**Does training fasted make you fast?**

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EXERCISE TRAINING allows one to perform the same absolute exercise bout with less of a challenge to homeostasis. The metabolic adaptations include increases in the activity of tri-carboxylic acid (TCA) cycle enzymes such as citrate synthase and the β-oxidation enzyme β-hydroxacyl-CoA dehydrogenase (β-HAD) as well as increases in glycogen content within the exercise-trained muscles. The same absolute exercise intensity can then be undertaken with higher rates of fat oxidation, lower rates of blood glucose use, delayed muscle glycogen depletion, and, as such, improved exercise performance.

Exercise training is essentially an accumulation of multiple acute exercise bouts. Therefore, examination of acute exercise is instructive in terms of the exercise training response. During acute exercise there is activation of various kinases that appear to play a role in both exercise metabolism and activation of pathways resulting in increased mitochondrial biogenesis. These include AMP-activated protein kinase (AMPK) and calcium-activated protein kinase II (CaMKII). Agents that increase AMPK activity and CaMK activity in muscle cells increase mitochondrial biogenesis (7). This is, at least in part, by increasing the nuclear localization, phosphorylation, or expression of the so-called master regulator of mitochondrial biogenesis, peroxisome proliferator-activated receptor-γ coactivator 1α (PGC-1α). Like exercise, chronic activation of AMPK by the pharmacological agent 5-aminoimidazole-4-carboxamide-1-β-D-ribofuranoside (AICAR) in rats increases skeletal muscle PGC-1α expression as well as increasing muscle glycogen and some TCA enzymes (5, 12).

Carbohydrate (CHO) ingestion during prolonged exercise improves endurance exercise performance in well-trained individuals (2, 11). There has been some concern, however, that because there is less of an energy imbalance during exercise when CHO is ingested (10), there may be less of an activation of signaling pathways, such as AMPK, and therefore less of a stimulus for adaptation to exercise training. Some therefore have felt that it might be a useful strategy to perform exercise training in the fasted state.

In their recent article in the *Journal of Applied Physiology* (1), Akerstrom and colleagues from the Copenhagen Muscle Research Centre have performed an excellent, complex study examining this question in detail. Nine physically active men performed one-legged knee extensor exercise training for 10 wk, ingesting a 6% glucose solution (0.7 g·kg⁻¹·h⁻¹) while training one leg and ingesting a sweetened placebo while training the other leg. The participants trained their respective legs 2 h at a time on alternate days on 5 days a week (1). Both before and after exercise training the overnight-fasted participants performed four experimental exercise bouts, exercise to exhaustion at 70% of the previously determined maximum peak power output (70% work max) with and without CHO ingestion as well as 3 h of exercise at 55% work max with and without CHO ingestion. The 3-h exercise bout involved muscle biopsies before, immediately after, and 2 h after exercise as well as infusion of glucose and fat tracers (1).

Endurance exercise training increased resting skeletal muscle citrate synthase and β-HAD activity and muscle glycogen content. It also increased fat oxidation during 55% work max one-legged exercise and time to fatigue during one-legged exercise at 70% work max (1). Importantly, there were no differences between the two legs in any of the measured variables either at rest or during exercise, and therefore it made no difference whether the exercise training was conducted in the fasted state or with glucose ingestion (1).

At first one may feel that this study is very similar to that of De Bock et al. that was published in the *Journal of Applied Physiology* last year (3). However, the De Bock study involved cycling exercise and two groups of moderately active men, with one group undertaking 6 wk of exercise training in the fasted state while the other group ingested CHO before and during exercise training (3). Peak oxygen consumption (V̇O₂peak), succinate dehydrogenase activity, GLUT4 protein, and hexokinase II protein content all increased similarly in the two exercise training groups (3). The participants in that study all ingested CHO before and during the experimental trials, with no fasted trial (3). What was missing in that study was an additional experimental exercise trial with the participants fasted, because the CHO ingestion during exercise in the experimental trials would have potentially provided too large a background for subtle effects on metabolism to be identified.

The study by Akerstrom et al. (1) involved a full set of comparisons since the participants not only exercise trained with or without CHO ingestion but also undertook the experimental exercise trials with and without CHO ingestion both before and after exercise training. That said, both Akerstrom et al. (1) and De Bock et al. (3) found essentially the same thing in that CHO ingestion during exercise training had little or no effect on metabolic adaptations to exercise training. In retrospect, these findings are perhaps not that surprising. Although Akerstrom et al. (1) found in a previously published paper with these participants that there was less activation of skeletal muscle AMPK during acute exercise when CHO was ingested, two other studies have found no such effect (4, 6). In addition, CHO ingestion during prolonged exercise, after an overnight fast, has been shown to have no effect on increases in skeletal muscle PGC-1α mRNA over 4 h after exercise (9). Unfortunately, neither skeletal muscle AMPK activation during exercise after training nor PGC-1α was examined in the Akerstrom et al. (1) and De Bock et al. (3) exercise training papers.

So, is it time to tell people that it makes no difference whether they exercise train in the fasted state or ingest CHO during training? This may be premature. Both the Akerstrom et al. (1) and De Bock et al. (3) studies involved overnight-fasted participants and compared exercise while remaining fasted compared with ingestion of CHO during the exercise.
Although these studies are valuable, we need to question how relevant they are to the real world since no one, especially athletes, is likely to start a training bout, or indeed a race, in the overnight-fasted state. In addition, both the Akerstrom et al. (1) and the De Bock et al. (3) studies used active but not specifically endurance-trained participants. This is an entirely reasonable approach since greater changes are observed during a training program in relatively untrained than endurance-trained individuals. However, these results may not be applicable to endurance-trained athletes. In addition, there is a need to conduct similar studies in females, especially as females have been shown to have less activation of AMPK during exercise than males (8). Finally, Akerstrom et al. (1) measured performance by time to exhaustion/fatigue at a fixed power output. Follow-up studies might consider the use of time trial-type tests that are more relevant to exercise performance.

Rather than CHO ingestion having a negative effect on training adaptations, it is possible that the opposite may actually occur in the real world. In both the Akerstrom et al. (1) and the De Bock et al. (3) studies the exercise training load in the CHO and fasted conditions was fixed (matched). Since one can exercise at a higher intensity when ingesting CHO during prolonged exercise (11), it is possible that a strategy of ingested CHO during exercise training may actually result in greater training adaptations. However, most studies examining the effect of CHO ingestion during acute exercise have been conducted in the fasted state, and the beneficial effects of CHO ingestion when fed are smaller. In addition, no studies have as yet examined whether it is actually possible to maintain a higher work intensity during several weeks of training when CHO is ingested during the training bouts. Finally, ingesting CHO drinks during exercise adds a considerable amount of “empty” calories to the diet, with possible ramifications on body weight.

REFERENCES