BARÇA INNOVATION HUB

SPORTS NUTRITION FOR FOOTBALL

An evidence-based guide for nutrition practice at FC Barcelona

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*"If you want to get better
you must train hard every day,
but without the right nutrition,
it will not be possible."*

Lionel Messi
FC Barcelona
#10

Summary

Carbohydrate Requirements for Football

CARBOHYDRATE REQUIREMENTS FOR FOOTBALL

Fuel provided from ingesting carbohydrate plays a major role in the performance of many types of exercise and sport.

Carbohydrate and fat are the main fuels from a quantitative point of view, and these fuels provide the player with the energy required for training and matches. Carbohydrate is the most important fuel from a qualitative point of view as this is the fuel that is linked to high intensity exercise performance as well as cognitive function. The relative contribution of carbohydrate and fat during exercise will depend on several factors, including the pre-exercise carbohydrate stores (muscle and liver glycogen), the exercise intensity and duration, and the training status of the player (Jeukendrup 2003) and is also genetically determined. Unfortunately, total body carbohydrate stores are limited and are often substantially less than the fuel requirements of the training and competition sessions undertaken by players. The depletion of body carbohydrate stores is a cause of fatigue or performance impairments during exercise, particularly toward the later stages of a 90 min game, prolonged or intense training sessions and if a match enters extra-time. This fatigue may be seen both in the muscle (peripheral fatigue) and in the central nervous system (central fatigue) (Noakes 2000; Nybo 2003). Therefore, strategies for the player include consuming carbohydrate before, during and in the recovery period between exercise bouts. Since 1. carbohydrate utilisation is highly individually determined, 2. has most likely a genetic component, and 3. carbohydrate utilisation is also position specific, it may be necessary to adopt individual approaches to carbohydrate intake advice for players or groups of players. Many studies have shown that exercise is improved by strategies that optimise carbohydrate status prior to exercise (Bergström et al., 1967; Bergstrom & Hultman 1967; Hultman 1967) and maintain carbohydrate status during exercise (for detailed reviews see (Hawley et al., 1997; Jeukendrup & Jentjens 2000; Jeukendrup 2004).

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TYPE AND QUALITY OF PROTEIN

The daily intake of carbohydrate should be proportionate to the estimated fuel cost of the training session or match (Impey et al., 2016). It is unlikely that players complete matches or high intensity sessions on a daily basis, especially during the season.

Therefore, current guidelines recommend that for low intensity, recovery or skill-based training players ingest 3-5 g of carbohydrate/ kg body mass (BM) per day. When the intensity or duration of training is increased i.e. when players complete moderate training, approximately 1 h a day, carbohydrate intake of 5-7 g/kg BM per day is recommended (Table 1) (Burke et al., 2011). Intake requirements above this range are less common in team sport athletes; however, during pre-season when the need to condition the players is of importance, and also in-season when the competition schedule exceeds 1 game per week, the daily carbohydrate range may be 6-10 g/kg BM/ day to support 1-3 hours of training per day (Burke et al., 2011) or matches. In a preparation phase a balance must be found between reducing energy intake if weight loss is targeted versus consuming enough carbohydrate to sustain the training (Chapter 2).

Muscle glycogen stores must be replenished prior to exercise and this can be accomplished with a higher carbohydrate intake. In the absence of muscle damage, muscle glycogen stores can be returned to normal resting levels (350-500 mmol/kg dry weight muscle) with 24-36 h of rest and an adequate carbohydrate intake (7-10 g /kg BM/ day) (Bussau et al., 2002). Normalized stores appear adequate for the fuel needs of events of less or equal to 60-90 min in duration. It is clear though that daily intake of 3 g/kg BW per day or less is insufficient to maintain performance. For example, Souglis et al. (2013) showed that a diet containing 8 g/kg BM per day of carbohydrate resulted in a 16% greater distance covered during a game than a diet with only 3 g/kg BW per day (Souglis et al., 2013). Inadequate carbohydrate intake during repeated days of exercise will lead to gradual depletion of muscle glycogen stores and impairment of exercise endurance (Costill et al., 1971). If competition or training is intense this may increase the prevalence and severity of overtraining symptoms and increase the risk of injury (Chapter 8) (Achten et al., 2004; Halson 2013; Nedelec et al., 2015).

