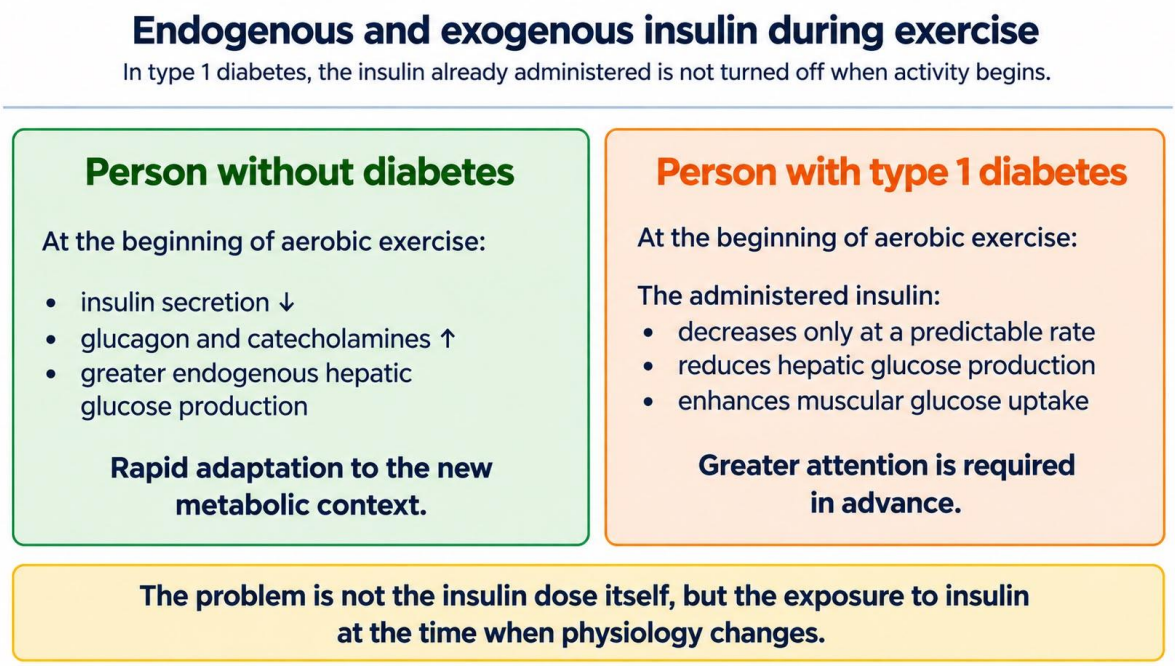


Figure 5.1. During exercise, endogenous insulin secretion can decrease rapidly, whereas exogenous insulin that has already been administered persists.

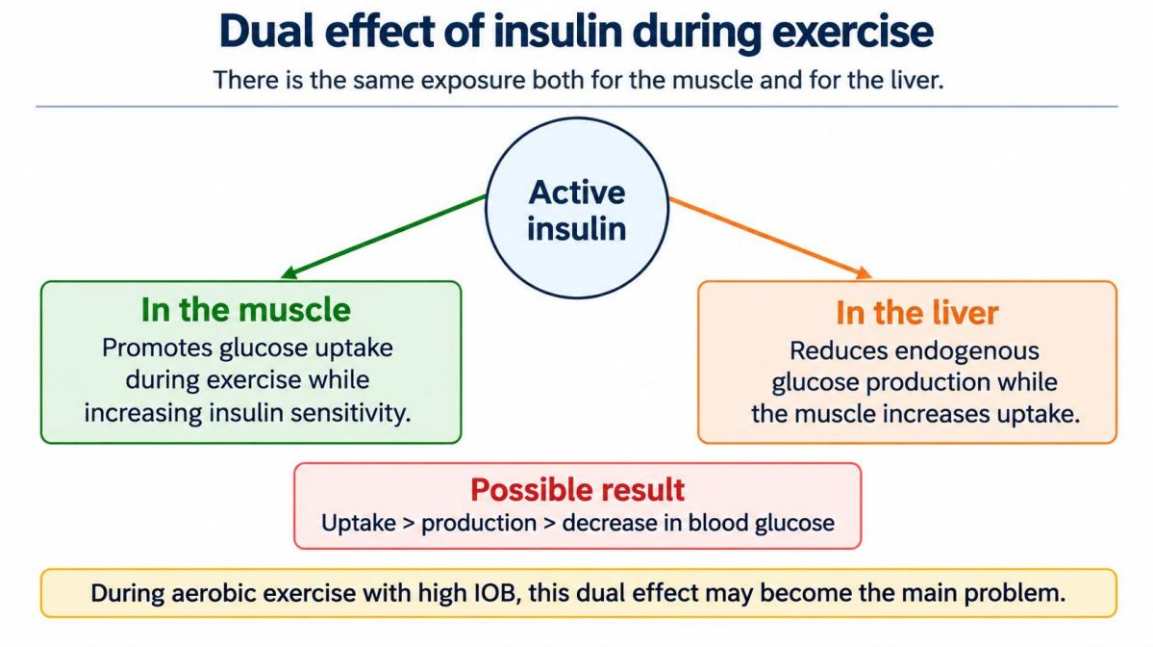


Figure 5.2. Insulin can promote peripheral uptake while simultaneously limiting hepatic glucose production.

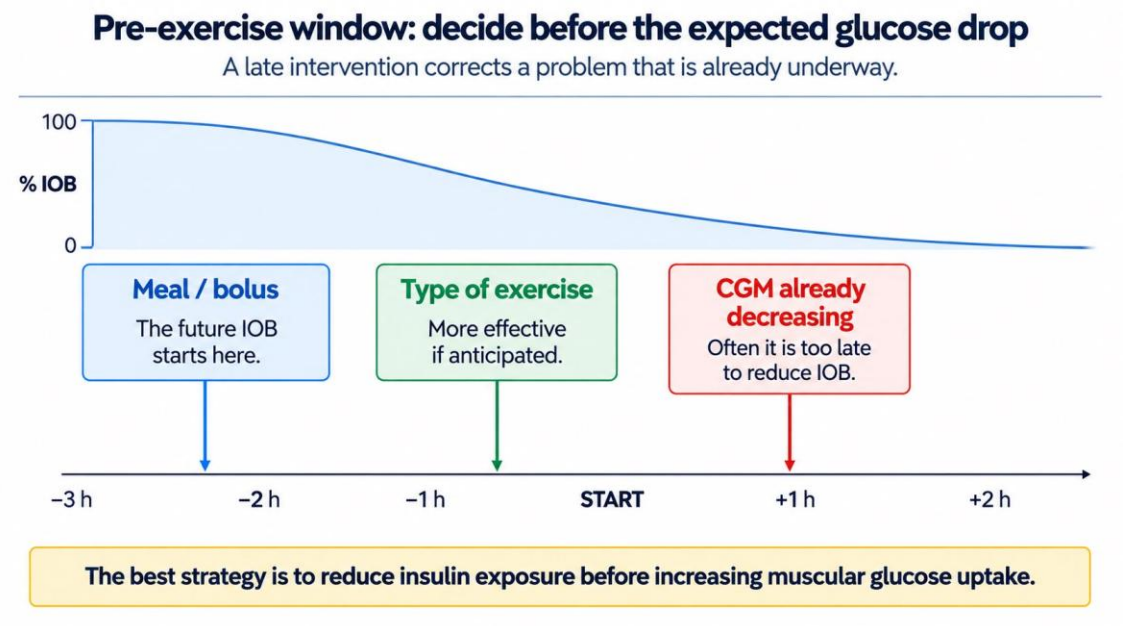


Figure 5.3. The pre-exercise window: early prevention may be more effective than a late correction.

5.10 From the concept of dose to the concept of insulin exposure

In daily practice, we tend to think in terms of units administered. During exercise, it is often more useful to think in terms of exposure: how much insulin effect is still present at the moment when muscle uptake, hepatic production and tissue sensitivity change.

This conceptual shift leads directly to the next chapter on IOB. The displayed IOB does not perfectly coincide with the biological effect, but it is a useful tool for estimating part of the recent insulin history.

Take-home messages

- exercise changes the context in which insulin acts,
- in people without diabetes, insulin secretion decreases rapidly during aerobic exercise,
- in T1D, insulin already administered cannot be removed and may become relatively excessive,
- aerobic and intense exercise can produce different glycaemic effects because of the different balance between uptake and hepatic production,
- effective management often begins in the pre-exercise window,
- the goal is not to reduce insulin to a minimum, but to achieve exposure appropriate to the context.

Essential references for further reading

Colberg SR, et al. Physical Activity/Exercise and Diabetes: A Position Statement of the American Diabetes Association. *Diabetes Care*. 2016;39(11):2065–2079.

Jensen TE, Richter EA. Regulation of glucose and glycogen metabolism during and after exercise. *Journal of Physiology*. 2012;590(5):1069–1076.

Riddell MC, et al. Exercise management in type 1 diabetes: a consensus statement. *Lancet Diabetes Endocrinol*. 2017;5(5):377–390.

Chapter 6 — Active insulin (IOB): the invisible variable that changes the game in sport

Guiding question

Why can two athletes with type 1 diabetes of the same weight and the same training level, perform the same physical activity and need completely different amounts of carbohydrates?

Key message

The most intuitive answer would be to attribute this difference to energy expenditure. Often, however, a substantial part of the variability depends on the amount of biologically active insulin during physical exertion. Exercise changes the relationship between muscle glucose uptake, hepatic glucose production, glycogen availability and carbohydrates ingested from external sources.

6.1 What do we mean by IOB?

IOB means Insulin on Board, i.e. insulin that is still active in the body after a previous administration. The term is often used as if it described a single, unambiguous quantity, but it is useful to distinguish at least three levels.

IOB displayed by the device

This is the amount that the insulin pump or AID system estimates to be still active on the basis of the insulin delivered, the time elapsed, the programmed duration of insulin action and the specific rules of the algorithm.

Pharmacokinetic IOB

This is the fraction of subcutaneous insulin that has not yet been completely absorbed or metabolised.

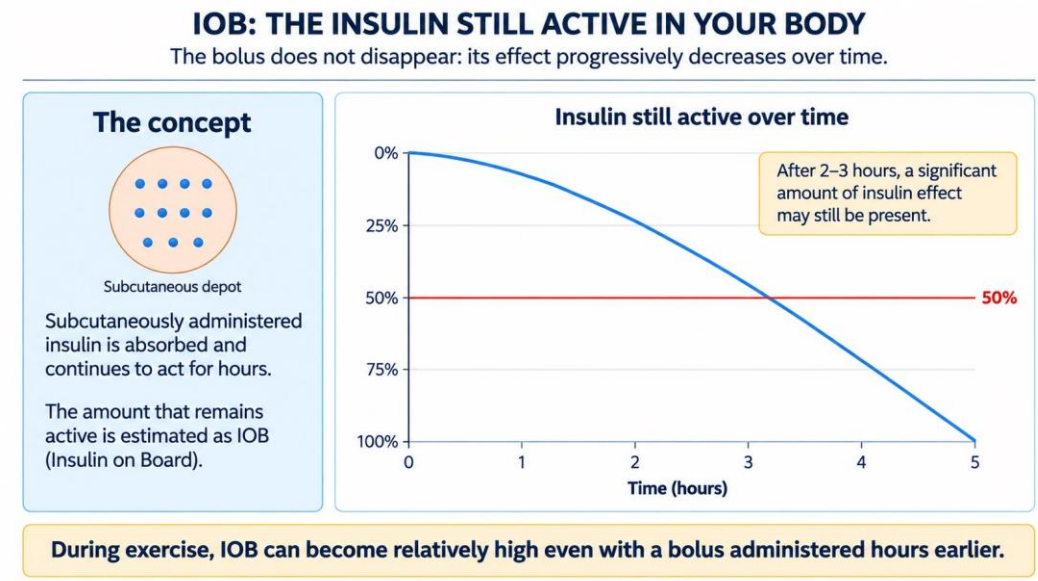


Figure 6.1. How we can conceptualise the relationship between insulin injected at a given time and IOB over time.

Biological IOB

This is the fraction that, at a given time, continues to exert a metabolic effect. The three quantities do not necessarily coincide; the value shown on the display is therefore a clinically useful estimate, not a direct measurement of insulin effect.

6.2 Why exercise amplifies the effect of insulin

During aerobic activity, the muscle increases glucose uptake through contraction-related mechanisms and simultaneously increases its insulin sensitivity. In a person without diabetes, pancreatic insulin secretion falls rapidly; in type 1 diabetes, insulin that has already been administered cannot be withdrawn from the circulation. As a result, an amount that is appropriate at rest may become relatively excessive during exercise.

6.3 Carbohydrate consumption and the need to ingest carbohydrates are not the same thing

Suppose that during a given activity the muscle oxidises a total of 80 g of carbohydrates. This does not imply that the athlete must ingest 80 g of CHO. Part of the energy comes from muscle glycogen, part from glucose produced by the liver, and only a fraction from carbohydrates ingested from external sources.

For the same energy demand, high IOB can increase peripheral glucose uptake and reduce hepatic glucose production. The same exercise may therefore require more externally ingested CHO to maintain blood glucose, not because the muscle consumes more energy, but because a proportion of those carbohydrates is also used to compensate for the insulin effect.

6.4 Two functions of carbohydrates during sport

For clinical reasoning, it is useful to distinguish two functions, while recognising that in practice they may overlap.

Performance carbohydrates

- support exercise intensity and duration, as well as volume and density
- contribute to substrate availability
- help maintain glycogen stores during prolonged activities.

Therapeutic carbohydrates

- prevent or treat hypoglycaemia
- compensate for relatively excessive insulin exposure
- correct a downward glucose trend when appropriate.

An athlete who consumes 60 g/h to avoid hypoglycaemia does not necessarily oxidise 60 g/h more than another athlete. They may simply be in a condition of greater insulin exposure.

6.5 The IOB–CHO conceptual model

For the same type, intensity and duration of exercise and the same training status, increasing insulin exposure tends to increase the likelihood of needing CHO for a therapeutic purpose. This model is qualitative and should not be converted into a rigid mathematical relationship.

6.6 IOB and timing of exercise

It is not only how much insulin is active that matters, but also when exercise is performed in relation to insulin administration. Immediately after a meal, prandial insulin may be close to its peak effect; after two or three hours, the residual amount is lower but still relevant; away from meals, the need for therapeutic CHO may be lower, especially when basal insulin or the AID system has been adjusted in advance.

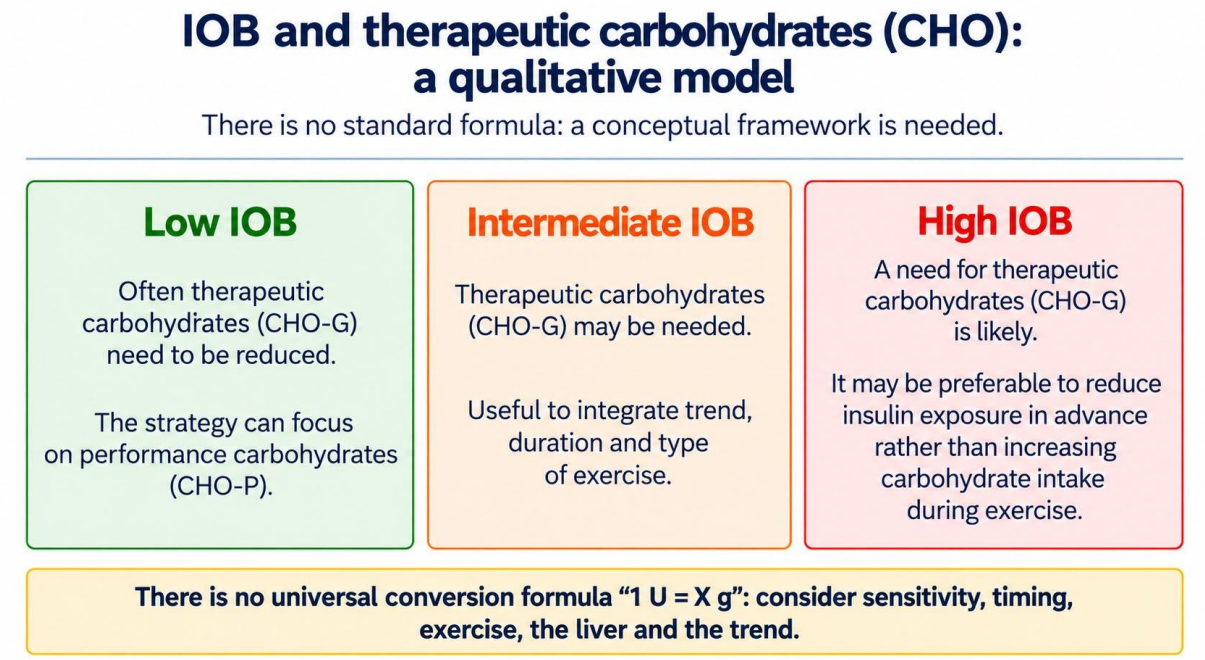


Figure 6.2. Qualitative relationship between insulin exposure and the likelihood of needing CHO for a therapeutic purpose.

Methodological caution

There is no universal conversion such as "1 U of IOB = X grams of CHO". Requirements also depend on body weight, insulin sensitivity, insulin type and timing, starting glucose, CGM trend, intensity, duration, glycogen availability, training status, temperature, adrenergic response and time of day.

6.7 IOB and AID systems

AID systems can reduce future insulin delivery, but they cannot eliminate insulin that has already been administered. This limitation explains why early activation of an exercise target and management of the preceding meal bolus are often more effective than an intervention made after glucose has already begun to fall. Different systems represent and use IOB according to different logics, but the underlying physiology remains the same.

6.8 IOB and basal–bolus therapy

The same principle applies to multiple daily injection therapy. The capacity for modulation changes, not the physiology. With MDI, reasoning should focus primarily on the preceding bolus, the basal dose, the timing of activity and any need for preventive CHO.

6.9 A practical example

Consider three highly trained athletes taking part in the same 10 km race. With approximately the same energy demand, the first starts with high IOB and requires repeated therapeutic CHO; the second has moderate IOB and requires less supplementation; the third starts with minimal insulin exposure and may not require therapeutic CHO during the event. Any numerical values used in an educational figure should be presented as examples and not as a therapeutic algorithm.

6.10 When too little insulin becomes too little

The principle of insulin reduction should not be taken to an extreme. Insufficient exposure may promote hyperglycaemia, excessive hepatic glucose production, ketogenesis and impaired performance. The aim is not to achieve “zero IOB”, but to obtain insulin exposure appropriate to the specific activity and the individual athlete.

6.11 Intense exercise: when the model changes

During very intense, intermittent or strength exercise, or activity with a strong competitive component, catecholamine activation can significantly increase hepatic glucose production. Blood glucose may therefore remain stable or increase even in the presence of high muscular carbohydrate consumption. The IOB–CHO model must be interpreted together with exercise intensity and the hormonal response.

6.12 Post-exercise

The end of activity does not coincide with the end of its metabolic effect. Increased insulin sensitivity, glycogen resynthesis and greater muscle glucose uptake may persist for hours afterwards. The risk of post-exercise hypoglycaemia therefore depends on insulin exposure, the duration and intensity of the event, the time of day and the recovery strategy.

6.13 What the athlete needs to learn

Planning should distinguish two consecutive questions: how many carbohydrates are metabolically required by the planned activity, and how many additional carbohydrates may be needed to maintain glucose stability in the presence of a given insulin exposure.

Table 6.1. Fundamental concepts for an athlete with T1D

1. Exercise	Type of activity, intensity, duration, frequency, volume and density
2. Metabolic demand	Energy expenditure and substrate utilisation
3. Insulin exposure	Expected IOB and timing of the most recent insulin administrations
4. Glucose status	Starting glucose and CGM trend
5. Glycaemic risk	Likely direction of the glucose response during activity
6. Strategy	Insulin adjustment and amount of CHO that may be required

Energy demand is therefore determined first and foremost by the activity. CGM does not quantify this demand: it enters the reasoning at a later stage, helping to understand how metabolic demand interacts with insulin exposure and the availability of circulating glucose.

6.14 Take-home messages

- the IOB displayed is a useful estimate, but does not necessarily correspond to the biological effect of insulin
- the energy demand of exercise and the therapeutic need for CHO are different concepts
- for the same exercise, greater insulin exposure may increase the need for therapeutic CHO
- reducing insulin excessively can be just as problematic as starting with an excess
- the strategy must integrate exercise physiology, IOB, glucose level, trend and individual context.

Chapter 7 — Nutrition, insulin and glycaemic stability in sport with type 1 diabetes

Guiding principle
First define what exercise requires of the athlete. Then determine how to adapt insulin, carbohydrates and technology so that diabetes interferes as little as possible with that requirement. Glycaemic control is a prerequisite of the strategy, not its only objective.

7.1 One word for two different problems — Two carbohydrate requirements: performance and glycaemic stability

In the everyday language of an athlete with type 1 diabetes, the phrase “I need to take carbohydrates” can indicate two profoundly different needs. The first arises from muscular work: an amount of substrate compatible with the duration and intensity of performance must be made available. The second arises from therapy: carbohydrates may sometimes need to be consumed to counteract a fall in glucose promoted by circulating insulin. Confusing these two problems can easily lead to strategies that appear effective on the CGM but are not necessarily optimal for performance.

To reason in an orderly way, we propose two abbreviations for educational purposes only. CHO-P indicates carbohydrates consumed primarily for performance purposes; CHO-G indicates those consumed primarily for glycaemic management. They are not different molecules. What changes is the reason for which they are consumed.

7.2 CHO-P: start from exercise, not from the CGM

Performance requirements depend on the discipline, duration, relative intensity, training status, glycogen availability, previous nutrition and the objective of the session. An easy forty-minute run, a 10 km race run at the limit, a long-distance cycling event and a marathon cannot be reduced to the same scheme simply because they are endurance activities.

The first question should therefore be: if this athlete did not have diabetes, what nutritional strategy would be reasonable to support the planned performance? Only after answering this question should the insulin-related issue be superimposed.

7.3 CHO-G: when carbohydrates compensate for insulin

In T1D, exogenous insulin cannot decrease as rapidly as endogenous secretion does at the start of exercise in a person without diabetes. If exercise increases muscular glucose uptake while a relevant amount of IOB remains, carbohydrate intake may become necessary even when the muscular work itself would not require that amount.

Exercise recommendations for T1D clearly show that, under conditions of relative hyperinsulinaemia after a bolus, 30–60 g/h of carbohydrates may be required. An appropriate reduction in insulin exposure can reduce or sometimes eliminate part of this need. This point is fundamental: the amount ingested does not automatically measure the energy cost of exercise.

7.4 Four scenarios

- High CHO-P, low CHO-G: long or intense activity with well-adapted therapy; most carbohydrates fuel performance.
- Low CHO-P, high CHO-G: relatively short activity started with excessive IOB; the athlete consumes CHO mainly to prevent glucose from falling rapidly.
- High CHO-P and high CHO-G: long activity associated with still-significant insulin exposure; management becomes complex and the gastrointestinal load (i.e. CHO dissolved in a liquid such as water which, especially when highly concentrated, may sometimes cause nausea, abdominal discomfort or diarrhoea) may increase.
- Low CHO-P and low CHO-G: short or metabolically minimally perturbing activity performed with appropriate insulin exposure.

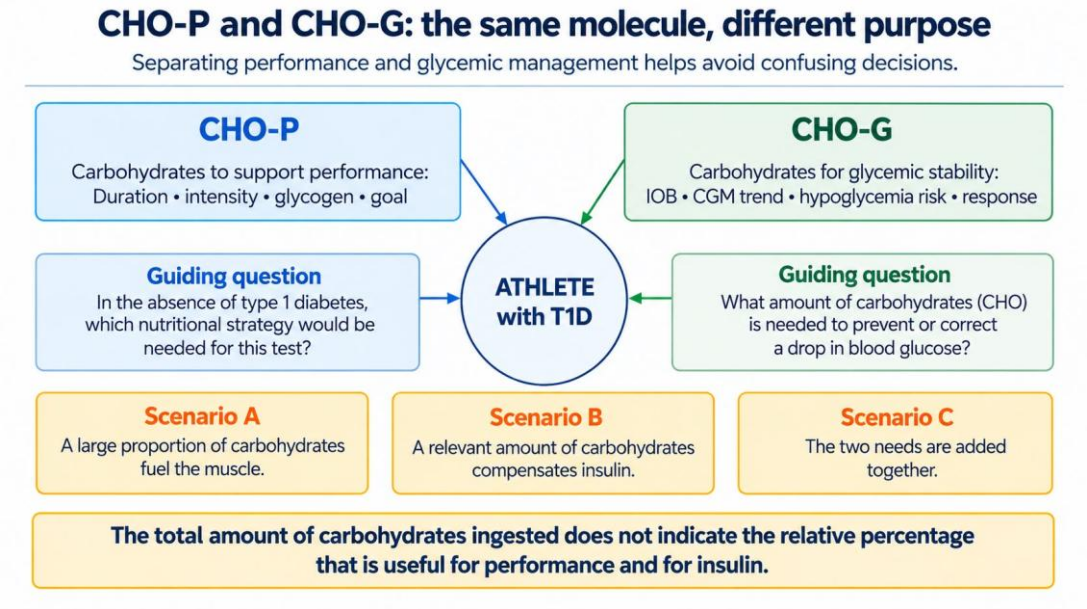


Figure 7.1. Difference between carbohydrates for performance and for glycaemic balance

Fuel the muscle or fuel the insulin?
The question is not intended to set nutrition against therapy. It is meant to clarify why an athlete is consuming carbohydrates.
If an increasing proportion is used solely to compensate for insulin, it may be more rational to correct the insulin strategy than to continue increasing carbohydrate intake.

7.5 The CGM does not determine energy requirements

The CGM describes the dynamics of interstitial glucose. It does not measure muscle glycogen, substrate oxidation or overall energy availability. A stable glucose profile may therefore coexist with carbohydrate availability that is insufficient for performance. Conversely, an adequate nutritional strategy may produce temporary glucose excursions that require better therapeutic adaptation.

The clinical objective is not to make the graph aesthetically perfect at any cost. It is to enable the athlete to sustain the planned work with reasonable glycaemic safety.

Chapter 8 — Carbohydrates: from structure to availability during exercise

8.1 What does monosaccharide mean?

A monosaccharide is a carbohydrate consisting of a single sugar unit that cannot be further hydrolysed into simpler carbohydrates. Glucose, fructose and galactose are monosaccharides. Disaccharides and polysaccharides, on the other hand, must be digested into absorbable units before crossing the intestinal epithelium. In sports-related reasoning, it is useful not to use carbohydrates, glucose and glycogen as synonyms. Carbohydrates are a nutritional category; glucose is a specific monosaccharide and represents a central hub of energy metabolism; glycogen is the polymeric form in which glucose units are stored mainly in muscle and liver.

