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Low- or high-carbohydrate diet for athletes?

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The paper addresses the issue of selection of nutritional strategies, i.e. low- or high-carbohydrate diets, for athletes. On the basis of recent research the authors discuss in detail both dietary models and present their advantages and disadvantages. The paper includes practical implications and one-day low-carbohydrate and high-carbohydrate sample menus.

KEYWORDS: low-carbohydrate diet, carbohydrate loading, athletes, endurance, body composition.

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What is already known on this topic?
The usability of low-carbohydrate diets in athletes still remains a controversial issue among researchers [1, 2, 3, 5, 7]. Although there have been publications on the positive effects of low-carb diets on body mass and body composition, e.g. in cyclists [1], the issue arouses mixed feelings among the majority of nutrition experts worldwide. On the other hand, the use of a high-carbohydrate diet, traditionally recommended for athletes, seems not to be the most effective solution either.

Introduction

In recent years there has been a growing research interest in nutrition and dietary supplementation of athletes [6, 7, 8, 9]. It is assumed that a properly selected diet with an appropriate supplementation regimen can greatly enhance training premises [10]. Sport nutritionists claim that appropriate nutrition and supplementation procedures can significantly contribute to the generation of energy during exercise, and accelerate the resynthesis of energy substrates and post-exercise recovery [5]. A proper diet is also an important component of pre-competitive preparation in those sports in which the athlete's body mass and composition are crucial. Most research studies on nutritional enhancement of physical performance have been concerned with high-carbohydrate diets of high energy quality utilized in sports such as road cycling, cross-country skiing, biathlon and triathlon [6, 5]. Carbohydrate loading procedures developed in the 1960s in Scandinavia are still used by athletes today in modified forms in order to ensure the optimal intake of energy substrates to augment muscle glycogen stores [7, 11]. There have been few studies examining the effects of low-carbohydrate, high-protein and high-fat diets on sport performance [1].

Low-carbohydrate diet

Many controversies regarding the relationship between low-carbohydrate diet and physical exercise are associated with the duration of following of this nutritional model by athletes. In the majority of studies the length of ingestion of a low-carbohydrate diet was 3-5 days, which is too short to trigger biosynthesis-related adaptive processes at the cellular level, e.g. lipases. The switch of high performance athletes from a mixed high-carbohydrate diet to a low-carbohydrate diet with a significant fat content is quite difficult and may last from 7 to 20 days [3]. During this transition athletes experience fatigue, and their nerve cells work less efficiently, which hinders athletes' concentration and performance of training tasks of high intensity [1].

Another important aspect of a low-carbohydrate diet is the quality of consumed fats. A diet dominated by animal saturated fatty acids may lead to gastric and mental disorders in athletes who train with high intensity [6]. Additionally, an excessive intake of saturated fatty acids increases morbidity and mortality due to higher risks of malignant tumors and atherosclerosis [1, 11].

Most international nutrition experts recommend fat consumption at about 30% of daily calorie intake. In 2009 the World Health Organization and the Food and Agriculture Organization of the United Nations [12] recommended the minimal daily fat intake of 15% and maximal fat intake of 35% of total dietary energy for sedentary individuals. Athletes are advised to consume about 30% of energy from fats [8]. However, the decisive influence on the amount of consumed fats in a sport diet is exerted by the type of practiced sport. The total daily fat intake should consist of no more than one-third of saturated fats, more than one-third of monounsaturated fats, and one-third of polyunsaturated fats. The WHO and the FAO [14] recommend that polyunsaturated essential fatty acids (PUEFAs) should supply the minimum of 3% of energy, including 2% from n-6 acids and 1% from n-3 acids. It must be stressed that excessive intake of n-6 PUEFAs is conducive to the rise in concentration of very reactive free radicals created during oxidation of fatty acids. Recent studies show that consumption of n-3 PUEFAs and antioxidants, especially vitamin E, inhibits cellular DNA damage and proliferation of cancerous cells [11]. It is therefore very important that a diet includes high-quality fats, e.g. marine fish fats and plant fats from such sources as sunflower, pumpkin seeds, corn, soy, nuts that contain high amounts of n-9 monounsaturated and n-3 polyunsaturated fatty acids whose health benefits have been described in numerous studies.

For many years there have been diverse opinions regarding the proper fat and carbohydrate content. In 2008 Accurso et al. [13] proposed the following categorization of carbohydrate-restricted diets:

- low-carb ketogenic diet (LCKD) with carbohydrate intake of less 50 g per day, i.e. 10% of a nominal 2000 kcal diet;
- low-carb diet (LCD) with carbohydrate intake between 50 and 130 g per day, i.e. 10-26% of a nominal 2000 kcal diet;
- moderate-carb diet (MCD) with carbohydrate intake between 130 do 225 g per day, i.e. 26-45% of a nominal 2000 kcal diet.