In contrast, it has also been suggested that training in a low glycogen state may have some beneficial effects on the adaptation of the muscle (Rauch et al., 1995; Hawley 2011; Philp et al., 2011; Bartlett et al., 2015). It is clear that further research is required to identify situations both in health and performance where training with low glycogen levels may be beneficial and practically possible. Until then, training low is not recommended in football during a season with a busy competition schedule, but could be used in the pre-season phase when there is a focus on longer term adaptations and less on repeated performance in matches.

It is important to express carbohydrate guidelines in g/kg BM (or grams) rather than as a percentage of total energy intake. Dietary guidelines for the general population often make recommendations for carbohydrate intake as a percentage of dietary energy intake (for example, to increase carbohydrate to greater than 55% of total energy intake).

However, players undertaking strenuous exercise have daily carbohydrate requirements based primarily on muscle fuel needs which are quantifiable according to the muscle mass of the player and the duration/intensity of their exercise program. Describing daily carbohydrate intake goals in terms of grams per kg of the players' body mass allows the practitioner to quickly calculate the carbohydrate requirement for a given situation - for example 6 g/ kg BM for a 75 kg player equates to 450 g per day. Meals and menus can then be constructed using information on food labels or in food composition tables to achieve this carbohydrate target.

PRE-EXERCISE MEALS

The ingestion of food and fluids consumed in the 4 h prior to an event has several important objectives. First, if glycogen stores are not fully restored after the last exercise session, carbohydrate ingestion can help continue to fill muscle glycogen stores and to restore liver glycogen. This is especially important for events undertaken in the morning where liver stores are depleted from an overnight fast. Second, the ingestion of fluid ensures that the athlete is well-hydrated and also helps to prevent feelings of hunger. Finally, it is the food ingested in the 4 h prior to exercise that becomes engrained into an athlete's preparation, impacting on psychology and superstition. Players should practice any pre-exercise nutrition strategies in training before adopting in competition, to determine personal tolerances and minimise adverse effects (Williams & Serratosa 2006; Williams & Rollo 2015).

Consuming carbohydrate-rich foods and drinks in the pre-exercise meal is especially important in situations where body carbohydrate stores have not been fully recovered and/or where the event is of sufficient duration and intensity to deplete these stores. The intake of a substantial amount of carbohydrate (~200-300 g) in the 3-4 h before exercise has been shown to enhance various measures of exercise performance compared to performance undertaken after an overnight fast (Sherman et al., 1989; Wright et al., 1991; Schabort et al., 1999). For example, the importance of glycogen to football performance has resulted in the widely utilised "pre-match meal" strategy. The focus of the pre-match meal is to ingest an easy to digest high-carbohydrate meal 3-4 hours before exercise, to increase resting levels of glycogen in the muscle and liver. On match day the relative gains in endogenous glycogen stores achieved with carbohydrate feedings will be dependent upon starting concentrations and the training status of the muscle. However, as a guide, after an overnight fast, ingesting a meal containing 2.5 g of carbohydrate per kg of the player's body mass has been reported to increase muscle glycogen by 11-15% and liver glycogen by 33%, 3 h after ingestion (Taylor et al., 1996; Wu & Williams 2006).

Immediately prior to the warm up or match (depending on individual preference) players may ingest carbohydrate (25-30 g) to blunt the release of glucose from the liver, thus sparing the hepatic store of glycogen (Howlett et al., 1998). The role of liver glycogen is the regulation of blood glucose concentrations (euglycaemia: 4-5.5 mmol·l-1).

