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Sugar and physical exercise; the importance of sugar for athletes

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Abstract

Muscle glycogen, the predominant form of stored glucose in the body, and blood glucose are the main energy substrates for muscle contraction during exercise. Sucrose is an ideal substance for athletes to incorporate because it provides both glucose and fructose. Therefore, it is essential that athletes monitor their diet to maintain and increase muscle glycogen deposits, since they are a major limiting factor of prolonged exercise performance. Carbohydrate-rich diets are also recommended for endurance and ultra-endurance exercise, because they are associated with increased muscle glycogen stores, as well as delayed onset of fatigue. In addition, high carbohydrate diets and carbohydrate intake before and during exercise have shown to be beneficial due to increased concentrations of hepatic glycogen and maintenance of blood glucose. The effect of carbohydrate intake on athletic performance mainly depends on the characteristics of the exercise, the type and amount of carbohydrate ingested and the time of intake. A combination of these factors must be taken into account when analysing individual athletic performance.

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Key words: *Carbohydrate intake. Endurance sports. Strength sports. Performance. Training.*

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EL AZÚCAR Y EL EJERCICIO FÍSICO; SU IMPORTANCIA EN LOS DEPORTISTAS

Resumen

El glucógeno muscular, principal almacén de glucosa en el organismo, y la glucemia sanguínea constituyen uno de los principales sustratos energéticos para la contracción muscular durante el ejercicio. El azúcar (sacarosa) es un estupendo suplemento al suministrar tanto glucosa como fructosa. Por ello, es esencial que los deportistas cuiden su alimentación, para mantener y aumentar los depósitos de este combustible, ya que las reservas de glucógeno muscular constituyen un factor limitante de la capacidad para realizar ejercicio prolongado. Las dietas ricas en hidratos de carbono se han recomendado para el ejercicio de resistencia y ultraresistencia debido a su relación con el aumento de las reservas musculares de glucógeno y la aparición tardía de la fatiga. Además de las dietas altas en carbohidratos, la ingesta de carbohidratos antes y durante el ejercicio, han demostrado ser beneficiosas debido al aumento de las concentraciones hepáticas de glucógeno y el mantenimiento de las concentraciones de glucosa en sangre. El efecto de la ingesta de carbohidratos sobre el rendimiento deportivo dependerá principalmente de las características del esfuerzo, del tipo y cantidad de carbohidratos ingeridos y del momento de la ingesta. La combinación de todos estos factores debe ser tenida en cuenta a la hora de analizar el rendimiento en las diferentes especialidades deportivas.

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Palabras clave: *Ingesta de carbohidratos. Deportes de resistencia. Deportes de fuerza. Rendimiento. Entrenamiento.*

Abbreviations

FFA: Plasma free fatty acids
ATP: Adenosine triphosphate.
HR: Heart rate Max.
HR: Maximum heart rate.
O_2: Oxygen.
TG: Triglycerides.
VCO_2: Carbon dioxide production.
VO_2: Oxygen consumption.
VO_{2max}: Maximum oxygen consumption.

Energy metabolism of carbohydrates and their importance in different types of exercise

The sugar (sucrose) we consume in our diet is an important source of glucose for the body, as it is a disaccharide formed from one molecule of glucose and one of fructose. However, by extension, all carbohydrates are included under the term sugar. Among the different kinds of carbohydrate that are consumed monosaccharides (glucose, fructose and galactose) and disaccharides (maltose, sucrose and lactose) and glucose polymers (maltodetrin and starch) stand out. Their differences in osmolarity and structure have an impact on palatability, digestion, absorption, hormone release and the availability of glucose to be oxidised in the muscles[1]. All the metabolic pathways of carbohydrates are reduced by the breakdown (catabolic pathways) of glucose (glycolysis) or glycogen (glucogenolysis), or the formation (anabolic pathways) of glucose (glycogenesis) or glycogen (glycogenosynthesis). Glucose is the only carbohydrate that circulates around the body and whose concentration can be measured in the blood (blood glucose). So all carbohydrates that are consumed in the diet are converted to glucose.

Muscle glycogen, the main form of stored glucose in the body, and blood glucose are the main energy substrates for muscle contraction during exercise, and they become progressively more important as exercise intensity increases. They are the most important substrates, as a quick source of energy for the body because their oxidation produces 6.3 moles of ATP (Adenosine triphosphate) per mole of oxygen (O_2) compared with 5.6 moles obtained from oxidising fats. One of the factors that may determine muscle fatigue is the depletion of carbohydrate reserves.

