Carbohydrates Energy Reserves as a Factor of Recovery after Training and Competitive Efforts

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Abstract: In physical education and sport recovery is assured by using many resources / natural or artificial exercises, related to the restoration of performance capacity after exercise or competitive activity. At present there is an intense accumulation of data on direct measurements of carbohydrate exchange. Purely anaerobic physical efforts, in a sense, are better known, understood and assimilated than aerobic ones. For anaerobic competition exercises is important not only to accumulate energy substrates but also to keep them intact until the real competition. Particularly, it is obligatory to achieve this imperative in short-term movements: jumping, throwing, weight lifting, key episodes of battles. However, there is felt a lack of synthesis work, which would contain thoroughly verified information, because only in this case are possible new formulations of the principles of practical use of the scientific results. Thus, the basic energy substrates for aerobic efforts are glycogen and lipids. The limited character of energy reserves of carbohydrates is a factor that regulates sports performance in aerobic physical effort. This is why increased attention is paid to the carbohydrate saturation food problems. Sports that require maximum and sub-maximal values of force, up to the values that are available to the world's elite and shall be carried out in 20-30 minutes, represent sports genres where carbohydrate-based energy is predominant, and the genetic traits of athletes are manifested by means of maximum levels of energy exchange: anaerobic and aerobic ones.

Keywords: *training effort; bioenergetic resources; carbohydrates; anaerobic and aerobic competition exercises; spectroscopy.*

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In many of the training and competitive efforts, energy reserves are made up of carbohydrates. This is determined by the need to develop a high physical performance in sport activity, as well as to maintain it in a certain amount of time. Consequently, the use of concrete bioenergetic resources must meet the criteria of the required physical performance that the individual can achieve ($N_{\max}$) and of the manifestation time ($t_{\lim}$). The criterion of maximum possible physical performance is sufficiently clear. It represents the speed of transformation of energy during a concrete movement. Of course, it is absolutely different if the energy reserves used are different.

If the human performs an effort with a certain force, it gradually becomes exhausted the energy substrates that ensure its production, namely the depletion of carbohydrate reserves. Subsequent effort can be made based on the use of basically inexhaustible lipid substrates. During fat burning, however, the rate of energy generation can only reach up to 60% of that which is possible during the use of glycogen or simultaneous of glycogen and lipids. If aerobic effort is longer, intracellular triacylglycerol endogenous reserves are gradually exhausted and, as reservoirs of oxidation metabolism, an increasingly important role is played by the free fatty acids which are assured by the blood. This further reduces the physical performance of the athlete (Manolachi, 2018).

Thus, taking into account the bioconversion of energy substrates, the athlete can develop a fairly high physical performance. It is determined by the speed of energy transformations.

The time-limit $t_{\lim}$ of maintaining the proper force $N_{\max}$ is determined by the reserves of the respective substrates of the energy change and the resources of the body making this change.

The values of these criteria can be and are determined by means of control tests. Subjects are required to perform a volume of effort with a certain force on the methodologically perfect veloergometers and record the maximum time of maintaining that force. The moment of considerable reduction is considered the time - limit $t_{\lim}$ for that force. In turn, this force is recognized as $N_{\max}$ for that time. If necessary, a wide range of athletes' force is tested: the stronger, the better. In this way, the $N_{\max}$ range is determined and the $t_{\lim}$ is preferable for the individual, which is very important for the exact choice of the sports trial and sports specialization. If the technical means of measurement and testing are missing, the athlete is tested in field conditions: running with constant speed, walking or running in the slope, etc. Methodology and evaluation of results are identical to those used in technical testing. The methodical particularities of the simplified $N_{\max}$ and $t_{\lim}$ notions are presented more detailed in our paper (Manolachi, 2012).

Of course, the measured values of criteria in whole body tests do not directly reflect the speed of the energy change as a whole, nor the one that occurs in the active muscles in particular, that is, the force in the bioenergetic sense. We have to comply with this situation because accurate measurements go beyond the limits of practical sports training conditions.

This also refers to the appreciation of resources, reserves of energy substrates, which is the basis of the meaning of the term t_{lim} . In this respect, a significant theoretical support is knowledge of the classification of physical effort according to the force with which it is performed.

The main division is: anaerobic and aerobic efforts, with considerable differences between them.