8.2 Absorption does not yet mean oxidation

For an ingested carbohydrate to contribute to energy production during exercise, it must be broken down into monomeric glucose units, absorbed from the intestine, reach the circulation or be transformed at the splanchnic level, and finally become available to the tissues that oxidise it. The rate of ingestion therefore does not automatically correspond to the rate of utilisation. What has just been described explains why many people with diabetes, after taking even simple carbohydrates to correct hypoglycaemia, may not understand why they do not see blood glucose rise rapidly (especially in the presence of high levels of circulating insulin).

8.3 SGLT1 and GLUT5: why glucose and fructose can work together

Glucose is absorbed predominantly through the sodium-glucose cotransporter SGLT1. Fructose predominantly uses GLUT5. When carbohydrate intake is moderate, combining multiple monosaccharides offers limited advantages over a glucose-only source. When intake becomes high and the capacity of the glucose pathway represents a bottleneck, adding fructose allows a second transport pathway to be used and may increase exogenous carbohydrate oxidation. It is not correct to describe this phenomenon as a simple temporal sequence, with glucose first and fructose later. The two sugars are absorbed through different pathways over the same time interval. Fructose then undergoes substantial intestinal and hepatic metabolism, enabling it to contribute to glucose and lactate availability during exercise.

8.4 Maltodextrins

Maltodextrins are glucose polymers obtained from the hydrolysis of starch and contain several thousand glucose molecules. They are widely used in sports drinks and gels because they make it possible to provide considerable amounts of carbohydrate without increasing sweetness as much as equivalent amounts of simple sugars. From the standpoint of final absorption, however, they still feed into the glucose pathway and do not use an alternative intestinal transporter.

8.5 Osmolality, concentration and tolerability

An athlete often needs to supplement very large amounts of carbohydrate and, to avoid taking in an excessive amount of water, may prepare concentrated (hypertonic) solutions. However, a highly concentrated drink is not necessarily more effective. High amounts of solutes may slow gastric emptying or promote gastrointestinal symptoms in predisposed individuals. Mixture composition, fluid volume, ambient temperature, exercise

intensity and the athlete's habitual practice interact with one another. The strategy should therefore be tested in training.

TYPES OF CARBOHYDRATES: ABSORPTION AND USE

A practical guide to understand rapidity, tolerability and role during exercise.

TYPE	EXAMPLES	ABSORPTION	MAIN CHARACTERISTICS	DURING EXERCISE
Monosaccharides	Glucose Fructose	Very rapid (5–15 min)	Immediately available High glycemic index	Ideal for high-intensity efforts or hypoglycemia
Disaccharides	Sucrose Lactose	Rapid (15–30 min)	Good tolerability Breaks down into simple sugars	Also useful in prolonged activities
Maltodextrins	Maltodextrins Isomaltulose	Moderate (20–60 min)	Progressive release Lower osmolality	Ideal for prolonged strategies
Fiber / complex polysaccharides	Whole grains Legumes	Slow (>60 min)	Promotes satiety and intestinal health Not for immediate effect	Better for meals far from exercise

Combining different sources can optimize energy availability and gastrointestinal tolerability.

Figure 8.1. Functional distinction among the different types of available carbohydrates.

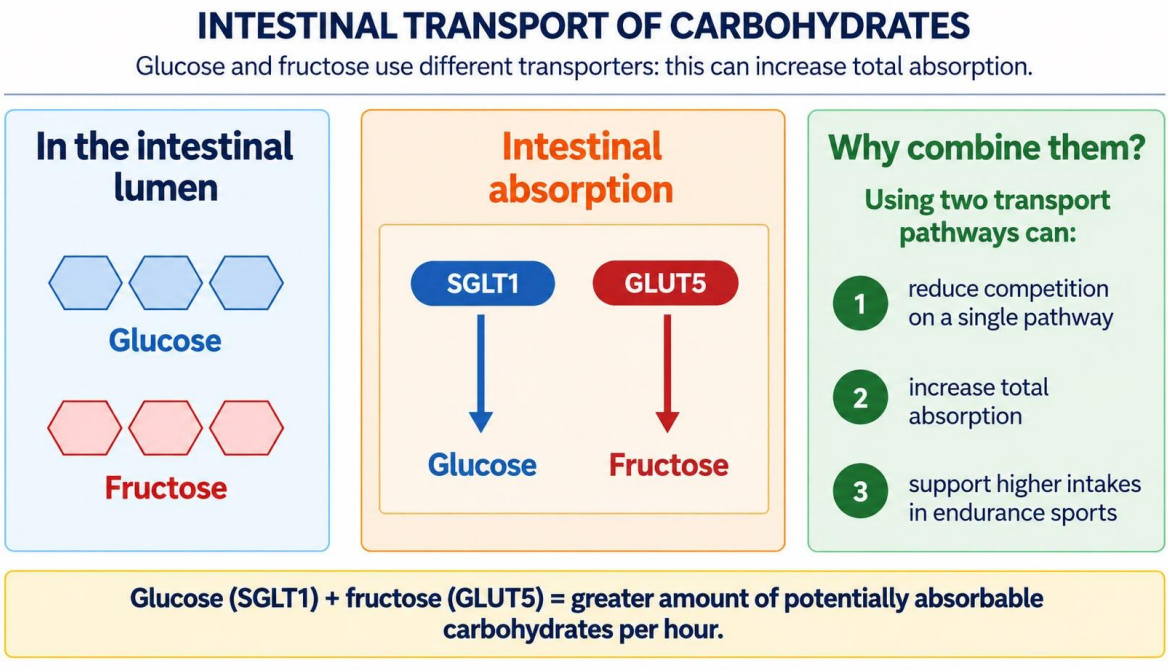


Figure 8.2. Absorption pathways of glucose and fructose

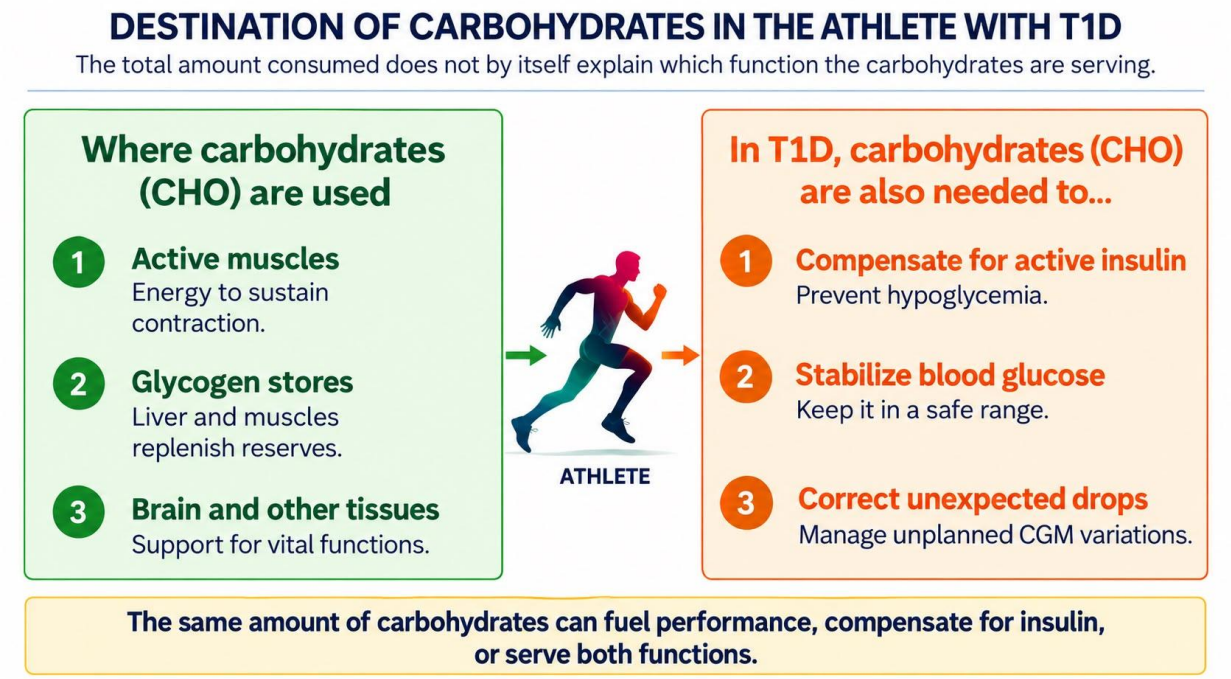


Figure 8.3. Fate of carbohydrates in the athlete with T1D

Take-home message

A greater amount of carbohydrates ingested does not mean a greater amount of carbohydrates oxidised. The limiting factor may be intestinal absorption, tolerability or the capacity for utilisation. Glucose-fructose mixtures become particularly relevant when carbohydrate intakes are high.

Chapter 9 — Integration during exercise: amounts, mixtures and “gut training”

9.1 Why duration changes the strategy

In short-duration activities, endogenous glycogen availability is generally sufficient and intake during exercise may not be necessary from an energy standpoint. As duration increases, exogenous carbohydrates become increasingly relevant, both to support carbohydrate oxidation and to preserve the ability to maintain intensity. Recommendations expressed in grams per hour are therefore practical tools rather than rigid biological thresholds. Actual requirements depend on the metabolic power required, expected duration, previous nutrition and individual tolerance.

9.2 From 30 to 90 g/h: how to interpret the ranges

Established recommendations frequently place intake in the range of 30–60 g/h during prolonged exercise and up to approximately 90 g/h in longer-duration events. When intake exceeds approximately 60 g/h, the use of carbohydrates that rely on different transporters—typically glucose or maltodextrins combined with fructose—becomes physiologically more rational. These amounts should not be transferred automatically to every sport. A match, a 10 km race, a marathon and a many-hour cycling event have different demands, feeding opportunities and gastrointestinal constraints.

9.3 Beyond 90 g/h

In recent years, endurance and ultra-endurance athletes have experimented with intakes around 100–120 g/h, and research is evaluating their tolerability and potential benefits. These data do not justify considering 120 g/h a new universal target. The evidence is more limited, athlete selection is important and gastrointestinal adaptation becomes decisive.

9.4 Gut training: training the gut as well

The ability to fuel during exercise is partly trainable. Repeated exposure to carbohydrate amounts similar to those planned for competition may improve tolerance to ingestion and reduce some gastrointestinal symptoms. Adaptations in intestinal transport have been proposed, but in humans the magnitude and mechanisms of these adaptations are not fully defined. Gut training does not mean suddenly forcing large amounts of carbohydrate, but progressively testing the race strategy in training: product, concentration, amount per hour, fluid volume, frequency of intake and environmental conditions.

9.5 T1D: the risk of adding CHO-P and CHO-G

The athlete with T1D may need to consume the carbohydrates planned for performance and, at the same time, additional carbohydrates because of a hypoglycaemic trend. If the total exceeds gastrointestinal capacity, the solution cannot simply be to keep eating. It is necessary to ask whether insulin exposure can be reduced on subsequent occasions.

9.6 Two tables for estimating the amount of CHO-P for different sports and roles

In a practical manual such as this, we believe it is necessary to provide useful guidance for anticipating carbohydrate requirements for individual sports and specific roles within them. For this reason, we include two tables which, although highly simplified, may serve as a guide for those who are not yet fully able to orient themselves in this area.

Table 9.1 Average percentage of glucose utilisation and energy system for the most common sports and specific roles within them.

Sport and Type	Specific Role / Phase	Intensity (% VO_2max Average)	% Energy from Glucose (Average)	Main Energy System
Football *(Fixed Time – Intermittent Activity)*	Midfielder (high running volume at mixed intensity)	75% - 85%	65% – 80%	Alternating Aerobic / Anaerobic
	Forward / Full-back (high frequency of sprints and bursts)	80% - 90% (active phases)	75% – 85%	Lactic / Alactic Anaerobic
	Centre-back (less total distance, strength-based marking)	70% - 75%	55% – 65%	Mixed (frequent aerobic pauses)
	Goalkeeper (very brief explosive efforts, long inactive periods)	< 60% (average)	20% – 30% (brief peaks at 100%)	Alactic Anaerobic (ATP-CP) / Fats at rest
Tennis *(Variable Time – Intermittent Activity)*	Baseline Player (long rallies, prolonged high intensity)	70% - 80%	60% – 75%	Mixed Aerobic/Anaerobic
	Attacking Player / Serve and Volley (short, explosive rallies)	Lower average intensity	45% – 60% (anaerobic peaks during sprints)	Explosive Anaerobic / Aerobic Recovery
Road Cycling *(Variable Time - Continuous/Endurance)*	Rouleur / Climber (steady high-intensity uphill pace)	75% - 85%	70% – 85%	Aerobic Glycolytic
	Sprinter (sheltered pace in the group, peak at the finish)	60% (in group) -> 150%+ (sprint)	40% (in slipstream) 95% (final sprint)	Lipolytic in slipstream Pure anaerobic in the final sprint
Marathon / Running *(Variable Time - Continuous)*	Elite Marathon Runner (steady pace close to anaerobic threshold)	80% - 85%	75% – 85%	Aerobic (Glucose + high lipid efficiency)
	Amateur Runner (moderate, prolonged pace)	65% - 70%	50% – 60%	Mixed Carbohydrates / Lipids (Fats)

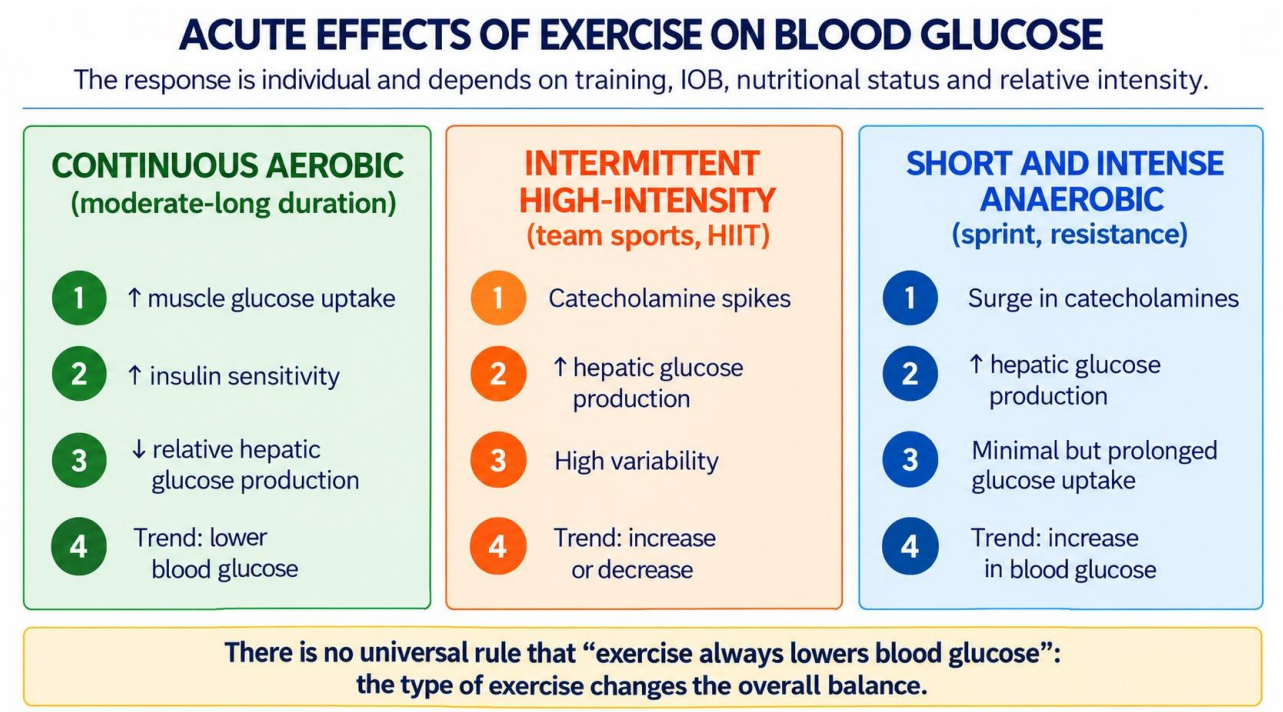


Figure 9.1. Acute effect of exercise type on glycaemia, also in relation to IOB

Table 9.2 Average percentage of glucose utilisation and main metabolic characteristic for other sports and specific roles within them

Sport and Category	Role / Specialty / Phase	Intensity (% VO_2max Average)	% Energy from Glucose (Average)	Main Metabolic Characteristic
Mountain Bike (MTB) *(Variable Endurance)*	Cross-Country (XC) (continuous steep climbs, accelerations, 1.5 hours)	80% - 88%	80% – 90%	Continuous carbohydrate use due to gradients and accelerations
	Enduro / Downhill (technical explosive descents, brief effort)	Muscle recruitment	65% – 75%	Lactic anaerobic effort combined with neural stress
Endurance Swimming *(Continuous Endurance)*	Open-water distance swimming (10 km, steady pace and smooth stroke)	75% - 80%	65% – 75%	Stabilised aerobic glycolytic (hydrodynamic efficiency)
Basketball *(Team Sport - Intermittent)*	Point Guard / Guard (rapid transitions, pressing, ball handling)	80% - 85%	75% – 85%	High anaerobic demand (glycolysis and ATP-CP)
	Centre / Pivot (battles under the basket, rebounds, fewer total km)	75% - 80%	65% – 75%	Strength/power efforts alternating with brief pauses
Handball *(Team Sport - Contact)*	Wings / Backs (rapid counterattacks, jumps, continuous changes of direction)	80% - 90%	80% – 90%	Very high density of sprints and shots (accelerated glycolysis)
	Pivot (physical blocking, intense body-to-body contact in the area)	75% - 82%	70% – 80%	Anaerobic component mixed with explosive strength efforts
Volleyball *(Explosive Intermittent)*	Outside Hitter / Opposite (continuous jumping, approach, attack, block)	Frequent peaks	60% – 70% (during actions)	ATP-CP system with strong glucose-driven resynthesis
	Libero (reactivity, dives, short low movements)	< 65% (average)	40% – 55%	Predominantly aerobic / lipolytic during inactive periods
Padel (*Intermittent - Changes of Direction*)	Left-side Player (more aggressive, smashes, recoveries)	70% - 78%	65% – 75%	Moderate/high glycolysis for short but intense rallies
	Right-side Player (build-up play, more controlled pace)	65% - 73%	55% – 65%	Slightly more balanced energy demand
Motor Racing *(Motorsport - Isometric Stress)*	Open-wheel Driver (F1) (up to 5G lateral forces, heart rate 160–180 bpm)	High stress	60% – 70%	Isometric effort; glucose supports the CNS and heart
	GT / Endurance Driver (very hot cockpit, long driving stints)	Thermal stress	50% – 60%	Consumption driven by thermoregulation and muscle tension
Motorcycling *(Motorsport - Whole-body Effort)*	MotoGP / Motocross Rider (physical control of the motorcycle, 30–40 min)	80% - 85%	70% – 80%	Very high muscular (whole-body) and cardiovascular demand

In AID systems, the reasoning outlined above becomes even more complex: large amounts of carbohydrates consumed preventively may cause glucose to rise and prompt the algorithm to deliver additional insulin. A strategy intended to prevent hypoglycaemia may therefore paradoxically help recreate the conditions for it.

Reasoned example

A cyclist has planned an intake of 75 g/h for a long-duration event. If they repeatedly need to add 15–20 g to compensate for continuous downward glucose trend arrows, it would not be correct to automatically redefine their performance-related carbohydrate requirement as 95 g/h. The difference may consist precisely of CHO-G required because insulin therapy has not been optimally adjusted.

Chapter 10 — Before, during and after: nutrition as a continuous process

10.1 The day before is not separate from the race

The glycogen availability with which an athlete starts an event also depends on previous nutrition and training load. A pre-race strategy cannot fully correct chronically insufficient carbohydrate availability. In important endurance events, nutritional preparation therefore begins before the final meal.

10.2 The pre-exercise meal

The meal should provide substrate, be digestible, and be timed at an interval compatible with gastric emptying and comfort. Amount and composition depend on the time of the event, its duration, and individual habits. Fat, fibre, and large amounts of protein can slow digestion; this effect may be useful in some contexts but unfavourable immediately before an intense competition.

In T1D, an additional question arises: how much of the insulin from the previous bolus will still be active when exercise begins? A nutritionally appropriate meal can become metabolically difficult to manage if the peak of insulin action coincides with the increase in muscle glucose uptake.

10.3 Morning exercise and nutritional state

Time of day should not be interpreted in isolation. Fasted morning exercise, morning exercise after breakfast, and postprandial afternoon exercise also differ in insulin exposure, substrate availability, and hormonal response. In T1D, fasted morning exercise tends in many individuals to produce a smaller fall in glucose and sometimes a rise (see the box on the “dawn phenomenon”), but this observation cannot be considered a universal rule.

10.4 During exercise

During prolonged exercise, the strategy should be simple enough to be implemented even under conditions of genuine fatigue. Small CHO intakes at regular intervals may be better tolerated than large intermittent nutritional boluses.

In T1D, CGM readings add information but should not end up interfering with the performance plan in response to every minor observed variation.

10.5 After exercise: recovery does not mean only avoiding hypoglycaemia

Recovery includes glycogen replenishment, protein repair and remodelling, rehydration, and electrolyte replacement when necessary. In T1D, the increase in insulin sensitivity and the risk of delayed hypoglycaemia must be considered at the same time. Systematically reducing the post-exercise bolus by a fixed percentage is not a universal solution. The response depends on the type of exercise, the amount of glycogen used, duration, time of day, therapy and, to a large extent, individual experience. A strength session, a long aerobic run, and a short high-intensity competition do not produce the same metabolic recovery.

10.6 Hydration

Hydration accompanies the entire nutritional strategy. Sweating, temperature, humidity, duration, and intensity modify fluid losses. Significant dehydration impairs performance and can make the overall interpretation of physiological data, including CGM values, more difficult.

The amount to drink should be individualised through experience and, when useful, estimation of sweat-related losses.

Guiding principle

Recovery does not begin with assessing the values reported by the CGM, but with what the body needs to replenish through carbohydrate intake.
CGM and insulin exposure serve to determine how to achieve this recovery safely.

10.7 Replacing lost fluids

When relatively rapid rehydration is required, the amount of fluid to be consumed after exercise can be estimated from the change in body weight. In practical terms, a loss of 1 kg corresponds approximately to a deficit of 1 L of water, taking into account any fluids consumed and urine produced during the activity.

Because some of the water consumed will inevitably be eliminated, over the following hours it may be appropriate to replace approximately 125–150% of the estimated deficit, distributing intake over time and combining it with an adequate sodium intake. When recovery can take place more slowly over the course of the day, this strategy can be less rigid and integrated with normal meals, fluid intake, and the stimulus of thirst.

Rehydration should not be confused with carbohydrate supplementation. A carbohydrate-containing drink can perform both functions at the same time when CHO are required for performance or recovery, but a fluid deficit does not automatically imply the need to consume glucose.

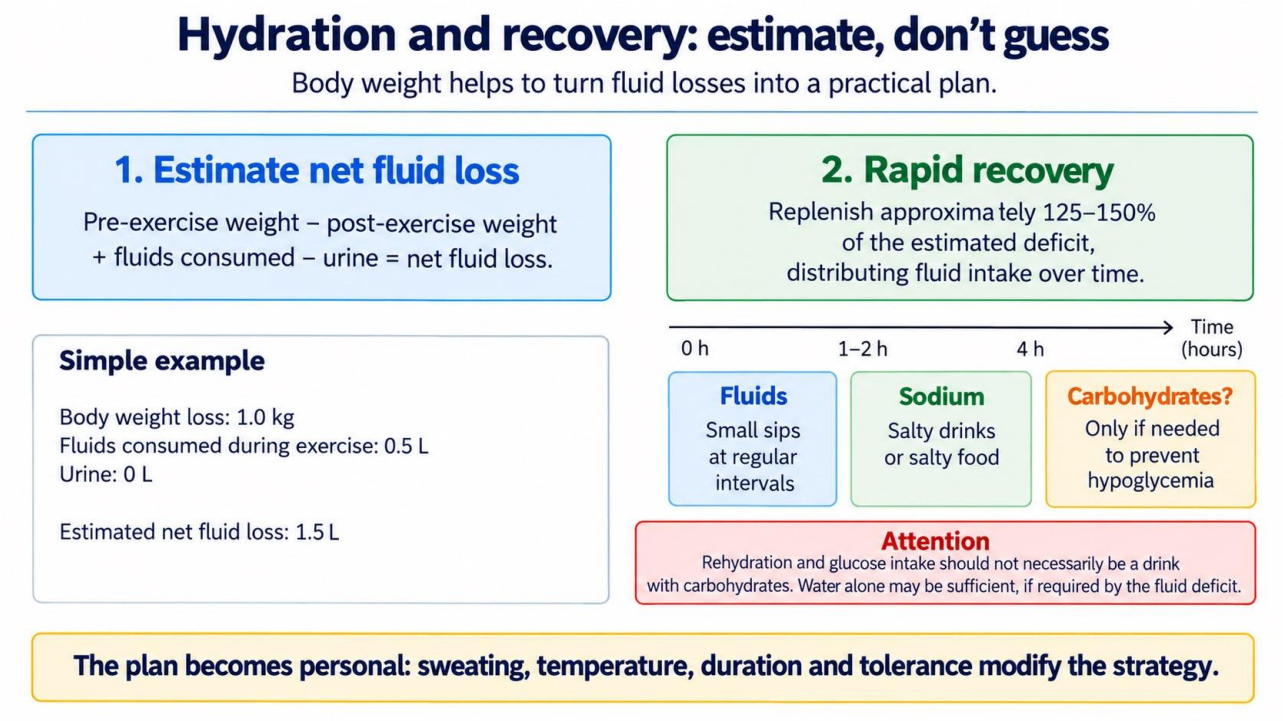


Figure 10.1. The importance of rehydration.

Chapter 11 — Translating nutrition into therapy

11.1 The common problem across all insulin therapies

In people without diabetes, endogenous insulin secretion can decrease rapidly when exercise begins. In T1D, insulin already administered continues to act according to its pharmacokinetics. This asymmetry explains why preparation must precede exercise.

11.2 IOB as a contextual variable

Higher IOB is associated with a greater risk of hypoglycaemia during activities that tend to lower glucose. However, the number displayed by the device does not correspond to the instantaneous biological effect: the calculation varies between systems and does not perfectly describe the time profile of insulin action. For this reason, throughout the book we will refer to functionally low, intermediate or high IOB in relation to the athlete and the activity, without imposing universal thresholds in units.