During low intensity aerobic activity (~30% of maximal oxygen consumption[VO_{2max}]) the total energy produced comes from 10-15% of carbohydrate oxidation. With an increase in intensity this percentage increases, and could reach 70-80% when VO_{2max} is ~85%, or even 100% during maximal or supramaximal intensity activities[2]. Besides exercise intensity, their use during exercise is influenced by various factors such as its duration (Fig. 1), the level of physical fitness, diet, gender, environmental conditions, etc. As most sports are carried out at intensities that are above 60-70% of VO_{2max}, carbohydrates from muscle glycogen and blood glucose are the main source of energy.

The role that carbohydrates play in energy metabolism during exercise highlights the importance of analysing adequate sugar intake for sports performance. The availability of carbohydrates during exercise, as well as the subsequent recovery of muscle glycogen deposits, plays a pivotal role in the performance of different sports. Skeletal muscle has a higher concentration of glycogen and is the tissue which has the largest deposits, as the liver (another glycogen store) only stores an eighth of the amount that muscle stores. For example, a 70 kg person with a muscle mass percentage of 45%, has 315 g of glycogen stored in their muscles. while there is about 80 g in the liver. The liver contains the glucose-6-phosphate enzyme which enables the dephosphorylation of glucose-6-phosphate and therefore supplies the rest of the organs and tissues with glucose. Liver function is vital during exercise to maintain blood sugar and supply the brain with glucose. For their part, muscles are able to use glycogen deposits independently. Therefore it's essential that athletes watch their diet so that they can maintain and increase these fuel deposits because muscle glycogen reserves are limiting factors in the capacity to perform prolonged exercise[3].

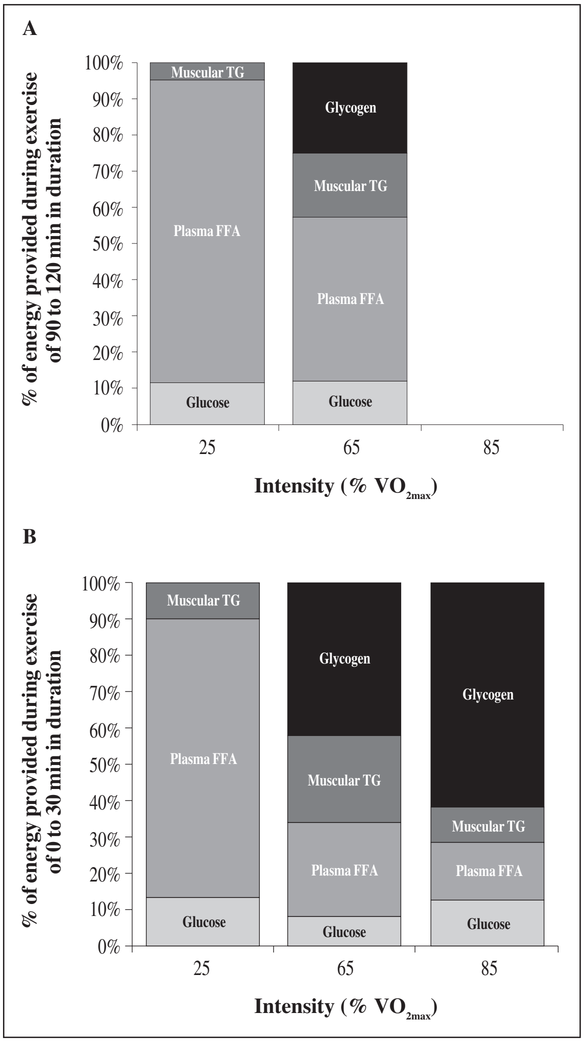


Fig. 1.—The effects of exercise intensity and duration in the use of metabolic substrates. The percentage of energy supplied by glucose, plasma free fatty acids (Plasma FFA), glycogen and muscular triglycerides (Muscular TG), during exercise from 90 to 120 min (A) and from 0 to 30 min (B) at intensities of 25, 65 and 85% of maximal oxygen consumption (VO_{2max}) (Adapted from[13]).

A person can store around 1,500-2,000 kcal as blood glucose and glycogen. In the blood we only have 50 kcal of glucose for immediate use. Hepatic glycogen can provide around 250-300 kcal. Muscle glycogen in trained long distance runners is around 130 mmol·kg^{-1}, which is a higher value than those found in sedentary subjects or people who practice other sports that are shorter in duration. Because carbohydrates have limitations during exercise, including in cases where fats were are used as the main energy source, an athlete's diet should be rich in carbohydrates to cope with the high energy consumption and to maintain full glycogen stores[1].

Then, the role of sugar in different kinds of exercise will be briefly analysed, specifically glucose and glycogen: submaximal, maximal or supramaximal and intermittent.