While following a low-carbohydrate diet it is recommended to consume foods rich in fat and protein, e.g. meat, fish, eggs, cheese as well as fruits and vegetables with low contents of carbohydrates, e.g. broccoli, cucumbers, tomatoes, lettuce, spinach, raspberries, nuts, and pumpkin and sunflower seeds.

Many authors argue that the low-carbohydrate diet is similar in content to the prehistoric diet, and that human beings have adjusted to it in the course of evolution [14]. The Paleolithic diet, i.e. the diet before the advent of agriculture, consisted of meat, fish, green vegetables, nuts and insects in various proportions [15]. An anthropological study of present-day tribes of hunter-gatherers revealed that the protein content in their diet amounted to 19-35% of daily energy intake, and the carbohydrate content – from 22 to 40% of daily energy intake.

Despite years of research there are still controversies regarding the effects of low-carbohydrate diets on aerobic and anaerobic performance. The most effective variant of a low-carb diet for speed-strength athletes is a weekly cycle during which an athlete adheres to a low carbohydrate diet (10-20% of daily energy intake) for 4 to 5 days, and then increases the carbohydrate daily intake to 60-70% for the remaining 2-3 days of the cycle. During the low-carbohydrate days the human body relies on fat oxidation, and the carbohydrate loading during the remaining days of the cycle enables replenishment of glycogen stores. It is necessary for performing training tasks of high intensity. In endurance sports, dominated by aerobic metabolism, longer training cycles based on low-carbohydrate diets can be planned. However, due to metabolic changes such cycles should be implemented at the pre-competitive training stage, when the training volume is high but training intensity is medium or low, in order take full advantage of fat metabolism [2].

Following a fat and protein rich diet not only has some energetic consequences but also involves endocrine changes. Some studies showed that a long-term low-carbohydrate diet containing PUEFAs, raises the blood levels of anabolic hormones such as testosterone, growth hormone (GH), and insulin-like growth factor 1 (IGF-1), and lowers the insulin level [8, 5]. At the same time, a low-carbohydrate diet does not significantly reduce speed and strength capacities, during which restoration of ATP is dominated by phosphate metabolism. In a few experiments on elite athletes, a long-term low-carbohydrate diet had no significant impact on muscle strength, but reduced the volume of performed muscle work and post-exercise lactate level, which indirectly indicated a reduced rate of glycolysis [5].

Hession et al. [4] made a systematic review of randomized controlled trials of low-carbohydrate vs. low-fat diets (at least 6-month long) published between January 2001 and March 2007. Their results revealed the dominance of low-carbohydrate diets over low-fat diets in the terms of body mass loss and reduced risk of cardiovascular diseases.

Positive aspects of following a low-carbohydrate diet:

- enhanced fat oxidation during long-lasting physical exercise;
- increased levels of testosterone, growth hormone (GH), and insulin-like growth factor 1 (IGF-1), but lower insulin concentration;
- reduction or maintenance of body mass and body fat in strength sports.

In high-performance endurance sports the low-carbohydrate diet can be applied for ultra-long (3-4 hour long) exercise, provided that muscle work intensity does not exceed 60-70% of VO_2max. However, in strength sports dominated by phosphate metabolism the low-carbohydrate diet can be followed for reducing or maintaining the body mass and adiposity.

Negative aspects of following a low-carbohydrate diet:

- varied length of human body's adaptation from a mixed diet to a low-carbohydrate diet (7-20 days);
- disturbances in the proportion of lipoprotein serum fraction;
- may increase the blood cholesterol level;
- may cause metabolic ketoacidosis;
- may limit the supply of vitamins and minerals.

Low-carbohydrate diet and arguments for carbohydrate loading

During exercise the proportions of the athlete's body's utilization of carbohydrates and fats as energy sources differ significantly. The factor deciding about the dominance of one energy source over the other is exercise duration and intensity. The shorter and more intensive exercise, the higher carbohydrate contribution to energy expenditure of muscle work [6]. In 2010, experts from the European Food Safety Authority (EFSA) proposed that carbohydrates should constitute from 45 to 60% of daily energy intake in the diet of an adult man, and more than 60% in the diet of an athlete. In both recommendations, 80-90% of carbohydrate energy should come from complex carbohydrates. In such cases, the mean carbohydrate intake amounts from 6 to 8 g per kg of body mass, and during carbohydrate loading up to 10 g per kg of body mass [8]. This considerable carbohydrate intake in the diet increases the risk of body fat mass growth. Factors that also affect body fat mass include body build type and metabolic type. If an athlete of endomorphic body type consumes carbohydrates at 55-60% of daily energy intake, including large amounts of simple carbohydrates, than – despite high daily energy expenditure – will most likely display a tendency to accumulate body fat.