At the onset of a match, muscular contraction will cause an increased uptake of glucose from the blood. In concert, liver glycogenolysis will be activated by the actions of glucagon and adrenaline. Interestingly, blood glucose has been reported to be elevated during repeated sprint activity and is rarely observed to decrease to concentrations that may impact on performance (Krustrup et al., 2006). These findings would suggest that the rate of glucose release from the liver is sufficient to compensate for the use of blood glucose throughout 90 min of football activity, in well fed players. In fact, during football blood glucose is only lowered during the "half time" period. This is most likely a consequence of the continued uptake of glucose by the previously active muscle and a reduction in liver glycogenolysis, via a lowered catecholamine level during this period of recovery (Krustrup et al., 2006; Russell et al., 2015).

It is important to note that during prolonged match play, i.e. into extra/over time and penalties, blood glucose concentrations will fall and if not replenished may result in hypoglycaemia (Foskett et al., 2008). Symptoms of hypoglycaemia include sub-optimal functioning of the central nervous system, which might have implications for physical and technical skill performance (Vergauwen et al., 1998; Nybo 2003; McRae & Galloway 2012).

The preservation of blood glucose concentrations appears preferential when executing complex skills that require high levels of central nervous system activation, particularly during high intensity intermittent activity (McMorris & Graydon 1997; Winnick et al., 2005). Therefore, it is reasonable to conclude that maintaining blood glucose would maintain "skill execution" under circumstances of fatigue and or hypoglycaemia (Harper et al., 2014).

However, it has also been suggested that carbohydrate intake before exercise may have negative consequences for performance, especially when it is consumed in the hour prior to exercise. Carbohydrate intake causes a rise in plasma insulin concentrations, which in turn lowers plasma glucose concentration and suppresses the availability and oxidation of fat as an exercise fuel.

The final result is an increased reliance on carbohydrate oxidation at the onset of exercise – leading to faster depletion of muscle glycogen stores and a further decline in plasma glucose concentration (rebound hypoglycemia) (Koivisto et al., 1981). There has been considerable publicity surrounding one study from the 1970s, which found that subjects performed worse after consuming carbohydrate in the hour before exercise than when they cycled without consuming anything (Foster et al., 1979). This has led to warnings that carbohydrate should not be consumed in the hour before exercise.

However, a far greater number of studies have shown that any metabolic disturbances following pre-exercise carbohydrate feedings are short-lived or unimportant (Hargreaves et al., 2004). These studies show that carbohydrate intake in the hour before exercise is associated with a neutral performance outcome (Jentjens et al., 2003; Jentjens & Jeukendrup 2003; Moseley et al., 2003).

Nevertheless, there may be a small subgroup of players who experience a true fatigue, associated with a decline in blood glucose levels (Jentjens & Jeukendrup 2002), if they start to exercise within the hour after consuming a carbohydrate snack. This problem can be avoided or diminished by a number of dietary strategies:

1. Consume carbohydrate 5-10 min before the start of the exercise or incorporate this into a warm-up. By the time insulin starts to rise, the exercise has already started and insulin release will be suppressed by catecholamines.
2. Consume a substantial amount of carbohydrate
3. (> 75 g) rather than a small amount, so that the additional carbohydrate more than compensates for the increased rate of carbohydrate oxidation during the exercise.
4. Choose a carbohydrate-rich food or drink that produces a low Glycemic Index (GI) response (that is, a low blood glucose and insulin response) rather than a carbohydrate source that has a high GI (producing a large and rapid blood glucose and insulin response).
5. Consume carbohydrate throughout the exercise session.
6. The type, timing and quantity of pre-event meals should be chosen according to the player's individual circumstance, experience and preference. Foods with a low-fat, low-fibre and low-moderate protein content are the preferred choice for the pre-event meal since they are less likely to cause gastrointestinal upsets (Jeukendrup & Killer 2010).

