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Nutrition and supplementation in football - practical guidelines based on current literature review

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Abstract:
It is said that football matches are the second most important thing in the world. Football is currently one of the most popular sports and brings record numbers of people together in stadiums and in front of TV sets. For many years, players were allowed to consume the products they preferred at the times they subjectively deemed appropriate. However, today's soccer has evolved due to self-improvement and players following elite athletes. This change in approach to the sport has coincided with an increase in the pace and intensity of top soccer games over the past two decades. In addition, the commercialization of the sport has resulted in increasing demands and continually increasing the level of sportsmanship. Nutrition is an important part of the sports training program. International guidelines, based on scientific research, recommend amounts, types and timing of food intake to ensure excellent training while reducing injuries and trauma. In order to achieve metabolic optimization, there must be a balance between nutrition, training, and recovery. Energy should be provided from optimal sources, and maintaining an adequate energy balance is critical for those who engage in physical activity, especially professional athletes. Supplements and foodstuffs for special nutritional purposes are widely used, so knowledge of the indications for their use, as well as the risks posed by inappropriate use, is essential.

Key Words: football, supplementation, athletes, nutrition

Background

Football is a sport that is constantly evolving as the physical and technical demands of match loads increase. Proper nutrition plays an important role in optimizing physical and mental performance among elite players during training and matches and maintaining good health throughout the season. Appropriate nutritional choices can support the health and performance of football players, but in recent times, the rapid development of the game itself and increased interest in the topic of nutrition in the field have led to uncertainty about appropriate nutrition solutions [1].

In 2020, the Union of European Football Associations (UEFA) brought together experts in sports nutrition research and practitioners working with elite football clubs, national associations and federations to issue an expert statement on numerous nutrition topics relevant to elite athletes. More than a decade ago, the first statement was issued, but in recent years an intensified amount of scientific research has necessitated an update as to the relevance and veracity of the guidelines at the time [2].

Nutritional recommendations

In recent years, there has been an upward trend in the physical and technical demands of football, and a similar trend applies to the financial consequences associated with winning or losing. Training regimens are therefore modified accordingly, resulting in increased loads to adapt the player to match demands [3,4]. The increase in the number of matches results in an increase in the risk of injury, moreover, players play matches at different times, adapted to television programs. The travel required to compete in international matches also places significant logistical demands. Continental, as well as intercontinental matches and the migration of foreign players, result in cultural differences in terms of nutrition as well [2]. In addition, there are many ambiguities and limitations regarding nutrition. For example, the RDA value is the average daily intake sufficient to cover the nutrient requirements of 98% of healthy people comprising a population, but it is not clear how these values should be interpreted in assessing the daily intake of football players and other sports groups [5].

UEFA-appointed experts endorse and support the "food first" philosophy, which states that food is the basis for proper functioning of the body in situations of exertional stress, and supplements can only support an appropriate nutritional strategy [2].

There are several limitations that cause complications in establishing dietary recommendations. The first is related to the small number of football-related studies, in addition, laboratory models developed to simulate the game are unable to replicate match requirements. Consequently, results must be extrapolated from different sports and simpler activities. It is a matter of record that when football is used in scientific research, the study group is made up of people who recreationally practice the sport. Very little data comes from elite athletes. In addition, the methodology used to assess football players' eating habits and nutritional status is often flawed and does not provide reliable information. It should also be noted that studies that show positive results are more likely to be published, for this reason, studies often present a false picture of the effectiveness of nutritional interventions especially when supplements are used [2-4].

The football season is divided into three periods: the preparation period, the starting period, and the transition period. Despite many years of research into the physical demands of match play, the exact analysis of the habitual training load of professional football players is still being learned [3,6]. The data obtained to date show that training loads are lower than match loads. The total distance covered in the case of training is less than 7km, while during a match the players cover 10-12km [6], the distance of fast running during training does not exceed 300m in a match situation is more than 900m. The same is true for sprinting distances, for training it is less than 150m, while during a match it is more than 200m [7], the average speed during training is less than 80 m/min, and during a match it increases to 100-120 m/min [3]. Total daily training loads depend on several factors including the phase of the season, the player's position, coaching philosophy, match frequency, athletic status, and the player's training goals i.e. rehabilitation after injury or manipulation of body composition [8]. In a traditional in-season scenario, where one match per week is scheduled, players may perform four to five on-field training sessions, where the total training load will be distributed periodically throughout the weekly microcycle depending on the proximity and relevance of the match. Players can perform additional off-field training an example is weight training [3]. It is worth noting that training sessions in the gym and on the field may not always be conducted in a systematic and orderly sequence, which can affect players' habitual macronutrient intake. Both the daily intake and distribution of macronutrient intake can affect performance, recovery, and modulate training adaptations [2].

Energy requirements in football

During a football match, players perform a variety of activities from walking to sprinting, changes of direction, jumping, striking the ball as well contact with the opponent [9]. In field players, the heart rate is maintained at an average of 85% of maximum heart rate and average relative exercise intensity at 70% of maximum oxygen uptake (VO2 max) throughout the match. These values correspond to an energy expenditure of ~1300-1600 kcal, with carbohydrates accounting for 60-70% of the total energy supply. Total energy expenditure was estimated at ~3500kcal [10].