11.3 Basal-bolus

With multiple daily injection therapy, basal insulin modulation is less reversible in the short term. The timing of exercise in relation to meals, any reduction in the preceding bolus, and knowledge of the effect of one's basal insulin therefore become central. The percentage reductions reported in guidelines are starting points to be individualised, not prescriptions that can be transferred without verification.

11.4 Conventional insulin pump (CSII)

CSII allows temporary reductions or suspensions of basal insulin. The advantage of flexibility does not eliminate the pharmacokinetic delay: reducing basal insulin at the start of exercise may be too late if the aim is to decrease circulating insulin during the first part of the activity. Moreover, when the mealtime bolus accounts for the dominant share of IOB, changing basal insulin alone may have a limited effect.

11.5 AID

AID systems add algorithmic modulation guided by CGM. Exercise-specific modes generally aim to reduce insulin exposure by raising the target or attenuating the algorithm's response. Here too, effectiveness is greater when the intervention precedes the planned activity.

The EASD/ISPAD position statement generally recommends low IOB at the start of activities in which a reduction in glucose is expected. It also suggests small amounts of carbohydrate, mostly 10–20 g, when needed close to or during activity, avoiding overtreatment that may produce rebound hyperglycaemia and renewed automated insulin delivery.

11.6 Planned and unplanned exercise

When activity is planned, it is possible to intervene on the preceding bolus, exercise mode and nutritional timing. With unplanned activity, the time margin disappears and carbohydrates often take on a greater role. It is therefore inappropriate to judge in the same way a strategy used for a planned competition and one adopted for an unplanned activity.

11.7 When exercise tends to increase glucose

Strength exercise, sprints, very intense intervals and competition can lead to stable or increased glucose in some athletes. In these circumstances, indiscriminately reducing insulin may worsen hyperglycaemia. The strategy must therefore start from the expected response to that specific exercise and the individual history.

11.8 A practical eight-step procedure

- Define the objective of the training session or competition.
- Describe the expected duration, intensity and metabolic characteristics.
- Estimate CHO-P and glycogen availability.
- Assess the preceding meal, bolus and expected IOB at the start.
- Determine the insulin adjustment possible with the therapy being used.
- Use glucose and CGM trend to define any CHO-G required.
- Observe what happens during and after the activity.
- Record the response and change one variable at a time in subsequent trials.

The real final clinical question is:

Not “how much insulin should the athlete take?” but: “what insulin exposure allows the athlete to perform a given activity with the nutritional strategy required for performance while maintaining reasonable glycaemic safety?”

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PART III – AID SYSTEMS: UNDERSTANDING THE DIFFERENCES WITHOUT RANKING THEM

This section translates the physiological and nutritional principles discussed in the previous chapters into the practical functioning of the main automated insulin delivery (AID) systems. The aim is not to establish which system is "better," but to understand how different algorithms address the same biological problem and how these differences influence exercise management.

Reading note

Device features may vary depending on software version, compatible sensors, regulatory indications, and country. The functions described should be verified against the specific version of the system actually being used and its corresponding instructions for use. This chapter describes principles and operational logic and does not replace device-specific training.

Chapter 12 — How an AID System Really Works

12.1 An AID System Is Not a Complete Artificial Pancreas

An AID system integrates three elements: a glucose sensor, a decision-making algorithm and an insulin pump capable of modifying insulin delivery. The word "automated" may suggest a system capable of understanding what the athlete is doing. In reality, the algorithm mainly observes the glucose detected by the sensor, its direction, the recent insulin history and some information entered by the user. It does not directly know exercise intensity, glycogen availability, catecholamine response, energy expenditure or the goal of the session.

This leads to an essential principle: the AID interprets the glycaemic result of physiological processes that it does not see. Rising blood glucose may result from a meal, an adrenergic response, insufficient correction or a preventive reduction in insulin; the same curve may therefore have different meanings and require different strategies.

12.2 The Three Levels: Sensor, Algorithm, Delivery

Sensor

The CGM estimates glucose concentration in the interstitial compartment. Under conditions of rapid change, a temporal discrepancy may appear compared with plasma or capillary glucose. During exercise, sensor accuracy may change, and studies show different results depending on the device, type of exercise and rate of glucose change. For this reason, the value should be interpreted together with the direction of the arrow, the context and symptoms.

Heat, sweating, dehydration and changes in peripheral perfusion may theoretically modify the relationship between the blood and interstitial compartments. The literature mainly documents that accuracy may vary during exercise and rapid excursions, and maintaining adequate hydration is important for performance and safety, but does not in itself guarantee sensor accuracy.

When the Data Do Not Seem Convincing
If the CGM value, symptoms and clinical situation are discordant, the athlete should not rely uncritically on the display. In the event of significant doubt, especially before an important therapeutic decision, it is reasonable to confirm the value with a capillary measurement according to the device instructions and the indications of the diabetes care team.

Algorithm

The algorithm combines sensor data with the insulin delivery history and system-specific parameters. Some systems are based mainly on predicting future glucose, others build an adaptive estimate of insulin requirements over time, and others combine continuous modulation and automatic boluses. The difference is not merely technological: it determines how the same pre-exercise error may be corrected or amplified.

Delivery

The pump can increase, reduce or suspend future insulin. However, it cannot remove insulin that has already been absorbed or cancel insulin still present in the subcutaneous depot. This temporal asymmetry is the central physiological limitation during exercise: if the athlete starts with high IOB, even a highly effective algorithm can only reduce what would otherwise have been delivered subsequently.

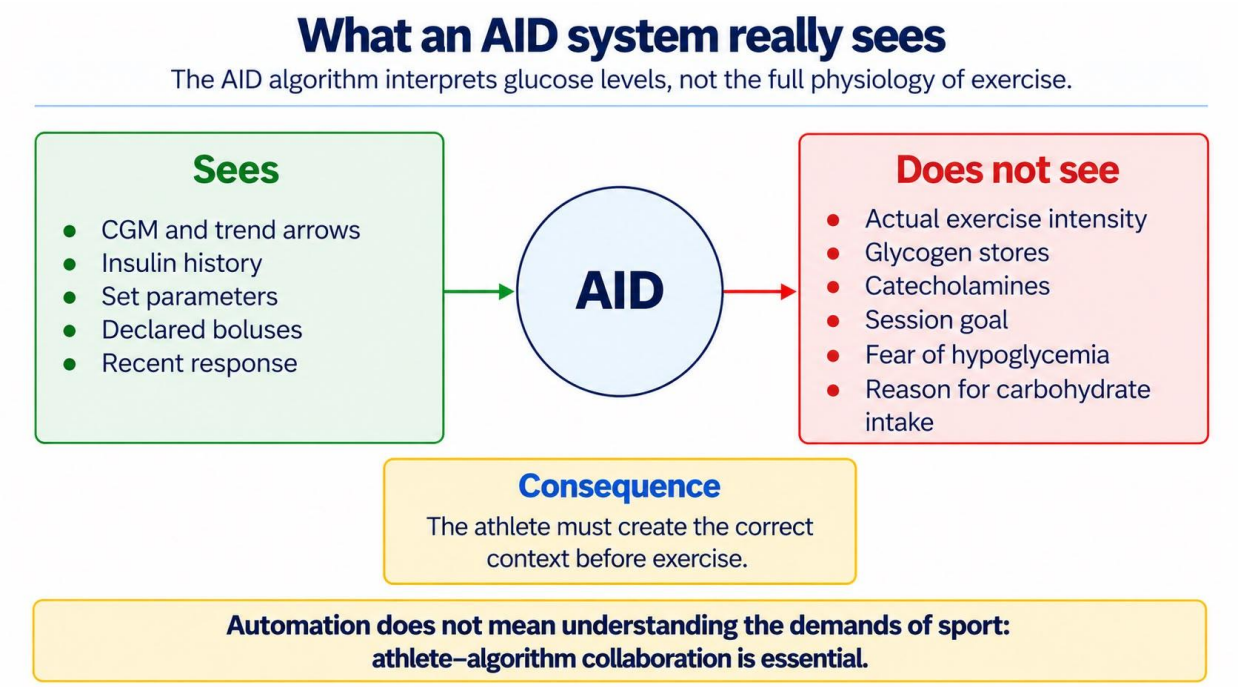


Figure 12.1. An AID system integrates sensor, algorithm and delivery, but does not directly know the physiological meaning of the activity.

12.3 Exercise Mode Is Not a Universal Switch

In different systems, the function dedicated to activity modifies different elements: target, predictive thresholds, algorithm aggressiveness, the possibility of autocorrection or the amount of automatic insulin. Saying generically “activate sport mode” therefore conceals important operational differences.

The common principle is timing. Activity-specific modes work better when they are activated early enough to reduce insulin exposure before muscle glucose uptake increases. Activating them when the CGM is already falling rapidly may be too late, especially if the IOB comes from a recent bolus.

12.4 Preventive Overtreatment

A still common practice is to take large amounts of carbohydrates before activity to “protect” against hypoglycaemia. In an AID system, this strategy may be counterproductive: the rise in glucose may trigger new insulin delivery and recreate, shortly before exercise, the exposure that was intended to be avoided. The contemporary strategy therefore tends to favour an early reduction in insulin and targeted use of carbohydrates when they are truly needed.

12.5 Displayed IOB and Biological IOB

The IOB value is not perfectly comparable across systems. Each algorithm defines in its own way which components of delivery are included in the calculation and how duration of insulin action is used. In this book, IOB will therefore be treated mainly as contextual information: functionally low, intermediate or high in relation to the athlete, the previous bolus, the type of exercise and the time phase.

12.6 The Real Goal of AID in Sport

Success does not mean either always relying on the algorithm or systematically disabling it. The goal is to create the context in which automation can work well: consistent insulin exposure, appropriate nutritional timing, activity mode set in advance, and knowledge of what the system can and cannot do.

Chapter 13 — MiniMed 780G: SmartGuard, Autocorrections and Temporary Target

13.1 The SmartGuard Logic

MiniMed 780G modifies insulin delivery based on sensor data and frequently updates the amount delivered. The system can modulate automatic insulin and deliver autocorrections. The selectable SmartGuard targets are 100, 110 and 120 mg/dL. For situations in which less insulin is desired, such as exercise, a fixed Temp Target of 150 mg/dL is available. During the Temp Target, automatic autocorrections are not delivered. This feature is particularly relevant in sport because it reduces the risk that a pre-exercise rise triggers an automatic correction while the athlete is about to begin an activity that tends to lower blood glucose.

13.2 Timing of the Temp Target

Medtronic documentation suggests considering activation of the Temp Target approximately 1–2 hours before activity. The reason is not to "give the algorithm time to understand that sport will be performed," but to progressively reduce insulin exposure before the start. The Temp Target can be set from 30 minutes up to 24 hours, in 30-minute intervals. The duration after exercise must be individualized. Some Medtronic materials suggest, in general terms, ending it immediately afterwards or continuing it post-exercise according to individual risk. There is therefore no universal post-competition duration.

13.3 The Bolus for the Previous Meal

The system can reduce future insulin, but an already absorbed mealtime bolus may dominate IOB at the start. The pre-exercise strategy must therefore integrate the temporary target, amount of carbohydrates, any bolus reduction and time elapsed since the meal. Focusing only on automatic basal insulin may be insufficient.

13.4 Safe Meal Bolus and Interpretive Limits

The 780G has a safety feature that can reduce the meal bolus when it predicts a risk of hypoglycaemia in the following hours. This protection does not, however, eliminate the need to plan exercise. A bolus considered safe in the ordinary context may still be excessive if muscle glucose uptake increases dramatically shortly afterwards.

13.5 When the System Seems "Too Aggressive"

Attributing an intrinsically aggressive personality to the 780G is of little use. The response results from the interaction between the selected target, active insulin time, I:CHO ratio, sensor trend and whether or not the Temp Target is activated. An athlete who takes defensive carbohydrates, observes a rise and leaves the system in standard mode may receive more insulin just before the run. The problem is not necessarily the algorithm, but the context created around the algorithm. At the time of publication, a smaller device and a further software update are planned and will be analysed in future editions of this document.

For Sport with 780G
Temp Target 150 mg/dL; autocorrections suspended during Temp Target; activation generally 1–2 hours before when exercise is planned; the previous bolus remains decisive; large amounts of preventive CHO followed by a new bolus may increase IOB at the start.

Chapter 14 — Tandem Movi / Control-IQ+: Prediction, Exercise Activity and AutoBolus

14.1 A Predictive Algorithm

Control-IQ+ uses CGM to predict glucose trends and modulate insulin. In Exercise Activity, the logic shifts toward higher predictive ranges than in standard mode. It is therefore more accurate to speak of decision thresholds than of a single fixed target.

In the current operating tables, with Exercise Activity active, the system tends to reduce or suspend basal insulin when it predicts low values, maintains or increases basal insulin when the glucose prediction is stable or rising, and may use AutoBolus when the prediction exceeds the specified threshold. The operational details depend on the software version and must be checked in the specific guide; for now, we report the framework updated as of the publication date.

Control-IQ - Normal Activity - Sleep - Exercise

		Control-IQ	Sleep Activity	Exercise Activity
Delivers	Delivers an automatic correction bolus if the CGM sensor value is predicted to be above 180 mg/dL within 30 minutes.	180	---	180
B Increases	Increases basal insulin delivery if the CGM sensor value is predicted to be above --- mg/dL within 30 minutes.	160	120	160
B Maintains	Maintains active settings in the current profile if the CGM sensor value is predicted to be between --- and --- mg/dL within 30 minutes.	112.5 - 160	112.5 - 120	140 - 160
B Decreases	Decreases basal insulin delivery if the CGM sensor value is predicted to be below --- mg/dL within 30 minutes.	112.5	112.5	140
0 Stops	Suspends basal insulin delivery if the CGM sensor value is predicted to be below --- mg/dL within 30 minutes.	70	70	80

Figure 14.1. The various activities currently provided by the Tandem Movi / Control-IQ+ system.

14.2 AutoBolus

Control-IQ+ uses AutoBolus up to once every hour when glucose is predicted to be high. Current Tandem documentation reports a limit of one AutoBolus per hour.

The clinical point nevertheless remains important: even a single AutoBolus in the hour before, or coinciding with, the start of exercise may increase IOB at a delicate time.

14.3 Why Exercise Activity Does Not Completely Eliminate the Risk of Correction

Unlike the 780G with Temp Target, Control-IQ+ may retain the possibility of AutoBolus during Exercise Activity if the prediction exceeds the threshold. This may be advantageous in activities associated with hyperglycaemia, but requires caution when the rise has been caused by preventive carbohydrates.

The system sees the glucose trajectory; it does not know that the rise in glucose depends on a gel taken for fear of future hypoglycaemia, nor that a run will begin in fifteen minutes or that intensity will increase. The user must therefore create a context consistent with the behaviour of the algorithm.

14.4 Personal Profiles and Flexibility

Tandem allows the use of personal profiles with different parameters. In sport, this flexibility may be useful on days with predictably different requirements, but it should not become continuous reactive manipulation. The construction of specific profiles should be based on repeatable patterns and verified with the diabetes care team.

14.5 The Problem of the Previous Bolus

Even with Exercise Activity, basal modulation cannot completely compensate for a still-significant mealtime bolus. One of the most relevant decisions therefore remains the actual amount of insulin to administer as a bolus for the meal preceding the activity and how much time elapses between the meal and the start of the session.

For Sport with Tandem

Exercise Activity shifts the predictive thresholds upward; AutoBolus may remain possible up to once per hour; avoid large unnecessary preventive CHO loads; always assess the previous bolus.

Chapter 15 — Omnipod 5: SmartAdjust, Activity Feature and Algorithm in the Pod

15.1 An Adaptive Philosophy

Omnipod 5 uses SmartAdjust, an algorithm integrated into the Pod. The system receives data from the compatible sensor, predicts the glucose trend and modifies automatic delivery. A characteristic element is the progressive adaptation of automatic insulin based on usage history, while settings such as the I:CHO ratio, correction factor and target continue to be relevant for boluses and specific functions.

15.2 Activity Feature: 150 mg/dL and Less Insulin

With Activity Feature active, Omnipod 5 reduces automatic insulin and sets the target at 150 mg/dL for the selected duration, from 1 to 24 hours. The most recent educational recommendations often advise activating it 60–120 minutes before planned activity. Some materials intended for users give shorter examples, such as 30–60 minutes. This is not a contradiction: timing must be individualized according to IOB, type and duration of exercise, and personal response. For planned aerobic activity with a tendency for blood glucose to fall, the reference of 1–2 hours beforehand is currently the one most consistent with the EASD/ISPAD consensus and the most recent HCP materials.

For unplanned exercise, it is recommended not only to apply the typical 25–33% reduction in the pre-meal bolus but also, if pre-meal glucose is below the set target value, to disable Reverse Correction, a bolus calculator feature that reduces the estimated insulin dose for the upcoming meal. In this case, rather than delivering the full dose calculated for carbohydrates, the device subtracts a certain amount of insulin, allowing part of the food about to be consumed to safely raise glucose toward the optimal target value.

In HIIT, when an adrenergic rise is anticipated, temporarily lowering the target to 110 mg/dL may instead be useful.

15.3 Why It Matters That the Algorithm Is in the Pod

SmartAdjust resides in the Pod. The controller or smartphone is used to interact with the system, for boluses and settings, but insulin automation can continue even if the control device is not in the immediate vicinity, provided that the Pod and sensor maintain the required communication. In sport, this avoids the need to ‘wear’ the controller during every phase of the activity.

The essential condition is Pod–sensor communication. For some sensors integrated with Omnipod 5, their relative position on the body and the so-called line of sight are important, meaning that the body should not continuously obstruct communication. Prolonged loss of sensor data may cause the system to enter Automated Mode: Limited, with behaviour different from full automation.

15.4 Activity Feature and Manual Boluses: No Alarm, but Clarity

Practical Example
During a match, the controller can remain at the sideline without automatically interrupting SmartAdjust. The athlete must, however, ensure that the Pod and sensor are positioned in a way compatible with communication and must be able to access the controller when it is necessary to deliver a bolus or change settings.

Activity Feature modifies automation: it reduces automatic insulin and sets the automation target to 150 mg/dL. However, it does not modify the target used by the bolus calculator when the user manually initiates a bolus. In other words, if a correction is requested during Activity Feature, SmartBolus uses the Target Glucose and the

‘Correct Above’ value programmed for that time period, not the temporary 150 mg/dL target of the Activity function.

This does not mean that Omnipod 5 automatically delivers aggressive corrections during Activity Feature. It means that a manual decision by the user remains distinct from automatic behaviour. The practical consequence is simple: during or immediately before exercise that tends to lower blood glucose, a manual correction must be assessed with particular caution because it can increase IOB despite Activity Feature being active.

15.5 Automated Mode: Limited and Connectivity

If the Pod does not receive sensor values for a prolonged period, the system may switch to Automated Mode: Limited. This deserves attention in sport because sweat, device position, physical contact, immersion or communication obstacles can affect data availability. A communication limitation should not be confused with an algorithm ‘failure’.

15.6 Adaptation and Insulin History

The algorithm uses information derived from insulin history and progressively adapts. For this reason, the preceding days and the overall pattern of insulin requirements may influence automation. This adaptation does not mean that the system ‘learns sport’ in a physiological sense; it mainly learns the observed insulin requirement.

For exercise with Omnipod 5

Activity Feature: target 150 mg/dL with reduced automated insulin delivery; timing is often 60–120 minutes before planned activity; duration 1–24 hours; the algorithm runs within the Pod; the controller is not required for continuous automated insulin delivery but is needed for certain actions; manual boluses use the bolus calculator settings rather than the Activity target.

Chapter 16 — mylife YpsoPump / CamAPS FX and Comparison Between Automation Philosophies

16.1 CamAPS FX: Personal Target and Adaptation

CamAPS FX uses an adaptive algorithm that works with a personal target and can be paired, in certain configurations and countries, with mylife YpsoPump and compatible sensors. The app provides functions that temporarily modify the system response, including Ease-off for situations in which less insulin is desired and Boost when a more incisive response is required. A fully automated system allowing unannounced meals has been developed at the time of publication of the present document.

16.2 Ease-off

Ease-off is designed for situations in which insulin requirements tend to decrease, such as exercise. The function temporarily increases the personal target and attenuates delivery, facilitating an early reduction in insulin. It can be started immediately or scheduled in advance, depending on the version and configuration.

The physiological principle is the same as that discussed for the other AID systems: activating Ease-off when the system has already reduced insulin almost to the minimum may add little. If blood glucose is already falling rapidly and IOB remains, it may be necessary to intervene with carbohydrates. Prevention remains more effective than late recovery.

16.3 Slowly Absorbed Meal

CamAPS FX has a function designed for meals with prolonged absorption. The algorithm can modulate insulin in the following hours in relation to the glycaemic response. The concept is relevant in sport because meals rich in fats, proteins or with high complexity can interfere with exercise timing and produce late rises.

16.4 Boost

Boost temporarily increases the insulin response of the algorithm. It is not a ‘sport mode’ and, during activity that tends to lower blood glucose, using it would generally be counterintuitive. It may instead have a role in different situations, such as periods of increased insulin requirements, always in accordance with the specific system instructions.

System	Exercise mode	Main logic	Corrections/boluses during activity	Key point
MiniMed 780G	Temp Target	Fixed target 150 mg/dL; less automatic insulin	Automatic autocorrections suspended during Temp Target	Activate in advance; the previous bolus remains decisive.
Tandem Movi / Control-IQ+	Exercise Activity	Higher predictive ranges	AutoBolus possible, up to one per hour according to current documentation	A glycaemic rise from preventive CHO may increase IOB.
Omnipod 5	Activity Feature	Target 150 mg/dL + reduction in automatic insulin	Manual boluses possible; they use programmed target/correct-above settings	Algorithm in the Pod; distinguish automation from manual correction.
YpsoPump / CamAPS FX	Ease-off	Personal target temporarily increased + attenuated algorithm	Depends on adaptive response; Ease-off reduces insulin pressure	If activated too late, it may add little because active insulin remains.

Comparison of the exercise-related operating logic of the four AID systems discussed.

16.5 Four Systems, Four Operating Logics

The comparison becomes useful when the question 'which is better?' is abandoned and one instead asks which decision is automated, which remains in the user's hands, and how the algorithm reacts to a glycaemic rise shortly before exercise.

16.6 How to Choose the System for an Athlete

The choice should not be reduced to a ranking. The type of sport, frequency of activity, tolerance of the catheter, need to remove the device, ability to plan, propensity to intervene manually, risk of hypoglycaemia, patterns of hyperglycaemia from high intensity and personal preferences all matter. The best system is the one the athlete understands and uses consistently with their own physiology and behaviour.

16.7 No System Cancels Insulin Already Absorbed

This is the point common to all AID systems. Algorithmic differences may be important, but no current technology eliminates the pharmacokinetic limitation of subcutaneous insulin. Effectiveness in sport therefore depends on the ability to create, in advance, insulin exposure appropriate to the expected performance.

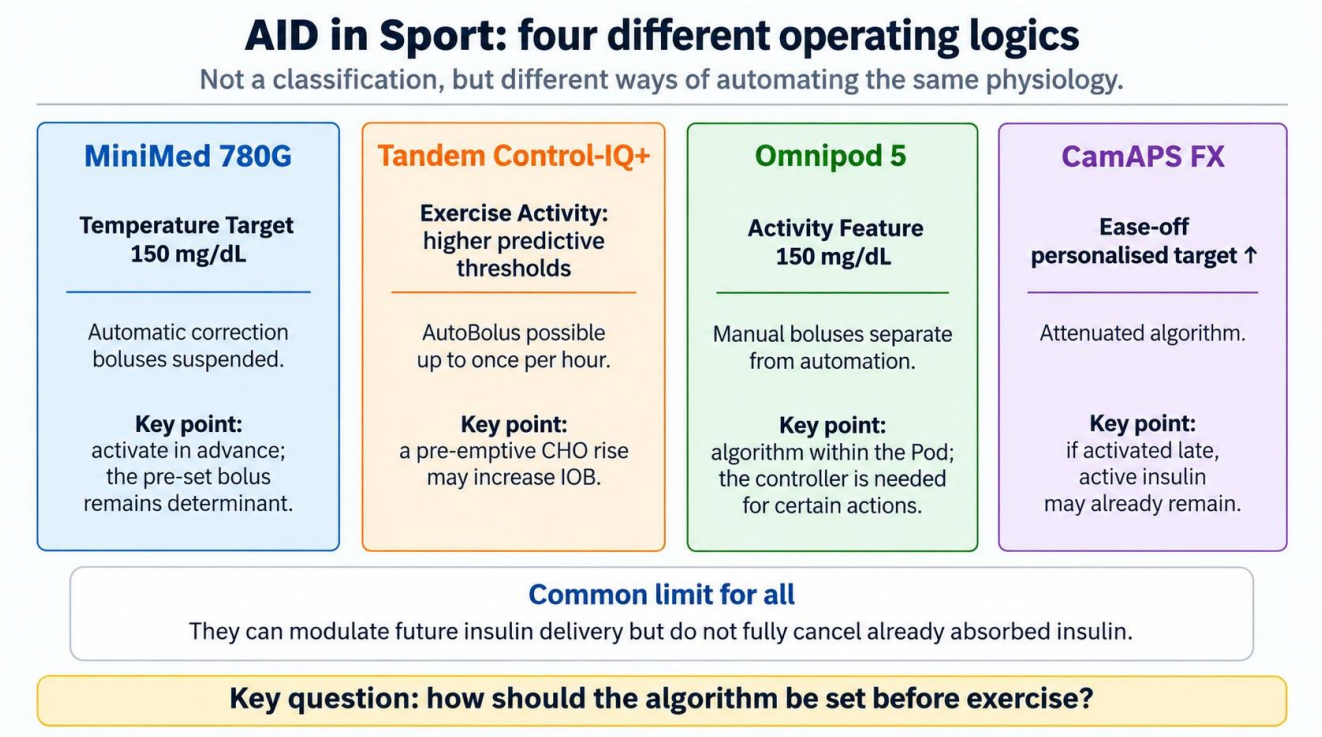


Figure 16.1. Essential comparisons among the insulin pumps most frequently encountered among Italian athletes at the time of publication of the current text.

EXERCISE FUNCTIONS IN AID SYSTEMS: A QUICK COMPARISON

These functions help, but they do not replace the strategy: the initial context remains decisive.

Item	Tandem Control-IQ+	Omnipod 5	Medtronic 780G	CamAPS FX
Function name	Exercise Activity	Activity Feature	Temp Target	Ease-off
Target / logic	higher predictive thresholds	target 150 mg/dL	target 150 mg/dL	personalised target ↑
When to activate	60–90 min before	60–120 min before	1–2 h before	60–120 min before
Automatic corrections	possible	manual boluses separate	suspended during Temp Target	attenuated algorithm
Active without controller	yes	yes (Pod + sensor)	yes	yes

Understanding the logic of your own AID is essential for decisions before exercise.

