

Fat loading strategies for endurance and ultra-endurance performance

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Introduction

Carbohydrate (CHO) stores in the blood and muscle are only sufficient to fuel 1-2 hours of submaximal exercise, and the depletion of these stores is associated with fatigue and impairment of exercise capacity. Typically, the nutritional strategies aimed at optimising the performance of endurance and ultra-endurance sports and exercise activities focus on increasing the availability of these limited fuel substrates. Strategies such as CHO loading, consuming a CHO-rich meal in the hours prior to exercise, and consuming CHO throughout an event have been shown to enhance endurance and performance when they are able to maintain or increase CHO availability during exercise (1). However, these strategies essentially provide an additional fuel source for the muscle rather than alter the depletion of the critically important muscle glycogen levels. An alternative angle for performance enhancement would be to find a fuel source to replace glycogen and slow its rate of use during exercise.

As a response to endurance training, well-trained athletes have an enhanced capacity to oxidise fat during sub-maximal exercise. This adaptation is useful, given that the fat stores of even the leanest athlete would be capable of fuelling moderate intensity exercise lasting at least several days in duration! The relatively larger body fat stores include fat found inside the muscle (intramuscular triglyceride or IMTG), as well as blood lipids and body fat stored in adipose tissue. It is tempting to consider these stores as a substrate that could be better exploited, and strategies such as fasting, supplementation with carnitine and caffeine, pre-exercise intake of high-fat meals, and intake of medium chain triglyceride fats during exercise have been attempted in the hope of enhancing rates of fat utilisation during exercise (2). Another strategy that has been tried is to expose the athlete to a high-fat diet.

Background to “Fat loading”:

The immediate effect of short-term (1-3 day) exposure to a high-fat, low CHO diet is to lower resting muscle glycogen stores, which impairs an athlete’s ability to perform prolonged exercise by causing premature depletion of this critical fuel (2). However, longer periods (> 7 days) on such a diet cause metabolic adaptations that enhance fat oxidation during exercise, and compensate for the reduced CHO availability. In fact, it has been suggested that “fat loading” strategies might enhance the performance of endurance and ultra-endurance athletes by making them better able to “tap into body fat stores”.

Despite the publicity for “fat loading” theories, there are few studies in which it has been tested in trained subjects, and most investigations of performance changes are clouded by problems of flaws in the study design. In the best-known study by Phinney et al., 5 well-trained cyclists

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cycled to exhaustion at a workrate eliciting 60% VO_{2max} before and after 4-weeks of adaptation to a high-fat (70% of energy), low-CHO (< 20g/d) diet (3). Although this study is widely cited in support of fat loading strategies, in fact, the cyclists achieved similar endurance times in both trials. However, the group results were skewed by an unusually large improvement in the performance of one cyclist, while the remaining subjects showed a neutral or negative reaction to the treatment. Furthermore, it should be noted that the treatment was applied with an order effect – all subjects were tested with their normal carbohydrate diet, followed by the high-fat treatment, allowing for the possibility of systematic changes in training status.

A second well-publicised study (4), used a cross-over design to investigate the effects of 2 weeks of an isocaloric high fat (70% of energy) or high CHO (70% of energy) diet on the capacity of well-trained cyclists to perform a battery of exercise protocols. This study found that following the fat adaptation treatment, cyclists cycled for a longer time before reaching exhaustion during a moderate-intensity endurance test (60% VO_{2max}). However, since this test was undertaken immediately after the completion of 2 separate high-intensity cycling tests, it is difficult to relate the results to real-life sporting conditions.

A final study of fat loading (5) also failed to find superior performance benefits when matched groups of well-trained subjects followed a 2-week treatment with either high-fat or high CHO diets. However, it found change to fuel metabolism (increased fat utilisation and decreased CHO oxidation during exercise) as a result of the high-fat treatment, with the major adaptations occurring within the first 5 days. This is an important finding since it suggests that athletes can achieve metabolic adaptations without having to undergo radical dietary change for lengthy periods. These extreme diets are not only hard for the layman to construct, but in the long-term may be associated with impaired training performance and adaptation, as well as health complications. If high fat diets are to be useful to athletes, a 5-day diet would be far more practical and better-tolerated than longer dietary periods.