Long term submaximal exercise

For this type of exercise, the higher the intensity the more muscular glycogen is used and the less energy is obtained from fat. However, the longer the durations the more fatty acids are used as a source of energy[4] (Fig. 1). Muscles are metabolically independent thanks to glycogen stores, although these stores are not inexhaustible. That's why fat tissues and the liver have to provide the muscle fibres with fuel. This inter-relationship between tissues helps prevent the complete exhaustion of glycogen stores, because its concentration is the main limitation on the ability to perform prolonged exercise. Furthermore. when energy mainly comes from fats, mechanical performance is reduced, therefore, the coordination between muscles, the liver and fatty tissue is imperative[3,4].

Short term maximal or supra-maximal exercise

The high intensity of this type of exercise means that it can be perform for a long period of time. Moreover, the aerobic metabolic pathway is not able to supply energy at the speed that it's needed, therefore, from a quantitative point of view, anaerobic metabolism is more important in this type of exercise. In the phosphagen system glucose and glycogen are the main sources of energy. The contribution of muscle glycogen in short term maximal intensity exercise could be as follows: 20% in the first 30 seconds, 55% from 60 to 90 seconds and 70% from 120 to 180 seconds[3].

Intermittent exercise

Combined periods of exercise and rest periods are known as intermittent exercise. These exercises are very common in training and in many sporting activities. The fuel used during this type of exercise depends on the intensity, the duration of the exercise, the length of the rest period and the number of times the exercise is repeated, therefore the possibilities are endless. Focusing on glycogen, the four characteristics above determine the decrease in glycogen stores, whilst their replenishment (hepatic and muscular) depends entirely on diet.

Specific recommendations of sugar intake for athletes

Information on this matter is extensive and there are numerous studies that have examined the effectiveness of consuming different amounts of sugar. Tables I and II summarise the recommended carbohydrate intake guidelines for athletes.

Endurance sports

During endurance exercise muscle glycogen gradually decreases and, as we have previously mentioned, performance deteriorates. An effective way of improving endurance is to increase the amount of glycogen stored in the skeletal muscles and the liver before starting exercise[5]. The availability of carbohydrates, as a substrate for the muscles and central nervous system, becomes a factor that limits performance during prolonged submaximal (> 90 min) and intermittent high intensity exercise[6].

Traditionally, diets rich in carbohydrates have been recommended for endurance and ultra-endurance training, because of the relationship between these diets, the increase in muscular glycogen stores and delayed onset fatigue. More recently diets high in

Table I

Recommended carbohydrate intakes in athletes. Translated and amended from[13]

	Intake recommendations
Daily requirements. These recommendations should take the total individual energy expenditure, specific training needs and performance into consideration.	
Light or low intensity activities	3-5 g·kg^{-1}·day^{-1}
Moderate intensity exercise programme (~1 h·day^{-1})	5-7 g·kg^{-1}·day^{-1}
Moderate to high intensity exercise programme (1-3 h·day^{-1})	6-10 g·kg^{-1}·day^{-1}
High intensity exercise programme (4-5 h·day^{-1})	8-12 g·kg^{-1}·day^{-1}

Table II

Carbohydrate loading strategies. Translated and amended from[13]

		Intake recommendations (in grammes of carbohydrates)
Strategies aimed at promoting high carbohydrates availability that enables optimal performance in competition or important training sessions.		
Carbohydrate loading	Preparation for events < 90 min of exercise	7-12 $g\cdot kg^{-1}\cdot day^{-1}$ (daily requirements)
Carbohydrate loading	Preparation for events > 90 min of exercise	36-48 hours of 10-12 $g\cdot kg^{-1}\cdot day^{-1}$
Rapid loading	< 8 hours of recovery between two intense training	1-1.2 $g\cdot kg^{-1}\cdot h^{-1}$ during for the first 4 hours, followed by daily requirements
Intake before exercise	One hour before exercise	1-4 $g\cdot kg^{-1}$ consumed 1-4 hours before exercise
Intake during exercise	<45 min	Not necessary
Intake during high intensity exercise	45-75 min	Small amounts
Intake during endurance training	1-2.5 h	30-60 $g\cdot h^{-1}$
Intake during ultra endurance training	2.5-3 h	90$g\cdot h^{-1}$

carbohydrates and carbohydrate intake before and during exercise, have been shown to be beneficial due to an increase in hepatic glycogen concentrations and the maintenance of blood sugar concentrations[7]. The daily carbohydrate requirements for training and recovery are summarised in table I. To address the specific carbohydrate needs of athletes it is important to express them with regard to body weight. Various articles have suggested that a carbohydrate intake of 8 to 10 $g\cdot kg^{-1}\cdot day^{-1}$ is needed to replenish glycogen[6-9], a higher intake (10-13 $g\cdot kg^{-1}\cdot day^{-1}$) is needed for athletes whose sports disciplines generate a greater depletion of glycogen reserves6. In female athletes it appears that glycogen synthesis may increase during the luteal phase, therefore, the menstrual cycle is an important consideration when it comes to carbohydrate consumption in female endurance athletes[6,7].

