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Mini Review

Train Low Compete High - Where is the Competitive Edge?

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Received: September 07, 2018; **Published:** December 28, 2018

DOI: 10.31080/ecnu.2019.14.00536

Abstract

Carbohydrate utilization in sport have been studied extensively, however, over recent years different strategies have been explored to enhance the use of fats as an energy source. This approach is suggested to increase the use as a primary energy source during training, to maintain maximal carbohydrate stores. Thus far this has been aimed at use in endurance sports, where in many cases mid intensity exercise is maintained for long periods of time with high intensity toward the end. This fluctuation in tempo has implications for the balance between energy sources used as fuel. This mini Review aims to show a brief overview of some of the studies which investigate this and provide a brief understanding of possible mechanisms involved to try and ascertain if training on low carbohydrate intake and competing on high carbohydrate intake provides a competitive edge.

Keywords: *Carbohydrates; Endurance; Train Low; Compete High*

The importance of carbohydrate utilisation in the sustainability of exercise is well-documented [1,2]. Its contribution to fuel varies depending on exercise type, intensity and duration, although carbohydrate stores are not limitless. In submaximal events in excess of two hours (endurance) or high intensity activities such as football, the role of carbohydrates in enabling an athlete to compete and stave off fatigue is in part due to blood glucose concentration and liver and muscular glycogen. Energy utilization during exercise is derived from a ratio of fat and carbohydrates, this ratio changes depending on the intensity and type of exercise. Lipids such as steric acid have a high density of energy (37.5 KJ/h) in comparison to glucose (16.9 KJ/h), due to the number of ATP molecules formed from their catabolism it is therefore believed that stored lipids can provide enough energy to support muscle contractions contributing to maintenance of a marathon running pace of 120 hours [3].

'Train low, compete high' is the suggestion that periods of training whilst carbohydrate restricted can lead to mitochondrial biogenesis [4], thereby potentially enhancing the use of fats in submaximal exercise. While still ensuring adequate glycogen levels for competitive periods this may lead to improved performance. During steady state activities like cycling or running, the contribution of fats to total energy increases as the intensity decreases. The dominant use of fatty acids as a source of energy poses an interesting concept worth investigating. This review will concentrate on the evidence on periods of fasted or low carbohydrate training on enhanced fatty acid oxidation and performance.

Carbohydrate needs of an athlete

Early dietary recommendations for carbohydrate intake varied, yet they were clear that the aim was to ensure adequate amounts of muscle glycogen to fuel performance; intake was presented as percentage of total energy. For endurance athletes one such value was > 60% of total energy [5] another was higher at 60 - 70% [6]. However, the latter is bordering on unachievable, particularly as dietary analysis of athletes has shown their intake to fall far short of this (55 - 60%) [7]. Recent recommendations have begun to specify how carbohydrate intake changes with exercise type, intensity, duration and during competitive periods [8]. It is also now represented in g.kg.d-1, which in the world of a competitive athlete, is easier to follow. Yet the use of other sources of energy, especially in sports like triathlons where sparing muscle glycogen whilst competing to a high level provides a performance benefit. Preservation of glycogen is beneficial, as depletion quickly leads to fatigue which results in impaired performance. Although carbohydrates have always been seen as 'King' with respect to performance, training with low glycogen availability potentially leads to grater activation of many cell-signalling proteins associated with mitochondrial biogenesis [9]. Still, with the high storage capacity and energy density of fats, their increased contribution to energy requires well-designed studies to link increased fatty acid oxidation to improved performance.

Carbohydrate needs of an athlete

Many studies have investigated dietary protocols which enhance β-oxidation with specific interest in enhancing utilization of fats as a dominant source of energy in both endurance and power based sports [10,11]. However, there is a distinct lack of evidence to suggest a performance benefit, and many studies even suggest down-regulation of Pyruvate Dehydrogenase (PDH) activity leading to impairment of glycolysis. Thus negating any beneficial effects of sparing muscle and liver glycogen [11], yet the interest in increasing the contribution of lipids to energy in athletes still prevails. Many other dietary protocols are also suggested to enhance fatty acid oxidation (FAO) including the use of L-Carnitine [12], n-3 PUFA [13], endurance training and dairy products [14,15] (for a review see Hawley, Brouns and Jeukendrup [16] or Gonzalez and Stevenson [17]).

Train low - nutritional strategies

Early studies (Table 1) were varied in their relevance to the 'train low' theory, although many were the first studies to use direct dietary manipulation to alter available carbohydrates. Several of the studies did not measure either muscle glycogen or FAO, which would have showed the metabolic benefits of the dietary restrictions imposed, this would act to provide evidence of protocol efficacy [18,19].