Although these studies have found that adaptation to high fat eating produces a “sparing” of muscle glycogen during sub-maximal exercise (a lower rate of muscle glycogen contribution to the exercise fuel mix), this observation could also be explained as an artefact of lower resting glycogen levels *per se*. After all, glycogen utilisation is influenced by total glycogen concentration. Therefore, true differences in the rate of glycogen utilisation can only be proved if subjects start each exercise protocol with similar muscle stores. Furthermore, restoration of muscle glycogen stores following a period of fat loading might offer the athlete an opportunity to take better advantage of both fat and CHO substrates. A number of studies have considered the possibility of “dietary periodisation” in well-trained athletes. In this model, muscle fat utilisation is optimised with the minimal necessary exposure to a high-fat diet, then followed by a period of high CHO intake, to restore muscle glycogen

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concentrations without allowing a “washing out” of the enhanced capacity for fat oxidation. This paper will discuss 4 studies recently undertaken on this theme; including 3 studies conducted at the Australian Institute of Sport (6,7,8,)

Methods Used in Dietary Periodisation Studies: Fat Loading and Glycogen Restoration

Figure 1 provides an overview of 4 studies undertaken on endurance and ultra-endurance athletes using a dietary periodisation protocol, each designed to investigate metabolic changes during exercise as well as a measurement of performance (6,7,8,9). In each study, highly-trained athletes were recruited to participate in a cross-over designed investigation, and considerable rigour was applied in ensuring compliance to the designated high-fat or high-CHO diets.

In the first 3 studies, a five- or six-day period of fat adaptation was undertaken, followed by a 24 hour period of carbohydrate restoration (6,7,8). Subjects were supervised to follow an identical training program of 15-22 hours per week of cycling on each treatment. Biopsy-determined measurements of muscle glycogen concentrations showed that the high fat diet lead to a depletion of muscle CHO stores, whereas subjects were able to maintain glycogen stores while undertaking the same training program on the high CHO diet. At the end of the 5-6 days of training and dietary treatment, a subsequent day of rest and high CHO eating was found to restore – in fact, supercompensate - muscle glycogen concentrations, regardless of the preceding diet. This loading day enabled subjects to start the performance trial with equally elevated glycogen stores despite their previous dietary treatment. The separate aims of each of the studies is summarised below:

Endurance study 1 (6): To investigate baseline metabolic conditions during exercise and provide a performance situation that might benefit most from “sparing” of intact muscle glycogen stores – i.e. allow no further CHO intake during the exercise

Endurance study 2 (7): To investigate dietary periodisation strategies when athletes compete under conditions of optimal CHO availability, according to the guidelines recommended by sports nutrition experts and practised by athletes in real life

Ultra-endurance study 3 (8). To investigate whether a longer exercise protocol, providing a greater risk of performance limitations from depleted muscle glycogen stores, would benefit from glycogen sparing.

In a fourth study (9), undertaken at the University of Cape Town, subjects followed a 10- day control diet or high fat diet in randomised cross-over order, followed by a 3 day high CHO phase designed to load muscle glycogen stores.

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Results and Discussion

A common feature of these dietary periodisation studies was the reporting of symptoms of lethargy, mild headaches and fatigue during the high-fat treatment. During the studies incorporating supervised training protocols, all subjects had trouble in completing at least one of their programmed training sessions – complaining of either an increased perception of effort, or difficulty in maintaining the desired training pace. These generalised symptoms appeared to decrease as the week progressed, but may be an important consideration in the completion of training programs based on perception of effort.

Performance was measured in all studies at the end of each treatment using a two-part model: 1) An initial portion in which the athletes rode at a steady-state pace indicative of the typical workload of their event, and 2) The immediate completion of a self-paced time-trial in subjects finished a certain volume of riding as quickly as possible. In this way, scientists endeavoured to monitor the metabolic responses to a standard exercise task, as well as have athlete–“compete” in a performance protocol that mimics the demands of a real-life sporting event.