Guidelines for the timing and amount of macronutrient intake in an athlete's diet should be supported by knowledge of how training and nutrient interactions affect energy systems, substrate availability, and training adaptations [1]. Physical activity is driven by an integrated series of energy systems that include anaerobic (phosphagen and glycolytic) and aerobic (fat and carbohydrate oxidation) pathways, using endogenous and exogenous substrates. Adenosine triphosphate and phosphocreatine belonging to the phosphagen system provide a rapidly available source of energy for muscle contraction, but not at a level sufficient to provide continuous energy supply for more than ~10 seconds. The anaerobic glycolytic pathway rapidly metabolizes glucose and muscle glycogen through the glycolytic cascade and is the main pathway supporting intense exercise lasting 10-180 seconds [11]. Since neither the phosphagen pathway nor the glycolytic pathway can meet the energy requirements to allow the muscle to contract at very high rates for events lasting longer, aerobic pathways provide the primary fuel for events lasting longer than ~2 minutes. Major substrates include muscle and liver glycogen, intramuscular lipids, adipose tissue triglycerides, and amino acids from muscle, blood, liver, and intestine [1,12].

When oxygen becomes more available to working muscles, the body uses more aerobic pathways and less anaerobic pathways [1,12]. Greater reliance on aerobic pathways does not occur suddenly, nor does the body ever rely solely on one pathway. Intensity, duration, frequency, type of training, the athlete's level of training, as well as prior nutrient intake and substrate availability, determine the contribution of pathways [11].

An athlete's skeletal muscle has remarkable plasticity, allowing it to respond quickly to mechanical loads and nutrient availability, resulting in metabolic and functional adaptations to specific conditions. These adaptations have implications for nutritional recommendations for performance according to which energy systems should be adapted during different types of training to ensure the most economical use of fuel during exercise, other strategies should ensure adequate substrate availability [13]. Adaptations that increase metabolic flexibility include increasing the number of transport molecules that deliver nutrients across membranes to their site of utilization in the muscle cell, increasing the number of enzymes that activate or regulate metabolic pathways, intensifying the ability to tolerate metabolic byproducts, and increasing fuel stores in muscle. Some muscle substrates-for example, adipose tissue-are present in relatively large amounts, while others may need to be manipulated as needed, for example, carbohydrate supplementation to replenish glycogen deficiencies after training [1,14].

During exercise, muscles consume energy at a rate directly proportional to intensity. During the activity, working muscles convert chemical energy into kinetic energy and heat, which must be dissipated through thermoregulatory mechanisms [15]. Energy is generated aerobically when oxidative processes of carbohydrates and fatty acids take place in muscle cells resulting in the production of ATP (a direct source of muscle energy). Even after intense exercise, ATP concentration drops only from ≈25.0 to ≈16.0 mmol/kg-1 dry weight, while phosphocreatine, the direct source of ATP resynthesis, drops significantly from ≈79.0 to ≈20.0 mmol/kg-1 dry weight. ATP concentration appears to be insensitive to training. ATP can also be produced by anaerobic metabolism through the phosphocreatine and glycolytic pathways [11,15].

Macronutrient requirements

Food provides essential nutrients to maintain body functions, and ensure proper functioning and growth. Food contains essential nutrients: protein, which is important for the growth and repair of the body's tissues, fat is an important source of energy for body function and exercise, it also has an important function in isolation, carbohydrates are the main source of energy for high-intensity activity. Minerals and vitamins present in food control metabolic processes and act as bioregulators. Although water is not a nutrient, it is essential for life as it supports the body in metabolizing nutrients efficiently. The aptly planned nutritional care of football players aims to provide adequate amounts of energy, supply the necessary components for recovery and repair, and ensure proper hydration [16].

It is well known that nutrition plays an important role in the training process. Athletes often seek to improve performance and use a variety of erogenous aids to enhance performance. An ergogenic aid is defined as any training technique, mechanical device, nutrient, practice, pharmacological method, or psychological technique that can improve physical performance or enhance training adaptations [17]. Ergogenic agents can help prepare an athlete for exercise, improve exercise performance, accelerate recovery from activity, or help prevent injury during intense training. Often, however, adjusting a standard diet to meet an athlete's needs would be sufficient. Although macronutrients cannot be directly classified as ergogenic aids they certainly have ergogenic effects [18]. Studies have shown that carbohydrates consumed immediately before or after exercise enhance an athlete's performance by increasing glycogen stores and delaying fatigue. Proteins can play an anabolic role by optimizing body composition. In addition, nutrition plays an important role in normal growth and development, maintaining health and well-being, and reducing the risk of illness, injury and disease. An optimal diet can avoid possible health complications. In addition to reduced performance, poor nutrition can hurt body function [17].

Carbohydrates

Carbohydrates are of great interest in the nutrition of physically active people because they have many special characteristics and play an important role in achieving high performance and adaptation to training. First, the size of the body's carbohydrate stores is relatively limited and can be highly manipulated each day through appropriate food intake or even a single training session [14]. Second, carbohydrates are a key fuel for the brain and central nervous system, as well as a versatile substrate for muscle work, where they can provide support during the exercise of a wide range of intensities through their use in both anaerobic and aerobic pathways [19]. In addition, there is evidence to suggest that performing with greater efficiency prolonged, uninterrupted or intermittent high-intensity exercise is possible through a strategy that maintains high carbohydrate availability (matching glycogen stores and blood glucose levels with fuel requirements during physical activity). At the same time, depletion of stores is associated with fatigue in the form of reduced work rate, impaired concentration skills, and increased perception of effort. These findings form the basis of various dietary strategies that provide carbohydrates before, during exercise, and during recovery between efforts to increase carbohydrate availability [14].