This decision makes it difficult to assess the contribution of fat to total energy usage, where glycogen and FAO data in muscle is unavailable the respiratory exchange ratio (RER) is provided. The RER is the amount of oxygen consumed and carbon dioxide produced in one breath and can often be used as a method of understanding the contribution of fats and carbohydrates to energy during exercise. Some studies have provided values therefore an inference can be made on the relative contributions of carbohydrates and fats. Values of 0.80 - 0.87 were recorded at a lower velocity (185 m/min), compared to higher values (0.88 - 0.96) at a higher velocity (238 m/min). This indicates a greater contribution of fats at a lower velocity, supporting the theory that carbohydrates are the primary source of energy at higher intensities [20]. Studies that directly measured the contribution of fatty acids (FA), analysed the activity of β-hydroxyacyl CoA (βHAD), an enzyme involved in FAO and citrate synthase, an enzyme involved in glycolysis. The study used well-trained male cyclists but showed no increase in FAO, βHAD activity or decrease in citrate synthase [21]. A more recent study separated groups by training methods, one group trained on alternate days consisting of aerobic and HIIT training (High), whilst group two trained twice a day, every other day with both aerobic and HIIT (Low) in one day. This study showed a significantly lower muscle glycogen content in the Low group after the first day of training but there was also an overall increase in resting muscle glycogen at the end of the study in this group. Data on substrate activity showed an increased level of FAO after 3 weeks in the low group and improved citrate synthase and βHAD activity [22]. This all suggests improved glycolysis and β-oxidation may have occurred in the low group, nevertheless, there was no significant difference in performance between each group as measured by peak power output (PPO). Another study used fasted and fed endurance trained cyclists then depleted their glycogen levels using HIIT training prior to an overnight fast, half were then fed 4 g.kg.bw, and the others were not. This study found that the subsequent 120m steady state (SS) cycle at 50% PPO, lead to a greater increase in PDK-4 mRNA in the fasted group [23], indicating a down regulation of PDH and conversion of pyruvate to lactic acid in the cytosol. An increase in FAO and a decrease in glucose oxidation in the fasted group was also shown ($p = 0.01$). This positively correlates with increased CPT1 activity post SS trial ($p < 0.01$) all of which indicate increased free fatty acid concentration, β-oxidation and the potential increased role of FA in providing energy in submaximal exercise. These studies constitute some of the few summarised studies (Table 1), which used athletes with the correct physiology for the assessment on endurance performance. Many of the studies have used swimmers and rowers who could be argued are not endurance athletes based on the length and speed of the sports. The potential difference in type 1 and 2 muscle fibres due to physiological adaptation to training, allow for the potential increased aerobic capacity in endurance athletes who often poses a higher percentage of type 1 fibres. This is due to the higher level of myoglobin and mitochondria, demonstrating a detriment to a study in using athletes with the incorrect sporting background. β-oxidation is known to occur at a much slower rate than glycolysis, hence the reluctance to recommend use in power and speed based sports, this is due to the necessity of data linking its use to a specific measure of performance and evidence of improvement.

Study	Athletes	Study Type and Duration	Daily CHO intake (g/kg/d)	Effect on muscle glycogen	Training Intensity and Protocol	Performance advantage with HCHO
Costill., *et al.* [24]	Well-trained swimmers (12M)	10d Self-selected	8.2/5.3	↓ MCHO; = HCHO	2 x 1.5h/day	No - Final performance; Yes - training performance;
Lamb., *et al.* [19]	Well-trained swimmers (12M)	9d Cross-over	12.1/6.5	NM	2 x daily HITT	No
Kirwan., *et al.* [25]	Well-trained runners (10M)	5d Cross-over	8.0/3.9	↓ Both, but greater reduction in MCHO	Increased by150 %	Yes - ↓ Running economy MCHO
Sherman, Doyle, Lamb, and Strauss, 1993 [26]	Trained runners (9M +9M)	7d Parallel design	10.0/5	↓ MCHO; = HCHO	2 x time to exhaustion 80% VO2 max.	No
Achten., *et al.* [27]	Well-trained runners (7M)	4d + 7d intense, cross over	8.5/5.4	↓ amount used at 50%, 77% VO_2 Max in MCHO	Pre-load 18 km treadmill TT on 16 km road TT overnight fasted.	Yes - deterioration in MCHO
Halson., *et al.* [18]	Trained cyclists (6M)	7d + 8d intense, 14 d recovery. Cross over	9.4/6.4	NM	Cycle time to exhaustion at 74%VO_2 max, Overnight fasted.	Yes - HCHO supplementation↓ onset of overreaching
Simonsen., *et al.* [28]	College rowers (12M, 10F)	28d parallel design	10/5	↑ HCHO; = MCHO	32500m rowing TT; HITT	Yes
Sherman., *et al.* [26]	Trained cyclists (18M)	7d Parallel design	10/5	↓ MCHO; = HCHO	2x cycle time to exhaustion at 80% VO_2 max	No
Vogt., *et al.* [29]	Well-trained duathletes (11M)	35d Cross - over	6.9/3.6	Maintained in both diets	VO_2 max, cycling TT	No
Cox., *et al.* [21]	Well-trained cyclists/ triathletes (16M)	28d parallel design	8/5.2	Maintained in both diets	100 min at 70% VO_2 max1 25-min	No
Yeo., *et al.* [22]	Trained triathletes and cyclists (18M)	21d parallel design	65% energy as CHO for all. LCHO manipulated by training.	↓ in LCHO group second HIIT training session. ↑ In LCHO group post rest at end of study.	Training every other day aerobic and HIT training. Twice every other day anaerobic then HIT.	No
Lane., *et al.* 2015 [23]	Trained cyclists (7M)	3d cross over	Fed- 4g.kg before overnight fast; Fasted - 0	↓ In fasted group.	HIT, overnight fast, 120 m SS cycle.	No