CARBOHYDRATE INTAKE DURING EXERCISE

Numerous studies show that the intake of carbohydrate during prolonged sessions of moderate-intensity or intermittent high-intensity exercise can improve endurance (i.e. prolong time to exhaustion) and performance. There is some evidence that increasing carbohydrate availability causes glycogen sparing in slow-twitch muscle fibres during running (Tsintzas et al., 1995), while alternative mechanisms to explain the benefits of carbohydrate feedings during prolonged exercise include the maintenance of plasma glucose concentration (sustaining brain function) and the provision of an additional carbohydrate supply to allow the muscle to continue high rates of carbohydrate oxidation (Coyle et al., 1986; Jeukendrup 2004). The precise mechanism remains subject to debate-however, it is likely to involve a combination of factors incorporating the maintenance of plasma glucose levels and carbohydrate oxidation rates, as well as the protection of muscle and liver glycogen stores (see (Cermak & van Loon 2013; Beelen et al., 2015), for reviews).

Important tasks such as decision-making and successful skill execution during a football match has been linked to carbohydrate intake during exercise (Russell & Kingsley 2014). Although mechanisms are currently unclear, it has been suggested that slightly higher blood glucose concentrations are responsible for an overall improvement in skill performance in football (Ali & Williams 2009; Baker et al., 2015). Bandelow et al. (2010) showed that high plasma glucose concentrations from sports drink ingestion during a football match were related to faster response speeds during several cognitive/motor skill tests, including fine motor skill, complex visual discrimination, working memory scanning, and psychomotor skill, following the football match (Bandelow et al., 2010). However, it is important to note that in this study the faster response speed in working memory came at the expense of reduced accuracy, so this may have simply been an artifact of a speed/accuracy "trade off".

A recent study reported that both a 9.6% carbohydrate solution (plus carbohydrate gel, 142 g carbohydrate/h overall) and a 5.6% carbohydrate solution (plus placebo gel, 54 g carbohydrate/h) before and at half time increased blood glucose concentrations compared with the ingestion of a placebo during a protocol which simulates football match play (Kingsley et al., 2014). Mean sprint speed was consistently faster in both the carbohydrate trials (9.6% solution: 5.73 m/s; 5.6% solution: 5.66 m/s) compared with placebo (5.58 m/s) from the start to end of 90 min. It is important to note, that it is not possible to distinguish if the improved performance was due to a dose dependent effect of carbohydrate ingestion on blood glucose concentration, as the participants also ingested caffeine (6 mg/kg body mass) with the 9.6% carbohydrate solution. A study by the same research group investigated the impact of carbohydrate (0.7 g/kg body mass) or placebo ingestion on physical and skill performance in the extra time period (Harper et al., 2016). In this study, carbohydrate was provided in the form of glucose and maltodextrin gels before extra-time only (fluid-electrolyte beverages were consumed before the exercise and at half-time in both trials). The carbohydrate trial resulted in higher blood glucose concentrations towards the end of exercise and was associated with improved dribbling precision in the extra time period (90–120 min). However, there was no attenuation of the reduction in sprinting and jumping performance observed in this time.

In a well-controlled performance trial, 11 University footballers were recruited and underwent 3 trials in a randomized order. Two of the trials involved ingesting a placebo beverage, and the other, a 7.5% maltodextrin solution. Such design improves the strength of the findings as it is more difficult for players to guess what treatment they are on. The protocol comprised of simulated match play: a series of ten 6-min exercise blocks separated by the performance of 2 of 4 football-specific tests, making the protocol 90 min in duration. The intensity of the exercise was designed to be similar to the typical activity pattern during football match play. Participants performed skill tests of dribbling, agility, heading and shooting throughout the protocol. There was a significant improvement in performance for dribbling, agility, and shooting ($P < .05$) when carbohydrate was ingested compared with placebo, with no difference in jumping height (Currell et al., 2009).