Recent work has shown that in addition to its role as a muscle substrate, glycogen plays an important direct or indirect role in regulating muscle adaptation to training [20]. Both the amount and distribution of glycogen in the muscle cell affect the physical, metabolic and hormonal environment in which the signaling response to exercise is elicited. For example, starting a series of endurance exercises with low muscle glycogen content triggers the activation of several mechanisms. These strategies improve cellular outcomes of endurance training, such as increased maximal mitochondrial enzyme activity and increased rates of lipid oxidation, along with increased responses that can be explained by increased activation of key signaling kinases, transcription factors, and transcriptional coactivators [21]. Considering the integration of such nutritional strategies along with the periodization of the training program are becoming an established part of sports nutrition practice [20,21].

Given the role of muscle and liver glycogen in supporting energy production during matches, it is important to consider their relevance in achieving training goals [22]. Unfortunately, there is a lack of specific data on muscle glycogen utilization during typical football training on the field, making it difficult to develop clear guidelines for carbohydrate intake beyond suggesting that they differ from the demands of match play [23]. Some conclusions can be drawn from a study of the energy expenditure of English Premier League players during a seven-day microcycle during the season, consisting of two matches and five training days. The average daily energy expenditure of players playing on the field was estimated at ~~3500kcal [10], and the energy expenditure of goalkeepers was ~600kcal less. In these studies, the average daily energy intake reported by players was comparable to energy expenditure and body weight did not change during the evaluation period. Players reported adjusting their daily carbohydrate intake according to the observed load, with ~4 and 6g/kg of body weight consumed on training days and match days, respectively. Given the importance of muscle glycogen in post-match preparation and recovery, it is recommended that athletes increase their carbohydrate intake on the pre-match, match, and post-match days to 6-8g/kg body weight. However, it is important to note that even with an intake of ~8g/kg body weight, the muscle glycogen content of type II fibers may not be completely restored even 48h after a match [24]. Alternatively, given the lower daily loads on typical training days (one session per day in a microcycle with one match day) combined with the fact that athletes typically do not perform any additional physical activity outside of the club, a daily carbohydrate intake of 3 to 6g/kg body weight may be sufficient to replenish energy and recovery [10].

Thus, most athletes do not require carbohydrate intake during training, but this is dependent on the duration and intensity of the training session, the timing of training relative to the last meal, and the potential benefits of stimulating the gut during exercise with carbohydrates to better absorb and tolerate intake during matches. Depending on the training scenario, match schedule, and athlete-specific training goals, daily carbohydrate intake on training days should range from 3 to 8g/kg body weight per day [1,11].

Protein

Systematic football training stresses musculoskeletal and tendon tissues so there is a need to repair protein-containing structures to maintain and improve their integrity and function. The requirement for the general European population is at the RDA level of 0.8g/kg body weight per day [25]. Current data suggest that a protein intake of 1.6 to 2.2g/kg body weight per day improves adaptation to training [26]. A higher intake may only be reasonable for short periods during intense training or during reduced energy intake. A mixed diet when energy intake is sufficient to meet training requirements will allow protein requirements to be met at an adequate level. Most players report protein intake at the required level. In professional English Premier League players, the reported daily protein intake was 2-2.5/kg of body weight per day and was consistent over a 7-day training microcycle [10]. Daily protein intake should be achieved through properly staggered meals containing moderate amounts of high-quality protein throughout the day [1]. With proper diet planning, protein supplements are not necessary for most football players, but they are a convenient and rapidly absorbed alternative to food, especially in the post-workout period [2]. When a protein supplement is consumed at 0.3-0.4g/kg body weight per meal, it is a good choice due to its high leucine content and digestibility. The benchmark is that an athlete should consume 3-4 meals containing protein at ~0.4g/kg body weight per meal, which is 4 meals would provide a supply of ~1.6g/kg body weight of protein per day [26]. An important issue is protein quality, which is related to several factors including leucine content. Leucine is an amino acid that acts as an activator for muscle fiber synthesis, the optimal intake of this amino acid oscillates in the range of ~2.5g per meal [27]. Consuming 25g of whey protein, 140g of lean beef or poultry or 5 eggs provides the recommended amount of leucine per meal. Plant-based proteins can also be successfully consumed by athletes, but a higher amount must be consumed compared to animal-based proteins to achieve the same effect on muscle protein synthesis [26].

As in the general population, football players often consume protein-containing meals at inappropriate times. The largest amount of protein is provided in the evening meal, i.e. dinner, decreases sequentially in the lunch meal, and breakfast and the smallest amounts are present in snacks. This potentially meets the optimal amount of protein that should be consumed during the day (~1.6g/kg body weight/day) however, this solution does not optimally stimulate protein synthesis [28]. Another important issue related to the timing of meals is the consumption of protein before bedtime. Nighttime is a natural phase of recovery and yet it is a time when nutrient intake is extremely low or non-existent. Preliminary data suggest that protein intake of ~0.4g/kg body weight within 3 hours before bedtime in a full meal or ~0.5g/kg body weight if a protein supplement is consumed about 1-2h before bedtime improves training adaptation during periods of high training volume [1,28]. Professional football players have reported intakes as low as 0.1g/kg body weight during this period, indicating the need for improved nutritional choices that can potentially improve training adaptation. During energy restriction, protein requirements increase due to the catabolic environment created by the energy deficit. It seems reasonable, therefore, to increase protein intake in these cases to a value of 2.0-2.4g/kg body weight per day, depending on the training load and other metabolic stresses, e.g., weight loss or recovery from injury [29].

