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Fat Loading for Endurance Sports

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Athletes in endurance sports (lasting one to four hours) and ultra-endurance sports (lasting over four hours), are constantly on the lookout for nutrition and training regimes to improve their performance. Our knowledge of how the body uses nutrients as fuel, has placed focus on dietary carbohydrates, with most serious athletes at least somewhat engaged in carbohydrate "loading." Now, however, many athletes are considering "fat loading" instead. This module explains the rationale behind fat loading and critically reviews the effects of fat-loading on the performance of trained endurance and ultra-endurance athletes.

Carbohydrate is stored energy. The depletion of the body's carbohydrate stores (muscle and liver glycogen and blood glucose) is associated with fatigue and impaired endurance performance. Nutritional strategies aimed at optimizing endurance performance have developed tactics to increase the body's carbohydrate stores. The most common are "carbohydrate loading," consuming a carbohydrate-rich meal just before exercise, and consuming carbohydrate during exercise. All have been shown to improve endurance performance by increasing or maintaining carbohydrate availability during the latter stages of exercise.

Because these methods are all geared towards providing additional carbohydrate, they are limited by the athlete's ability and opportunity to consume, and the body's ability to store, energy. They do nothing to slow the rate of carbohydrate utilization. The justification for fat loading is to utilize an alternative, more concentrated, fuel source to save carbohydrate stores and/or to slow down the rate of carbohydrate use during exercise. If you can use fat-derived energy, the theory goes, you will save carbohydrate.

The body's fat stores (intramuscular fat, adipose tissue, and blood lipids) are an abundant alternative fuel source. Whereas the total glycogen stores (in muscle and liver) provide only about 2000 kcal, each pound of fat supplies 3500 kcal. The amount of energy stored as fat is about 110,000 kcal for an 80 kg man and about 135,000 kcal for a 60 kg woman with average body composition (1). Thus, it is theorized that a high-fat diet will increase the rate of fat utilization and thus improve endurance performance.

To understand if and how this might work, a brief explanation of fat metabolism during exercise and the effects of endurance training on fat metabolism is necessary.

Fat metabolism during exercise

Lipolysis, the breakdown of adipose (fat) cells to release their energy, requires activation of a lipase enzyme and results in the release of free fatty acids and glycerol into the cytoplasm of the cell. The enzyme hormone sensitive lipase (HSL), which stimulates lipolysis in both adipose and muscle cells, is activated by the sympathetic nervous system and the hormone epinephrine, and inhibited by insulin and lactic acid. Circulating epinephrine activates HSL by stimulating the cyclic AMP system, which then changes HSL into its active form. Insulin inhibits HSL by stimulating the activity of phosphodiesterase, an enzyme that inactivates cyclic AMP. Lactic acid also inhibits HSL (1).

The hormonal environment generated by exercise (increased epinephrine and decreased insulin) promotes lipolysis and mobilization of fatty acids from intramuscular triglycerides and adipose tissue triglycerides. During low- to moderate-intensity exercise (below 65 percent of VO_2max), the rate of appearance of plasma free fatty acids closely matches the rate of fat oxidation. Relative fat oxidation is maximal at low to moderate intensities, whereas during high intensities (above 85 percent of VO_2max), carbohydrate is the major fuel (1,2).

The substance that actually is used by cells is adenosine triphosphate (ATP), which has been called the body's "energy currency." Because only a few ounces of ATP are present in the body at any given time, it must be constantly replenished to meet demands.

Per unit of time, more ATP can be generated from carbohydrate than from the oxidation of fat. When blood-borne fatty acids are oxidized, the maximum rate of ATP formation is about 0.40 mol/minute, whereas the aerobic or anaerobic breakdown of endogenous glycogen can generate about 1.0 to 2.0 mol/minute, respectively. During high-intensity exercise, the rate of ATP breakdown is too high to be matched by the rate of ATP formation from free fatty acids. This is the major reason that carbohydrate is the essential fuel for high intensity exercise (1).

High-intensity exercise also suppresses lipolysis, thereby reducing the availability of fatty acids to the muscles. The increased rate of glycogenolysis, glycolysis, and lactic acid production during intense exercise also hinders the oxidation of fat by reducing the entry of long-chain fatty acids into the mitochondria (3).