Anaerobic processes in active muscles essentially result from closed systems. The probable force and duration of effort are predetermined by the internal reserves of energy substrates: ATP, CP, glycogen. But for different people and for every individual, at some point, these reserves are in a larger or smaller volume. The trained individuals are assumed to have larger reserves. In addition, they spend them much more efficiently: thanks to biochemical adaptation, due to rationally structured movements and fair competitive behaviour. These are particularly important for anaerobic competitive exercises (Manolachi, 2012). It is problematic to hope for large quantitative reserves of anaerobic bioenergetic substrates in the muscle. On the other hand, multi-annual training is accompanied by a whole complex of changes in biochemical adaptation mechanisms. The most important are: adaptation of fermentation systems, adaptation of the fermentative environment, adaptation of the metabolic pathways performance (Fig.1). Obviously, these are done in a closed interdependence.

Fig.1. Multi-annual training is accompanied by a complex of changes in biochemical adaptation mechanisms

Is it possible to increase the reserves of anaerobic substrates for concrete exercises? Above we mentioned that excessive accumulation of substrates in muscle cells is difficult: there are limits to such accumulations (homeostasis, energy cycles, etc.). However, the problem can be solved indirectly by providing maximum or optimal hypertrophy of the muscles or of particular actions or even of special motor units that ensure the competitive exercise. From the point of view of providing substrates, hypertrophy represents a considerable quantitative increase. This approach has an incontestable biological confirmation (Maughan, Gleeson, Greenhaff, 1997).

For anaerobic competition exercises it is important not only to accumulate energy substrates but also to keep them intact until the real competition. It is especially necessary to achieve this imperative in short-term movements: jumping, throwing, weightlifting, key episodes of battles etc. (Fig. 2).

Fig. 2. Short-term movements for competitive anaerobic exercises

In this respect, a special impression is created by weightlifting competitions, if the TV operator surprises the athlete in all stages of the competition. The athlete is obliged to concentrate all the energy accumulated in a single lift movement of unusually high weight. At the same time, the athlete actively tends to catch the moment when his body is absolutely ready

to do the maximum effort. The difficulty lies in the fact that there are no direct signals to achieve the "energy explosion" in the true sense of the word. A simultaneous combination of muscle effector signals, the leading of vegetative processes, a timely secretion of hormones, mediators, "inclusion" of fermentation processes is required. In such movements, the expression "energy explosion" is almost not a metaphor: the level of energy expenditure increases instantly with a third-order power (≈ 2000 times), fact reflected by the experimental data quoted above. We also mention that movements performed with supramaximal force are not made from static positions. Often, prior to the main movement, athletes execute rhythmic, balancing preparatory movements: the weightlifter flexes their feet a few times at their own pace, trying to "catch" the right moment for the final move; the athlete who is about to perform a jump before the momentum, moves from one foot to the other, running in small steps, anticipating it in mind. By the way, similarly the representatives of the feline family prepare for their decisive jump upon their prey.

From this point of view, the beginning of the speeding run from the absolute sedentary start position - the mandatory competition rule - is incorrect. This shift from total immobility to supramaximal energy expenditure is unnatural.

Purely anaerobic physical efforts, in a sense, are better known, understood and assimilated than aerobic ones. Information on these processes is available in accessible teaching and methodological literature (see relevant physiology guidelines, biochemistry for sporting institutions). It can be said, however, that current scientific research, and in this direction, will allow to concretize many of the insufficiently analysed issues. This takes place with the accumulation of data on the direct determination of the kinetics of the exchange of macro-energetic substances in "in vivo" efforts using nuclear magnetic resonance (NMR). NMR spectroscopy allows to study the reactions of metabolism directly in living tissues and organs. Macroergic substances contain phosphorus, a substance useful for carrying out NMR. It provides peaks that are accurately identifiable in the NMR spectrum depending on its chemical environment. In this way, is measured the content and kinematics of the ATP, DNA, AMP, CP exchange or phosphorylated derivative carbohydrates (Shulman, 2012).

NMR spectroscopy is based on the fact that nuclei of odd-numbered nucleons (protons and neutrons) possess magnetic properties that transform each nucleus of this type into a magnetic bipolar with a certain orientation. Respectively, in living tissues there are natural signs for NMR: proton (^1H), phosphor (^{31}P). For research into the kinetics of carbonate carbohydrate

metabolism, it is necessary to introduce in their body the carbon "signs" ^{13}C (Shulman, 2012).