Fat

Fat is an essential component of a healthy diet, provides energy, is an important component of cell membranes, and facilitates the absorption of fat-soluble vitamins [1]. An adequate intake of linoleic acid and α-linolenic acid is 10% of the total dietary energy intake of physically inactive people [30]. Athletes should adjust fat intake to allow for protein and carbohydrate requirements about overall energy goals. In addition, guidelines for limiting trans fatty acid intake and prudent use of saturated fatty acids should be followed. This usually leads to a fat intake of 20-35% of the daily total energy value of the diet [2]. Fat intake by athletes should be individualized based on training level and body composition goals [1]. Some athletes intentionally restrict fat-containing products out of health misconceptions. Such a phenomenon leads to limiting fat intake to <15-20% of daily energy, resulting in the avoidance of many products containing valuable nutrients [2]. Another important aspect is the interest in the ketogenic diet, characterized by a low carbohydrate supply and high fat content [31]. To date, there are no observational studies or interventions on team sports and the validity of a ketogenic diet. It has been shown that trained muscles can consume greater amounts of fat at relatively high exercise intensities (VO2 max up to 75%) when carbohydrate availability is limited. However, this is associated with increased oxygen consumption and reduced exercise economy, which may partially explain the loss of performance at higher exercise intensities. Due to a lack of evidence, low-carbohydrate and high-fat diets are not recommended for football players [32].

Hydration

The average sweat loss, fluid intake, and percent change in body weight among athletes are 1.5l/h, 0.7l/h, and 1.5%, respectively. Note that the average values distract from the significant deviations in both sweating and fluid intake behavior among athletes [33].

During physical activity, the primary mechanism of heat loss from the body is the evaporation of sweat across skin surfaces. This is an essential mechanism for controlling internal body temperature and can lead to sweat-induced dehydration. Dehydration is called the process of water loss in the body and is often described as a change in body weight during intense exercise. For example, 2% dehydration is defined as a water deficit equal to 2% of body weight. Sweating due to thermoregulation is the main source of weight loss during intense physical activity, but there are also other factors, i.e. loss of water vapor and carbon dioxide with exhaled air. We should also mention the phenomenon of water gain in the body, this occurs through the production of metabolic water and the dissociation of water from glycogen. It is assumed that relatively small changes in body weight are caused by respiration and metabolism, so for practical purposes, it is assumed that a loss of 1 kg of body weight represents ~1l of water loss [34].

Performance in football depends on many aspects of physical fitness, e.g., endurance, strength, power, and athletic ability. Dehydration can negatively affect endurance performance, and some players may be more or less susceptible, but it is assumed that the level needed to induce performance is about 2% of body weight loss [35]. Cardiovascular load is an important mechanism by which dehydration can impair performance in football. Total blood volume is reduced, and less blood and oxygen may be available to active skeletal muscle and skin to support thermoregulation. Other mechanisms may include altered CNS function, altered metabolic function, or a combination of these. The exact mechanism by which dehydration impairs performance is currently unknown [34].

Body fluid balance is the ratio of individual fluid intake to fluid loss (sweating) during physical activity. Electrolytes, primary sodium, are also lost with sweat. Electrolyte replenishment is associated with hydration, as compensating for sodium loss increases retention of ingested fluid [36].

Rehydration is an important part of post-exercise recovery. If athletes observe a weight deficit, they should aim to completely replenish fluid and electrolyte losses before the start of the next training session or match. To rehydrate the body, it is recommended to drink ~1.5 liters of fluids for every 1 kg of body weight deficit. In addition, taking fluids supplemented with sodium or eating snacks and foods that contain it helps replenish lost sodium with sweat, stimulates thirst and retains consumed fluids [36]. It is often observed that football players begin training already dehydrated, probably as a result of cumulative dehydration from previous training sessions and matches, and for this reason, daily fluid intake is as important as replenishment strategies during games [35].

Dehydration can be easily identified by observing urine color or measuring urine-specific gravity. A clear to light yellow urine color indicates normal hydration, while a dark yellow to brown color characterizes an increasing dehydration state. A urine-specific gravity above 1,020 g/ml indicates dehydration. In addition, it is important to measure body weight before and after activity to estimate the amount of fluid lost. The goal of hydration before, during, and after exercise is to prevent loss of <2% of body weight, which will limit the onset of loss of exercise capacity [34].

Matchday nutrition

The game of football involves a variety of activities alternating from walking to sprinting, spontaneous changes of direction, jumping, striking the ball, and interacting with opponents. Field players maintain a heart rate at an average of 85% of maximum heart rate, while the average exercise intensity is at 70% of VO2 max throughout the game, this corresponds to an energy expenditure of ~1300-1600 kcal [9]. The estimated energy expenditure on match day is ~3500kcal. To date, no studies have been conducted to assess the physiological requirements of goalkeepers. From the limited data available, it appears that goalkeepers perform longer pre-match warm-ups (~45-60 minutes), but the distance they cover is shorter and the amount of high-intensity exercise is lower [37]. In recent years, an increase in the technical and physical demands presented during match play can be observed in professional players. This is probably related to the tactical modifications introduced [3]. During a match, players playing in all field positions, i.e. defenders, midfielders, and forwards, have increased the number of high-intensity runs and the distance covered during these runs, the number and distance covered during sprints have increased, in addition, players make more passes and they are more effective [4]. Increased workloads and expectations for athletes make properly selected nutritional strategies even more important to support their technical and physical capabilities [4,26].

