"Biodoping" with Beetroot? Speculations about Improved Efficiency

„Biodoping" mit Roter Bete? – Spekulationen über einen besseren Wirkungsgrad

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Searching for „beetroot and sports" by Google yields 48000 hits (in the German version). The first ones are: „Beetroot: Natural doping" and "Biodoping with beetroot juice". Beetroot is suggested to improve efficiency during exercise. Since some years such messages haunt the internet. And in doping control labs red colour makes stand out part of the urine samples. As beetroot is a normal non-forbidden food, its consumption is no doping but possibly a performance-enhancing nutrition similar as carbohydrate-rich food before a marathon race.

What did cause this "hype"? Since some years it is known that the vasodilating monoxide of nitrogen NO is not only split off from arginine. It originates also by a detour from nitrate in food. Nitrate resorbed in the intestine is highly concentrated in saliva and secreted into the mouth. Anaerobic bacteria on the tongue reduce it to nitrite (NO_2^-) which is swallowed and resorbed (1). It can be reduced to NO in the tissues. When using disinfecting mouthwash the method does not work. In 2007 Larsen et al. (11) published that intake of nitrate seems to improve the efficiency during muscular exercise and reduces oxygen uptake during moderate intensity. Exercise physiologists in Exeter wanted to investigate this effect, too, but pharmacological application of nitrate is restricted in Great Britain. Therefore they had the idea to administer nitrate-rich beetroot juice to their test subjects. They, too, found a reduction of oxygen uptake during submaximal exercise. Because there is a continuous search for performance-improving measures, this was immediately known and distributed in the internet.

Also for altitude stays a rise of efficiency is discussed controversially since long time (e.g. 3,4,6,12), because often but not regularly a reduction in oxygen uptake is measured. As an increased NO content is found in the expired air of Tibetans (2), an equal explanation as for the beetroot effect might be probable.

The conclusion from a reduced oxygen uptake to an improved efficiency is, however, not compelling, There are other possible causes. First precondition is to avoid methodological traps.

Meassurement of efficiency

Efficiency is the ratio (given as percentage) between usable mechanical energy (mostly measured with an ergometer) and energy consumed by metabolizing nutrients (calculated from gas exchange). In spite of spiro-ergometry being a routine method there is a number of problems. An ergometer does not measure muscular work for ventilation, body stabilization or accompanying movements. On a cycle ergometer the latter may be largely neglected, but the pedaling rate plays a role because of the varying cost for leg movement. Therefore it has to be fixed also when using a rate-independent ergometer (e.g. by a metronome). For more complex movements like running the measurement of muscular performance is difficult even on a treadmill with slope, because muscles and tendons store energy like a spring when landing after the flight phase of a step and reuse it for the push. Efficiency rises to more than 40% (15). In spite of this the bicycle with only 20-30% is saving energy in flat terrain, because body mass must not be carried. This advantage disappears in the mountains.

Energy consumption is measured by indirect calorimetry (determination of gas metabolism). With this the aerobic energy yield especially from fat and carbohydrates (protein consumption is low) is measured. At rest fat consumption predominates, during muscular exercise the proportion of carbohydrates rises and supplies nearly all aerobically liberated energy over 80% of maximal oxygen uptake. Indirect calorimetry can be performed without problems only up to moderate intensities in steady state without rapid rise of lactate and hyperventilation.

It is essential to know the caloric equivalent, the energy yield from nutrients per liter consumed oxygen. The value (approximately 20 kJ/l or 5 kcal/l) is lower for fat than for carbohydrates; the ATP-yield is even smaller (about -16%, 5.6 instead of 6.5 mol/mol O_2). From the ratio of expired CO_2 to inspired O_2 (respiratory exchange ratio RER) the relation of fat versus carbohydrate consumption may be estimated. Therefore measurement of CO_2 output is indispensable for exact determinations, but was frequently neglected in the investigations with nitrate!