It is vital for athletes to replenish glycogen reserves following exercise, with a view to providing enough energy for the next training session or competition. A high carbohydrate diet can be effective, on its own, at quickly replenishing glycogen stores, but there are a variety of strategies that can increase efficiency, such as adding proteins. Glycogen stores can be increased 1.5 times more than normal, for example, by consuming a high carbohydrate diet for 3 days prior to competition, after having followed a low carbohydrate diet for the 3 previous day (for a total period of 6 days before competition). Furthermore, if we take citric acid, which inhibits glycolysis, at the same time as following a high carbohydrate diet, glycogen stores increase even more because of the inhibiting effect they have on glycolysis[5]. In table II the strategies employed by athletes to increase and replenish glycogen stores are summarised.

Strength sports

Strength training, as a basic physical quality, has a major impact on nearly all of the homeostatic regulation systems of the body and also has significant metabolic consequences in terms of energy supply. Muscles do not differentiate between sporting activities, what they do differentiate between is the number of motor units that are recruited and the amount of time they are active (% in relation to maximal voluntary contraction), the rest are cultural differences that don't have any physiological implications. For example running a marathon is no more than a sequence of very small frequent muscle contractions at a moderate or low intensity and for a very long time, whereas running the 100 metres requires a very high proportion of muscle fibres available in a short space of time.

Strength training has a number of peculiarities that have a direct and important impact on the choice and use of different fuels. For activities that are longer than 120 seconds, total energy expenditure in strength training is less than aerobic activities because they are performed with an embedded rhythm. In this respect, for stand-alone exercises like the bench press or squats, anaerobic energy expenditure may be more than 30% of total energy[10], in the case of circuit training this requirement is no more than 10%, as can be seen in figure 2. Carbohydrate requirements are important, in fact, when training intensity is high hypoglycaemias can be very common. However the total energy expenditure is not high. In figure 3 we can see that circuit training with weights does not require more than 35% of VO_{2max}, whereas the required heart rate is higher than 90%.

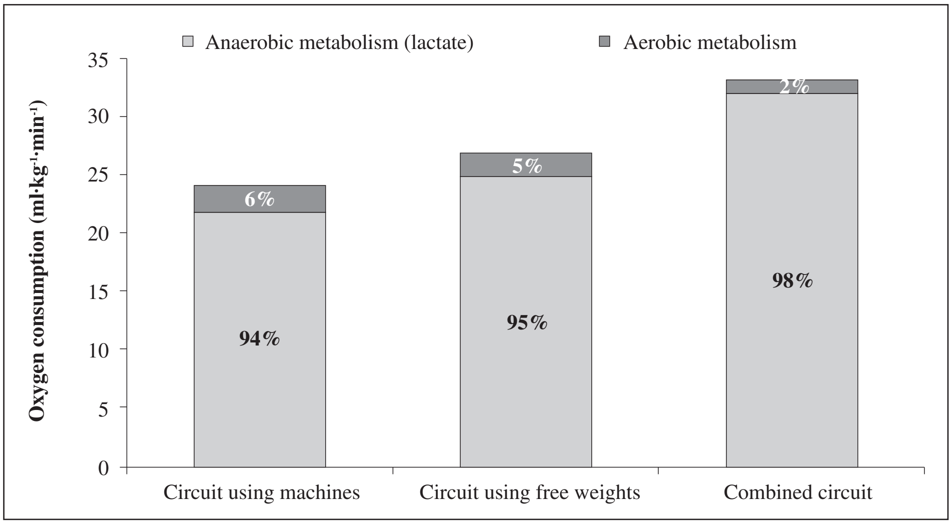


Fig. 2.—The proportion of energy provided and oxygen consumed during three rounds of circuits with weights, with 8 exercises without rest at 65% of intensity and for 54 min.

Although there are clear benefits to following a high sugar diet for endurance sports, the situation for strength training isn't as clear, as the small amount of energy that this kind of exercise usually needs is easily supplied by our energy system[11]. What can often happen, and primarily due to the inadequate progression of training variables (amount and intensity), is that, due to the limited amount of energy, in the form of sugars in the blood, a very rapid demand for glucose (intense strength training) can exhaust these small reserves and this means that the liver is not able to supply glucose to the bloodstream as quickly, so the likelihood of hypoglycaemia occurring is very high.