Carbohydrates and fats are fuels whose role is to provide the athlete with the energy required for training and match play. The relative contribution of these compounds depends on several factors including pre-training carbohydrate stores, intensity and duration of exercise, and the training status of the athlete. However, during high-intensity exercise, i.e. sprints and jumps, carbohydrates are the primary energy substrate and are therefore a key nutrient in an athlete's preparation for a match [37]. The pre-match day is characterized by a low training load, but carbohydrate intake should be at 6-8g/kg of body weight to increase muscle and liver glycogen stores [8]. Strategies for increasing endogenous glycogen before competition used in the past included a 7-day model involving a "depletion phase" followed by a "loading phase." However, it is now known that the muscles of well-trained athletes can super compensate for glycogen stores without a prior "depletion phase." Moreover, they can store more glycogen compared to untrained muscles [38]. Studies show that both type I and type II muscle fibers show significant glycogen depletion after games, with about 80% of fibers empty or nearly empty. Although glycogen is depleted in both types of muscle fibers, there may be specific glycogen depletion in type II muscle fibers, resulting in a loss of baseline matrix during repeated sprints [36]. In addition, low glycogen levels may contribute to impaired muscle contractility, which is related to calcium flow. It is worth noting the consequences of low muscle glycogen levels beyond providing the energy required for work. Low glycogen levels have been shown to affect the central nervous system, which can result in impaired decision-making [38]. When the schedule includes a large number of matches, carbohydrate intake should be maintained at 6-8g/kg body weight per day for 48-72h between matches to promote proper glycogen storage [10]. Given the difficulty for athletes to consume adequate carbohydrates, increased carbohydrate intake should be consciously planned at the expense of fat intake to ensure adequate glycogen levels [2].

On the match day itself, carbohydrates are again the most important factor. Ensure a supply according to the guidelines of 6-8g/kg of body weight, in addition, it is important to consume a meal containing carbohydrates in the amount of 1-3g/kg of body weight about 3-4 hours before the start of the match. The pre-match meal is particularly important to ensure glycogen stores in the liver taking into account that after an overnight fast, stores can be depleted by about 50%, which may be particularly important for matches starting at lunchtime [2]. A pre-game meal containing carbohydrates at 2.5g/kg body weight has been shown to increase muscle glycogen by 11-15% and liver glycogen by 33% within 3 hours of the meal [39]. This meal should have been easily digestible to reduce gastrointestinal problems. Studies show that high carbohydrate intake before and during a match can delay fatigue and increase the ability to perform intermittent high-intensity activities. In addition, they may affect increased dribbling speed, as observed in a study conducted on a group of young professional football players (they consumed breakfasts containing 250kcal and 500kcal including 60% of energy from carbohydrates, 135 minutes before exercise) [38].

Adequate carbohydrate and fluid intake are two major nutritional factors during a match. Studies typically report performance benefits during matches when carbohydrates are consumed during an activity at ~30-60g/hour or when 60g is consumed before each half. Therefore, it is recommended to consume ~30-60g of carbohydrates after the warm-up and again the same amount should be consumed after the first half of the match. Carbohydrate consumption also appears to improve shooting efficiency, dribbling speed, and passing [2].

Current practices of English Premier League players report carbohydrate intake at the lower end of recommended values (at ~32g/hour before and during the match). This is likely related to the fear of gastrointestinal problems during the match [10]. To minimize discomfort, carbohydrate drinks and gels may be the preferred source of carbohydrates [2]. However, there is growing evidence that carbohydrate intake may have other effects on the body, namely that it can affect the central nervous system and reduce the sensation of exertion. It has been shown that simply rinsing the mouth with a carbohydrate solution can show endurance benefits [37]. The implications of such treatment in football are still unclear, but mouth washing with a carbohydrate solution during halftime of a match has the potential football enhance performance in situations where carbohydrate intake is limited by gastrointestinal issues [40]. A special situation is matches where there is an overtime period of two 15-minute halves; in these situations, special care should be taken to ensure adequate carbohydrate supply during the match and any breaks. In addition, it is worthwhile at training sessions and low-ranked matches to develop individual protocols of management suitable for individual players [38].

The most important task after the match is to reduce the time required for complete recovery. Adequate post-exercise carbohydrate intake has been shown to maximize the restoration of muscle glycogen stores, allowing for more frequent and better quality training sessions, better training adaptation, and a positive impact on the rate of recovery [40]. Post-match meals and snacks should contain carbohydrates at ~1g/kg body weight per hour for 4 hours. Consuming drinks and snacks in the locker room, post-match meals at the stadium, while traveling, and at home facilitates intake [24]. The type of carbohydrate provided is also important; foods rich in carbohydrates with medium and high glycemic indexes appear to have some advantage in the rate of glycogen resynthesis, while the solid or liquid form does not affect the rate of reserve recovery [40]. In the situation of an athlete's reduced appetite or inability to prepare a meal, specialty foods for athletes can be a very good solution [24].

Professional football players may encounter difficulties in rebuilding glycogen reserves after evening games, which is particularly problematic in situations with busy match schedules. An intake of 6-8g/kg of body weight should be maintained within 24 hours after a match but should be extended to 48-72 hours after a match in situations with crowded match schedules. An additional strategy involving higher intake may be required in situations of muscle soreness, as glycogen synthesis is impaired in such a case [2,40]. To optimize protein synthesis necessary for fiber repair and adaptation, meals and snacks should provide 20-25g of high-quality protein at 3-4 hour intervals. There is emerging evidence that consuming 30-60g of casein protein before bedtime can positively affect nocturnal protein synthesis [41].