At present there is an intense accumulation of data on direct measurements of carbohydrate exchange. However, there is a lack of synthesis work, which would contain thoroughly verified information, as only new formulations of the principles of practical use of scientific results are possible.

Aerobic physical efforts differ principally in the fact that the energy supply of the muscles is achieved in an open system. During the effort, they are supplied with blood, due to which they acquire energy substrates and other compartments (parts) of the body. Therefore, the total amount of energy during such an exercise depends both on the endogenous muscle reserves of the substrates and on the "external" supplies. Aerobic efforts of short or longer duration are generally provided by red and intermediate muscle fibres. Naturally, the forces demonstrated in these cases (i.e. $N_{\max}$ for this range of efforts) depend on the potential for catalysing their oxidative systems and the opportunity, the force of the "deliveries" of external substrates (Manolachi, 2018).

The basic energy substrates for the aerobic efforts are glycogen and lipids. In red and intermediate fibres there are "fuel" reserves of both types - in the liver, in the adipose tissue, etc. If the training and the competitive efforts have a force close to the maximum one, then the energy carbohydrate substrates are enough for human body man about 20-30 minutes. Of course, if the competitions are of a lesser duration (performed with great force) there is an aerobic-anaerobic or anaerobic-aerobic type of energy. The genres of sports were formed according to empirical criteria, not based on energy biochemistry data (Holloshi, 1982).

The limited character of energy reserves of carbohydrates is a factor that regulates sport performance in aerobic physical effort. That is why special attention is given to the saturation food problems of the body with carbohydrates.

The overall strategy on the issue of "energy carbohydrate resources - sports performance" can be formulated laconically. Sports that calls for maximal and sub-maximal values of force to the values that are available to the world's elite and is achieved within 20-30 minutes limit represents a sport type in which dominates carbohydrate-based energy supply. From this general principle derive the respective requirements regarding the composition of food rations, the rational selection of the training efforts and all the objectives of recovery, of competitive conduct and of life.

In real sports training, it is difficult to apply this principle in pure form, lots of time even impossible. There are several interrelated fundamental causes:

Much of the sporting competitions and, above all, the duration of the training exceeds the 20-30 minute interval, otherwise they exceed the stable possible time of maximum strength achieved only on the basis of bioenergy carbohydrate substrates.

In high-performance sports, there are practiced two, and sometimes even three, trainings per day. This means that towards the beginning of the next training, in the body undoubtedly, is inadequately restored the carbohydrate substrates from the muscle and liver.

In contemporary sports, the calendar of major, important, commercial competitions is quite extensive (intense, expanded, etc.). The real factors of the competition activity are not only the energy expenditures for the competitive efforts themselves but also the unprofitable expenses of the energy substrates for the associated factors of the competitions (Fig.3): emotional stresses, shifting, possible dehydration states, modification of the usual food regimes. Above all these, overcomes the tendency of organizers, coaches and athletes themselves (the causes are the most diverse) to take part in as many competitions as possible - at all competitions corresponding to their level of training.

Fig.3. Unprofitable expenditures of energy substrates

In sports where is done the weight category division, due to the sports rivalry, but also for other reasons, athletes are required to participate in the smallest weight categories. Despite the fact that there are a number of well-developed and well-founded methodological recommendations for this compartment, weight loss is basically gained on energy expenditure of the most lean carbohydrate and fluid substrates of the body. In other words, there happens a negative synergistic effect: it lowers carbohydrate reserves and, first of all the glycogen ones, and dehydration intensifies this process (Manolachi,2012).

The restoration of energy carbohydrate substrates in training (without long breaks) and of long-lasting competitions is possible within very small limits.

Therefore, the underlying causes listed would hinder the improvement of sports outcomes if bioenergetics were based exclusively on carbohydrate substrates.

In fact, the contradiction presented above can be solved. Its solution is provided in two ways: providing energy in many competitive and training efforts takes place due to carbohydrate and fat substrates; multi-annual sports training provides, on the basis of different mechanisms, better adaptation of the body to different physical efforts. In other words, in sports have importance and are really used the mixed energy (carbohydrate - lipid) mechanisms, and the efficiency of energy assurance increases due to training.

We will analyse the first way more detailed. In the case of higher intensity efforts, which last more than 20-30 minutes, up to 2-3 hours and even more, glycogen and fat are used as substrates. That is determined according to respiratory coefficient (RC) values: if this is less than 1, it means that not only carbohydrates are metabolized but the fats also. Therefore, for the energy catabolism of fatty acid molecules, the body spends more oxygen.