The effects of sugar consumption on sports performance

The effect of carbohydrate intake on sports performance depends mainly on the kind of exertion (intensity, duration, etc), the type and amount of carbohydrates eaten and when they are consumed. The combination of all these factors should be taken into consideration when analysing performance in different sports. In the following points, the effects of consuming sugars before, during and after exercise will be explained, as well as the main features of low carbohydrate diets.

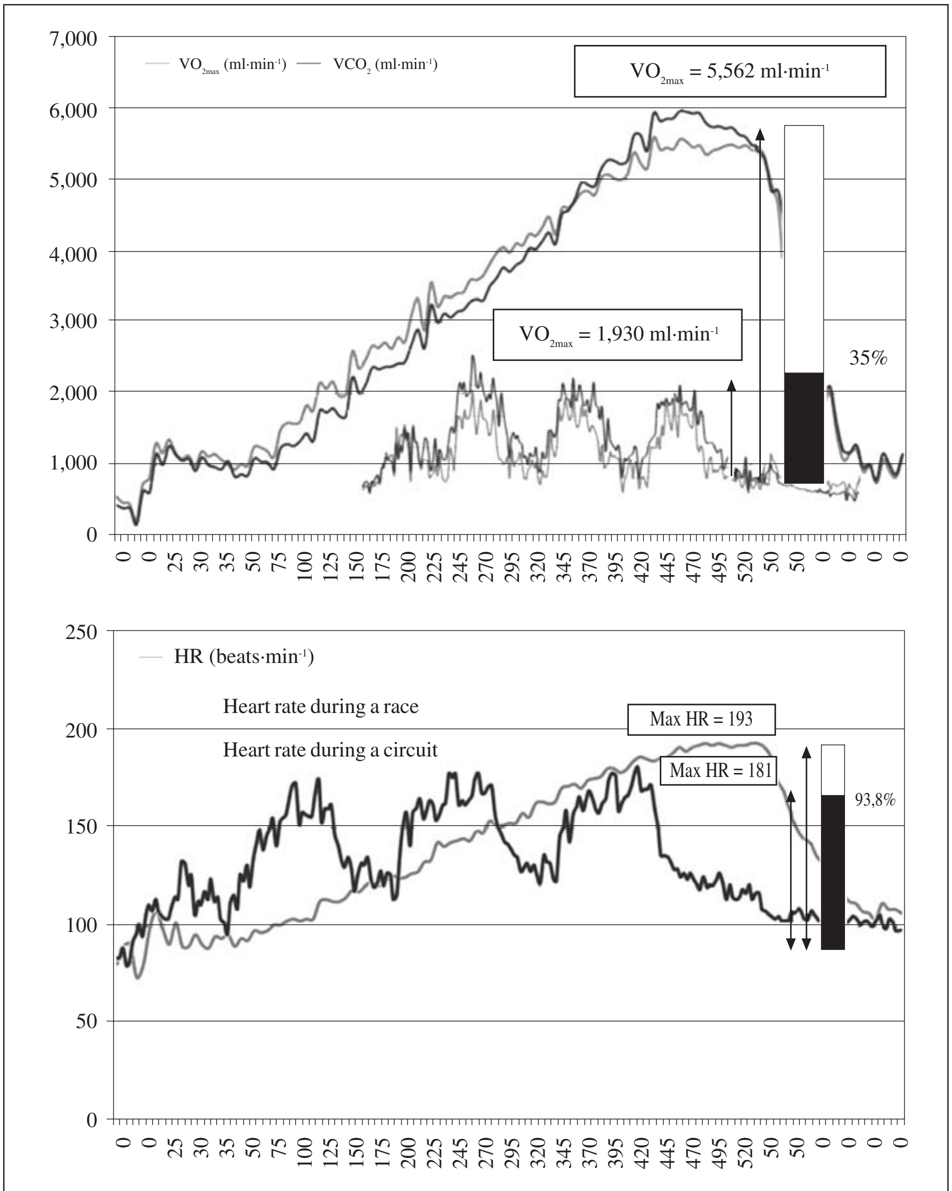
Carbohydrates should provide 55-60% of athletes total daily calorie intake. During periods of increased training this percentage should be increased to 65-70%[1-6]. When they should be consumed will be discussed below.

Intake before exercise

The general recommendations for carbohydrate intake before exercise stipulate that dinner on the day before competition should be high in carbohydrates (250-250 g), that the meal before (3-6 hours before) should include the intake of 200-350g and 60-30 minutes before competing 35-50 g of glucose, sucrose or glucose polymers should be consumed. The foods consumed should be low in fat, fibre and proteins, well tolerated, not in large portions and with a high or medium glycaemic index[1]. On the other hand, certain studies indicate that the intake of glucose 30 or 45 minutes before exercise causes muscle fatigue more quickly than when it's not consumed (due to changes in glucose and insulin concentrations). However, if fructose is consumed plasma glucose and insulin concentrations do not change drastically before exercise[12].