The effect of post-exercise protein intake on protein synthesis has been repeatedly demonstrated, but the effect of protein or branched-chain amino acid consumption on reducing post-exercise muscle soreness is small [79]. Consumption of sour cherry juice containing polyphenols has been a common nutritional intervention to accelerate muscle recovery in various sports. Studies have failed to prove improvements in recovery rates and subjective soreness. In addition, the reduction in muscle inflammation and free radical production induced by exercise can negatively affect adaptive processes in muscle, especially when high single doses of antioxidants are used [42].

Fluid intake is the only way to replenish water losses with sweat, thereby reducing the degree of dehydration. Players should try to start the match in a state of optimal hydration by consuming 5-7ml/kg body weight of fluid 2-4 hours before the start of the match. This allows excess fluid to be excreted before exercise, resulting in the urine of the desired light yellow color [2].

Sweating rates vary significantly between athletes. During training and matches, the sweating rate ranges from 0.5 to 2.5l/h. In football, the opportunity to consume fluids is limited to halftime or an unscheduled break in the match, such as when providing medical assistance to an injured player. According to the Rules of the Game 2020/21 issued by IFAB (The International Football Association Board), players may be assigned additional breaks to "cool down" the body, lasting from 90 seconds to 3 minutes, their purpose being to lower the body temperature when the games are played in special weather conditions (high humidity and temperature). In addition, breaks to replenish fluids may also be introduced, they vary in duration and their length must not exceed 1 minute. Special attention is required for matches in which overtime is played, lasting 2x15 minutes. Athletes should take in fluids in such quantities as to replenish the amount lost, but not lead to weight gain. Sodium should be supplemented additionally in situations where sweat loss is high, especially when exercise lasts longer than 2 hours. Therefore, athletes need to work with a nutritionist to develop the best hydration strategy to avoid significant dehydration, especially in warm climates [43].

Players should aim to replenish fluid and electrolyte deficits after a match. In most situations, it is possible to restore hydration and electrolyte balance with normal eating and drinking practices. In cases of dehydration <5% of body weight, 1.5L of fluid should be consumed for every 1kg of body weight lost and these fluids should be supplemented with sodium to maintain water-electrolyte balance [36].

Supplementation

As defined by the International Olympic Committee, a dietary supplement is "a food, food ingredient, nutrient or non-food compound that is intentionally taken in addition to the customary diet to achieve specific health and/or performance benefits" [44]. Athletes use supplementation for a variety of reasons, often driven by manufacturer advertising. It is important to remember that the supplement industry is driven by financial motives and responds to consumer demand and preference. There is often a lack of scientific evidence of the validity of the use of particular substances and the measurable benefits of the supplementation introduced [45].

Supplementation is an area of interest for athletes and the use of supplements is widespread in this group. The nutritional program of football players should be based on the principle of "food first," while supplements should be used only to achieve specific health and/or performance goals. Both the duration and dosage of supplementation should be monitored by a nutritionist or sports physician [44].

Vitamins and minerals

Regular training and matches can increase professional football players' demand for particular macro and micronutrients vitamins that support the body's metabolic processes [46].

Football is a sport that uses both aerobic and anaerobic energy systems. B vitamins have key functions in energy metabolism, so they are extremely important for an athlete's energy production. Athletes who meet their increased energy needs through the use of a properly balanced diet meet the body's requirement for vitamins of this group with their diet [47].

Pre-season preparation camps, a long and intense match season, and intense training sessions shape the lifestyle of football players. Although regular training has a positive effect on the activity of antioxidant enzymes, after intense training or matches, the production of reactive oxygen species (ROS) is increased, resulting in increased oxidative stress. This imbalance leads to muscle fatigue and reduced performance. Vitamins with antioxidant properties (vitamin C, A, beta-carotene) strengthen the body's defense system against free radicals. However, it has been proven that long-term use of antioxidants in the form of supplementation adversely affects the body's natural defense system and adaptations to training. It is necessary to supply these compounds from food sources through adequate consumption of raw fruits, vegetables, spices, and vegetable oils. The use and duration of supplementation during the training period should be determined by a physician and nutritionist [48].

Vitamin D is a controversial topic in sports nutrition. Inadequate serum levels of this vitamin have been found to interfere with muscle function and recovery and adversely affect the immune system. Therefore, it is important to properly identify athletes with a deficiency and implement appropriate treatment. Vitamin D can be synthesized in the skin through exposure to sunlight, while <20% of the daily requirement can be covered with diet [49]. The ability to synthesize vitamin D depends on latitude and body exposure. In many latitudes, UVB radiation is insufficient to produce adequate amounts of vitamin D, especially during the fall and winter. Black and Hispanic individuals have an increased risk of vitamin D deficiency, but paradoxically a lower risk of osteoporosis [50]. Many football players live in countries where skin synthesis is limited; in addition, they use SPF sunscreen during the summer months and therefore occasional deficiencies of this vitamin are observed in this group. Currently, the target serum 25(OH)D concentration set by the European Food Standards Agency is 50 nmol/L, but it should be considered whether it would be appropriate for athletes to increase this value to 75 nmol/L [46]. There is growing evidence that athletes are taking too high doses of vitamin D during supplementation, so supplementation with 2000IU per day of vitamin D3 and a repeat test to determine post-supplementation levels is recommended [46,49].