Thus, there is growing evidence showing improvements in various aspects of skill performance especially later during exercise when fatigue sets in (Baker et al., 2015). Although blood glucose concentrations have sometimes been used to explain these observations, there

may be another explanation. Recent studies have provided preliminary evidence that there are additional benefits to be gained from carbohydrate eating strategies apart from increasing fuel stores for exercise. For example, there are a growing number of investigations that have reported that mouth rinsing a carbohydrate solution (without swallowing the solution), improves exercise performance (for reviews see (Jeukendrup & Chambers 2010; Rollo & Williams 2011). The cited potential mechanisms include activation of brain areas involved with exercise regulation and reward through stimulation of receptors in the mouth.

Mouth rinsing carbohydrate has also recently been reported to benefit football specific exercise performance (Rollo et al., 2015; Kasper et al., 2016). Thus, these findings highlight the potential for both metabolic and central benefits of carbohydrate ingestion during football activity. Carbohydrate can be delivered just before a match and at half time in various forms (drinks, gels, chews, solids) and the choice may depend on personal preferences but will also depend on hydration needs. When hydration needs are high, drinks may be preferred (Chapter 6). Carbohydrate intake during and after exercise also appears to assist the immune response to exercise (Gleeson 2000; Gleeson 2006; Nieman & Bishop 2006; Nieman 2007). Cellular immune parameters are often reduced or compromised after a prolonged workout. It is reasonable to assume that acute improved immune status, via carbohydrate ingestion, may result in less sick days experienced by the player. However, this is still to be determined.

POST-EXERCISE CARBOHYDRATE INGESTION

Restoration of muscle glycogen concentrations is an important component of post-exercise recovery and is challenging for players who train and compete more than once each day or play multiple competitive matches in a week. The main dietary issue in glycogen synthesis is the amount of carbohydrate consumed, with an optimal intake for glycogen storage reported as 7-10 g/ kg BM /day (Jentjens & Jeukendrup 2003). There is some evidence that moderate and high GI carbohydrate-rich foods and drinks may be more favourable for glycogen storage than some low GI food choices (Jentjens & Jeukendrup 2003).

In addition, glycogen storage may occur at a slightly faster rate during the first couple of hours after exercise (Ivy 2001). However, the main reason for encouraging a player to consume carbohydrate-rich meals or snacks soon after exercise is that effective refuelling does not start until a substantial amount of carbohydrate (~ 1 g/kg BM) is consumed. When there is limited time between matches (<48 h-72 h) it makes sense to turn every minute into effective recovery time by consuming carbohydrate as soon as possible after the first session. However, in general the player can afford to follow their preferred and practical eating schedule as long as goals for total carbohydrate intake are met over the day. Under these circumstances muscle glycogen can be restored to resting levels, 24 h after exercise (Parkin et al., 1997). Interestingly, recent studies have suggested that the rate of muscle glycogen re-synthesis may be slowed following competitive high intensity intermittent exercise i.e. a football match. It has been demonstrated that glycogen synthesis is impaired after muscle-damaging eccentric contractions and has been associated with reductions in GLUT 4 content and translocation as well as reduced glucose uptake. Glycogen stores were reported to be lower than pre-match concentrations 48 h post match, despite the ingestion of a high carbohydrate diet (Bangsbo et al., 2006; Krustrup et al., 2011). Football-specific activities, such as frequent changes in direction and decelerations from sprints, have a high eccentric component. Eccentric contractions in combination with contact between players results in muscle damage, which in turn may impair glycogen synthesis (Krustrup et al., 2011). This is particularly important because exercise with muscle damage may increase glycogen utilisation, thus making glycogen loading before exercise even more important (Hughes et al., 2013).

This phenomenon is not alleviated by a diet high in carbohydrate and whey protein (Gunnarsson et al., 2013), despite certain amino acids having a potent effect on the secretion of insulin, which is a stimulator of glycogen re-synthesis (van Loon et al., 2000). Nevertheless, recovery goals also include attention to the immune system, muscle building and injury repair. Therefore, it may be useful to eat nutrient-rich forms of carbohydrate foods and drinks during the recovery period to provide a range of valuable nutrients (Betts & Williams 2010). Finally, in an attempt to speed player recovery and reduce muscle soreness, cryotherapy "ice baths" have become a common strategy adopted by many football teams. Due to the vasoconstrictive consequence of cryotherapy, concerns have risen as to whether glycogen re-synthesis would be impaired due to reduced availability of substrate as a consequence of a reduction in blood flow to the muscle.