The *American College of Sports Medicine* (ACSM) maintains that the amount of carbohydrates that enhances performance varies between 200 and 300g for meals 3-4 hours before exercise, at the rate of 30-60 $g \cdot h^{-1}$ in intervals of 15-20 min (primarily in the form of glucose), for exercise that lasts more than an hour[9]. Furthermore, consumption of 0.15-0.25 g of protein·kg^{-1}, 3-4 hours before exercise, with a ratio of 3-4:1 (glucose: protein), can stimulate the synthesis of proteins during endurance exercise, but it has not been proven to improve performance[9]. Genton et al. propose the consumption of 1-4 $g \cdot kg^{-1}$ 1 to 4 hours before exercise to increase carbohydrate availability during prolonged exercise sessions, and 0.5 to 1 $g \cdot kg^{-1}$ during moderate intensity or intermittent exercise sessions > 1 h[5].

When exercise is performed for a long period of time, such as a marathon, consuming carbohydrates immediately before or during exercise is an effective way of improving endurance. Under such conditions, it is desirable that athletes consume mono- or oligosaccharides, because they are quickly absorbed and transported to the peripheral tissues for use. On the other hand, carbohydrate consumption inhibits the breakdown of fats and stimulates insulin secretion. This



VO_{2max}: Maximum oxygen consumption; Max HR: Maximum heart rate.

Fig. 3.—Oxygen consumption response (VO_2) and heart rate (HR) during a strength training circuit, compared with the response during stress test until exhaustion (Adapted from[16]).

leads to a deterioration in energy production through the metabolism of fats and accelerates glycolysis as a way of producing energy. As a result, muscle glycogen consumption increases. Therefore it's necessary to consume carbohydrates that don't inhibit fat metabolism. It has been suggested that supplements containing fructose stimulate insulin release less and it is unlikely that they inhibit lipolysis, instead of common carbohydrates such as glucose and sucrose. Moreover, the simultaneous consumption of citric acid and arginine can facilitate energy consumption from fats through the inhibition of glycolysis, delaying glycogen depletion. Therefore, consuming both together with carbohydrates that slowly stimulate insulin secretion, before or during exercise, could be an effective way of improving energy metabolism and providing an optimal source of energy during prolonged exercise[7].

Some studies show a reduction in muscle glycogen use when carbohydrates are consumed before and during exercise. Others have reported a reduction in hepatic glucose synthesis, the maintenance of normal blood sugar and high levels of glucose oxidation during the final stages of exercise, but not a reduction in glycogenolysis. However, high levels of circulating insulin reduce lipolysis and therefore reduce the contribution of muscle fat during exercise. Consequently, the amount of carbohydrates provided should be sufficient to cover energy demands from exercise and the energy lost from fat oxidation[7-8].

A temporary reduction in blood sugar levels usually occurs when carbohydrates are consumed before exercise. This is probably due to an increase in glucose uptake in the plasma, as a result of increased insulin levels and the suppression of hepatic glucose synthesis. This imbalance causes a reduction in plasma glucose concentration that is subsequently offset by an increase in the intestinal absorption of glucose, with the aim of normalising plasma glucose levels. For the majority of individuals this reduction in blood sugar concentrations is temporary and of no functional significance[12].

Intake during exercise

High intensity and long duration endurance tests (> 65% VO_{2max}) are characterised by a steady gradual decrease of glycogen in the active muscles. Although glycogen is not the only source of energy, it is necessary for maintaining intensity and it will be compensated by plasma glucose if it decreases, which is compensated by the liver (stored glycogen and the conversion of substrates like lactate or alanine in glucose). The reduction in plasma glucose, which occurs during prolonged exercise, is an indication that the liver cannot provide enough glucose once its glycogen stores are exhausted. Under these conditions, additional glucose may benefit performance[8]. Therefore, the aim of eating during exercise is to provide a readily available source of oxygen fuel, since the endogenous glycogen stores are exhausted[7].