Figure 16.2. Essential comparisons among functions usable before starting an exercise session in the insulin pumps most frequently encountered among Italian athletes at the time of publication of the current text.

Concluding Message of Part III

AID systems are not interchangeable from an operational point of view, but they share the same biological limitation: they can modulate future insulin, not cancel insulin already absorbed. The best strategy arises from the combination of exercise physiology, nutrition, IOB and specific knowledge of the algorithm.

Essential References for Further Reading

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PART IV — TRAINING THE ATHLETE AND APPLYING PRINCIPLES TO SPORT

Chapter 17 – Preparing the Athlete with Type 1 Diabetes: Training, Adaptation and Performance



Figure 17.1. Training the person means integrating load, recovery, metabolic safety and performance goals.

Practising physical activity and training are not synonymous. Physical activity includes every daily bodily movement produced by muscles that increases energy expenditure; when it is structured, planned, repetitive and aimed at improving one or more components of physical fitness, it takes on the meaning of physical exercise. For the athlete, training has an additional meaning: it is a systematic process, repeated over time, with progression, overload, specificity, recovery and assessment; stimuli, recovery and the physiological, structural and functional adaptations of the body are planned and programmed to produce better performance. Both physical exercise and training are reversible and individualized.

In DMT1 this process does not lose its sporting nature. The athlete with diabetes should be trained according to the same five physiological principles that guide the preparation of every other athlete: overload, progression, specificity, individualization and supercompensation/recovery. The difference is that the session takes place in a more complex metabolic context. Exogenous insulin, carbohydrate availability, blood glucose, CGM trends, previous hypoglycaemia, stress, sleep and meal timing may modify the acute response (adjustment) to the same session.

The challenge is therefore not to create “athletic preparation for people with diabetes”, but to integrate DMT1 correctly into well-constructed athletic preparation, in which chronic structural adaptations (greater muscle

capillarization, number of mitochondria and resting GLUT4, better cardiac efficiency, etc.) and functional adaptations (improved basal insulin sensitivity, lower daily insulin requirement, lower glycaemic variability, higher anaerobic threshold, better metabolic flexibility, cardiovascular adaptation, etc.) can be achieved. In DMT1 the principle does not change; the safety check does, and the glycaemic diary and/or CGM become part of the load diary. Without adjustments during the training stimulus the session cannot be completed; without adaptations there is no chronic improvement.

Guiding question
How can training be programmed to produce adaptation and performance without turning blood glucose into the criterion by which the quality of the session is judged?

17.1 The First Goal: Know the Athlete Before the Diabetes

Programming begins with the person, the sport practised and the athlete's motor background: age, experience, competitive level, injury history, available time, goals, calendar and technical characteristics of the sport. DMT1 adds essential information, but does not replace this assessment.

An athlete preparing for a half marathon, a midfielder, an endurance cyclist and a strength athlete may have the same HbA1c and use the same AID system, yet require completely different planning and programming. Prescription arises from the performance demand; diabetes management makes it possible to perform safely.

The initial functional and kinesiological assessment depends on the goals and should therefore include resting parameters (blood pressure, HR, SpO_2, RPE or perceived exertion, 0–10 neuropathic pain scale, capillary glucose/CGM), cardiorespiratory and neuromotor function and foot assessment, strength, joint mobility and motor control when relevant, body composition if useful, recent load and injury history, recovery and sleep. Metabolic data enter as a second level of interpretation: they do not say which adaptation should be trained, but help explain the conditions in which training is performed and interpret the response to the training stimulus.

17.2 From Testing to Programming: What Do We Want to Adapt?

Training means administering a sufficiently specific stimulus to perturb homeostasis and allow temporary and reversible adjustments during effort and recovery, as well as appropriate programmed adaptations—stable chronic responses produced by correct adjustment + recovery + repetition—after weeks or months of repeated stimuli. Specificity is fundamental: improving aerobic capacity requires different stimuli from those needed to develop maximal strength, neuromuscular power or tolerance to repeated sprints.

In DMT1 there may be a temptation always to choose the exercise that "moves glucose less". This would be a methodological error. If the athlete needs to improve power, it is not rational systematically to replace the necessary sessions with moderate exercise merely because it is metabolically more predictable. Instead, the required stimulus must be learned and managed safely.

17.3 Volume, Intensity, Frequency and Density

Training load is not a single variable. Volume describes how much work is performed (metres/km, total kg, minutes/hours); intensity expresses its relative or absolute quality (%HRmax, %1RM, speed, watts, RPE); frequency indicates how many exposures are distributed over time; density describes the work:rest ratio and the recovery between efforts. Duration includes the time of the individual repetition/continuous effort;

complexity or type of exercise describes what is done. Their combination determines the overall stimulus and defines external load.

In DMT1, the error is to look only at internal load—how the body responds: glucose, lactate, HR, etc.—because without programming external load, glucose is always a surprise. The same change in load may also have different metabolic consequences. Volume is the variable that most influences the fall in glucose over the following 24 hours: more volume = more glycogen depletion = greater risk of nocturnal hypoglycaemia. Intensity is the variable that decides the direction of glucose: increasing intensity may accentuate the catecholaminergic response and, in some contexts, favour stability or an increase in glucose. Frequency is preferable when muscle sensitivity is maintained without exhausting everything in one day and without major nocturnal hypoglycaemia. Density can be used as a protective variable: the same intensity with more recovery may reduce hypoglycaemia; high density allows lactate accumulation and type IIa fibre recruitment with rapid glucose decline, whereas low density allows type IIx fibre recruitment with less glucose consumption.

17.4 External Load and Internal Load: Two Sides of the Same Session

External load is what the athlete does: kilometres, speed, watts, repetitions, kilograms lifted, accelerations, jumps and duration. Internal load is the body's response: heart rate (HR), heart-rate variability (HRV), oxygen consumption (VO_2max), lactate when measured, perceived exertion, fatigue and recovery. A more recent metric, TRIMP, can quantify and monitor training load to improve performance, particularly in endurance sports, and help identify fatigue and prevent overtraining. TRIMP considers three key factors: training duration, intensity and HR; its limitation is that it is influenced by factors such as age, sex and fitness and may be less accurate for short-duration endurance sports such as swimming.

In DMT1 it is useful to add a third dimension, which we can call the metabolic context of the session (or metabolic–therapeutic load): starting glucose, CGM trend, active insulin/IOB and basal insulin delivered by AID, recent meals, carbohydrates taken, previous hypoglycaemia, TIR and glucose coefficient of variation (CV%) during exercise, and ketone bodies. These are not measures of training load, but explain why an identical session may be experienced and managed differently on different days.

External load	Internal load	Metabolic context
Speed, distance, watts	HR, RPE, lactate, fatigue	Glucose, trend, IOB
Repetitions, kg, jumps	Cardiorespiratory and neuromuscular response	Meal, CHO, previous hypoglycaemia
Duration and density	Perceived and objective recovery	Timing and insulin mode

Table 17.1. External load, internal load and metabolic context: distinctive elements.

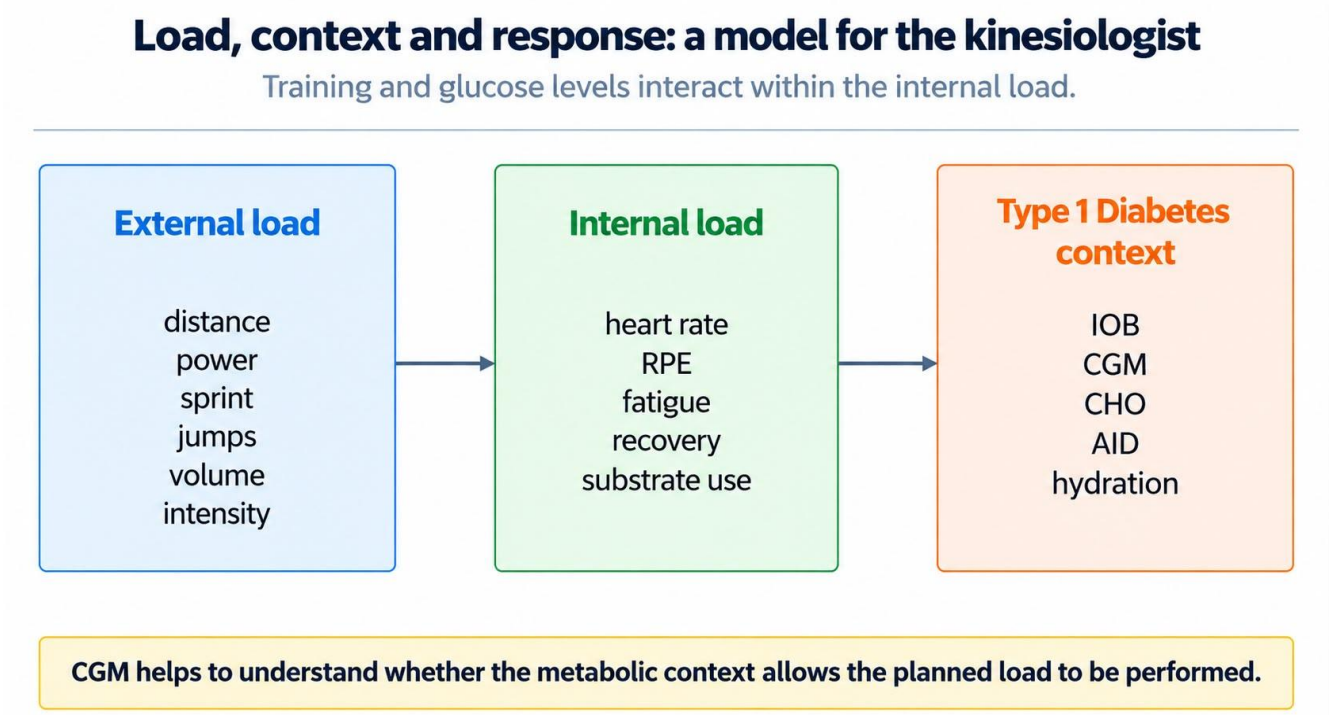


Figure 17.2. External load, internal load, and metabolic context: three distinct but complementary levels for interpreting a training session.

17.5 Load Monitoring Must Not Generate Anxiety

The same training session can cost much more if the previous night's TIR was 70%. Example: the same 5×5 squat session at 100 kg:

a) Day A: good sleep, previous night TIR 95% and TBR 0%, good recovery → 5×5 costs RPE 6;
b) Day B: fragmented sleep, previous night TIR 70% and TBR 15% because of two nocturnal hypoglycaemic episodes with alarms, depleted glycogen and an alert nervous system → 5×5 costs RPE 8.5.

In DMT1, programming must therefore consider external load but also what the previous night cost. With high nocturnal TBR, the training day should provide a lower external load, otherwise there is a risk of overreaching. Among internal-load variables, RPE may be more important than HR: in the presence of hypoglycaemia, poor sleep because of an alarm, or little insulin on board, HR may be low while RPE is high and indicates the cost to the nervous system. Fatigue during or at the end of the session can be rated on a 0–10 scale as light (3), hard but manageable (5), very hard (8–9) and maximal (10). If RPE rises by 2 points at the same external load for 2–3 days, this is an early sign of poor load tolerance and possible overreaching. Another important parameter is sRPE (RPE × duration in minutes), which allows calculation of weekly load, monotony, strain and ACWR.

Example: (a) weights RPE 7 × 60 min = 420 AU; (b) easy running RPE 4 × 90 min = 360 AU.

Although the run is longer, the weights cost more in terms of perceived intensity and weekly load. At the same external load, if sRPE rises for 3–4 consecutive days and nocturnal TBR (>4%) and sleep worsen, with CV >36%, the load is not tolerated: this is not merely a glycaemic problem and unloading is needed. Conversely, if TIR falls only for 2–3 days after an increase in volume, but RPE and sleep are good and there are no delayed hypoglycaemic episodes, this may represent metabolic adaptation rather than overtraining. If more CHO are required to face the same session, the athlete with DMT1 is evidently not recovering adequately.

Load monitoring in DMT1 is important to prevent delayed hypoglycaemia, but not to the point of creating anxiety, which itself raises glucose and disrupts sleep. A simple test of pure neuromuscular fatigue, less influenced by glucose, insulin and emotional state than HR and HRV, is the fasting morning countermovement jump (CMJ). A fall >5–6% for two consecutive days indicates accumulated fatigue and poor load tolerance before performance declines; it may be appropriate to reduce that day's load by 30–40% even if TIR is good, or when nocturnal TBR is high.

The minimum daily log is a practical tool for the master kinesiologist LM67/LM68 to monitor load in an athlete with DMT1. It integrates perceived internal load, recovery and metabolic–therapeutic load and refers to five essential parameters:

- internal load (RPE and sRPE);
- recovery (sleep hours + awakenings);
- metabolic cost/recovery marker (night TIR/TBR/CV%);
- tolerability (hypoglycaemia 0–24 h post);
- therapeutic cost (extra CHO + insulin corrections needed to train).

These parameters help build metabolic predictability: "this type of session, with this active insulin, costs me X". After 3–4 weeks of a minimum daily log, an individual repertoire of load response—the "cost–load mapping"—can be built, moving from reactive to proactive management: for the same training session, duration, RPE, and IOB, the LM-67/LM-68 exercise professional can, by actively collaborating with the person with diabetes, anticipate the metabolic and therapeutic demands and plan strategies to prevent delayed hypoglycaemia.

17.6 Usefulness of a Recovery Indicator

In DMT1, a recovery indicator is useful if it is stable, non-invasive, minimally influenced by emotional state, and able to guide a decision. Conversely, if it creates anxiety without changing CHO intake, insulin management, or training load, the data should be disregarded to avoid over-monitoring. In addition to a minimal daily log, which provides high utility at low cost and can be used to decide whether to train, reduce the training load, or increase food intake, weekly load monitoring may also be useful, particularly morning resting HR, DOMS [diffuse muscle soreness], mood, motivation, and weekly TIR trends. Conversely, daily HRV monitoring, detailed analysis of CGM traces (especially overnight), and the use of commercial methods (CK and lactate measurements, readiness scores, questionnaires) may be counterproductive, as they risk increasing cognitive burden in T1D and disrupting sleep, thereby impairing recovery.

17.7 CGM Is Not a Measure of Training Quality

A flat glucose curve does not prove that the session was well constructed; excessive glycaemic variation does not prove that training was wrong. CGM measures interstitial glucose and provides valuable information for safety and individual learning, but does not directly measure training stimulus, energy expenditure, glycogen depletion, technical quality or adaptation. It is not a performance datum or a marker of load/adaptation, but an important metabolic datum—a feedback tool for risk management and for individualizing the insulin–carbohydrate strategy around exercise.

Confusing these levels can produce excessively conservative preparation: metabolically "beautiful" sessions are rewarded and physiologically necessary ones penalized. The team's task is instead to learn how to make manageable even those training sessions that by their nature generate less linear glycaemic responses.

17.8 Periodization: Organizing the Stimulus Over Time

A single session may be excellent yet useless if poorly placed. Periodization organizes work over different time scales: individual session, microcycle, mesocycle and season/macrocycle. Periodizing means providing the right stimulus at the right time so that daily adjustment becomes adaptation after about one month. The goal is to distribute load and recovery consistently with the priorities of the sport and the competition calendar.

In DMT1, repeatability has additional value. Repeating similar sessions under sufficiently documented conditions allows the athlete to recognize personal patterns: how much glucose tends to decrease during a 60-minute easy session, how it responds to interval training, and what happens after an evening strength-training session. The aim is not to turn training into a continuous experiment, but to use experience to progressively reduce uncertainty. The microcycle also helps avoid overlapping peaks of insulin sensitivity; the mesocycle is important for reassessing basal insulin requirements, on average every three weeks. In DMT1, insulin and carbohydrates should also be periodized together with load.

17.9 Endurance: Building Capacity Without Chasing Glucose Alone

Endurance preparation usually combines low- and moderate-intensity work, threshold sessions, high-intensity intervals and volume progressions. The relative contribution of substrates changes with intensity, duration and training status; in DMT1 the glycaemic response is further modulated by circulating insulin.

The kinesiologist (master's degree LM67/LM68 for high performance) defines the training stimulus needed to create adaptation by modulating load parameters; the diabetologist and athlete build the metabolic strategy that allows it to be performed safely and tolerated (the former determines what to do, while the latter determine how to make it possible). This separation of responsibilities is fundamental: the planned intensity is not reduced merely because glucose tends to fall if there are safe ways to manage the decline; similarly, a session is not forced when clinical conditions make it inappropriate. In DMT1 it is more appropriate to speak of "co-managed exercise" rather than "prescribed exercise": the athlete is at the centre and closes the loop with CGM feedback and sensations.

17.10 Strength and Power: Often Underestimated Components

Strength is not only a quality for weightlifters. It contributes to performance, movement economy, maintenance of muscle mass, bone health and injury resilience. The ADA 2026 recommendations include 2–3 weekly resistance-training sessions on non-consecutive days for most adults with diabetes.

Strength sessions and very intense exercise can produce glycaemic responses different from continuous endurance. Greater sympathetic activation may limit the fall or cause a transient rise in circulating glucose. There is no universal response: exercise order, volume, rest periods, muscle mass involved, recruitment of fibres/motor units, fed state and active insulin all modify the picture. For glycaemic response and strength adaptation, what matters is not simply how much muscle is present, (a determinant of metabolic cost) but which muscle fibres and motor units are recruited and how (a determinant of the type of metabolism).

17.11 Intermittent Sports: The Problem of Variability

Football, basketball, tennis, and many team sports alternate aerobic phases, accelerations, sprints, pauses, technical actions, and emotional components. Average heart rate or speed poorly captures this complexity. In T1D, the main challenge or limiting factor is not the total metabolic load, but the unpredictability of the load (the inability to predict when and how much energy will be expended). In addition to high intra-session glycaemic variability—characterised by alternating aerobic oxidative phases that tend to lower glucose and anaerobic glycolytic or catecholamine-dependent phases that may raise glucose—there is also substantial inter-session variability: no two matches are ever the same, as demands depend on the player's role, the opponent, the

referee, the score, and strategies that can never be exactly replicated. This creates a dual risk: hypoglycaemia during lower-intensity phases and in the delayed period, particularly overnight due to glycogen depletion associated with repeated sprints, but also end-of-session hyperglycaemia driven by adrenaline.

Preparation should therefore consider the ability to repeat high-intensity efforts, recover rapidly, maintain technical quality under fatigue, and tolerate sometimes unpredictable exercise duration. From a glycaemic perspective, the intermittent nature of these activities may attenuate the glucose decline typically associated with continuous aerobic exercise, but it does not eliminate the risk of hypoglycaemia during or after activity. High glycaemic variability makes a fixed insulin/CHO strategy ineffective and instead requires an adaptive approach based on CGM data, experience, and retrospective classification of exercise intensity.

17.12 Recovery: Part of Training, Not the Interval Between Two Sessions

Adaptation occurs when an appropriate recovery period follows the training stimulus. Sleep, nutrition, glycogen replenishment, fatigue management, and the distribution of training sessions influence the ability to sustain the programme (periodisation) and to transform acute adjustments into chronic adaptations; they represent the practical tools through which the exercise professional organises recovery within the microcycle: two closely spaced hard sessions do not allow adequate recovery and adaptation, even when nutrition and sleep are appropriate. In T1D, the post-exercise period requires additional attention because increased insulin sensitivity may persist for several hours. The consensus document by Adolfsson et al. (ISPAD) highlights that the risk of hypoglycaemia may increase during, immediately after, and for up to 24 hours following exercise in young people. Sports recovery and the prevention of delayed hypoglycaemia should therefore be planned together, without, however, confusing energy replenishment with the preventive treatment of a relative excess of insulin. Metabolic recovery is therefore also important in T1D: if glycogen stores are not adequately replenished and/or overnight basal insulin is not appropriately managed, the risk of hypoglycaemia increases, with consequent sleep fragmentation and disruption of the adaptation process.

17.13 Overreaching, Overtraining and Signals That Should Not Be Oversimplified

Effective training planning alternates overload and recovery to induce adaptation. A short period of functional fatigue may be intentionally planned (functional overreaching); however, as already discussed, a persistent decline in performance, sleep disturbances, irritability, loss of motivation, or inadequate recovery are warning signs (non-functional overreaching and overtraining syndrome) and instead require discontinuation of the overload and reassessment of the training programme. In DMT1, no single glycaemic pattern (TBR, declining TIR, high glycaemic variability) can be used to diagnose overtraining, because glucose fluctuations may accompany stress, illness, insufficient or fragmented sleep, changes in training load, or the menstrual cycle, and must therefore be interpreted within the overall context. Here too, metabolic data represent contextual signals that should be interpreted within the broader clinical and training picture and cannot, on their own, establish a sports-related diagnosis.

17.14 Tapering and Competition: Reducing Load Without Losing Adaptation

Before an important competition, volume may be reduced while maintaining some intensity, with the aim of dissipating fatigue while preserving adaptations and reaching supercompensation. In DMT1, tapering may also modify usual insulin requirements because total activity volume decreases while maintained intensity keeps insulin sensitivity high. A metabolic strategy effective during high-load weeks should therefore not automatically be transferred to the days before competition. Tapering is also the time to stabilize.

Competition also adds emotional stress with massive catecholamine release, different schedules and specific nutritional behaviours. For this reason, the competition strategy should, as far as possible, be tested in simulation training.

17.15 Training Metabolic Predictability

Metabolic predictability does not mean the reproducibility of a single glucose value (i.e., it does not mean obtaining the same glycaemic response every time), but rather the ability to reduce uncertainty in the response through structured experience. Recurrent training sessions, recorded in an essential and consistent manner, make it possible to recognise individual response patterns (standardising conditions in order to learn, collecting data within the same context, establishing an expected range rather than a fixed value, and reducing error) and to develop progressively more reliable strategies, thereby refining the ability to be proactive.

Since excessive data can become "noise" and increase cognitive burden, it is useful to record only those variables that may influence a decision: type and duration of the session, intensity, time of day, initial glucose level and trend, IOB when available, main insulin and CHO interventions, and outcomes during the session and in the following hours.

Optimal performance is not achieved by pursuing perfect glucose levels, but by systematically replicating conditions in order to build individual experience that makes it possible to anticipate both the direction and magnitude of change and to prepare a correction strategy (rather than aiming for absolute prevention).

Example of building metabolic predictability:

weeks 1–2, collect data without changes and simply observe;
weeks 3–4, patterns begin to appear:

- Leg weights, RPE 7, 60 min with IOB = 1.5 U → glucose stable during, +35% TBR at night, −20% nocturnal basal + 15 g extra CHO before bed.
- Easy run, RPE 4, 90 min with IOB = 0.5 U → slow 40 mg/dL fall, 20 g CHO during.
- HIIT, RPE 8, with high IOB → peak at 200 mg/dL from adrenaline and then a fall at 3 h.

Before the minimum daily log: fear of hypoglycaemia → eats randomly → hyperglycaemia → corrects → hypoglycaemia.

After the minimum daily log: the athlete already knows before the session how much it will cost in CHO, insulin and sleep → it can be programmed rather than reacted to. Control is not perfect, but predictable; and if it is predictable, it is trainable.

Operational principle
Record fewer variables, but record those useful for making a decision. The goal is not to create a perfect archive: it is to recognize sufficiently reliable patterns to improve training and autonomy.

17.16 Teamwork and Professional Boundaries

LM-67 specialists (Master's degree graduates in Preventive and Adapted Physical Activity Sciences—AMPA, within the preventive-therapeutic domain) or LM-68 specialists (Master's degree graduates in Sports Sciences and Techniques, specialising in elite athletic preparation) prescribe and modulate the training load within the scope of their respective competencies in order to induce adaptation; the diabetologist defines clinical safety and therapeutic strategies to ensure that the training load is tolerated; the dietitian or nutritionist, when involved, structures nutrition in terms of energy provision and recovery (e.g., total CHO intake, protein requirements for synthesis, and daily distribution of food intake); as a "co-decision-maker," the athlete contributes lived experience and real-life context, preferences, and knowledge of their own responses (real-time feedback, responsibility, and autonomy). None of these competencies is ancillary, and communication among the various stakeholders is not optional.

The shift from the traditional to the new model is characterised by a transition from team decision-making followed by athlete execution to shared decision-making, in which the team and the athlete jointly select the

most effective and sustainable strategy, based on evidence combined with field experience. Integrating the experiential expertise of the athlete with T1D does not diminish the professionalism of the team; rather, it makes it more effective and, above all, helps ensure that a prescription that is correct on paper can become a behaviour that is sustainable over time.

Collaboration becomes particularly important when a problem appears to belong to a single domain. A training session that is repeatedly interrupted because of hypoglycaemia is not merely a glycaemic problem: it prevents the planned training load from being achieved; the therapeutic adjustment made by the diabetologist therefore becomes a new "constraint" for training-load modulation. An excessively demanding programme is not merely a sports-related problem: it may increase the difficulty of daily diabetes management and reduce adherence; CGM data observed by the exercise professional therefore become clinically relevant information for the diabetologist.

Frequent conceptual error
Considering a session "good" only when the CGM curve is flat. Training quality depends on the planned stimulus and the adaptation sought; the quality of metabolic management depends on the ability to perform that stimulating work under safe and sustainable conditions.

17.17 A Practical Model for the Session

Before: define the training objective and verify that clinical conditions allow the session.
During: monitor external load, internal response and metabolic safety without chasing every sensor fluctuation.
After: assess whether the stimulus was completed and how it was tolerated, how glucose behaved and how recovery is progressing.
Over time: use comparable sessions to personalize both the programme and the metabolic strategy (clinical and nutritional).

17.18 Return to Sport After a Stop Due to Injury or Illness

This is the period in which errors are most likely because deconditioning, inflammatory state and fear of hypoglycaemia coexist.

Correct management in three phases, based on markers rather than simply on days off, can be useful for both the athlete with DMT1 and the master kinesiologist LM67/LM68.

a) **Acute phase** (illness/injury still active): the main focus is stabilization rather than training; maintain only mobility and walking at RPE 2–3 with minimal IOB; do not force return if there has been fever in the previous 24 h, nocturnal TBR >4% for two nights, morning CMJ −8%, or resting RPE >4/10.
b) **Return phase** (first 7–10 days): do not double the load; regulate ACWR (example: 50% volume, 70% intensity in the first week), remap for 3–4 sessions, rebuild insulin sensitivity, use an intelligent training sequence (e.g. days 1–2 light full-body strength RPE 4–5; days 3–4 easy continuous aerobic exercise 20–30 min RPE 4; reintroduce HIIT only after 4–5 days without TBR), and prevent delayed hypoglycaemia.
c) **Rebuilding phase** (weeks 2–4): progress load by no more than +10–15% sRPE per week. Criteria for progression:
    - nocturnal TBR <4% for three consecutive nights and CV% <36%;
    - CMJ within −3% of the pre-stop baseline;
    - RPE at the same external load equal to before;
    - no severe hypoglycaemia 0–24 h post.