If RC consists about 0.9, it means that we have a mixed energy: $\approx 60-65\%$ due to the carbohydrate oxidation, and the rest - due to oxidation of fatty acids. With the increase in the duration of high intensity efforts ($> 2-3$ hours), the RC value is reduced, namely an increasing share of energy is ensured by the fats. The long lasting efforts are only possible due to fat substrates (Batmanghelidj, 2012).

In high intensity and long-lasting efforts, there is initially a thoroughly regulated use of both substrates (glycogen and fat), after which a full passage of the muscles occurs in fat division. And in this case, the body is forced to consume very economically glucose in order to feed the tissues and organs that depend in a mandatory way on carbohydrate bioenergetics.

We will formulate a direct question: what is suitable for sports and does not harm the body? It is convenient to use thrifty the carbohydrate substrates for muscle activity and, of course, to provide tissues and organs that function mainly on carbohydrate energy.

For long-lasting intense efforts, optimal compromise is the provision of mixed-type energy (glycogen + lipids). In this case does not manifest significant decreases in physical yield. Moving to substrate assurance is accompanied by reduction of physical yield to approximately level of 60% of the strength produced by carbohydrate bio-energy. For performance sport, this represents a substantial reduction of strength, thus being limited the subsequent increase in sports scores in the respective genres of sport. For the time being, it is unclear why the shift towards an energogenesis of lipids is accompanied by such a substantial reduction in physical performance. A number of causes are assumed (Figure 4).

Figure 4. Causes of shift towards an energogenesis of lipids that is accompanied by a reduction of physical performance

Competition between bio-energogenesis of carbohydrates and lipids also occurs at an inter-organic level. The interaction of the fatty acids and of the glucose takes place within the glucose-lipid cycle of Randl, the direction of which is determined by the concentration and use of its substrates. At the reduction in glucose concentration in blood plasma leads a mobilization of fatty acids from adipose tissue as a result of lipolysis intensification (Cheung, 2007).

As mentioned above, the common catabolism of carbohydrates and fats is energy-efficient. Aerobic training intensifies the endogenous deposition of triacylglycerol in muscle cells and is accompanied by increased use of fatty acids.

The aerobic trained muscles perform a better blood O_2 extraction: an arterio-venous difference greater than O_2 , a partial O_2 pressure lower in the venous blood. Causes of better absorption of O_2 by trained muscles are insufficiently studied.

It is not excluded that lactate from the muscles involved in motion is used instantly by red muscle fibers.

Multi-annual sports training is accompanied by increased mitochondria number and increased of their fermentation activity. These are deep biological changes that result after training.

Aerobic training is accompanied by increased activity of glycolytic ferments, at least one of these ferments - hexokinase.

Gluconeogenesis into efforts which reduce carbohydrate reserves increases 2-10 times, but for the time being, it is unclear whether training can increase the intensity of this process more than once.

Thus, the changes of the bio-energy under the influence of sport training are quite significant and, in fact, result in all links of the substances' exchange. At first glance, at a superficial analysis, issues and goals of sports nutrition are elementary, not too complicated. Indeed, it seems that nothing is simpler: a certain athlete has to consume certain foods in a certain amount and in some proportions, making these recommendations have beneficial effects.

Secondly, there are a multitude of sports-type, specializations, and sport posts. And in each case the specifics of the training efforts, the character, the duration of the competitions are also very different. The age of athletes, the level of training, gender, ethnicity (genofond), individual traits (genotype) undoubtedly require an individual solution of all the problems relating to nutrition.

It is possible and, in our opinion, necessary to acquire the knowledge regarding this matter itself at least in the volume in which it is presented in this paper or in any other work of this type. The coach, the specialists and the athletes themselves can interpret the assimilated knowledge by referring them to their own problems, tasks, questions. If necessary, they can get advice from specialists on strictly personal issues to enhance nutritional culture. Obviously, this path is much more complicated than, for example, the consumption of doping substances or nutritional supplements,

energizers, artificial preparations, etc., which, according to the advertisements, have miraculous effects.

We mention that ingestion of carbohydrates before and during the training exerts an influence on the mobilization of fatty acids and oxidation, making the muscle even more dependent by carbohydrates for energy during exercises.

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