Anemia is a serious health problem that affects aerobic capacity and reduces the performance of football players. Vitamin B12 or folic acid deficiency can result in the development of anemia. Athletes, due to the redistribution of blood from the gastrointestinal tract to working muscles during exercise, are at risk of malabsorption of these compounds. Athletes following a vegan diet are at particular risk for vitamin B12 deficiency, and appropriate supplementation should be used in such cases, as there is no way to meet the requirement for this vitamin with the diet [47].

Iron is a functional component of hemoglobin and myoglobin, and an essential component of nonheme sulfur enzymes and heme cytochromes involved in aerobic ATP production. Therefore, iron deficiency anemia, as well as the deficiency of this compound itself, can impair muscle function and limit work capacity, leading to impaired training adaptation and reduced performance. This is extremely important in the case of football due to the high proportion of aerobic metabolism in this sport [51]. Iron deficiency in athletes is common, occurring in approximately 5-11% of professional male players [52]. Iron deficiency can be identified by a blood test and determination of serum ferritin levels. When ferritin levels are reduced and hemoglobin levels are normal, iron deficiency is determined. It is recommended to evaluate iron levels once a year in male athletes [46]. Football players should aim for an iron intake with a diet of >8mg/day. If a deficiency is found, the intake of heme iron-containing foods, i.e. animal products, should be increased, as well as vitamin C, which increases the absorption of this compound [51]. In the case of iron deficiency anemia, manifested by reduced ferritin and hemoglobin values, iron substitution should be used. Oral supplementation with iron preparations may also be indicated in patients with low ferritin levels to compensate for deficiencies [51]. Intravenous supplementation is indicated in exceptional situations, i.e., pathological impairment of iron absorption or when there are side effects after supplementation with oral preparations [52].

Calcium influences the maintenance of bone tissue, skeletal muscle and cardiac contraction, and nerve conduction. Serum calcium concentration is tightly regulated by calcitonin and parathormone regardless of intake. The largest store is in the skeleton and is activated when calcium intake is insufficient, leading to the demineralization of bone tissue. The main dietary source of calcium is dairy products, but green leafy vegetables, nuts, and soybeans also contain some amounts [46,53]. The RDA for calcium for men of the Polish population aged 19-65 years is 1000mg/day [54]. However, an athlete's diet should provide a greater supply of calcium, about 1500mg/day, in situations where calcium intake in food products is insufficient supplementation should be considered. Calcium can be excreted with sweat, despite small amounts, this can reduce the concentration of ionized calcium in serum, increasing parathormone production and stimulating of bone resorption. Consumption of 1350mg of calcium 90 minutes before exercise has been shown to mitigate calcium resorption from bone [53]. This suggests that calcium loss with sweat or urine although small may be an important factor. Therefore, special attention should be paid to athletes competing in high ambient temperatures, especially if they have low calcium intake in their diet [54].

Magnesium is a mineral involved in more than 300 metabolic reactions in the body. It participates in protein synthesis, influences normal muscle and nerve function, blood pressure, immune function, cardiac excitability, and sugar metabolism, and aids in calcium absorption. Because of magnesium's role in energy production and storage, proper muscle function, and maintenance of blood glucose levels, it has been made a highly essential part of an athlete's diet [55]. The RDA for magnesium for men of the Polish population aged 19-30 years is 400 mg/day, and for men >30 years of age 420 mg/day [56]. Athletes who do not provide adequate amounts of this element are not immune to the chronic inflammatory response, which affects health and athletic performance. Most studies report insufficient dietary intake of magnesium in athletes [55].

Special circumstances, such as the use of a low-energy diet for weight reduction, restriction or elimination of a large group of foods, or abnormal eating habits may result in insufficient intake of vitamins and micronutrients. In such situations, the use of a suitable multivitamin supplement under the care of a nutritionist may be an appropriate solution to cover 100% of the RDA for all vitamins and minerals. However, one should first try to ensure an adequate supply of nutrients with food and then consider supplementation [51].

Moreover, in properly nourished athletes, the ergogenic benefits of mineral supplementation are highly questionable and may contribute to body dysfunction. For this reason, an analysis of the athlete's nutritional status should be performed before supplementation is used, either by determining daily intake or by analyzing the blood chemistry profile. Then one can consider increasing the intake of natural products rich in deficient components or selecting a suitable preparation to supplement the diet [45].

Another group of supplements is measures aimed at improving player performance. In their statement, EUFA experts list several substances with potential benefits for football players, these include caffeine, creatine, ß-alanine, and nitrates [46].

The ergogenic properties of caffeine are well established, with studies confirming beneficial effects on performance in the interval, endurance, and resistance exercise [57,58]. There is evidence that caffeine consumption can benefit performance in team sports, with data suggesting improvements in the physical and technical elements of performance necessary for football. Caffeine consumption at a dose of 2-6mg/kg body weight improves performance in repeated sprints and jumps, reactive agility, jump height, and passing accuracy. The mechanism by which caffeine provides an ergogenic effect is likely multifactorial, with the most likely being CNS stimulation i.e., adenosine antagonism with decreased sensation of exertion and pain, increased reaction time, and improved cognitive function and mood [58]. Recommendations for caffeine supplementation in football players suggest that the appropriate dose is 3-6 mg/kg body weight in the form of caffeine anhydrous (taken in capsule or powder form) taken ~60 minutes before exercise. Another regimen involves taking the first dose of <3g/kg body weight (~200mg) before match exercise and a second dose after the first half of the match along with a carbohydrate source. To estimate the appropriate caffeine dose, start with smaller amounts and gradually increase it while observing the body's response [46]. Currently, caffeine is included in the World Anti-Doping Agency's monitoring program and caffeine may be reclassified as a banned agent [59].