The maximum oxidation rate for exogenous carbohydrates during moderate intensity exercise is 0.8 to 1.0 g·min^{-1}. This proportion is slightly less than 1mJ of energy, whereas some forms of exercise need four times this amount. This suggests that there is the potential for supplementing with fat during exercise. Various studies have used medium-chain triglycerides as a source of additional fuel during exercise. Therefore, the consumption of both carbohydrates and fats together during exercise could prevent the decrease in fat metabolism that is observed when only carbohydrates are consumed[13]. The rate that limits the oxidation of ingested carbohydrates is due to its intestinal absorption, specifically, the type of transport mechanism. So, if glucose is consumed in combination with a glucide such as fructose, which is absorbed via a different transport mechanism, the total rate of carbohydrates consumed may be higher than 1.5 g.min^{-1}. Following this, recommendations for glucose and fructose intake have been raised to 80-90 g·h^{-1}, at a ratio of 2:1. Furthermore, it has been shown that the time to exhaustion increases with the consumption of fructose and is dose-dependent[12]. Improvements in performance are significantly higher when the subject receives larger amounts of fructose. The possible mechanism, by which fructose intake might spare muscle glycogen, involves its influence on plasma lipids, as they enable the increased use of fats[1.9]. So, sugar (sucrose) becomes an excellent supplement to both glucose and fructose.

On the other hand, during tests of less than 60 min. in length recommendations suggest not giving any specific carbohydrates. However, consuming 300-500 ml of drink with a carbohydrate concentration of 6-10% every 15 min at a temperature of 8-12ºC, could help preserve muscle glycogen and balance fluid loss, especially if the exercise is carried out during high temperatures. For events of between 1 to 3 hours it is recommended that 800-1,400 ml·h^{-1} of liquid are consumed, with a carbohydrate concentration of 6-8% and a sodium concentration of 10-20 mmol·l^{-1}. When the exercise duration exceeds 3 hours it is advisable to drink around 1,000 ml·h^{-1} of liquid with 23-30 mmol·l^{-11} of sodium.

Post exercise intake

After physical exertion of more than an hour, muscle glycogen stores may be empty, with a loss that could be around 90%. As a result, an exogenous supply of substrates is requires to achieve the levels of glycogen prior to exercising. The full replenishment of glycogen stores following exercise takes between 24 and 48 hours, as the resynthesis rate is directly proportional to the amount of carbohydrates in the diet during the first 24 hours[13]. The recovery of muscle and hepatic glycogen is a key objective of recovery between training sessions or competition events, particularly when the athlete engages in multiple training sessions during a condensed period of time[6.8]. Previously it was though that 48 hours of rest were needed to recover muscle and liver stores. Now it is accepted that, in the absence of severe muscle damage, glycogen reserves can normalise after 24 hours of reduced training and adequate fuel consumption[7.8].

The diet after each exercise session should contain sufficient carbohydrates to replenish glycogen reserves and to maximise subsequent performance (an average of 50 g of high carbohydrate foods for every 2 hours of exercise). The aim should be to consume a total of approximately 600 g of high carbohydrate foods with a high and moderate glycaemic index in a 24 hour period[6]. After intense exercise, muscle glycogen synthesis needs to recover about 100 mmol·kg^{-1}, with a glycogen synthesis rate of 5 mmol·kg^{-1}·h^{-1}, requiring about 20 hours to recover (normalise) glycogen stores. Carbohydrate consumption during the first 2 hours after exercise allows a slightly faster rate of synthesis than normal (7-8 mmol·kg^{-1}·h^{-1}). For this reason, athletes should consume enough carbohydrates following exercise as soon as possible, especially during the first hour after exercise due to the activation of the glycogen synthase enzyme by glycogen depletion, an increase in sensitivity to insulin and the permeability of muscle cell membranes to glucose. Glycogen synthesis throughout the day is similar, whether the carbohydrates are consumed in large meals or as a series of small snacks, with no differences between consuming them in liquid or solid form, the only important thing is the total amount of carbohydrates consumed. Primarily, high carbohydrates foods should have a high glycaemic index (they increase muscle glycogen stores as much as possible), whereas those with a low glycaemic index should not constitute more than a third of recovery meals[1,6,9].

The recommendation, according to the type of activity, (grams of carbohydrates) are as follows (Table I and II)[6]:

- Immediate recovery after exercise (0-4h) 1.0-1.2 $g \cdot kg^{-1} \cdot h^{-1}$, every 2 hours.
- Daily recovery < 1 $h \cdot day^{-1}$ from low intensity exercise: 5-7 $g \cdot kg^{-1} \cdot day^{-1}$.
- Daily recovery < 1 $h \cdot day^{-1}$ from moderate to intense resistance training: 7-10 $g \cdot kg^{-1} \cdot day^{-1}$.
- Daily recovery < 4 $h \cdot day^{-1}$ from moderate to very intense training: 10-12 $g \cdot kg^{-1} \cdot day^{-1}$.