Endurance training and fat metabolism

A major metabolic adaptation to endurance training is an increased capacity for fat oxidation (4). The contribution of fat to the total energy expenditure increases after endurance training at both the same relative and absolute exercise intensity (5,6,7). Most importantly, the trained muscles of athletes have a greater mitochondrial and capillary density, which enables them to oxidize more fat compared to the untrained muscles of sedentary people (5,8). This "glycogen sparing" effect allows the athlete to exercise longer before experiencing glycogen depletion and associated fatigue.

Trained individuals are more sensitive to the hormonal milieu created by exercise, which promotes an increase in the activity of HSL in the trained compared to the untrained person. Endurance training also decreases the secretion of insulin both at rest and during exercise.

Trained individuals deliver more blood and oxygen to the muscles due to a higher cardiac output and increased arterio-venous oxygen difference (a higher VO_2max). Trained individuals also produce less lactic acid at the same absolute and relative workloads due to a higher lactate threshold. Both of these adaptations to endurance training facilitate fat oxidation.

Simply put, fat is a more concentrated form of energy, readily stored by the body. Since trained endurance athletes can utilize fat efficiently, the theory goes, they should "load" fat instead of carbohydrates. In testing that theory, researchers have found conflicting results.

Long-term fat loading

Adaptation to a high-fat diet or fat loading has been recommended to promote fat oxidation, slow the rate of carbohydrate utilization, and enhance endurance performance. Compared to a high-carbohydrate diet (60 to 70 percent energy from carbohydrate), fat loading (60 to 70 percent energy from fat) increases the contribution of fat oxidation to total energy expenditure and spares muscle glycogen during submaximal exercise (<70 percent of VO_2max).

Phinney and colleagues examined the effects of 28 days of a high-fat diet (85 percent of calories) versus an isocaloric diet containing 66 percent carbohydrate on submaximal cycling time to exhaustion (9). The exercise time to exhaustion at 63 percent of VO_2max was not significantly different on the two diets (147 and 152 minutes, respectively). After adapting to the high-fat diet, muscle glycogen utilization dropped four-fold, glucose utilization dropped three-fold and fat utilization rose to make up the difference during the ride to exhaustion. Although fat loading improved fat oxidation, it did not improve performance (9).

Lambert and colleagues investigated the effects of two weeks of a high-fat (67 percent fat) or a high-arbohydrate (74 percent carbohydrate) diet on exercise performance in trained cyclists (10). The subjects did three consecutive cycle tasks with 30 minutes of rest between each test: a Wingate test of peak muscle power; cycling to exhaustion at 90 percent of VO_2max (HI); and cycling to exhaustion at 60 percent of VO_2max (MOD).

The maximal power output for the Wingate test was the same for both diets. Although starting muscle glycogen content was lower on the high-fat diet (68.1 mmol/kg) versus the high-carbohydrate diet (120.6 mmol/kg), the exercise time to exhaustion during HI was not significantly different. However, the exercise time to exhaustion during the subsequent MOD was significantly longer on the high-fat diet (79.7 minutes) compared to the high-carbohydrate (42.5 minutes) despite a lower muscle glycogen content on the onset of MOD (32 mmol/kg versus 73 mmol/kg). Despite the unorthodox study design, this suggests that submaximal exercise capacity can be preserved in spite of low muscle glycogen stores when trained individuals have adapted to a high-fat diet (10).

Both the Lambert and Phinney studies used a much lower intensity (60 percent of VO_2max) compared to the intensities used by most endurance athletes in training and competition. It isn't reasonable to maintain a radical diet for two to four weeks when there is no definite performance benefit. A high-fat diet may also impair high intensity training and have adverse health consequences over the long term (3).

Short-term fat loading

A series of studies have evaluated the effects of a five-day fat adaptation period (60 to 70 percent energy from fat) followed by one day of carbohydrate restoration (10 gm carbohydrate/kg) on exercise metabolism and performance in endurance-trained athletes (11-14). The one day of carbohydrate restoration normalizes muscle glycogen stores without negating the metabolic adaptations favoring increased fat metabolism. A five-day time frame represents a more manageable period for extreme dietary change and minimizes the potential health and training disadvantages caused by longer periods of fat adaptation.