Sports such as team games, track and field, swimming, martial arts, tennis, fencing, badminton, gymnastics and weight lifting involve physical exercise of high intensity, during which the carbohydrates are the dominant energy source for the working muscles [2, 8]. Considering the crucial role of carbohydrates in exercise metabolism, nutritionists worldwide have been studying all dietary aspects connected with enhancement of carbohydrate metabolism [8].

Recent research confirms that what we consume before, during and after exercise affects our performance and recovery capabilities [9]. The amount of muscle glycogen in the 70 kg body of an adult non-training man is about 450 g. In athletes following a specific exercise regimen and a high-carbohydrate diet this amount can be increased to about 900 g. An increase in the muscle glycolytic capacity improves the body performance [7, 8]. Furthermore, the use of a high-carbohydrate diet for a few days before competition increases the respiratory quotient and exercise duration until refusal as compared with a low-carbohydrate diet. The primary objective of carbohydrate ingestion before, during and after exercise is, first and foremost, to supply glucose to the working muscles [6]. The secondary aim is to supply glycogen to the liver for glycogen resynthesis.

The most crucial impact on muscle glycogen restoration is exerted by the amount and quality of consumed carbohydrates as well as by the time of their consumption [9]. Experimental studies showed that an ingestion of 25 g glucose solution at 2-hour intervals after exercise led to a 2% restoration of glycogen per hour. A glucose dose of 50 g increased the muscle glycogen resynthesis rate to 5-6% per hour; however, greater carbohydrate dosages had no effect on the glycogen resynthesis rate. These results indicate that the optimal post-exercise glycogen resythesis rate is attained after the consumption of 50 g of carbohydrates at two-hour intervals. In the first hours after exercise it is highly advised to consume carbohydrates with a high glycemic index, most preferably as fluids, that would allow a quick release of glucose into the bloodstream. In this case drinks with 6 g of glucose and other carbohydrates per /100 ml of water can be consumed. This is highly significant for athletes who train two or three times a day, and in whom glycogen restoration between the training sessions is the most decisive determinant of the body's recovery. To ensure the most efficient glycogen resynthesis, 500 g to 800 g of carbohydrates should be consumed within 24 hours after exercise.

In sports in which the competitive effort is longer than 90 min a procedure called the carbohydrate loading is recommended for athletes. It involves a 1-2-day modification of the diet and ingestion of carbohydrates at 10 g per kg of body mass per day as well as a change in training loads. In result, glycogen supercompensation takes place [16]. The positive effect of ingestion of such high amounts of carbohydrates on the body's carbohydrate loading capacity occurs only when, apart from the carbohydrates, the body is also supplied with proper amounts of vitamins, minerals and water. If an athlete does not consume the appropriate amounts of water during carbohydrate loading water is supplied from other tissues, which may lead to disturbances of body water homeostasis.

Positive aspects of following a high-carbohydrate diet:

- performance of long-lasting exercise can be prolonged until refusal;
- enhances glucose oxidation during exercise of high intensity;
- elevates the respiratory quotient;
- preceded by depletion of muscle glycogen stores, it produces the effect of glycogen supercompensation.

In practice, a great number of sports, e.g. cycling, triathlon or long-distance running, require carbohydrate loading. However, in all sports, what is important, is the last meal before training or competition [9]. This meal should contain about 100-200 g of carbohydrates and small amounts of proteins and fats. If the muscle glycogen level is supercompensated before the meal, the ingested carbohydrates can have a medium or low glycemic index. In this situation such food products as oatmeal, Basmati or paraboiled rice, pasta, or pearl barley groats are recommended [8]. They should all be properly heated but never overcooked. Such a dietary procedure guarantees gradual release of glucose to the bloodstream. If the recovery period is too short and the saturation of muscle cells with glycogen is incomplete, it is more advisable to consume carbohydrates with a high glycemic index, such as short- and medium-grain rice, millet seeds, dried fruit, e.g. dates or raisins, honey, jam and white bread [8]. These easily digestible foods enable a faster glucose release and therefore the rate of muscle glycogen restoration [8].