If the delivered mechanical power is divided by total energy consumption, one obtains gross efficiency. It increases with mechanical power, because the proportion of resting metabolism with zero efficiency loses importance in relation to total energy consumption. For comparisons net efficiency (delivered mechanical power divided by total energy consumption minus resting consumption) is more suitable, because it is rather constant over a large range of work rates.

Is efficiency trainable? Yes and no. If it is possible to improve coordination by repeating of complex movements (e.g. ice dance),

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the energy need is reduced. In contrast, however, trainability of metabolism has never been proven. Also a number of other influences like age, performance capacity, preceding exercise, oxygen breathing and erythropoietin application are without effect (1,5).

Increase of efficiency by nitrate?

In the investigations after nitrate application oxygen uptake during muscular exercise decreased by up to 5% (reviewed in 1). Therefrom these authors conclude that efficiency was improved. However, approximately one third of the effect may be ascribed to a rise in carbohydrate metabolism (10). When checking various articles one finds a tendency for a rise of RER. In single papers it is often not significant, but it seems to be rather regular especially after correction of obvious calculation errors in some tables (9,16).

In order to explain the reduced oxygen need 2 hypothesis were formulated. Bailey's group speculates that the ATP need for the contraction decreases, possibly by slowing of myosin movements. Larsen et al. (10) hypothesize that a performance rise follows from an improved mitochondrial function: less H^+ ions necessary for ATP synthesis shall be lost across leaks in the mitochondrial membrane.

Altitude

The often observed reduction of O_2 uptake for a given power during an altitude sojourn may be interpreted in first line as increase of carbohydrate metabolism in relation to fat combustion (14). This seems to be appropriate in hypoxia.

It is under discussion (6,12), if also an improvement of efficiency play a role. Before the NO-hypothesis there was already speculation about an increased ATP-yield in the mitochondria (8). I suppose that the "proofs" partly result from methodological mistakes during ergometry (3).

Temperature regulation

Body temperature markedly influences energy consumption which has not at all been considered by the supporters of an ergogenic effect of NO. According to the Q10 temperature coefficient the velocity of metabolic processes increases by 10-20% per degree Kelvin. During muscular exercise body temperature rises, the additional heat is dissipated by increased cutaneous perfusion and sweat evaporation; for both No plays an important role. Osaka (13) has measured a decrease of internal temperature by 0.7° (with a concomitant rise of skin temperature by 6°) and a reduction of oxygen consumption by 7% in rats after injection of Nitroprusside into the cerebral center ofthermoregulation. In man sweat production decreases during exercise after blockade of NO liberation (17). When in presence of high NO concentrations cooling is improved and thus body temperature rises less, also total energy consumption and therefore oxygen need increase less. Such an effect has nothing to do with efficiency. For clarification experiments with measurement of temperature during ergometry are necessary.

Side effects

Consumption of large amounts of nitrate causes methemoglobin formation and other damages by radicals. The quantity supported with beetroot juice in the published experiments (ca. 5.5 mmol in 0.5 l juice/day during 6 days) shall not be harmful. But it is to be feared that some athletes consume more.

Conclusions

As result one may state that the improvement of efficiency is not sure and small (1-3%) at best. But is perhaps a reduction of body temperature favorable? Yes, if there is a long-lasting exercise with eventual heat stress (7). On the other hand the muscle needs a high working temperature for optimal performance; this is one of the reasons for warming up. Is an increase of carbohydrate use with concomitant reduction of fat metabolism useful? Yes, if oxygen uptake is limited, i.e. during exhausting exercise or at altitude. During long-lasting work without difficulty to meet oxygen demand, however, fat burning is more favorable, because the reserves last for weeks. In contrast glycogen in muscles and liver may be consumed within less than half an hour.

What are the practical consequences? You may drink beetroot in moderate amounts without fear. It does not damage, the money earned helps the farmers and at least the faith helps you.

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