Burke and colleagues evaluated the effects of a five-day fat adaptation period (65 percent of energy or 4 gm of fat/kg) followed by one day of carbohydrate restoration (10 gm of carbohydrate/kg) on fuel usage and performance during two hours of submaximal cycling followed by a 30 minute time trial (11). The fat loading group burned significantly more fat than a high-carbohydrate control group (94 gm versus 61 gm) and less carbohydrate (271 gm versus 342 gm). Muscle glycogen sparing accounted for the reduced carbohydrate oxidation.

Time trial performance was 8 percent faster for the fat loading group (30.73 versus 34.17 minutes) and mean power output during the time trial was also higher (281 watts versus 260 watts) but these differences were not statistically significant. Although fat metabolism was significantly increased, there was no clear evidence that fat adaptation improved performance (11).

Burke and colleagues conducted a follow-up study and provided a pre-exercise meal (2 gm of carbohydrate/kg) one hour prior to cycling and carbohydrate feedings during exercise (0.8 gm of carbohydrate/kg each hour) to reproduce dietary practices of athletes. The athletes consumed a high-fat diet (4.3 gm of fat/kg) for five days followed by one day of carbohydrate restoration, then completed a time trial after cycling for two hours at 70 percent VO_2max (12).

The fat-loading group burned significantly more fat (73 gm versus 45 gm) than a high-carbohydrate control group and significantly less carbohydrate (354 gm versus 419 gm). Time trial performance (approximately 25 minutes) was similar for both groups. The adaptations to a short-term high-fat diet persisted in the face of high carbohydrate availability before and during exercise, but failed to confer a performance advantage (12).

In theory, fat adaptation should provide the greatest benefits for ultra-endurance athletes. They compete at intensities (about 65 percent of VO_2max) and durations (over four hours) that significantly reduce the body's carbohydrate stores. Fat oxidation also has the potential to meet a large proportion of the fuel requirements for ultraendurance events.

Carey and colleagues (13) evaluated the effects of a six-day fat adaptation period (4.6 gm of fat/kg) followed by one day of carbohydrate restoration on fuel usage and performance during four hours of submaximal cycling followed by a one hour time trial. Carbohydrate feedings were also provided one hour before (3 gm of carbohydrate/kg) and during exercise (100 gm of carbohydrate per hour) to reproduce nutritional strategies commonly used during ultra-endurance events.

The fat loading group oxidized significantly more fat than a high-carbohydrate control group (171 gm versus 119 gm) and less carbohydrate (597 gm versus 719 gm). Total glucose utilization (ingested glucose plus blood glucose) was similar for both groups. The mean power output during the time trial was 11 percent higher for the fat loading group (312 watts versus 279 watts) and the distance covered during the one hour time trial was greater (44.25 km versus 42.1 km) but these differences were not statistically significant (13). Despite marked differences in fuel utilization favoring fat oxidation during ultra-endurance exercise and maximizing carbohydrate availability before and during exercise, fat adaptation failed to enhance performance.

Does brief fat loading work?

Short-term fat adaptation significantly increases fat oxidation and reduces muscle glycogen utilization during moderate-intensity exercise (below 70 percent of VO_2max) compared to an isocaloric high-carbohydrate diet. These higher rates of fat oxidation during exercise persist even under conditions in which carbohydrate availability is increased, either by having athletes consume a high-carbohydrate meal before exercise and/or ingest carbohydrate during exercise (3,15).

Staudacher and colleagues (16) found that short-term adaptation to a high-fat diet does not alter whole-body glucose tolerance or an index of insulin sensitivity of highly-trained individuals, despite greater fat oxidation during endurance exercise. Stepto and associates (17) established that competitive endurance athletes can undergo intense interval training and maintain high rates of fat oxidation during three days of exposure high-fat diet. However, these training sessions were associated with greater ratings of perceived exertion compared to a high-carbohydrate diet (17).

The metabolic changes that occur with dietary fat adaptation suggest an upregulation of fat metabolism. If so, why doesn't the dramatic increase in fat metabolism improve performance during prolonged exercise? Burke and Kiens propose that what was initially viewed as "glycogen sparing" following fat adaptation may actually represent a down-regulation of carbohydrate metabolism "glycogen impairment" (18).