During the first few hours meals with 70-80% carbohydrates should be eaten to avoid consuming lots of protein, fibre and fats, which besides suppressing hunger and limiting carbohydrate consumption, may cause gastrointestinal problems, in which case liquid preparations are preferred. At the same time, sports drinks, which fundamentally aim to create an anabolic environment, should cause an increase in blood sugar and consequently raise insulin, thereby enhancing the effects of different anabolic hormones to stimulate the synthesis of muscle and liver glycogen[14].

Low carbohydrate diets

After addressing. at great length, the importance of consuming large quantities of carbohydrates for sports, the opposing alternative will be discussed: low sugar diets. It suggests that low carbohydrate diets that provide less than 50-150 $g \cdot day^{-1}$, and their influence on sports performance has also been studied.

Low carbohydrate and high fat diets have been considered as a potential mechanism for improving performance in endurance exercises. However, amongst athletes these diets are perceived negatively when it comes to performance. The authors that proposed these diets suggest that this dietary practice provides large amounts of lipids as energy substrates to synthesise ATP. Low carbohydrate diets result in metabolic and hormonal adjustments that can improve the oxidation of fats and encourage muscle glycogen conservation during exercise. Like with endurance training adaptations, there is a shift towards increased fat oxidation as fuel, at rest or during exercise, which may be due to a combination of an increase in oxidative enzymes, an increase in mitochondrial density, the increased storage and use of intramuscular triglycerides and the increased muscle uptake of plasma free fatty acids. This combination of mechanisms leads to a reduction in muscle glycogenolysis and carbohydrate oxidation and contributes to the increased use of free fatty acids during exercise[14].

The low amount of glucose stored in the human body restricts the ability to maintain a high power output during prolonged endurance exercise. It had been argued that one of the consequences of a low carbohydrate diet can be a reduction in muscle glycogen content before exercise, particularly in untrained individuals, which could defeat the purpose of creating a glycogen sparing effect. Therefore, studies indicate that an increase in carbohydrate consumption tends to cause less disruption in sports performance compared to low carbohydrate diets[14,15].

Weaknesses

In general physical exercise has very specific energy and sugar demands. Therefore, metabolic activity during physical activity and training can cause problems with homeostasis in healthy people, and more so in at-risk populations, if the performance-based requirements are not met. In this way, the qualified professionals' ignorance and lack of consultation of these requirements could involve the implementation of a series of initiatives (eliminating foods and encouraging others) that could carry an unwarranted and unreasonable risk in many cases.

Threats

The difficulty in establishing the specific requirements for each physical activity, according to the intensity and volume of exercise, poses a major threat, as well as the proliferation of advertising campaigns or miracle diets that discredit the benefits of consuming sugar for sport. At present, the methods of quantifying physical activity help determine the energy requirements of each activity, although a number of confounding factors such as age or gender, could influence the accuracy of these measurements. Even so there is still a long way to go before specific sugar requirements can be quantified with real accuracy, for each person in every situation.

Strengths

This text takes a pedagogical approach to understanding general sugar requirements according to the type of physical exercise: endurance or strength.

Nowadays the requirements for many activities are known, as well as the significance or influence that adequate intake may have on performance. However, more work is needed in this line of research.

Opportunities

The demand to know the exact sugar requirements adapted to each person and situation creates work opportunities for research groups that are dedicated to studying specific blood sugar requirements. These groups are working on both healthy and populations with medical conditions. Certain lines of work will help improve the administering of insulin in diabetics, as well as its interaction with exercise.

Recommendations

All the carbohydrate intake recommendations have already been outlined throughout the text, however we should remember that it is important to assess the type of exercise performed, because sugar intake depends on these characteristics. In at-risk populations, the monitoring of blood sugar levels during exercise should be common practice.

Conclusions

The skeletal muscle and liver are the main stores of glycogen in the body. These stores, together with blood glucose, are the main source of energy for most athletes. Therefore, carbohydrate availability during exercise, as well as the subsequent recovery of muscle glycogen reserves, plays a pivotal role in the performance of different sports. The reduction in muscle glycogen levels (a substrate of the muscles and the central nervous system) becomes a factor that limits performance. There is evidence that consumption of a high carbohydrate diet, before and during exercise, is beneficial due to the increase in concentrations of hepatic glycogen and the maintenance of and blood sugar concentrations. Its effect on sporting performance depends primarily on the kind of the exercise, the type and amount of carbohydrates eaten and when they are consumed. It is also important for athletes to replenish glycogen stores after exercise, with a view to providing enough energy for the next training session or competition, through a high carbohydrate diet with a high and moderate glycaemic index, enabling glycogen synthesis to be enhanced through the addition of protein. In conclusion, sugar (sucrose) becomes an excellent supplement to both glucose and fructose.

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