Otherwise repeat the week.

In the athlete with DMT1, return to play/sport is guided not only by pain or influenza/inflammatory status, but also by metabolic tolerance. After illness/injury, chronic load is reset and the individual profile of metabolic tolerance to load—the "cost–load mapping", i.e. how much each type of training session costs in terms of CHO, insulin and risk of delayed hypoglycaemia—is rebuilt with well-structured progression (ACWR <1.3). The goal is not simply to return to the pre-stop load, but to return to stable metabolic predictability.

Take-home messages

- The athlete with DMT1 should be trained according to the principles of training physiology, not according to the CGM response alone.
- Diabetes modifies the context in which the stimulus is performed, not the physiological objective of the stimulus.
- External load, internal load and metabolic–therapeutic load must be distinguished and then integrated.
- Repeatability of sessions can transform experience into metabolic predictability.
- Collaboration between the athlete, the master kinesiologist LM67/LM68 and the diabetes care team makes it possible to pursue safety and performance simultaneously.

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PART V — FROM SPORT-SPECIFIC FEATURES TO INTERPRETING THE RESPONSE

Chapter 18 – Endurance Sports: Running and Cycling



Figure 18. Running and cycling: the same endurance principle, but different nutritional opportunities and mechanical demands.

18.1 Short- and Long-Duration Running: the Same Discipline but Different Specialties and Metabolic Problems

18.1.1 There Is No Single "Running"

A slow thirty-minute run, a 10 km run at the limit, a half marathon and a marathon belong to the same discipline but do not share the same physiological dynamics and problem (clinical risk) in DMT1, because the "engine" itself (or dominant energy system) changes, as does the limiting factor. Relative intensity, duration, rate of glycogen use, contribution of exogenous carbohydrates, catecholamine response and the probability that active insulin becomes excessive relative to the demands of the moment all vary.

For this reason, the strategy should not start from distance as a label. It is more useful to describe the event through expected duration, relative intensity (%VO_2max, %threshold), nutritional state and expected IOB at the start. Distance acquires meaning only through these variables. A 10 km run in 36 minutes and the same distance covered in 70 minutes share the mileage but not the same relative intensity, not the same duration of exposure to active insulin–IOB, not the same ratio between endogenous/exogenous carbohydrates (the CHO/h mapping varies), not the same internal load (sRPE × duration), not the same endocrine-hormonal response, and not the same mechanical and thermal cost (contact times, force peaks, dehydration, etc.).

18.1.2 Relatively Short-Distance Running in the Trained Athlete

In a highly trained athlete, a 40–60 minute event may produce limited glycaemic disturbance when insulin exposure is appropriate and hepatic production compensates for muscle uptake. Stability does not mean low energy cost: a high-intensity 10 km run may use a great deal of glycogen while showing a relatively flat curve.

The clinical point is to distinguish stable blood glucose from absence of metabolic demand. The former describes the momentary balance between glucose entering and leaving the circulating compartment: consumption is high (even 20–25 kcal at 20 km/h), but hepatic glucose production and muscle uptake are perfectly balanced (high carbohydrate turnover with high flow, not low energy cost) thanks to adaptation; the latter would instead concern external muscular work, which may be high. In relatively short events, therefore, the problem may consist less in "fueling the race" and more in avoiding starting with excess insulin. Glycaemic stability describes the momentary balance between glucose entry into and exit from the blood compartment, not the magnitude of the flow, and in DMT1 it may become a "trap" if only the CGM curve is read: the true cost is paid later through glycogen depletion and the related insulin hypersensitivity 6–12 h later, and when the adrenergic peak ends, with a subsequent fall 2–3 h later if post-run hyperglycaemia has been corrected.

A 10 km Is Not Metabolically "Insignificant"

The relatively short duration may limit the need for CHO-P during the event, but does not necessarily reduce glycogen use. In the trained athlete, the CGM curve may remain stable while metabolic work remains high. Sensor data must not be used as a surrogate for energy cost.

18.1.3 Half Marathon: When Time Changes the Problem

The half marathon is a particularly instructive distance because duration can vary enormously. For a high-level athlete, little more than one hour may separate start and finish; for an amateur, the event may exceed two hours. Nutritional guidance therefore cannot derive from the distance "factor".

As exercise continues, the importance of glycogen availability and exogenous intake progressively increases. In DMT1 it also becomes more likely that CHO-P and CHO-G will add together. If the athlete enters the race with excessive IOB, part of the planned supplementation is used not to produce work but to defend against hypoglycaemia. Total intake rises, but performance requirements do not necessarily rise with it; this is the error easily seen in those who look only at grams ingested at the end of the race and translate this as "I consumed 70 g/h", when perhaps 30–40 g/h is the performance requirement (to sustain 75–80% of threshold and maintain external power) and 20–30 g/h is the defensive cost of corrective anti-hypoglycaemia CHO.

18.1.4 Marathon: Plan Before Correcting

The marathon makes the systemic nature of management evident rather than presenting an isolated metabolic problem. Substrate availability (glycogen + exogenous CHO), hydration + sodium, gastrointestinal tolerability, continuity of insulin delivery and decision-making capacity must all be maintained simultaneously for several hours. A plan that requires continuous correction of blood glucose, insulin and nutrition becomes intrinsically fragile precisely as cognitive fatigue increases—technically termed "cognitive-load fragility"—which in practice reduces the resources available to manage it. The principle of robustness in DMT1 during a marathon is to favour anticipatory regulation with a low decision frequency rather than continuous reactive regulation: a protected start (low IOB 90 min beforehand), automatic nutrition routines (e.g. 30 g CHO every 30 min regardless + synchronized water intake), glycaemic ranges and intermediate checkpoints (10th, 20th, 30th km).

The nutritional strategy must be tested during long training sessions. Competition should not be the first setting in which a new glucose–fructose mixture, an amount of CHO per hour never previously tolerated, or a major insulin reduction is tried. Recovery must also be planned: after several hours of exercise, glycogen restoration and increased insulin sensitivity may keep the risk of hypoglycaemia high beyond the finish line.

18.1.5 Running and Cycling Are Not Interchangeable

A meta-analysis in people with DMT1 showed, on average, a greater reduction in blood glucose during running than during cycling, a sport examined in detail below. This finding should not be turned into an individual prediction, but it reminds us that the type of exercise matters. Muscle recruitment, mechanical impact and cost, body position, the intensity actually sustained and the possibility of feeding modify the metabolic context. For the same duration, running entails greater glycaemic disturbance, but the individual response remains dependent on starting IOB, glycogen status and the repertoire of responses to load built in the field.

18.1.6 Final Sprint and Post-Race Rise

A finishing sprint may rapidly increase catecholamines and hepatic glucose production. Blood glucose may therefore remain stable or rise despite high muscular carbohydrate consumption (from a reservoir different from blood glucose: local glycogen and lactate); this may represent the trap of a sprint finish in DMT1. Immediately correcting a post-race rise without considering IOB, the exercise just completed and the subsequent increase in insulin sensitivity may predispose to a delayed hypoglycaemic episode. The more robust strategy provides for a 30–60 min observation window before any fractionated correction.

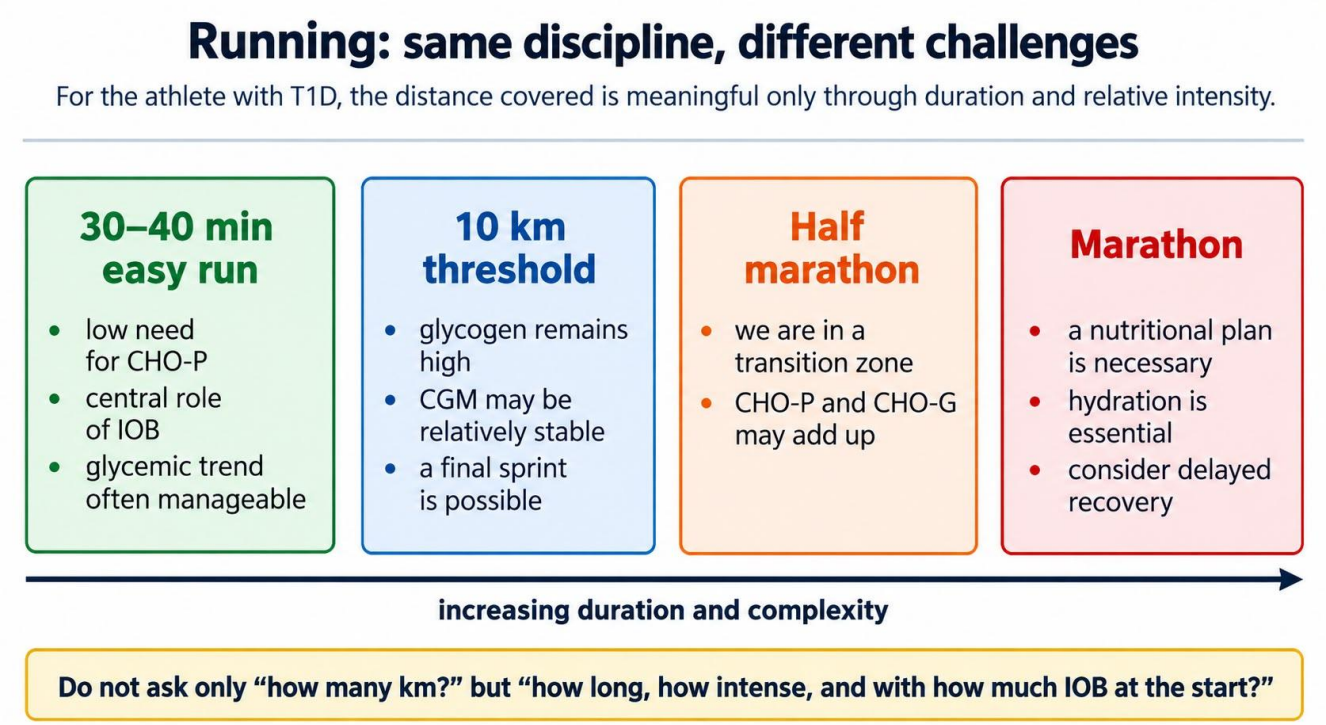


Figure 18.1. In running, the relative weight of IOB, glycogen, supplementation and recovery changes with duration and actual intensity.

Questions to Ask Before Running

How long will it really last? At what relative intensity? With how much IOB will the athlete start? Which CHO are planned for performance and which might become necessary only for glycaemic management? What usually happens in the following two hours?

18.2 Cycling: Power, Duration, Continuous Feeding and Device Management

18.2.1 The Advantage of Measuring External Work

In cycling, a power meter in watts makes it possible to describe external work accurately regardless of environmental conditions and the athlete's state (wind, gradient, sleep, glycaemic levels).

Two athletes may produce the same absolute power but at different percentages of their own capacity:

- ✓ Day A: FTP 350 watts, at 71%, in high Zone 2–3. Fat oxidation, stable glycogen, slow fall in blood glucose;
- ✓ Day B: FTP 280 W, at 89%, at threshold. CHO oxidation, lactate at 4 mmol, elevated catecholamines, marked initial rise in blood glucose.

Moreover, the same athlete may maintain the same power (e.g. 250 watts) on days when the internal work/cost (heart rate, perceived exertion and glycaemic response) is different:

- ✓ Day A: good sleep, low IOB, full glycogen → HR 135 bpm, RPE 4/10, stable CGM;

- ✓ Day B: 3 h cycling, post-stress, high IOB, dehydration → HR 155 bpm, RPE 7/10, CGM collapse.

A kind of dissociation is therefore created between external load (objective and reproducible) and internal load (which reflects metabolic cost in a specific context).

This distinction is particularly useful in DMT1: the CGM (which describes glycaemic balance) does not indicate how much power the cyclist is producing, whereas power and duration help identify the energy demand generated by the session and make the load reproducible. Metabolic cost is variable: IOB, glycogen, sleep, hydration, acute load. The glycaemic response does not depend on absolute power, but on the internal cost and the metabolic context in which that power is expressed.

18.2.2 Climbs, Flat Sections and Variability of Demand

A long ride is not necessarily uniform. With climbs, accelerations, wind, changes of group and technical sections, it is useful to anticipate that some segments will require rapidly available energy and that, during very intense sections, eating or digesting will be more difficult (a phase of lower digestive tolerance and capacity due to redistribution of blood flow and sympathetic activation). The effective strategy is therefore anticipatory rather than reactive, separating intake from the moment of metabolic use according to the following scheme:

- 10–15 min before the intense section: 15–20 g in liquid form + water (reaches the blood when the effort begins);
- during the surge: water only (digestion should not be forced);
- at the end, during the 2–3 min recovery: complete supplementation (intestinal blood flow reopens, absorption improves), considering that taking in or digesting food or drink is more difficult during very intense sections.

18.2.3 Long Endurance and Carbohydrate Mixtures

The possibility of hydrating and feeding frequently, in a stable position, makes cycling an ideal context for strategies using "multiple transportable carbohydrates" (for example glucose–fructose mixtures in a 2:1 ratio). When carbohydrate intake is high, glucose or maltodextrin–fructose mixtures (with low osmolarity) and gut training (intestinal training, functional adaptations) may increase exogenous oxidation (less hepatic glycogen use → lower glycaemic variability and risk of delayed hypoglycaemia = better stability of glycaemic balance during prolonged physical exercise) and tolerability, because they use different intestinal transporters (SGLT1 and GLUT5). In DMT1 the challenge (in training, not in competition; in Zone 2–3, not at pure threshold) is to prevent additional CHO-G from pushing the total beyond what the intestine tolerates while simultaneously training the stomach to empty even under exertion with high sympathetic activity (fewer sensitized stretch receptors → less nausea).

18.2.4 Running and Cycling: Why the Same Percentage Intensity May Not Produce the Same Curve

Aggregated literature shows that running tends to cause a greater fall in blood glucose than cycling. The explanation is probably multifactorial (muscle mass recruited and eccentric contractions, difficulty compensating with exogenous CHO, mechanics and energy cost, hormonal response) and should not be reduced to a single cause. The finding nevertheless reminds us that exercise type, even at the same percentage intensity (%FTP/HR), modifies the response (different glycaemic curve) and that a nutritional and insulin strategy tested on the bike cannot automatically be transferred to running.

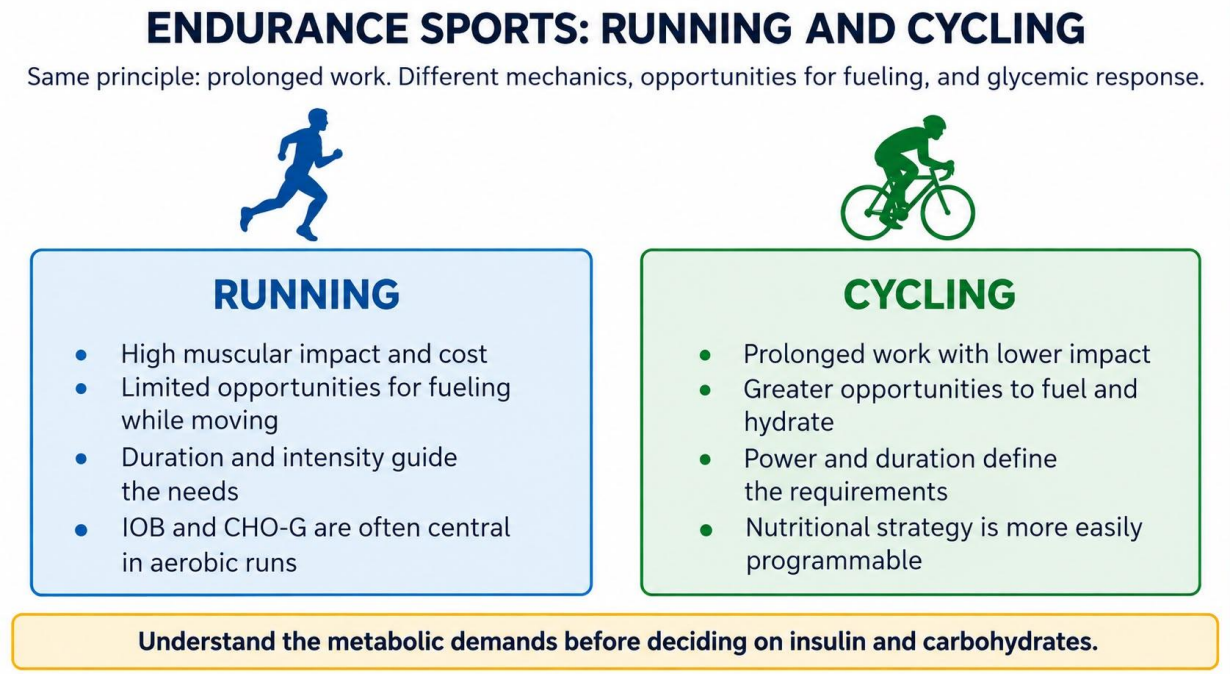


Figure 18.2. The most significant differences between running and cycling for people with DMT1.

18.2.5 Device, Infusion Set and Safety

On long rides, practical aspects that are sometimes overlooked become decisive: sensor and infusion-set position, management of sweat and friction, device protection, availability of backup insulin and the possibility of confirming blood glucose with a capillary measurement when data are doubtful. A prolonged interruption of

delivery with an insulin pump can become clinically relevant more rapidly than with multiple-injection therapy precisely because there is no depot of long-acting basal insulin.

Practical Rule

If total carbohydrate intake continues to increase solely to prevent hypoglycaemic episodes, it is necessary to ask whether the main problem is really performance fuel or inappropriate insulin exposure.

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Chapter 19 – Intermittent, Team or Combat Sports

In this chapter, we consider intermittent sports not as a list of disciplines, but as families of problems. Football, basketball and volleyball alternate phases of different intensity and offer different decision-making windows; rugby and other contact sports add impacts, device protection and possible interruptions in delivery; judo, wrestling, karate and related disciplines combine high intensity, a strong adrenergic component and body-to-body contact. The criterion remains that of the entire Atlas: first describe the real demands of the sport, then understand how they interact with IOB, CHO, CGM and technology.

19.1 Team Sports: Intermittency, Glycogen and Real-Time Decisions



Figure 19.1. Intermittent and contact sports: the technical action also changes the practical management of technology.

19.1.1 Football

Why Football Is Not a Ninety-Minute Run

A match alternates walking, low-intensity running, accelerations, sprints, changes of direction, jumps, tackles and pauses. The average load may appear aerobic, but many decisive actions require high power and rapid glycogen use. The final glycaemic effect results from the succession of different metabolic phases, the adrenergic response and the emotional component of competition.

The nominal duration of 90 minutes also conceals differences between roles, technical level, style of play, temperature, substitutions and actual activity time. The clinical problem is therefore not deciding whether football is aerobic or anaerobic, but understanding which mixture of metabolic demands occurs in that specific athlete.

19.1.2 External Load and Internal Load

GPS, total distance, average/maximum speed, accelerations/decelerations and number of sprints, changes of direction, jumps, estimated metabolic power and mechanical work describe the external load. Heart rate, %HRmax, RPE, lactate, ventilation, VO_2max, glycogen availability and hydration status are components of internal load. In DMT1, components of metabolic-glycaemic load are added: IOB, blood glucose, trend, previous meal and CHO timing, AID/delivery mode, glycogen and residual insulin sensitivity.

Two footballers who cover the same distance may therefore experience metabolically different matches. One may have performed many sprints and changes of direction, finishing with reduced glycogen (especially fast glycolysis, lactate, increased post-exercise insulin sensitivity); the other may have covered more metres at a moderate pace with lower glycolytic cost (predominantly oxidative type I fibre work, low glycogen consumption). The same CGM value at the end does not summarize these differences (two different metabolic destinies) nor predict the risk of delayed hypoglycaemia in the same way: in the first case there is muscle glycogen debt (for supercompensation) and hepatic glycogen debt with a relatively high risk of nocturnal hypoglycaemia, whereas in the second carbohydrate reserves remain. Therefore, in DMT1 it is important to detail the external load because its various components determine the real internal glycaemic load by predicting glycogen depletion, not the total kilometres.

19.1.3 The Pre-Match Meal and the Risk of Turning CHO-P into CHO-G

The pre-match meal must support glycogen stores and be compatible with digestion times and match schedule. In DMT1, the difficulty lies in not turning a performance meal into a source of hyperglycaemia at the start or hypoglycaemia from insulin overdosing (high IOB). Bolus reduction, when indicated, must be individualized according to timing, meal composition, therapy and previously observed response; it should be tested in training, not in competition, with the specialist team.

A frequent error is to correct fear of hypoglycaemia by adding carbohydrates and then covering them with insulin. The athlete may enter the field with high blood glucose but also significant IOB, setting up a later fall precisely when the aerobic component of play increases.

19.1.4 Half-Time: an Observation Window, Not Just a Time to Eat

Half-time makes it possible to integrate different data. The CGM shows what is happening to glucose; the athlete can report fatigue, hunger, perception of heat, first-half intensity and difficulty maintaining sprints. Stable blood glucose may coexist with substantial glycogen use; a downward trend may depend mainly on IOB.

Carbohydrate intake at half-time should therefore answer two separate questions: is fuel needed for the second half? Is a therapeutic amount needed for the glycaemic trend? When both answers are yes, the amounts may add together; when only one is positive, it is useful not to confuse the problems.

19.1.5 Extra Time, End of the Match and Recovery

As duration increases, fatigue, depletion of reserves and difficulty maintaining high-intensity actions increase. In extra time, the importance of CHO-P becomes greater. After the match, recovery must consider glycogen restoration and the risk of delayed hypoglycaemia, without automatically applying a standard insulin reduction.

19.1.6 The Role of the Emotional Context as a Psycho-Physiological Internal Load

The same technical drill may produce a different glycaemic profile in competition. Result pressure, spectators, selection and decisive moments are components of acute psychosocial stress capable of increasing the neuroendocrine response (sympatho-adrenal axis in 10–20 seconds → increased hepatic glucose production; hypothalamic–pituitary–adrenal axis in 15–30 minutes → transient insulin resistance) to a variable extent (in training activation is moderate, proportional to physical load). For this reason, a nutritional and insulin strategy that works in training should also be progressively validated in the competitive context.

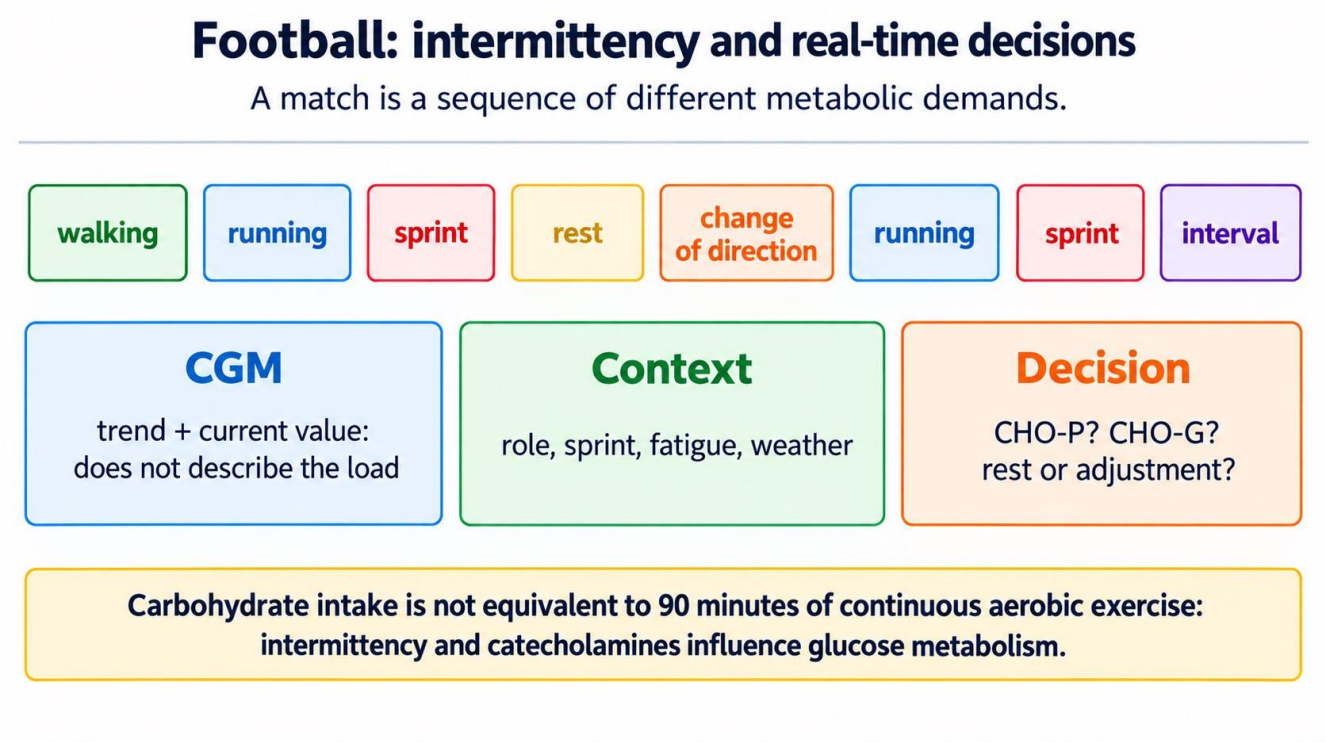


Figure 19.2. Football is a sequence of different demands: average intensity does not describe sprints and accelerations.

Frequent Conceptual Error

Classifying football as simple aerobic exercise and expecting a constant fall makes no sense. Intermittency, sprints, pauses, adrenergic response and IOB can produce very different profiles in the same person.

19.2 Volleyball and Similar Sports: Fragmented High Intensity, Pauses and Role Variability



Figure 19.1. Intermittent and contact sports: the technical action dominates.

19.2.1 A Point-Based Sport Is Not Continuous Exercise

Volleyball, a purely intermittent sport, alternates very brief and intense actions (explosive phase) with frequent pauses (rotations, time-outs). Jumps, accelerations, lateral movements and explosive actions require high power, while the overall duration of the match may extend unpredictably.

Blood glucose may remain relatively more stable during the match than during continuous aerobic exercise of the same duration, without glycogen consumption being negligible (metabolic cost is not low), with delayed hypoglycaemia masked. A possible strategy in DMT1 during post-competition recovery is basal reduction/prolonged activation of activity mode on AID; otherwise, if the post-exercise glycogen gap is not anticipated, there is a risk of delayed hypoglycaemia.