Stellingwerff and colleagues found that fat adaptation/carbohydrate restoration was associated with reduced activity of pyruvate dehydrogenase at rest and during exercise (14). This would impair rates of glycogenolysis at a time when muscle carbohydrate requirements are high (14,18).

Havemann and colleagues applied the fat adaptation/carbohydrate restoration model to an endurance cycling protocol that involved several features of a real-life race (19). The cyclists paced themselves during a 100 km time trial and bouts of high-intensity cycling (1 km sprints) were interspersed during the time trial. The authors found that fat adaptation/carbohydrate restoration had no effect on overall time trial performance but compromised the ability of well-trained cyclists to perform 1 km sprints during the time trial.

Competitive success in endurance and ultra-endurance sports requires more than the ability to exercise for hours at a moderate intensity — athletes still need a "big gear" (3,18). The strategic moves that occur during these sports — breaking away, surging during an uphill stage, and sprinting to the finish line — all depend on the athlete's ability to work at high intensities, which are in turn fueled by carbohydrate. Since fat adaptation appears to impair this critical ability and does not enhance prolonged endurance exercise, there appears to be no specific support to recommend this dietary strategy (3,18, 19).

Just as the "low carb" craze for weight loss is diminishing, so is the notion that fat adaptation enhances performance during prolonged exercise. As in all such fads, we need to pay attention to the science, not the anecdotal reports and promotions.

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Examination for FLE10

1. Fat loading is used by endurance athletes to:
   A. Promote fat oxidation
   B. Slow the rate of carbohydrate utilization
   C. Lose body weight/body fat
   D. Prevent dehydration
   E. A and B

2. The Phinney study demonstrated that fat loading:
   A. Improved fat oxidation and athletic performance
   B. Improved fat oxidation but not athletic performance
   C. Did not improve fat oxidation or athletic performance
   D. Decreased body fat
   E. Improved aerobic capacity

3. The Lambert study demonstrated that fat loading:
   A. Improved cycling time to exhaustion at 60 percent of VO_2max
   B. Increased cycling time to exhaustion at 90 percent of VO_2max
   C. Decreased body fat
   D. Reduced recovery time from exhaustion
   E. Improved long-term performance at all intensity levels

4. The Lambert and Phinney studies have been criticized because:
   A. They used a relatively low intensity compared to the intensities used by most endurance athletes in training and competition
   B. There was absolutely no evidence in either study that fat loading increased fat oxidation
   C. A high fat diet may have adverse health consequences over the long term
   D. A and C
   E. B and C

5. The Burke studies demonstrated that brief fat loading followed by one day of carbohydrate restoration:
   A. Increased fat metabolism during submaximal exercise
   B. Reduced blood glucose utilization
   C. Improved time trial performance
   D. Caused athletes to crave carbohydrates
   E. Had no effect on performance

6. Fat loading is proposed to benefit ultraendurance athletes because:
   A. Fat oxidation has the potential to meet a large proportion of the fuel requirements for ultraendurance events
   B. Ultraendurance athletes compete at an intensity and duration that significantly reduces the body's carbohydrate stores
   C. Fat loading reduces the ultraendurance athlete's percentage of body fat
   D. A and B
   E. A, B, and C

7. The Carey study provided carbohydrate feedings before and during exercise to:
   A. Reproduce nutritional strategies commonly used during ultraendurance events
   B. Evaluate the influence of carbohydrate feedings on metabolism and performance
   C. Negate the metabolic adaptations favoring increased fat metabolism in the fat-loading group
   D. Restore critical hydration-blood glucose balance
   E. A and B

8. The Carey study found that fat loading:
   A. Significantly increased fat oxidation compared to the control group
   B. Significantly decreased power output during the time trial
   C. Increased power output during the time trial, but this was not statistically significant
   D. A and C
   E. A and B

9. Burke and Kiens note that:
   A. Fat-adaptation/carbohydrate restoration strategies do not provide clear benefits to the performance of prolonged endurance exercise
   B. All ultraendurance athletes should fat load to improve their performance
   C. All ultraendurance athletes should fat load to increase fat metabolism
   D. Dietary fat should be maximized by all athletes and moderate exercisers
   E. None of the above

10. Fat loading lasting longer than two to four weeks:
   A. Provides no definite performance benefit
   B. May impair high intensity training
   C. May have adverse health consequences
   D. Isn't practical
   E. All of the above

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