DAILY ACTIVITY	SITUATION	CARBOHYDRATE TARGETS G/KG BM/DAY	TYPE AND TIMINGOF INTAKE
Daily Intake	Low intensity, recovery or skill based activities	3 - 5	Timing of intake should promote speedy replenishment of glycogen or to provide carbohydrate intake around the training sessions of the day. As long as carbohydrate needs are provided, the pattern of intake can be governed by convenience and individual choice. Protein and other nutrient-rich foods or meal combinations will allow the athlete to meet other acute or chronic sports nutrition goals.
Exercise	Moderate exercise program 1h per day Match day	5 - 7	
High	Fixture congestion or double daily training sessions	6 - 8	Timing of intake should promote speedy replenishment of glycogen or to provide carbohydrate intake around the training sessions of the day. As long as carbohydrate needs are provided, the pattern of intake can be governed by convenience and individual choice.
ACUTE EXERCISE OCCASION	**TIMING**	**CARBOHYDRATE TARGETS**	**ADVICE**
Before Match Play	3-4 h before exercise < 30 min before match	2.5g / kg BM 25 - 30g	The timing, amount and type of carbohydrate foods and drinks should be chosen to suit the practical needs of the event and individual preferences/ experiences. Choices high in fat/protein/fibre may need to be avoided to reduce risk of gastrointestinal issues during the event. Low GI choices may provide a more sustained source of fuel.
During Training Short Duration Exercise	<30 min before match	-	Timing of intake should promote speedy replenishment of glycogen or to provide carbohydrate intake around the training sessions of the day. As long as carbohydrate needs are provided, the pattern of intake can be governed by convenience and individual choice.
During Training Continuous High Intensity Exercise	30 - 60 min	Small quantity needed / mouth rinse	Players may benefit from rinsing their mouths with carbohydrate solution
During Match Play	90 min (120 min extra time)	30 - 60 g/h	A range of drinks and sports products can provide easily consumed carbohydrate. A range of everyday dietary choices and specialised sports products ranging from liquid to solid may be useful. The player should practice carbohydrate inake during training before adopting in competition. This will help determine their individual goals and preference considering hydration needs and gut comfort.
Post-Match Intensive Training	← 8h recovery between two demanding sessions or playing 2-3 competitive games per week	1.0 - 1.2g in the 4 hours post exercise, then resume daily carbohydrate needs	The player should practice to find the fueling plan that suits their individual goals including hydration needs and gut comfort.

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Table 5.1.. Daily and acute carbohydrate needs for fuel and recovery
Daily guide for carbohydrate intake in relation to exercise requirements. Adapted from Burke et al. (2011). These recommendations should be refined with individual considerations of total energy needs, specific training needs and feedback from training / competition performance. The acute guidelines are designed to promote high carbohydrate availability to promote optimal performance in key training sessions and competition (Burke et al. 2011).

SUMMARY

In summary, football activity reduces the body store of glycogen which is a cause of fatigue, leading to a decrease in the general work rate during training and matches. Ingesting appropriate quantities of carbohydrate daily and acutely around training and matches (Table 5.1) ensures that muscle glycogen stores are well stocked and helps delay fatigue. There is sufficient evidence for the players to develop a personalised exercise nutrition plan to combine their carbohydrate needs with their preferences (Burke et al., 2011). This includes carbohydrate ingestion in a pre-exercise meal, during exercise (to support performance) and post exercise to accelerate the rate of glycogen re-synthesis. The carbohydrate nutrition plan should be practiced in training before adopting in competition and formulated in the context of other nutritional requirements, such as fluid and protein

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