19.2.2 Role Changes the Metabolic Demand

Middle blocker, libero, setter and outside hitter do not have the same action profile. Number of jumps, movements, rally duration and competitive level modify neuromuscular and metabolic load; external-load descriptors determine internal metabolic load and the corresponding glycaemic risk profile. For personalization in DMT1, it is therefore more useful to describe the role and actual load than to apply a generic strategy to the word “volleyball”.

19.2.3 Pauses as an Operational Advantage

The frequent pauses typical of volleyball provide opportunities to observe the CGM trend, take small amounts of fluids or carbohydrates and reassess sensations. This intermittent structure may reduce the need for large preventive CHO intakes. In an AID system, however, it should be remembered that an automatic or manual correction made during a transient rise may increase IOB and the related risk of hypoglycaemia in subsequent sets.

19.2.4 Technical Training, Match and Tournament

A technical session with many pauses, a single match and a tournament with several matches on the same day represent different problems. In a tournament, recovery between matches becomes particularly important: restoration of fluids, carbohydrate availability, meal quality and insulin management must allow the athlete to restart without accumulating either an energy deficit or excess IOB.

19.2.5 Post-Exercise

The high neuromuscular component and intermittency, as well as task variability, make the post-exercise glycaemic response less predictable than after a continuous aerobic session. A structured diary of similar sessions may become more informative than a general rule, especially when it records role, actual duration and number of sets: it enables the transition from a prescription based on the discipline to one based on the load actually experienced.

19.3 Contact and Combat Sports



Figure 19.3. Contact sports: the technical action is not everything.

19.3.1 Judo, Wrestling, Karate and Related Disciplines

In combat sports, the metabolic and mechanical problems are inseparable. Brief sequences of high intensity, maximal isometric contractions, throws/sprints (alactic + lactic anaerobic power), grips and incomplete recoveries may cause substantial glycogen use and a marked adrenergic response (combat stress). Blood glucose may therefore remain stable or increase during a bout even when muscular carbohydrate cost is high, concentrated mainly in the forearms–back–core. In the presence of significant IOB, however, the risk of a fall does not disappear: high intensity does not automatically mean protection from hypoglycaemia.

19.3.2 The Device Becomes Part of the Sporting Problem

Gripping, rubbing and body-to-body contact make it inappropriate to propose a universal site for the sensor or insulin pump. The choice depends on the discipline, regulations, type of device, body build and athlete experience. A CGM may require a less exposed site and additional fixation systems; a tubed insulin pump may need to be disconnected in some activities; a tubeless system does not offer the same possibility of temporary removal and must also be assessed in relation to the risk of impact or detachment. The decision should be tested in training and be compatible with federation or organizer rules.

19.3.3 Disconnecting the Pump Does Not Mean Cancelling Insulin

When an insulin pump is disconnected, insulin already absorbed continues to act: in the early stages the athlete retains a reserve of active insulin (residual IOB), while as the interruption continues the opposite problem emerges, namely a progressive lack of rapid-acting insulin with possible hyperglycaemia and ketone production. The EASD/ISPAD position statement considers swimming, diving and contact sports among the circumstances in which suspension or disconnection may be necessary; in planning, disconnection should be managed not as “suspension of insulin”, but as a time window with an initial tail of residual insulin and subsequent progressive deficiency. Prolonged interruptions require an agreed strategy, not simply removal of the device at the time of competition.

19.3.4 The CGM May Not Always Be Available

A protected sensor may continue to provide data, but impacts, detachment, loss of communication or inability to consult the receiver during the bout may temporarily reduce the operational value of CGM. For this reason, the safety plan must also include what the athlete will do if the value cannot be read or does not appear consistent with symptoms and context. Technology helps, but in contact sports it cannot be the only safety tool.

Practical Box – Before a Contact Sport

- What type of contact will the athlete realistically experience?
- Can the CGM remain worn and protected without creating danger for the athlete or the opponent?
- Can the insulin pump remain in place, must it be protected, or should it be disconnected?
- If delivery is suspended, what IOB is present and how long can the interruption last?
- How will blood glucose be checked if the CGM becomes temporarily unavailable?
- What do the regulations of the specific discipline or federation provide?

19.4 Rugby: Intermittency, Contact and Technology



Figure 19.3. An intermittent and contact sport that can modify the practical management of technology.

19.4.1 A Metabolic and Mechanical "Hybrid"

Rugby combines intermittent running, accelerations, sprints, static phases, tackles and collisions. The demand varies greatly with role and level of play: a forward and a back may share the same nominal duration but accumulate different external and internal loads. From a glycaemic perspective, the risk of a fall related to IOB and aerobic work therefore coexists with possible glycaemic stabilization or rise due to intense phases and the adrenergic response typical of competition.

19.4.2 Where Should the Sensor and Insulin Pump Be Applied?

The question does not have one site that is valid for everyone. Tackles, scrums, falls and protective equipment alter the most exposed areas; moreover, regulations and devices are not identical. The useful principle is to reduce direct exposure to impact and rubbing, secure the sensor with appropriate fixation systems and assess during training whether the insulin pump can remain worn. With tubed systems, disconnection may be a solution in some circumstances, but it must be planned while taking account of insulin not delivered.

19.4.3 Competition, Psycho-Physical Stress and Recovery

The competitive component may increase blood glucose before or during the match and lead the AID to increase delivery. The athlete may therefore finish with greater IOB precisely when muscular load and glycogen restoration increase insulin sensitivity. Monitoring does not end at the final whistle: the post-match phase and the following night are part of the therapeutic strategy.

Essential References for Further Reading

Moser O, Zaharieva DP, Adolfsson P, et al. The use of automated insulin delivery around physical activity and exercise in type 1 diabetes: EASD/ISPAD position statement. Diabetologia. 2025;68(2):255–280.

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Chapter 20 – Swimming, Triathlon and Other Combined Disciplines



Figure 20.1. Swimming, cycling and running: in triathlon each leg metabolically prepares the next.

Swimming deserves specific attention not only because it is practised by many athletes with DMT1, but because water simultaneously changes access to carbohydrates, the possibility of consulting the CGM and insulin pump management. In triathlon these difficulties become even more interesting: swimming, cycling and running are not three independent events, but a sequence in which each leg metabolically prepares the next.

20.1 Swimming: Same Water, Different Metabolic Demands

A continuous session at a moderate pace, short high-intensity sets, technical training, a pool race and an open-water race do not have the same metabolic profile. Continuous swimming may favour a fall in blood glucose when IOB is high; intense sets and competition may increase the adrenergic response and attenuate the fall. Water temperature, duration and training status further modify the individual response and, in particular, immersion in cold water slows insulin release from subcutaneous depots.

20.2 In the Water, the Problem Is Also Access to Data

Sensor water resistance, data transmission and the possibility of reading the value are not synonymous. A device may tolerate water without guaranteeing that communication between sensor, pump and receiver remains continuous during immersion. Behaviour depends on the system used, the distance between components and the characteristics of wireless communication. For this reason, before a session or competition, it is necessary to know what happens to one's own system when entering the water and what will happen upon resurfacing.

20.3 Insulin Pump: Remain Connected or Disconnect

Some systems remain worn in water, while others can be disconnected. The choice is not purely technical: interrupting delivery may be useful or necessary, but the absence of insulin delivery progressively becomes relevant. The EASD/ISPAD recommendations consider aquatic activities among the situations in which suspension or disconnection may be required and emphasize the risk of insulin deficiency during prolonged interruptions. The plan must therefore include duration, method of suspension, any reconnection and subsequent monitoring.

20.4 Open-Water Swimming: Safety Before Precision

Hypoglycaemia has a different significance in open water than in settings such as a track or gym: stopping exercise, taking CHO or receiving assistance may take time. The strategy should therefore be more conservative with regard to hypoglycaemia risk, include appropriate companionship when required, make rapidly usable carbohydrates available in ways permitted by the activity, and carefully consider environmental conditions.

20.5 Triathlon: One Race, Three Legs, Two Transitions

Triathlon cannot be classified as the arithmetic sum of swimming, cycling and running. The swimming leg is undertaken with limited access to nutrition and technology; cycling offers the greatest opportunity to eat, hydrate and adjust the strategy; the final run begins when glycogen, hydration and fatigue are already the result of the preceding hours and the initial IOB is running out. In this sense, T1 and T2 are therefore not merely equipment-change moments, but true decision-making windows.

20.6 The Bike as the Main Nutritional Window in Triathlon

In long-distance events, the cycling leg is often the most favourable time to distribute CHO-P, fluids and electrolytes. This does not mean fuelling only the cycling phase: part of the strategy serves to prepare the subsequent run. If during cycling the athlete is repeatedly forced to add CHO-G to compensate for excessive IOB, they may reach the run with a high gastrointestinal load and with an already compromised performance strategy.

20.7 AID and Very Long Races

In long-duration events, the AID system must avoid two opposite errors: excessive insulin during phases that favour a fall in blood glucose and insufficient insulin availability because delivery has been reduced or suspended during hours in which adrenaline is at its highest. International recommendations for events such as Ironman, triathlon, road cycling and prolonged trekking emphasize the need for regular nutrition, close monitoring and attention to the risk of ketosis when the delivery rate remains very limited for long periods.

20.8 Recovery: the Race Does Not End at the Finish Line

The longer the event, the more recovery must be considered part of management: fluid replacement, carbohydrate replenishment, glycogen restoration and increased insulin sensitivity may extend for many hours. After evening or prolonged competitions, the following night deserves specific planning.

Take-home Messages

- in swimming, water resistance and real-time availability of CGM data are different issues
- insulin pump disconnection must be planned because the absence of rapid-acting insulin delivery becomes progressively relevant
- in triathlon, the cycling leg is often the main window for fuelling the subsequent run as well

- T1 and T2 are metabolic decision-making windows as well as logistical ones
- in long events, the risk is not only hypoglycaemia: insulin delivery that is too low and prolonged may favour hyperglycaemia and ketosis.

Essential References for Further Reading

Moser O, Zaharieva DP, Adolfsson P, et al. The use of automated insulin delivery around physical activity and exercise in type 1 diabetes: EASD/ISPAD position statement. Diabetologia. 2025;68(2):255–280.

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Chapter 21 — Tennis and Other Individual Intermittent Sports



Fig. 21.1. Alexander Zverev, a current symbol of T1D in tennis

In this chapter we focus mainly on tennis, to which we are also emotionally connected through the experience of Alexander Zverev, whose great performances, most recently the achievement of his first career Grand Slam title at Roland Garros and the US Open in 2026, we have unfortunately seen undergo unexpected, sudden collapses on some occasions because of "small errors". These, in fact, concerned the assessment of IOB (which, since he does not wear an insulin pump, the athlete could only estimate very approximately) and above all involved underestimating the possible discrepancy between the value shown by the sensor and the actual blood glucose concentration measurable with a glucose meter, certainly facilitated by performance anxiety and by the difficulty of distinguishing symptoms of sporting fatigue from symptoms of glycaemic variation.

By analogy, however, we could also consider related disciplines: squash, padel, badminton and table tennis.

21.1 Uncertain Duration Changes the Way Planning Is Done

In tennis, in particular, it is not possible to know precisely how long the match will last. A match may end quickly or continue for hours. The strategy must therefore be modular: adequate availability at the start, resources to prolong fluid and CHO intake, the possibility of adapting insulin, and a recovery plan if the match extends beyond expectations.

21.2 Intermittency, Pauses and the Adrenergic Response

Short rallies, accelerations, pauses, serving and competitive pressure generate a variable glycaemic response. Adrenergic activation may attenuate the fall or promote rises, especially at decisive moments. It is therefore not prudent to automatically apply strategies developed for continuous running of the same duration.

21.3 Changeovers as Decision-Making Windows

Regular pauses make it possible to distribute the intervention. Small intakes of fluids and carbohydrates can be titrated more easily than a large preventive load. The advantage is not only nutritional: the pause makes it possible to compare the CGM trend, sensations and the course of the match before deciding.

21.4 When the Match Becomes Endurance

If the duration exceeds two hours, glycogen availability and exogenous intake become progressively more important. The strategy shifts from predominantly glycaemic management to genuinely performance-oriented

supplementation. In DMT1, the risk is realizing too late that the carbohydrates taken up to that point were almost all CHO-G and that the performance plan remained insufficient.

21.5 Tournaments and Multiple Matches on the Same Day

Management between matches is often more difficult than the individual match. Recovery is required without creating excessive IOB for the next match, while maintaining hydration and tolerating meals or snacks within time windows that are not always predictable. The plan must therefore include several scenarios, not a single strategy.

Chapter 22 — Strength, Gym Training and HIIT: When Exercise Does Not Necessarily Lower Blood Glucose



Figure 22.1. Intense and intermittent work: a high power demand does not automatically result in a fall in blood glucose.

22.1 Strength: Brief but Intense Energy Demand

Short high-intensity sets require a substantial contribution from phosphocreatine and glycolysis. The adrenergic response and the pauses between sets make glycaemic dynamics different from those of continuous aerobic exercise. In many individuals, blood glucose remains stable or rises during the session. This pattern does not mean that insulin is irrelevant. In postprandial conditions with a bolus still active, strength exercise may also be accompanied by a fall in blood glucose. Eating behaviour and the amount of circulating insulin may explain the glucose pattern much better than the simple label of intensity.

22.2 HIIT: Intensity Does Not Automatically Mean Hyperglycaemia

HIIT (High Intensity Interval Training) alternates intense intervals and recovery. On average, it may produce a smaller acute fall in blood glucose than continuous moderate exercise, but the response depends on the protocol, interval and total duration, work/recovery ratio, training status, previous food intake (pre-exercise and training CHO) and IOB, the hidden cost. Saying that HIIT “protects” against hypoglycaemia is therefore excessive.

22.3 The Order of the Components

When strength and aerobic exercise are performed in the same session, the order may modify the glycaemic response. Some studies clearly show that performing strength exercise before aerobic exercise attenuates the expected fall in blood glucose during the subsequent component. In paediatric settings, moreover, a 10-second sprint performed at the end of an aerobic session has also been shown to interrupt the initial progressive fall in blood glucose, with stabilisation and sometimes a slight increase in values. This finding is interesting but should not be turned into a universal prescription: the sequence should be tested and selected first and foremost according to training goals and individual responses.

22.4 Transient Post-Exercise Hyperglycaemia

After very intense effort, a transient rise may occur as a result of the massive release of catecholamines and the consequent increase in hepatic glucose production. The temptation to correct hyperglycaemia rapidly in this

case should be restrained in view of the increase in insulin sensitivity expected over the following hours. It is therefore inappropriate to rely on the single value at that moment: trend arrows, IOB, magnitude of the rise, presence of ketones and the individual pattern help address the choice more carefully and certainly less emotionally.

SYMPTOMS, CAUSES AND ACTIONS: QUICK GUIDE DURING EXERCISE

Before acting, distinguish a true metabolic need from a single number on the display.

SYMPTOM / CONDITION	POSSIBLE CAUSES	RECOMMENDED ACTIONS
Decreasing glucose level (↓ downward arrow)	• High IOB (insulin on board) • Insufficient carbohydrates • High intensity	• Take carbohydrates (often CHO-G) • Reduce or suspend insulin if planned • Reevaluate intensity and duration
Increasing glucose level (↑ upward arrow)	• Insufficient IOB • Recent carbohydrate intake • Stress / catecholamines	• Assess trend and context • Avoid impulsive corrections • Consider IOB and recovery
Stable glucose level (→ horizontal arrow)	• Balance between insulin, CHO and activity • Appropriate intensity	• Maintain the plan • Monitor trend and symptoms • Prepare for recovery
Gastrointestinal discomfort	• Inappropriate CHO choice • High osmolality • Insufficient hydration	• Reduce intensity if necessary • Small sips of fluids • Prefer more tolerated carbohydrates

Listen to the symptoms, consider the context, then act using clear criteria.

Figure 22.2. Quick guide to choices to be made during physical exercise.

22.5 Different Goals: Health, Hypertrophy, Maximum Strength, Performance

Nutritional and therapeutic prescription must take the goal into account. A strength session for metabolic health, a hypertrophy programme and a weightlifting workout do not have identical density and volume and therefore do not have the same carbohydrate requirements. DMT1 management should accompany the programme, not determine it.

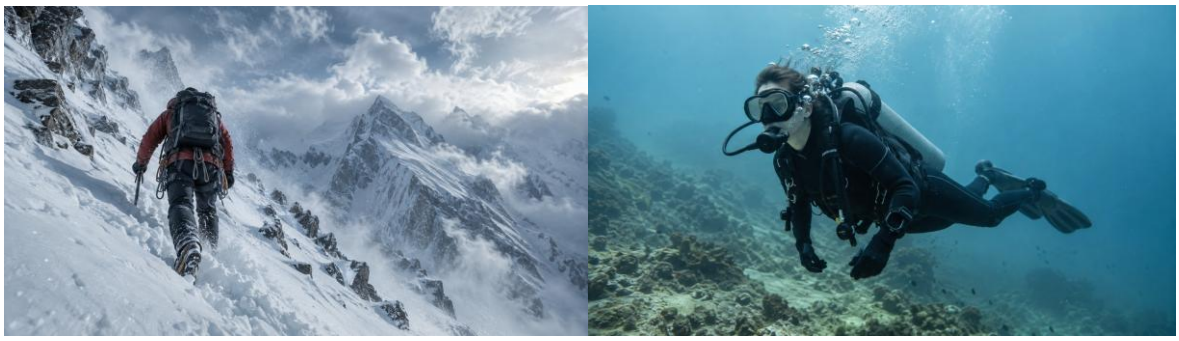
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Mountaineering, Scuba Diving and Activities in Special Environments



Some disciplines are practised by a numerically limited proportion of people with DMT1, but they show particularly well how the environment can change the meaning of ordinary management rules.

In mountaineering, altitude, cold, unpredictable duration, isolation, CHO availability and difficulty receiving assistance require planning that extends beyond blood glucose alone. The available literature is limited and the strategy must be individualised, especially at high altitude.

Scuba diving requires an even greater degree of caution because, in such a particular environment, hypoglycaemia may have immediate safety consequences. Eligibility, training, the presence of an appropriately trained dive buddy, shared procedures and specific protocols cannot be replaced by a few generic rules. In Italy, the association Diabete Sommerso ODV has developed a series of activities dedicated to people with DMT1 interested in scuba diving, with courses, events, training and a specific multiprofessional approach. This Atlas therefore only highlights the issue and refers practical implementation to dedicated expertise.

General Principle

The more the environment makes it difficult to stop the activity or receive assistance, the more safety planning becomes an integral part of performance.

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PART VI – DATA, TECHNOLOGY AND DECISIONS

Chapter 23 – How to Read a CGM Curve in Sport Without Attributing to It What It Does Not Measure

23.1 The Curve Represents a Result; It Is Not Physiology Itself

A CGM curve shows the trend of interstitial glucose. It does not directly measure glycogen consumption, hepatic production, catecholamines, intestinal absorption or the biological effect of insulin. Interpretation must therefore proceed only through physiological hypotheses and verification.

23.2 The Pre-Exercise Phase

Before starting, the context must be reconstructed: meal, bolus, recent corrections, AID mode, preventive CHO, competitive stress and activity performed in the preceding hours. A pre-competition rise may be nutritional, adrenergic, iatrogenic or combined. The same curve shape may therefore require opposite decisions.

23.3 During Exercise: Three Basic Patterns

A progressive fall during aerobic exercise suggests that peripheral uptake exceeds hepatic production. IOB helps explain why. A relatively stable curve does not demonstrate low energy consumption: it may indicate a balance between opposing flows. A rise during sprints or competition may reflect hepatic production sustained by catecholamines.

23.4 Trend Arrows Are Not an Infallible Prediction

The arrow summarizes the recent rate of change and may be useful, but during exercise rapid changes in perfusion, interstitial lag and sudden metabolic variations may alter the trajectory. For this reason, the arrow must be read together with the value, IOB, the phase of exercise and sensations.

23.5 Immediately Afterwards

The immediate post-exercise period must be interpreted cautiously. High blood glucose after a final sprint is not equivalent to hyperglycaemia on a sedentary day; normal blood glucose close to the lower limit after prolonged activity may require attention even if it has not yet crossed the formal threshold for hypoglycaemia.

23.6 The Following Hours

Increased insulin sensitivity and glycogen resynthesis may promote delayed hypoglycaemia. The reading of a session should therefore extend beyond the finish line. When possible, it is useful to observe the subsequent period and distinguish the immediate result from the delayed metabolic cost.

23.7 A Method in Seven Questions

1. What was the athlete actually doing at that stage?
2. With how much IOB did the athlete start, and how did it change?
3. What had the athlete eaten, and when?
4. What trend was present before the activity?
5. What physiological mechanism may explain the curve?
6. Did the sensor data agree with symptoms and context?
7. What happened in the following hours?

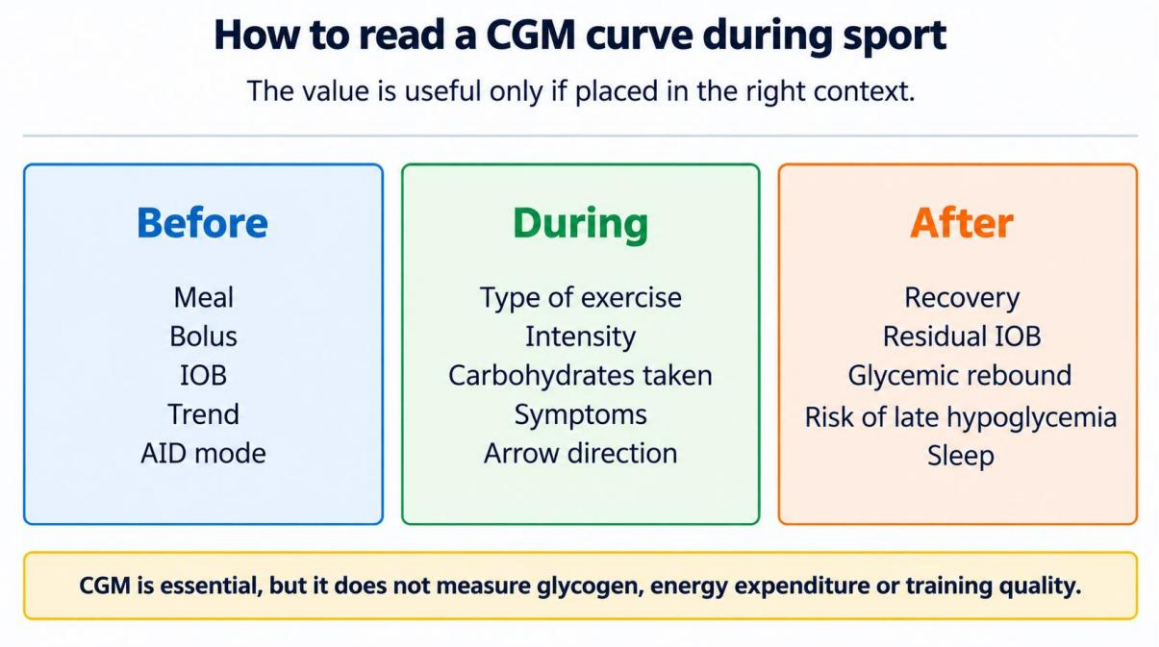


Figure 23.1. Contextual method for reading a CGM curve in sport without attributing to it information that it does not measure.

Interpretive Caution

CGM is indispensable for safety and therapeutic decision-making, but it must not become a measure of muscle fuel, training status or performance quality.

Chapter 24 – Each Insulin Pump Has Its Own Specific Features

24.1 How to Choose an Insulin Pump for a Person Who Practices Sport

24.1.1 There Is No Single Best System in Absolute Terms

The choice should start from the sport practised, the athlete's behaviour and the way in which the system manages exercise. Hardware, the presence of tubing, the possibility of temporary removal, the algorithm, exercise mode, sensor, interface and personal preferences carry different weight for different people.

24.1.2 Translating Technical Features into Personal Questions

- Does the sport involve physical contact, water or a high risk of detachment?
- Is the activity planned or often unexpected?
- Does the athlete tolerate tubing or prefer a patch system?
- How willing is the athlete to intervene manually?
- Is the athlete more afraid of hypoglycaemia or hyperglycaemia?
- Does the athlete typically experience rises during intense activities?
- How accurate is the athlete in counting CHO?
- Does the athlete easily understand the behaviour of the algorithm?
- Is the athlete willing to carry a controller or smartphone during sport?
- How much value does the athlete place on simplicity compared with the possibility of personalization?

24.1.3 Performance and Usability

A technically sophisticated system may become a mediocre choice if the user does not understand its logic or does not tolerate the hardware. Conversely, a system with features that appear less suitable "on paper" may work very well when it matches the athlete's preferences and behaviour.

24.1.4 The Choice Must Be Reassessable

Technology and the person change. An athlete who starts cycling may have different needs from when they only trained in the gym; a young person who joins a competitive team may discover new constraints. The choice should not be experienced as definitive, but as part of a pathway.

Principle

Technology choice is a balance between safety, performance, usability and preferences. A general ranking of systems is less useful than a map of operational differences.

24.2 – Training the Person with DMT1 and Decision-Making Flowcharts

24.2.1 The Educational Goal Is to Teach the Use of Technology Without Creating Dependence

Training does not consist of showing where to press buttons. The goal is to enable the person to understand what the system is doing, what it cannot know and why some decisions must be made before activity.

24.2.2 First Level: Safety

- Insertion and replacement of components.

• Hypoglycaemia and emergency carbohydrates.
• Hyperglycaemia, ketones and suspected interruption of insulin delivery.
• Loss of sensor signal or connectivity.
• When to confirm the reading with capillary blood glucose.
• Emergency plan in the event of failure or detachment during sport.

24.2.3 Second Level: Meals, Bolus and IOB

The person must understand the relationship between bolus, time, IOB and activity. Without this step, exercise mode can easily become a late remedy for a problem created in the preceding hours. The ability to read IOB does not mean assigning it an absolute value, but integrating it with timing and personal response.

24.2.4 Third Level: Planned and Unexpected Exercise

Training should include examples of planned activity, unexpected exercise, high intensity and long duration. It is useful to teach the person to change one variable at a time and record what happens rather than changing bolus, target, CHO and timing simultaneously.

24.2.5 From Rules to Autonomy

A good educational pathway progressively reduces the need to ask for instructions for every session. The professional remains necessary for therapeutic decisions, but the athlete must develop the ability to recognize patterns, formulate hypotheses and ask increasingly precise questions.

Sign of Good Training

A well-trained person not only knows what to do in a familiar situation, but can also recognize which variables have changed when the situation does not perfectly match the protocol that was taught.

24.3 Clinical Flowcharts: Turning Principles into Operational Questions

24.3.1 Why a Flowchart Should Prompt Questions, Not Impose Doses

A useful flowchart does not replace clinical judgement and cannot provide universal answers. It should help the person following it to arrange information in the correct sequence. The first alternative question should not be “how many carbohydrates?” but “what activity is planned and with how much IOB?”.