Creatine as a supplement is considered one of the best studied and effective ergogenic nutrients available to athletes. Creatine supplementation increases creatine stores in muscle and can improve exercise capacity and training adaptation [60]. Creatine is a naturally occurring guanidinium compound composed of two amino acids, arginine and glycine, and is found mainly in animal muscle, with about 95% found in skeletal muscle and the remaining 5% present in the brain and testes. About 2/3 of the total pool of creatine found in muscle is phosphocreatine (PCr), and the rest is free creatine (Cr). The cellular metabolism of creatine degrades about 1-2% of creatine per day to creatinine, which is excreted in the urine. Therefore, the body needs to supplement about 1-3g/day to maintain normal creatine levels [61]. Studies have shown that the effective dose of creatine supplementation is in the loading phase ~20g/day in 4 equal portions per day for 5-7 days. This is followed by a maintenance dose of 3-5g/day in one serving for about 28 days. After chronic creatine supplementation, approximately 4-6 weeks are required for creatine levels to return to baseline [46]. It has been shown that supplementation can improve performance during high-intensity exercise, leading to better training adaptation. In addition, it can increase the rate of glycogen replenishment, which may benefit athletes performing prolonged submaximal exercise or engaging in repetitive high-intensity exercise concerning aerobic and anaerobic metabolism [61]. Creatine supplementation can cause an increase in body weight of about 1-2kg, which is associated with water rehydration. There are no adverse health effects following appropriate supplementation protocols [46].

ß-alanine is a very popular ergogenic agent, with about 61% of athletes in team sports using this supplement [62,63]. ß-alanine supplementation can increase muscle carnosine levels, increase intramuscular buffering, improve performance during high-intensity intermittent exercise, and is a World Anti-Doping Agency (WADA) code-compliant supplement [63]. The use of supplementation is a potential nutritional strategy to delay fatigue and improve performance, mainly in high-intensity exercise, during which there is a high involvement of glycolytic pathways and high hydrogen ion accumulation [62]. The recommended dose is ~65mg/kg body weight taken in a divided-dose schedule so that 0.8-1.6g is taken every 3-4h. The daily amount of ß-alanine administered should be ~6.4g and should be taken for 4 to 12 weeks. Further research is required on long-term supplementation lasting >12 weeks. A side effect of taking ß-alanine is temporary paresthesias, which can be eliminated by reducing the dose to <1g per serving [46].

Nitrate and nitrite have previously been considered inert byproducts of nitric oxide (NO) metabolism, but recent observations suggest that nitrate may serve as a precursor for nitric oxide by converting nitrate to nitrite and ultimately to nitric oxide. Studies have shown an increase in plasma nitrate and nitrite after nitrate supplementation from food in a dose-dependent manner [64]. Nitric oxide plays an important role in modulating skeletal muscle function with improved exercise performance, including reduced ATP cost for muscle force production, increased mitochondrial respiration efficiency, and increased blood flow to muscle [64]. The optimal dose has not been determined because it is an individual issue, but benefits are likely observed within 2-3 hours after a nitrate bolus containing 5-9 mmol (310-560mg). Longer periods of nitrate intake (>3 days) may also be beneficial in terms of performance, especially in trained athletes [65,66]. Foods high in nitrates include green leafy vegetables such as spinach, arugula, and root vegetables such as celery and beets, which may be the first food solution for long-term use [46].

The risk of a positive doping test resulting from the use of dietary supplements has been evaluated for two decades. Analyses by independent laboratories and analytical audits by the US Food and Drug Administration (FDA) have shown contamination of supplements with pharmaceuticals that are not visible on the supplement label [67]. The cause of the contamination is improper manufacturing processes and intentional contamination with many banned substances. Anabolic steroids are most commonly found in supplements that build muscle mass, while stimulants and anorectic agents are found in weight loss supplements. In recent years, new supplements have appeared on the market; banned stimulants have been found in workout or pre-workout boosters and endurance supplements [68]. Inadvertent doping can furthermore occur after the use of traditional Asian drugs. In football, supplements should be administered to the entire team under the supervision of a nutritionist or doctor. The same mixture or a different combination should be used for each player. WADA regulations state that if at least three players from the same team violate anti-doping rules at the same time then the entire team can be disqualified from the competition [46].

During a training or match day, players have specific guidelines that must be met to maintain high performance and adequate recovery. Due to a large number of training units and limited breaks between training or matches, athletes do not always have the opportunity to consume food in the form of meals. In such a case, foods designed for physically active people can provide a convenient alternative to achieve target nutritional values. Such products include carbohydrate-electrolyte drinks, carbohydrate gels, bars and candy for athletes, recovery shakes, protein drinks, high-protein foods, and liquid meals [46,69].

Conclusions

Correct nutritional choices and an adequate supply of nutrients are essential to support training and improve the physical performance of professional athletes. Inadequate knowledge of professional football players' nutrition can lead to inappropriate nutritional behavior. This results in disturbed energy balance, weight gain or loss, reduced exercise capacity of the body or increased risk of injury and trauma. Therefore, the use of appropriate research-backed recommendations related to the type and amount of food consumed, fluid intake, timing of consumption and supplementation are important with regard to the sports performance of football players.

Conflicts of interest - The authors declare no conflict of interest.

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