Table 1: *Studies investigating the effects of HCHO and MCHO on athlete performance. Adapted from (Burke, Kiens and Ivy).*

M: Male; F: Female; TT: Time Trial; NM: Not Measured.

Performance benefit

Performance benefits that result from carbohydrate restriction are suggested to enhance mitochondrial biogenesis via cell-signalling pathways involving AMPK, PGC-1α and p53 (Figure 1) [4] thereby improving the physiological capacity to produce aerobic energy regardless of substrate.

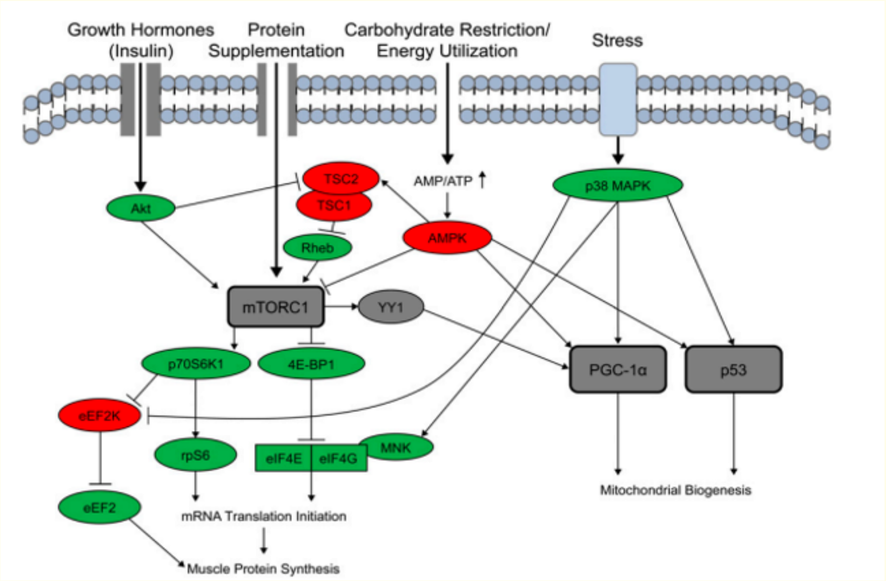

Figure 1: *Muscle hypertrophy pathways and mitochondrial biogenesis intracellular signalling, taken from Margolis and Pasiakos [4].*

Though specific performance benefits are still under question, maintained PPO on a HCHO or preservation of running economy has been reported [18,25,28]. There are several studies, which have failed to show any performance benefit of HCHO diets [22,23]. This is suggested to be due to a lack of sensitivity in measuring small increases in performance and therefore an increased measurement error or poor choice of measurement protocol. However, many of these studies, except for that by Yeo., et al. [22] are more than 10y old, thereby raising the question of their relevance and highlighting subsequent developments in analytical methods. An interesting follow-up to that by Yeo., et al. [22] could add an exercise to exhaustion test as an additional protocol after the SS cycle and after carbohydrate feeding, thus simulating 'compete high'. This would better mimic the situation found in many endurance sports where increased reliance on glycogen is found toward the end of a race where the level of intensity increases. This should adopt a cross-over design which would help to produce data in a similar environment to that found during endurance events. Thus, helping to provide more relevant data from which specific, evidence based advice can be given [30].

Conclusions

In conclusion, recent studies have shown an increase in FAO and utilization after a fasted or LCHO diets. However, there is a lack of good, recent evidence to show specific performance benefits for endurance sports. More relevant studies with realistic protocols and with the use of relevant subjects need to be conducted in order for specific advice to be developed in relation to improving athletic performance in endurance sports.

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Volume 14 Issue 1 January 2019