24.3.2 Planned Exercise

1. Define type, duration and intensity.
2. Estimate CHO-P and glycogen availability.
3. Assess the meal, bolus and expected IOB at the start.
4. Set the insulin strategy or exercise mode in good time.
5. Use CGM and trend to define any CHO-G.
6. Plan recovery and post-exercise observation.

24.3.3 Unexpected Exercise

When the time margin disappears, carbohydrates often take on a greater role. The first assessment concerns blood glucose, trend and IOB. If IOB is high and the activity tends to lower glucose, treatment with CHO may become the most important immediate measure. The lesson for the next time, however, will not necessarily be

“eat more” but, perhaps, when the activity becomes in some way predictable, reduce the insulin dose to be delivered beforehand.

24.3.4 Low or Rapidly Falling Blood Glucose

Safety comes before performance. Treat according to the individual plan and reassess. In AID systems, future insulin may already have been reduced, but active insulin remains. Overtreatment may produce a glucose rise and new insulin delivery; undercorrection may fail to stop the fall.

24.3.5 High Blood Glucose

It is necessary to distinguish a glucose rise due to catecholamines, a meal, insulin underdosing, prolonged suspension or a delivery problem. In the event of marked or unexpected hyperglycaemia, ketone assessment follows the clinical plan. An aggressive correction immediately before aerobic exercise may create new IOB and precipitate a subsequent event.

24.3.6 Evening Activity

Duration, intensity, amount of glycogen used, residual therapy and the post-exercise meal influence overnight risk. The goal is not to maintain indiscriminately higher targets throughout the night, but to build a strategy consistent with the individual pattern.

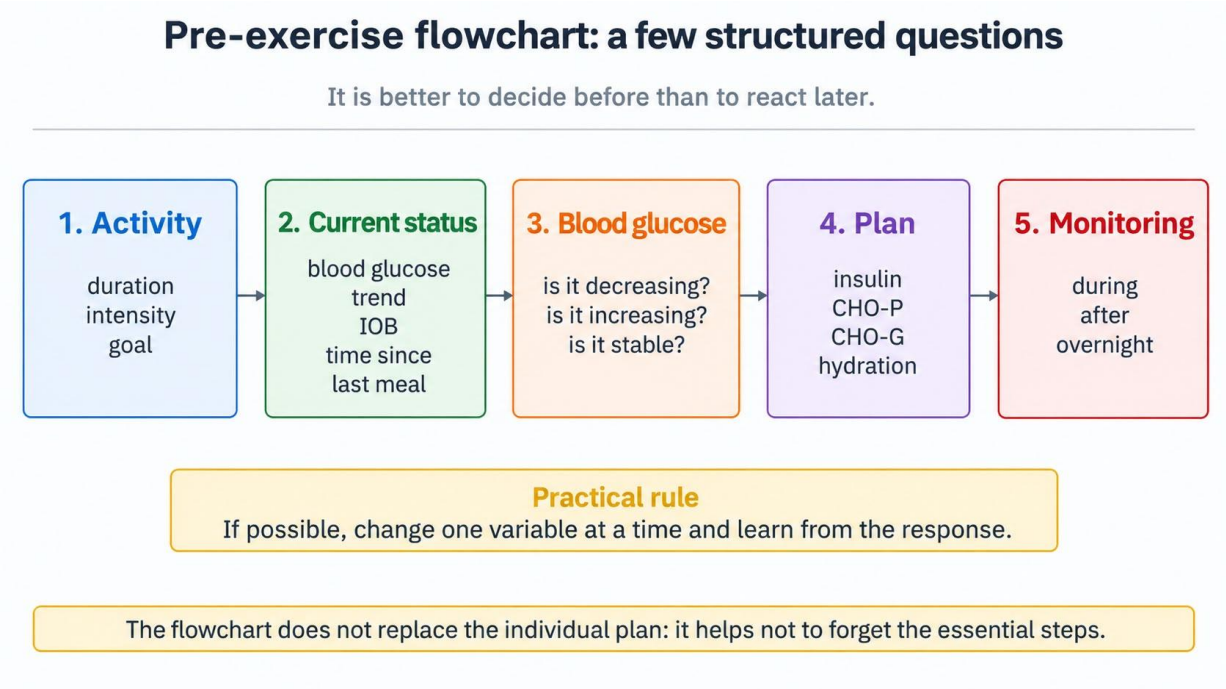


Figure 24.1. Conceptual pre-exercise flowchart: it serves to order the questions, not to replace clinical judgement.

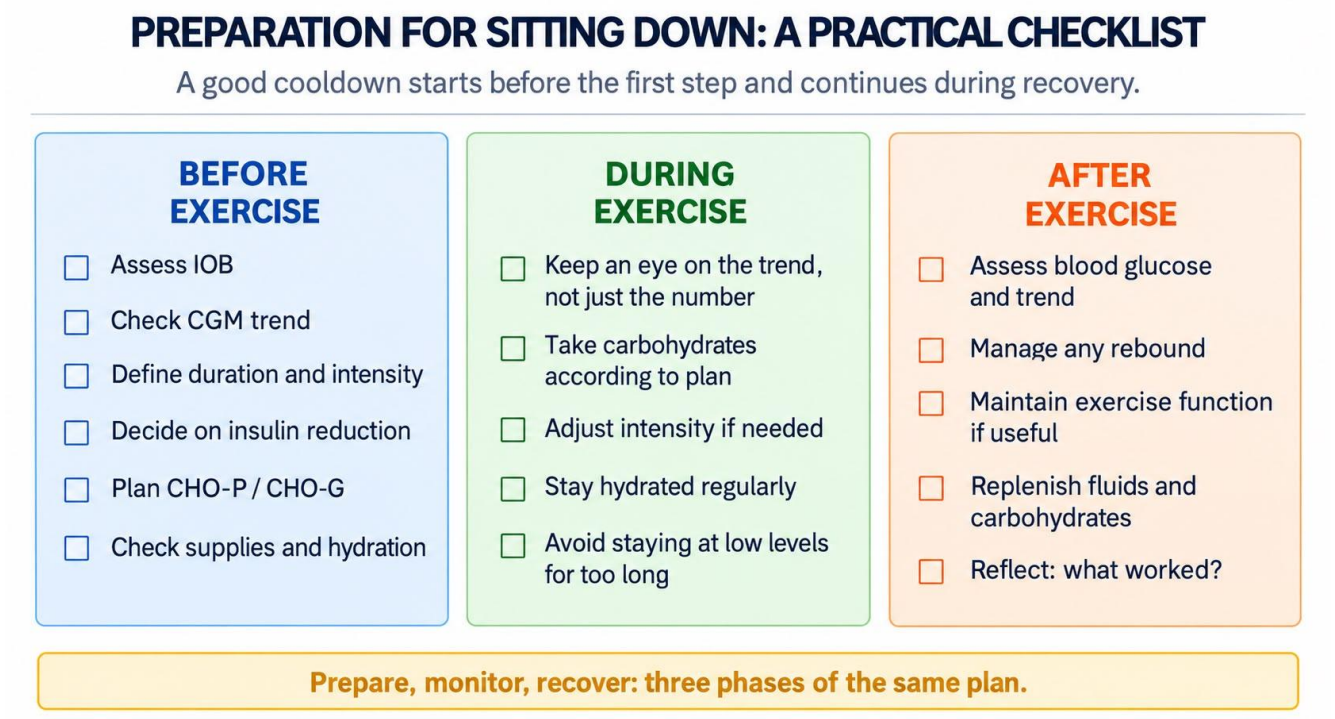


Figure 24.2. Useful checklist for the "start".

Chapter 25 – Why Two Trained Athletes Do Not Respond in the Same Way

25.1 Variability Does Not Mean Randomness

The glycaemic response often appears unpredictable because many variables change together. Training, muscle mass, glycogen availability, IOB, time of day, meal, sleep, stress, temperature, degree of humidity, menstrual cycle and recent activity can modify the same session. Variability should therefore not be interpreted as a failure of physiology, but as the sum of conditions that are not always controlled.

25.2 Training and Adaptation

The trained athlete performs the same absolute work at a lower relative intensity and uses substrates more efficiently than a beginner. Improved fitness can make a strategy that worked months earlier obsolete. Therapy must therefore follow the evolution of the athlete, not only that of diabetes.

25.3 Stress and Competition

In competition, a session that is mechanically identical may produce a different response because of greater adrenergic activation. A strategy validated in training is an excellent starting point but does not guarantee an identical response in the competitive context.

25.4 Time of Day and Fed State

The chronobiology of exercise in DMT1 is an emerging field. Differences between morning and afternoon cannot be separated from fasting, prandial bolus and substrate availability. Recent data suggest that fed state and insulin exposure explain an important part of the differences attributed to time of day.

25.5 The Value of a Reasoned Diary

Recording a few relevant variables after repeatable sessions makes it possible to transform variability into patterns. A useful diary may contain: type of activity, duration, intensity, previous meal and bolus, IOB at the start, AID mode, CHO-P, CHO-G and post-exercise trend. The aim is not to accumulate data, but to identify those that truly modify the decision.

PART VII – THE PERSON AND INDIVIDUAL VARIABILITY

Chapter 26 – Training the Person: Motivation, Autonomy and Coaching in Sport with Type 1 Diabetes

As just observed in the previous chapters, sport with DMT1 requires decisions that other athletes are not required to make: checking the glucose trend before starting, deciding whether to take carbohydrates, assessing active insulin, managing an alarm during a session, and sometimes accepting a change in the programme. If these demands are considered only as technical problems, an essential part of the sporting experience is lost.

The person does not practise sport to obtain a perfect glucose curve. They may seek health, performance, pleasure, belonging, identity, competition, freedom, or the feeling of being able to do something that the diagnosis seemed to have called into question. Understanding this meaning is the starting point for truly useful coaching.

Guiding Question
How can we help the athlete with DMT1 become more competent and autonomous without turning diabetes into a permanent judge of performance?

26.1 Meaning Comes Before the Goal

“I want to run a marathon” describes a goal, but does not explain why that goal is important. For some it represents a competitive challenge; for others, a return to normality after diagnosis; for others still, a project shared with friends or family. The same goal may therefore have very different psychological meanings.

The effective coach does not impose motivation from the outside. The coach helps the person make their own reason explicit, because goals supported by personal meaning tend to withstand difficulties better than those pursued only for approval, fear or guilt.

26.2 Intrinsic Motivation, Extrinsic Motivation and Quality of Motivation

Motivation is not simply “high” or “low”. A person may train because they love running, because they want to improve a time, because they fear complications, because their doctor recommended it, or because they do not want to disappoint the group. These motivations may coexist.

In sports coaching it is useful to foster a climate that supports autonomy, competence and belonging. The literature on athlete development emphasizes the value of mastery-oriented and autonomy-supportive environments, associated with greater intrinsic motivation and less stress, especially in young people.

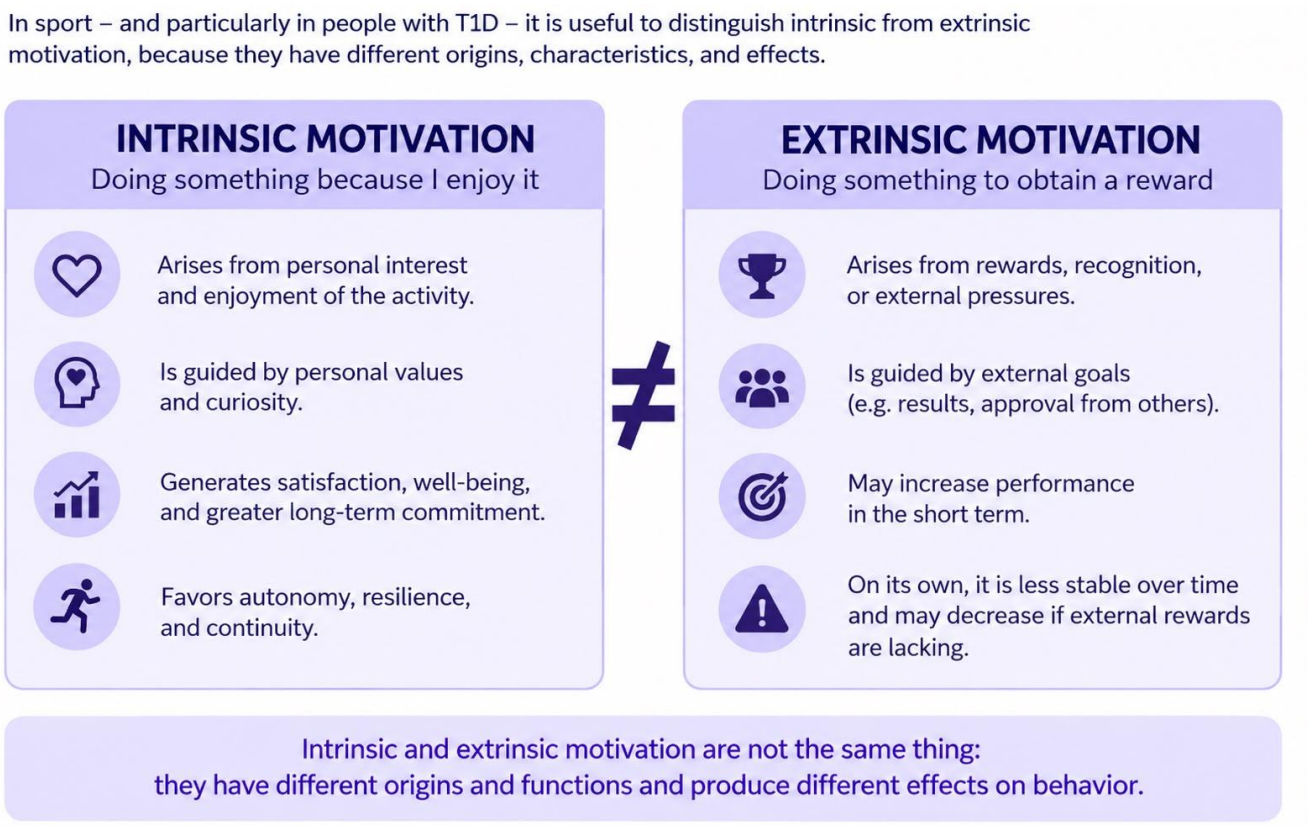


Figure 26.1 – Motivation: Fundamental Differences Between Intrinsic and Extrinsic Motivation

26.3 Self-Efficacy: "I Know I Can Manage It"

Self-efficacy is not the same as optimism; it is the conviction, built through concrete experiences, of possessing sufficient tools to face a situation. In sport with DMT1, it concerns both performance and the ability to manage diabetes while practising sport.

An athlete who has repeatedly experienced hypoglycaemia while running may know the recommendations perfectly and still not trust their own body. Self-efficacy grows when the person has progressive experiences of success, understands why a strategy worked and knows how to react when it does not.

26.4 Goal Setting: Outcome, Performance and Process Goals

An outcome goal also depends on others: winning a competition, making the team, qualifying. A performance goal concerns one's own standard: completing a 10 km in a given time. A process goal concerns what can be done today: completing a session, preparing equipment, applying an agreed strategy.

Result	**Performance**	**Outcome**
Win the competition	Run in 45 minutes	Carry out the agreed pre-competition strategy
Also depends on others	Depends mainly on oneself	Directly controllable
Useful but not very controllable	Measures progress	Builds daily competence

In DMT1, process goals are particularly valuable because they reduce the temptation to evaluate the day solely through a number. "I managed a difficult situation well" can represent a success even if the glucose curve was not perfect.

26.5 Fear of Hypoglycaemia: Rational, Protective, Sometimes Limiting

Fear of hypoglycaemia should not be trivialized. Hypoglycaemia is a real risk and can compromise safety and performance. However, when fear leads to avoiding activity, deliberately maintaining high glucose levels or systematically taking excessive amounts of carbohydrates, the protective function can become a barrier.

Fear of hypoglycaemia continues to emerge as one of the main barriers to physical activity in DMT1. Recent data from the BETTER registry indicate that the problem persists even in the era of CGM and AID: technology can increase safety and information, but does not automatically eliminate fear or the feeling of loss of control.

Coaching does not replace psychological intervention when fear is clinically significant, but it can help create gradual experiences, realistic goals, non-judgmental language and collaboration with the diabetes care team.

26.6 Error as Information, Not Blame

A strategy can fail: glucose may fall more than expected, a competition may begin with high values, a gel may be taken too early. In a complex system, error does not demonstrate incompetence; it indicates that the model used did not correctly anticipate all the variables.

The team's language is decisive. Questions such as "what did we learn?" encourage analysis and autonomy; moralizing expressions such as "you were good/bad with your diabetes" turn data into personal judgment. This distinction is particularly important in perfectionist athletes.

A question that changes the climate

Not: "What did you do wrong?" Better: "What variable might explain what happened, and what would we try differently next time?"

26.7 Perfectionism and the Search for the Perfect Curve

Technology makes almost every glucose fluctuation visible. This availability can be useful, but it can also fuel the need for absolute control. In sport, where the athlete is already accustomed to measuring times, watts, kilometres and loads, CGM may become another indicator on which to build self-evaluation. An imperfect curve is not equivalent to failed management. Coaching should help distinguish excellence from perfectionism: the former seeks an increasingly better process; the latter can make normal biological variability intolerable.

26.8 Diabetes, Distress and Cognitive Load

DMT1 requires a continuous flow of micro-decisions. Sport adds others: timing, meals, insulin, sensor, emergency supplies and programme changes. Even a highly motivated athlete may experience decision fatigue. The team's task is not only to add instructions, but also to simplify. Reliable routines, essential checklists and previously tested strategies reduce the number of decisions to be made at the moment of greatest stress. Autonomy does not mean doing everything alone: it means knowing what is important and when to ask for help.

26.9 Technology: Safety, Freedom and Surveillance

CGM, AID, smartwatches and sharing platforms can increase safety and opportunities for participation. However, they can also produce a feeling of continuous surveillance, especially when many people observe the same data.

The principle should be simple: sharing must serve the person, not replace their autonomy. In minors, adult responsibility is inevitably greater; in adults, the athlete should be able to define who sees the data, when they intervene and at what thresholds, except for specific agreed clinical situations.



Figure 26.2. Success as an athlete requires bringing many elements to bear on performance, not only technical ones but, to a large extent, essential human factors.

Principle of digital autonomy

Increasing the amount of available data does not automatically lead to greater psychological safety. Data sharing should have a clear purpose, agreed rules for intervention, and agreed boundaries.

26.10 Identity: Athlete with Diabetes or Person with Diabetes Who Does Sport?

Words influence the way a person interprets themselves. Some prefer to define themselves as athletes with diabetes; others do not attach importance to the distinction. The point is not to impose identity terminology, but to prevent the diagnosis from absorbing every other dimension.

Sport can become a space in which the person experiences competence, belonging and freedom. In some cases it can also help rebuild a sense of biographical continuity after diagnosis. This value cannot be measured with TIR, but it can be decisive for quality of life.

26.11 Competition: When Stress Changes Both Mind and Glucose

Competition is not training with a race bib. Expectations, spectators, comparison, fear of failure and adrenergic activation modify perception of effort and behaviour and, in DMT1, can also modify the glycaemic response, making a strategy that seemed perfect in training less transferable.

Coaching can work on pre-competition routines, attention to controllable elements, management of activation and acceptance of a degree of unpredictability. The diabetes strategy must be sufficiently tested so that it does not become an additional cognitive task during competition.

26.12 Communication: From Advice to Shared Decision-Making

Effective communication does not mean avoiding clear indications, but explaining the logic of the indications and checking whether they are compatible with the athlete's real life. A theoretically perfect strategy that is too complex to apply during a match is an incomplete strategy.

The coach can help translate abstract goals into concrete behaviours, but must not enter into insulin prescription. The diabetologist can define safety limits and metabolic strategies, but should not use diabetes to impose sporting goals that do not belong to the person.

26.13 Autonomy: The True Educational Goal

At first, the athlete may need very precise instructions. Over time, however, a good pathway should reduce dependence on the professional. The person must learn to recognize recurring situations, understand the main variables, choose among agreed options and know when a situation lies outside their margin of autonomy.

Success is not measured by how often the athlete does what the team has told them, but by whether they can make reasoned decisions consistent with the principles learned and discuss them afterwards without fear of being judged.

26.14 The Team Around the Athlete

The diabetes care team, kinesiologist, trainer, coach and family can be resources or, if they do not communicate, sources of contradictory messages. The athlete should not be forced to mediate alone between incompatible prescriptions.

It is useful to define responsibilities and a common language. The physician is responsible for clinical safety and therapy; the training professional for load and preparation; the coach for the process of awareness, goals and behaviour within the limits of their training. Overlaps must become dialogue, not intrusion into another professional's field.

26.15 One Athlete, Three Perspectives

The same episode can be read in different and complementary ways. A glucose drop during a quality session may be, for the diabetes care team, a problem of insulin exposure; for the kinesiologist, an interruption that prevents completion of the stimulus; for the coach, an event that may reduce confidence and willingness to try again. No interpretation, in isolation, is sufficient.

26.16 When Coaching Is Not Enough

Persistent anxiety, depression, eating disorders, disabling fear of hypoglycaemia, severe burnout or potentially dangerous management behaviours require appropriate professional assessment. Recognizing the limits of one's competence is part of the quality of coaching.

The coach can observe changes, listen, facilitate access to help and maintain a supportive sporting relationship, while they are absolutely not required to diagnose or treat psychological conditions for which they do not possess clinical expertise.

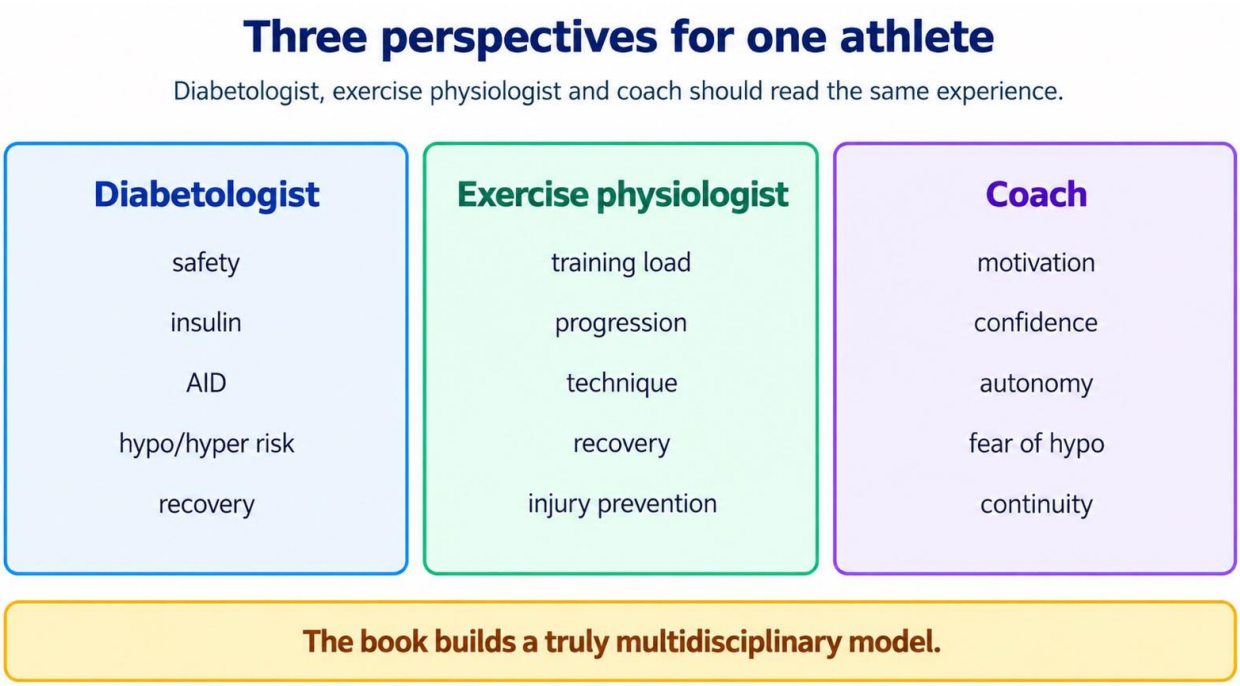


Figure 26.3. One athlete, three perspectives: clinical safety, training quality, and personal sustainability must work together without blurring professional roles.

Perspective	Main question	Risk if isolated	Contribution
Diabetologist	Is it safe?	Reducing everything to glucose	Metabolic safety and therapy
Kinesiologist	Is it training-effective?	Ignoring clinical constraints	Stimulus, adaptation and performance
Coach	Is it sustainable and meaningful?	Psychologizing technical problems	Motivation, autonomy and continuity
Athlete	Does it work for me?	Being left alone in decisions	Experience, preferences and real feedback

Table 26.1. The perspectives of athlete, diabetologist, kinesiologist and coach.



Figure 26.4. The virtuous cycle that leads from review to growing awareness.



Fig. 26.5. Coaching and the team in an athlete-centered ecosystem.



Figure 26.5. Coaching and the team in an athlete-centered ecosystem.

Figure 26.6 – Leadership Styles



Figure 26.7 – Activities That Ensure Optimal Coaching at Different Ages of Life

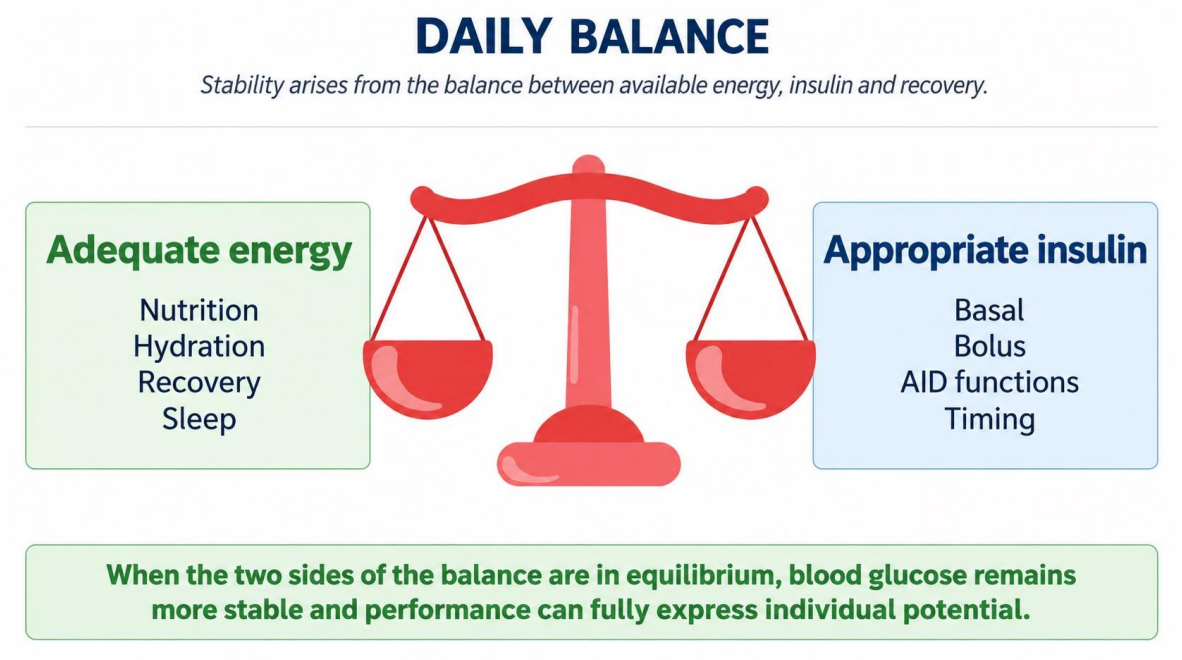


Figure 26.8 – What Must We Absolutely Maintain as the Ultimate Goal? Balance

Take-home Messages

- The most sustainable motivation arises from the personal meaning attributed to sport, not from fear of complications.
- Fear of hypoglycaemia is a real barrier and may persist even with advanced technologies.
- Glucose data must become information for decision-making, not a grade assigned to the person.
- Autonomy is built through progressive experiences of competence, not by leaving the athlete alone.
- Coaching and clinical psychology are not interchangeable; recognizing professional boundaries protects the person.
- The best strategy integrates safety, training quality and human sustainability.