A significant aspect of preparation of meals for athletes are their own dietary preferences. Athletes should be able to choose the products they like, especially after training, when their appetite is curbed by elevated levels of catecholamines. If a meal is not tasty, an athlete may simply not consume it and expose his/her body to serious energy, vitamin, and mineral deficiencies.

Negative aspects of following a high-carbohydrate diet:

- accumulation of body fat;
- increased body water;
- lowered growth hormone concentration;
- disturbed proportion of lipoprotein serum fraction;
- intake of large amounts of simple carbohydrates elevates blood glucose level;
- increased appetite.

The carbohydrate intake is a key element of nutritional strategy for athletes performing exercise longer that 90 min. Researchers confirm the phenomenon of severe depletion of glycogen stores after 90-180 minutes of continuous exercise at 60-80% VO_2max [6]. The ingestion of carbohydrates during such exercise allows continuing muscle work for another 30 to 50 min at a similar intensity. Additionally, carbohydrate ingestion during such exercise delays the onset of fatigue, but does not eliminate it completely. The most easily digestible form of carbohydrate intake during exercise are 8-10% glucose or maltodextrine aqueous solutions, from 600 to 1000 ml per hour [8, 10]. The advantage of intake of such solutions is their capability of hydration of an already dehydrated body

Low-carbohydrate and high-carbohydrate one-day sample menus

Low-carbohydrate diet one-day sample menu	High-carbohydrate diet one-day sample menu
Breakfast: soft-boiled eggs, breakfast cereal: *Ingredients: eggs, soy milk, rolled oats, honey, hazelnuts, berries, raspberries*	Breakfast: omelet, toasted bread with jam, fruit, tea with honey: *Ingredients: eggs (1 whole egg, a few egg whites, light rye bread), low-sugar pineapple jam (on bread and omelet), peaches in syrup, tea, honey*
Midmorning snack: salmon tartare: *Ingredients: fresh salmon, onions, brined pickles, pickled capers, egg yolk, green pepper, lemon*	Midmorning snack: rice with yoghurt and fruit: *Ingredients: paraboiled rice, natural yoghurt, raspberries, berries, low-sugar black currant jam, pineapple juice*
Lunch: sirloin steak, steamed vegetables, rice: *Ingredients: sirloin steak, green pepper, vegetables: broccoli, cauliflower, olive oil, wild rice*	Lunch: spaghetti pasta in tomatoe sauce with tuna, juice: *Ingredients: spaghetti pasta, tuna chunks in brine, olive oil, canned tomatoes, tomato puree 30% , garlic, onion, oregano, sea salt, beetroot juice*
Snack: mix of nuts *Ingredients: hazelnuts, walnuts, cashew nuts*	Snack: banana-strawberry-honey cocktail: *Ingredients: ripe bananas, strawberries, soy milk, honey, maple syrup*
High tea: shrimp salad with olives and mozzarella *Ingredients: cooked or grilled shrimp, lettuce, cherry tomatoes, mozzarella cheese, green olives, lemon juice, spices, olive oil*	High tea: millet seeds with berries: *Ingredients: millet, apple juice, black currant nectar, berries, blackberries, raspberries, natural yoghurt, maple syrup*
Supper: mackerel and vegetables with low GI: *Ingredients: smoked mackerel, radishes, brined pickles*	Supper: roast cod with herbs and rye crispbread: *Ingredients: cod fillet, lemon, olive oil, spices: thyme, rosemary, sea salt, rye crispbread*

and prevention of hypothermia. It is very important in sport practice, especially in the last minutes of training or competition, for example, for cross-country skiers who often compete in adverse weather conditions and their sport discipline requires performance of maximal physical exercise until the very end of a competition. In their case ingestion of carbohydrates at the last stage of competition enables the skiers to continue their muscle work with the maximal intensity for the whole duration of the competition.

Conclusion

Since it is rather difficult to determine which nutritional model is appropriate for athletes, the correct dietary choice should account for a number of factors such as:
- type of sport;
- body build type;
- metabolic type (basal metabolic rate – BMR);
- dietary preferences;
- volume and intensity of training loads (e.g. preparatory or competitive training stages).

The low-carbohydrate diet is recommended for athletes, who mostly perform physical efforts with a medium and high intensity at 60-75% VO_2max. In the case of high-intensity exercise the energy demand increases, therefore during muscle exercise over 80% VO_2max, the athlete's diet should contain much greater amounts of carbohydrates. The most important aspect of selection of an appropriate dietary strategy for athletes is individualization of nutrition and supplementation.

What this paper adds?

The authors propose introducing some radical changes in nutritional strategies for athletes and stress individual approaches to developing athletes' diets and supplementation regimens.

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