The Synthesis
A truly good strategy should simultaneously be safe, training-effective and sustainable. If one of the three dimensions is missing, the result may work in the short term but is unlikely to become a stable sporting practice.

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PART VIII — PERSONALIZATION AND INTEGRATED MODELS

Chapter 27 – From Protocol to Personalization: Load, Context and Learning

27.1 Guidelines Are Coordinates, Not Itineraries

Percentages of bolus reduction, starting targets and amounts of CHO are indispensable for getting started, but they cannot represent the end point. The protocol describes what works on average in a defined condition; personalization describes what works in that person, for that activity and in that context.

27.2 One Variable at a Time

When a strategy does not work, changing bolus, basal, target, CHO and timing at the same time makes it impossible to understand which intervention produced the result. In trial sessions, it is preferable to correct one main variable at a time, when safety permits.

27.3 External Load, Internal Load and Metabolic Context

The concepts of external load, internal load and metabolic context were developed in Chapter 16. Here they are recalled only for their value in personalization: the same session may require different strategies when training status, recovery, IOB, blood glucose, trend and carbohydrate availability change.

The point is not to construct a new numerical index, but to recognize which variables truly modified the response and use them for the next session.

27.4 Building a Personal Library of Situations

The athlete may come to define different strategies for a morning fasted run, a postprandial run, an evening gym session, a match and a long bike ride. These are not rigid protocols but personal starting points built through repetition. A library of situations reduces the need to reinvent the strategy each time.

276.5 When Experience Differs from the Protocol

If an individual choice differs from the standard recommendation but repeatedly produces safety, performance and absence of undesirable late effects, it deserves to be understood before being corrected. The athlete's experience is clinical data: it does not replace evidence, but complements it.

27.6 Three Professionals, Three Readings of the Same Data

The diabetologist interprets the therapeutic context; the kinesiologist describes load and adaptation; the coach helps to understand the sustainability, motivation and meaning of the strategy. None of the three perspectives is sufficient on its own. This integration is developed in a complementary way in Chapters 16 and 25, devoted respectively to athletic preparation and to the motivational and coaching dimension.

General rule

Personalization does not mean improvisation. It means starting from the evidence, observing the response, integrating the actual training load, and progressively building a repeatable strategy.

Essential Reference for Further Reading

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Chapter 28 Artificial Intelligence, Complex Systems and the Human Dimension in Type 1 Diabetes

We have now almost reached the end of this journey and, to complete and emphasize some of the key concepts expressed so far, it seems important to propose a critical technological analysis of the operational limits, system risk and humanistic perspectives of clinical automation brought about by the use of Artificial Intelligence in the world of diabetes.

28.1 The Algorithm-Centric Revolution and the Redefinition of Care

The introduction of Artificial Intelligence (AI) and predictive algorithms into the management of Type 1 Diabetes (DMT1) represents an unprecedented paradigm shift in the history of modern diabetology. Traditionally, DMT1 management has imposed an incessant decision-making burden on the person, requiring dozens of daily mathematical and pathophysiological calculations and assessments to estimate the insulin dose in response to food, movement, stress and hormonal fluctuations. The advent of closed-loop systems (Automated Insulin Delivery - AID), advanced continuous glucose monitors (CGM) and digital assistants promises to transfer this computational burden from the individual's shoulders to sophisticated mathematical models. However, a purely technocratic view risks obscuring the true nature of the condition: type 1 diabetes is not simply a problem of engineering regulation or numerical optimization, but a complex biological and existential condition. The effectiveness of AI cannot be measured exclusively through quantitative parameters (such as Time in Range or glycaemic variability), but must be analysed in the context of the profound interaction between the algorithm, the non-linear physiology of the human body and the real life of the person using it.

28.2 Comparative Analysis: Strengths and Limitations of AI in Diabetes Technologies

To understand its real impact, it is necessary to critically examine the intrinsic strengths and weaknesses of AI in the different technological applications currently available.

28.2.1Closed-Loop Systems (AID) and Insulin Delivery Algorithms

- **Strengths:** Control algorithms (whether based on Proportional-Integral-Derivative (PID) logic, Model Predictive Control (MPC) or neural networks) show extraordinary effectiveness in basal glycaemic stabilization, especially during overnight rest. The ability to continuously remodel insulin delivery in microdoses makes it possible to prevent severe hypoglycaemia and reduce hyperglycaemia on waking, offering constant protection independent of the user's attention.
- **Weaknesses and Limitations:** All current AID systems, however, face an insurmountable physiological limitation: the delayed pharmacokinetics of subcutaneously administered insulin. While the algorithm calculates requirements in a few milliseconds, insulin needs 15–20 minutes to enter the circulation and up to 60–90 minutes to reach peak action. This time gap makes algorithms intrinsically reactive rather than fully proactive when faced with rapid events such as unannounced meals or sudden physical exertion.

28.2.2 Glucose Sensors (CGM) and Predictive Trend Analysis

- **Strengths:** The integration of so-called 'stochastic' algorithms (i.e. based on probability calculations) into CGM makes it possible to extrapolate the glycaemic trajectory 15–30 minutes ahead, alerting the user before hypoglycaemia or hyperglycaemia actually occurs. This enables timely and measured corrective interventions.

- **Weaknesses and Limitations:** Sensors measure glucose in interstitial fluid, which has a physiological delay ('lag time') of 5–15 minutes compared with blood concentration. During phases of rapid change (for example during intense aerobic exercise), the algorithmic estimate may be chronologically offset, thus leading to false alarms or inappropriate corrections based on data that are not updated in real time.

28.2.3 Nutrition, Carbohydrate Counting and Digital Assistants

• **Strengths:** The use of computer-vision-based Apps with AI image recognition simplifies estimation of the plate, reducing macro-nutritional estimation error in less experienced users.

• **Weaknesses and Limitations:** Nutritional AI tends to consider carbohydrates as isolated arithmetic values, ignoring the complexity of the food matrix (the presence of fats and proteins that delay gastric emptying), the actual glycaemic index, the training status of muscle tissue and variability in intestinal absorption (SGLT1/GLUT5 transporters), thus still requiring continuous human interpretive intervention.

28.2.4 Physical Activity Planning and Sport Management

• **Strengths:** The presence of functions dedicated to exercise (e.g. exercise mode, temporary targets, Ease-off or Boost profiles) provides a safety margin by reducing the aggressiveness of the algorithm before exertion.

• **Weaknesses and Limitations:** Physical exercise produces very complex metabolic responses, extensively described in this text, while AI is currently unable to predict the amount of residual muscle and liver glycogen or delayed nocturnal hypoglycaemia potentially induced by replenishment of energy stores after training.

Technology Summary
The algorithm excels in optimizing equilibrium states and managing slow variations. It fails, however, when faced with rapid physiological discontinuities that have not been mathematically modelled, where the person's intuition and experience remain irreplaceable.

28.3 The Relationship Between the Person and Artificial Intelligence

The introduction of AI radically repositions the human being within the therapeutic process, transforming both the individual's experience of the condition and the healthcare relationship with the diabetes care team.

28.3.1 Transformation of the Patient’s Role: From Executor to Supervisor

In the conventional model, the person with diabetes acts as a 'manual micro-manager' who must evaluate every single variable in order to make executive decisions. With AI, the role shifts toward that of a 'flight-system supervisor'. The person no longer has to calculate every single micro-dose, but must monitor the correct functioning of the algorithm, intervene in the event of anomalies and provide AI with contextual information that it cannot perceive autonomously (such as the imminent start of physical exertion or a change in emotional state).

28.3.2 Cognitive and Emotional Load: New Forms of Therapeutic Stress

While AI reduces decision fatigue by automating routine processes, on the other hand it introduces new forms of psychological stress:

1. Alarm and Hyper-Surveillance (Alarm Fatigue): The constant presence of alerts, predictive notifications and real-time tracking can generate a state of permanent alertness, fragmenting sleep and daily concentration.

2. The Feeling of Algorithm-Centric Judgment: The continuous quantification of life through rigid metrics may make the user feel perpetually examined by a digital entity that is insensitive to personal or social difficulties at that moment.

28.3.3 The Therapeutic Alliance and Shared Decision Making

In the relationship between the physician/diabetes care team and the person with diabetes, AI can act as an unwelcome third party or as a powerful catalyst, as when the consultation adopts a shared decision-making model by exploiting the graphical simplification of glucose diary analysis to avoid critical judgments that could negatively affect the relationship and to focus on a shared analysis of glycaemic profiles and personalize system settings according to the individual's real life priorities.

28.4 Limits and Risks in Users' Use of AI

Human interaction with complex automated systems is subject to behavioural distortions that may undermine the safety and effectiveness of therapy. Two pathological extremes are particularly evident:

28.4.1 Excessive Delegation and Therapeutic Passivity

The illusion that AI can 'treat' or 'autonomously manage' diabetes may lead the user to excessive passive delegation. This phenomenon entails the progressive loss of basic diabetes-management skills (e.g. personal estimation of the insulin dose for a bolus or emergency management). If the automated system suddenly stops because of a technical failure, depleted batteries or sensor detachment, the user who has lost the ability to interact with their own condition becomes vulnerable because they may no longer be able to deal with the situation promptly and safely.

28.4.2 Hyper-Monitoring and Anxious Micro-Management (Over-riding)

At the opposite extreme is the tendency to interfere continuously with the algorithm. Faced with transient hyperglycaemia, the anxious user administers manual correction boluses or overrides system decisions without waiting for the physiological action time of insulin already delivered by the algorithm. This practice (known as 'stacking' or insulin accumulation) destabilizes the mathematical predictive model, triggering severe hypoglycaemia in continuous succession, followed by phases of rebound hyperglycaemia.

28.4.3 The Competence Paradox

A fundamental paradox thus emerges: the safe and effective use of technologies equipped with artificial intelligence does not require less knowledge at all, but a higher level of physiological and technological competence. The user must understand the logic by which the algorithm works in order to know when to trust it and when, instead, it is essential to take manual control of the system.

28.5 Strategic Limits and Risks of AI Applied to Complex Systems

When Artificial Intelligence is applied to a complex system such as the human body, structural limitations emerge that are linked to the very nature of mathematical models.

28.5.1 The Non-Linear Complexity of Human Physiology

Glucose balance is governed by a multilevel network of interconnected variables that respond to complex, far from linear functions: counter-regulatory hormones (glucagon, adrenaline, cortisol, GH), variations in insulin sensitivity linked to the circadian cycle, emotional stress, ambient temperature, sleep and the coexistence of low-grade inflammatory states often not perceived by the person themselves. AI, which works by processing historical data or current signals, cannot measure the factors just described precisely because they cannot yet be transformed into digital parameters. Biological variables invisible to sensors therefore represent a causal 'background noise' that may lead the algorithm to make incorrect decisions.

28.5.2 The Pharmacokinetic Bottleneck

As already mentioned, the main limitation of current closed-loop systems lies not in AI's computational capacity but in the means used to deliver the hormone: the subcutaneous route. As long as insulin is administered into subcutaneous adipose tissue rather than intraperitoneally or, better still, through the portal route (as physiologically occurs when it is released by the pancreas), there will always be an irreducible time delay between the algorithmic command and the actual metabolic effect.

28.5.3 Algorithmic Blindness and Critical System Failures

A primary risk in complex systems concerns failures that are transparent to or not detected by the algorithm ('algorithmic blindness'):

• **Partial occlusions or detachment of the cannula needle:** If the pump catheter bends or subcutaneous infusion fails, the algorithm records hyperglycaemia and responds by continuously increasing the theoretical delivery of micro-boluses. In reality, insulin is not entering the circulation. Believing that it has delivered large doses, the system may stop further delivery or remain blocked, while the actual total absence of insulin delivery into the subcutaneous tissue, if not appropriately recognized and countered, can rapidly lead to metabolic decompensation up to Diabetic Ketoacidosis (DKA).

• **Sensor pressure artefacts (Compression Lows):** During sleep, mechanical pressure on the CGM sensor may cause a false collapse in glucose concentration. The AID algorithm, reading false hypoglycaemia, immediately suspends basal insulin delivery for hours, causing marked hyperglycaemia on waking with potential ketosis.

System Risk
Blindly relying on an automatic system intended to regulate a complex pathophysiology risks turning a small undetected mechanical malfunction into an acute medical emergency. Informed human supervision remains the primary safety safeguard.

28.6. The Humanistic Dimension and the Humanization of Artificial Intelligence

In view of technological limitations and behavioural risks, it becomes essential to promote a humanistic vision of Artificial Intelligence in the care of type 1 diabetes.

28.6.1 Valuing the Person's Lived Experience and Autonomy

The person with diabetes is not merely a 'vector of glycaemic data' or a biological system to be calibrated. They possess an irreplaceable wealth of bodily experience, intuition, awareness of their own internal signals (interoception) and emotional resilience. AI must be conceived as a prosthetic tool, aimed at expanding freedom and autonomy in the service of the person, rather than conditioning or limiting each individual's life choices.

28.6.2 From the Tyranny of Metrics to Holistic Well-Being

Current clinical culture sometimes tends to subject the individual to the 'tyranny of metrics': the obsessive pursuit of a perfect Time in Range or ideal glycated haemoglobin may come at the cost of enormous sacrifices in spontaneity, serenity and quality of life. Humanizing care requires redefining the very concept of therapeutic success: good metabolic control has value only if it translates into holistic well-being, reduced anxiety and full participation in social, working and sporting life.

28.6.3 Toward Empathic, Transparent and Person-Oriented AI

In a future that today seems difficult to imagine, but which events have taught us may become foreseeable in the short term, truly 'humanized' and ethical Artificial Intelligence in healthcare should respect the following guiding principles:

• **Transparency and Intelligibility:** Algorithms must not act as incomprehensible 'black boxes'. The user has the right to understand why the system made or suggested a given therapeutic decision.

• **Adaptability to Lifestyle:** AI must adapt to the person's life (their schedules, passions and imperfections), not the other way around. It must tolerate flexibility and avoid punitive or blaming language or alerts.

• **Respect for Autonomy and Dignity:** The algorithm must always guarantee the user the possibility of rapid deactivation or modification, reaffirming the primacy of human decision-making and dignity over any technological automation.

In conclusion, Artificial Intelligence does not represent the definitive solution or a replacement for human care, but a formidable ally. The future of diabetology does not lie in pure technocracy, but in a harmonious synthesis between the computational power of algorithms and the irreplaceable humanity, sensitivity and wisdom of people with diabetes and the healthcare professionals who accompany them.

Chapter 29 – Integrated Models for Reasoning: Insulin–CHO–Exercise Triangle and IOB–Exercise Map

After what was reported in the previous paragraph, we will try to summarize the message of the entire Atlas in a few points.

29.1 Why Conceptual Models Are Needed

The decisions to be made when facing an exercise session become complex when one tries to remember dozens of rules that are not integrated with one another.

A conceptual model does not replace guidelines but helps organize the variables. To be effective, however, it must possess two fundamental characteristics: simplicity, so that it can be remembered, and scientific rigor, so as to avoid falling into the trap of excessive confidence in predetermined mathematical calculation.

29.2 The Insulin–CHO–Exercise Triangle

The response to exercise can be read as an interaction among three vertices: insulin exposure, carbohydrate availability and the metabolic demand of exercise. None of the three explains the curve in isolation. The insulin side includes bolus, basal, IOB, sensitivity and AID behavior; the carbohydrate side includes glycogen, CHO-P, CHO-G, timing, absorption and tolerability; the exercise side includes intensity, duration, intermittency, muscle recruitment and hormonal response.

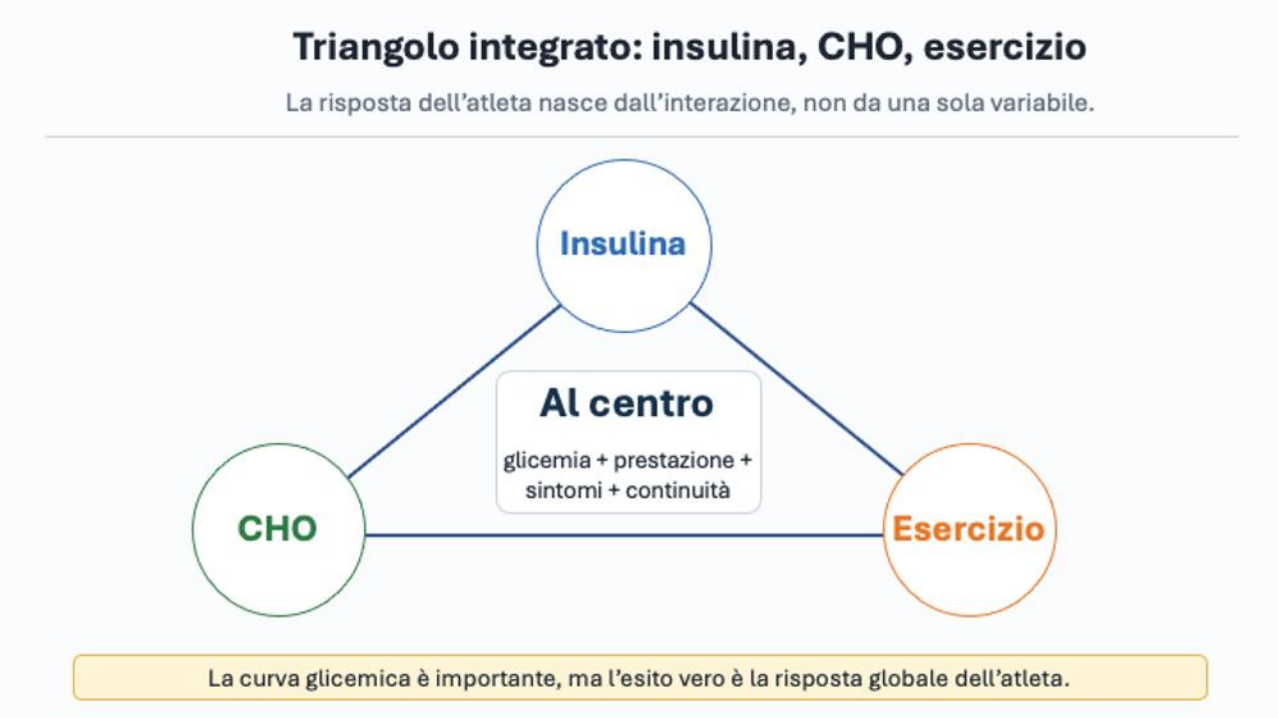


Figure 28.1. Insulin–CHO–Exercise Triangle: at the centre is the athlete's overall response, not only blood glucose.

29.3 At the Centre There Is Not Only Blood Glucose

At the centre of the triangle it is more useful to place the athlete's response: blood glucose, performance, symptoms and ability to continue. This choice prevents the objective from being reduced to a single CGM

number. A strategy that produces a perfect curve but systematically limits performance is not automatically optimal.

29.4 The IOB–Exercise Map

There is no universal conversion between units of IOB and grams of carbohydrates required. Insulin sensitivity, weight, bolus timing, intensity, duration and hepatic production modify the relationship. The qualitative principle nevertheless remains useful: for the same activity that tends to lower blood glucose, greater insulin exposure generally increases the likelihood of having to use CHO-G.

29.5 When the Map Changes

During very intense or competitive exercise, adrenergic hepatic glucose production may compensate for or exceed peripheral uptake. A non-negligible IOB therefore does not guarantee a fall in blood glucose. The model must be modulated according to the type of activity and the individual response.

29.6 A Qualitative and Semiquantitative Matrix

IOB / expected response	**Exercise tends to lower blood glucose**	**Exercise with relatively stable blood glucose**	**Exercise tends to raise blood glucose**
Low IOB	CHO-G often limited; assess CHO-P	Monitoring and performance plan	Avoid excessive insulin reductions
Intermediate IOB	Risk of additional CHO-G	Individual response becomes decisive	Assess the context before correcting
High IOB	Greater risk of a fall; CHO-G more likely	Stability possible but fragile	Adrenergic response may temporarily mask the insulin effect

The matrix must not be used as a therapeutic algorithm. Its function is to show that the same IOB takes on different meanings when the structure of exercise changes and that the name of the sport is not sufficient to predict glycaemic behavior.

IOB × TYPE OF EXERCISE: RISK OF HYPOGLYCAEMIA

A qualitative guide to help reasoning, not a universal prescription.

INITIAL IOB	Moderate–long aerobic exercise	Intermittent / team sport	Short–intense anaerobic exercise	Note
LOW (<0.5 U)	Low risk	Low–moderate risk	Low risk	Monitor CHO-P
MODERATE (0.5–1.5 U)	Moderate risk	Moderate risk	Moderate risk	CHO-G possible
HIGH (>1.5 U)	High risk	High risk	Medium–high risk	Reduce IOB in advance

At the same exercise intensity, the need for CHO-G tends to increase with IOB.

Figure 29.2. Qualitative IOB–Exercise map: the same IOB level takes on different meanings in relation to the structure of the activity.

Matrix of hypoglycaemic risk by type of exercise based on IOB

A qualitative guide for individualization, not a universal prescription.

IOB	Moderate aerobic exercise	Long-duration aerobic exercise	Intermittent exercise	High-intensity and short-duration
Low	Low risk	Monitor CHO-P	Variable	Low risk
Intermediate	Moderate risk	CHO-G possible	Depends on sprints	Variable
High	High risk	High risk	Medium–high risk	Blood glucose does not always decrease

At the same exercise intensity, the need for CHO-G increases with IOB; exercise intensity changes the direction of the glycaemic response.

Figure 29.3. Semiquantitative IOB–Exercise map.

29.7 The Final Message of the Model

The question “how much should I eat?” becomes more useful when reformulated: what performance demand must I support, and with how much insulin am I starting? In this way, blood glucose data return to their proper role: informing safety and therapeutic adaptation without replacing the physiology of performance.

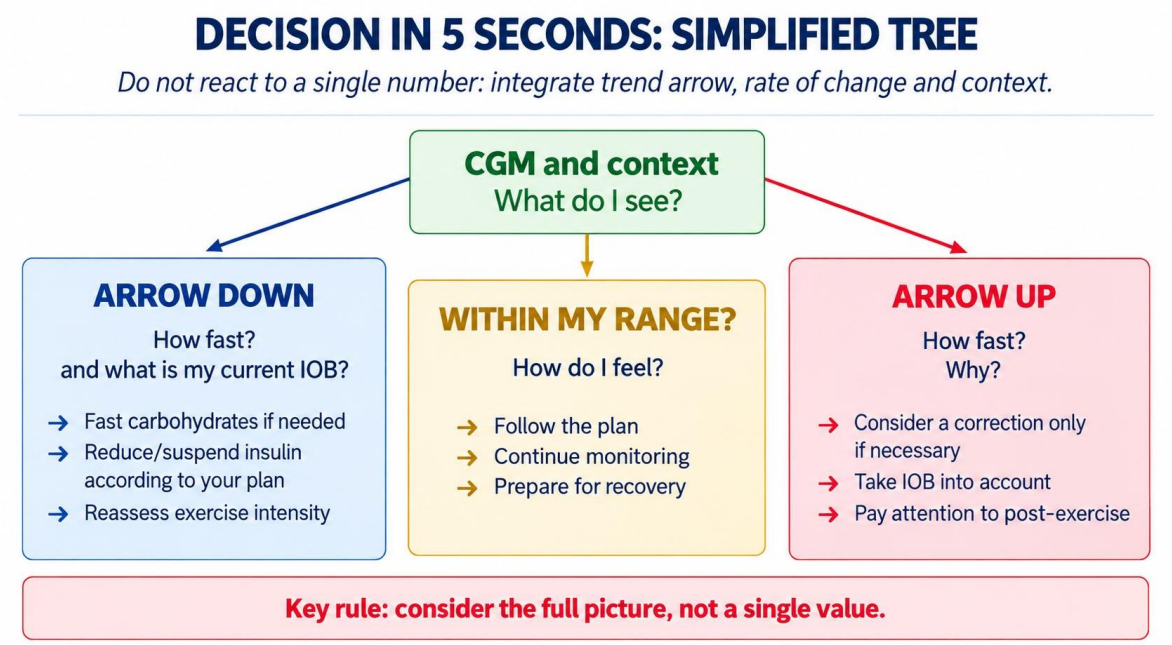


Figure 29.4. Immediate decisions to be made in a semi-automated but logical way.

CONCLUDING MESSAGE

Modern management of sport in DMT1 does not consist of seeking a perfect curve in every session.

It consists of creating the conditions for the person to train and compete safely, progressively distinguishing what belongs to performance from what belongs to therapy.

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TO THE FRIENDS FROM THE EARLY DAYS

In Memory of Dr Mariano Agrusta

The authors wish to remember Dr Mariano Agrusta, a founding member of ANIAD and a master of therapeutic education, who, as an enlightened specialist, shared the world of diabetes and sport with sensitivity and commitment.

In Memory of Dr Giuseppe Di Blasi

ANIAD Lazio remembers, in particular, Dr Giuseppe Di Blasi, an athlete with DMT1 who, with constant commitment and enthusiasm, launched the Association in his region and also made a contribution at national level through the organization of the Giro del Lazio relay (2000), the Nettuno–Treunreut International Relay (2001), and no fewer than twenty consecutive Rome Marathons up to the COVID-19 epidemic.