Rates of total fat oxidation and total CHO oxidation were calculated for the steady-state portion of each performance protocol. In each study the fat-adaptation treatment was associated with substantially higher rates of fat utilisation, and lower rates of CHO oxidation, with these differences being maintained throughout the duration of the steady-state ride. Equally, these differences were maintained even under the conditions of maximal carbohydrate availability, achieved by having the athletes consume a high CHO meal prior to cycling, and continue to consume CHO during the ride. Thus, the high fat diet caused powerful metabolic adaptations, which persisted and were independent of body CHO availability. The use of muscle biopsies, and glucose tracers enabled researchers in some studies to determine that the reduction in CHO use during exercise was almost entirely accounted for by a sparing of muscle glycogen stores (6,8). As previously noted, this should be considered to represent a true case of glycogen sparing, since muscle glycogen stores were equalised at the onset of each performance test. Other results showed that there were no differences in the rate of utilisation of blood glucose or CHO derived from drinking a sports drink throughout the performance ride (8). The techniques used in these studies were unable to determine the source of the additional fat used as a muscle fuel.

In the first endurance study, undertaken without further intake of CHO before or during the exercise protocol, subjects showed a gradual decline in blood glucose concentrations during the ride (6). However, this decline was less severe following the fat adaptation treatment, and

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appeared to protect 2 subjects from developing symptoms of hypoglycemia as occurred while on the control (high CHO) treatment. The performance of the time-trial in this study showed no statistically significant benefits from the fat adaptation treatment among the group, despite all subjects started the time-trial with substantially greater muscle glycogen stores. Nevertheless the two subjects who developed hypoglycemia with CHO deprivation on the control treatment, clearly performed better on the fat adaptation trial. Of course, in the second endurance study (7) when CHO was consumed before and during exercise in accordance with recommendations and current practice, all problems of blood glucose maintenance were overcome. In this study, time-trial performances were identical between treatments. Thus, we concluded that fat-adaptation strategies were not useful for the performance of athletes who undertake events of 2-2.5 hours duration. We felt that in these events, muscle glycogen stores were not limiting, and athletes could compete optimally with the use of the recommended strategies to promote CHO availability.

It was initially predicted that the ultra-endurance scenario in which the prolonged duration of exercise draws heavily on muscle glycogen would be the only situation in which fat-adaptation/dietary periodisation could be a useful nutritional strategy. However, performance in the ultra-endurance study showed individual subject responses, without a clear group benefit from the fat-adaptation strategy (8). Overall, a 4% enhancement of TT performance was shown for the fat-adaptation treatment compared to the control trial. However, this effect was not statistically significant and the likely range of true responses ranged from a clear performance improvement (11%) to a performance decrement (-3%). Even though the subjects were highly trained and well-accustomed to riding in laboratory trials, it is possible that the reliability of time-trials undertaken at the end of such a long event is not sufficiently sensitive to detect small but real performance improvements. On the other hand, it is possible that aggressive tactics of CHO intake during ultra-endurance events (consuming sports drinks, sports gels and other CHO-rich foods) is sufficient to achieve optimal performance. Finally, this study observed in agreement with other investigations that individuals may show variability in response to fat adaptation treatments, with some being “responders” to the treatment.

Finally, in the study involving 10 days of adaptation to a high fat diet, followed by 3 days of CHO loading, subjects reported a 4% improvement in TT compared with the control trial (9). Although this study introduced other elements, such as the intake of medium chain triglyceride (MCT) oils before and during the performance ride, the overall enhancement is in agreement with the changes seen in the ultra-endurance trial (8)

Further investigations are warranted to pursue the benefits of dietary periodisation strategies to individual athletes and individual situations of prolonged exercise.

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Conclusions

Despite causing substantial metabolic adaptations to fuel utilisation during exercise, fat loading or adaptation strategies are unlikely to improve the performance of endurance sports or exercise activities (90-120 min), when strategies to promote CHO availability are undertaken. Furthermore, dietary periodisation strategies fail to provide a clear benefit to ultra-endurance events. Since high-fat, low-CHO diets are difficult to construct and follow, most athletes should continue to focus on the well-supported guidelines for consuming CHO before, during and after their exercise activities. Nevertheless, studies should continue to investigate dietary periodisation strategies for prolonged events (3 hours +) with the focus on identifying situations and individuals that may benefit or “respond” to these strategies.

The following co-authors in the Australian Institute of Sport studies are recognised: Damien J. Angus², Andrew Carey³, Sally Clark¹, Gregory R. Cox¹, Nicola K. Cummings¹, Ben Desbrow¹, Mark A. Febbraio², Kathryn Gawthorn¹, John A. Hawley³, Michelle Minehan¹, David T. Martin¹, Mark Hargreaves⁴, Heidi Staudacher³

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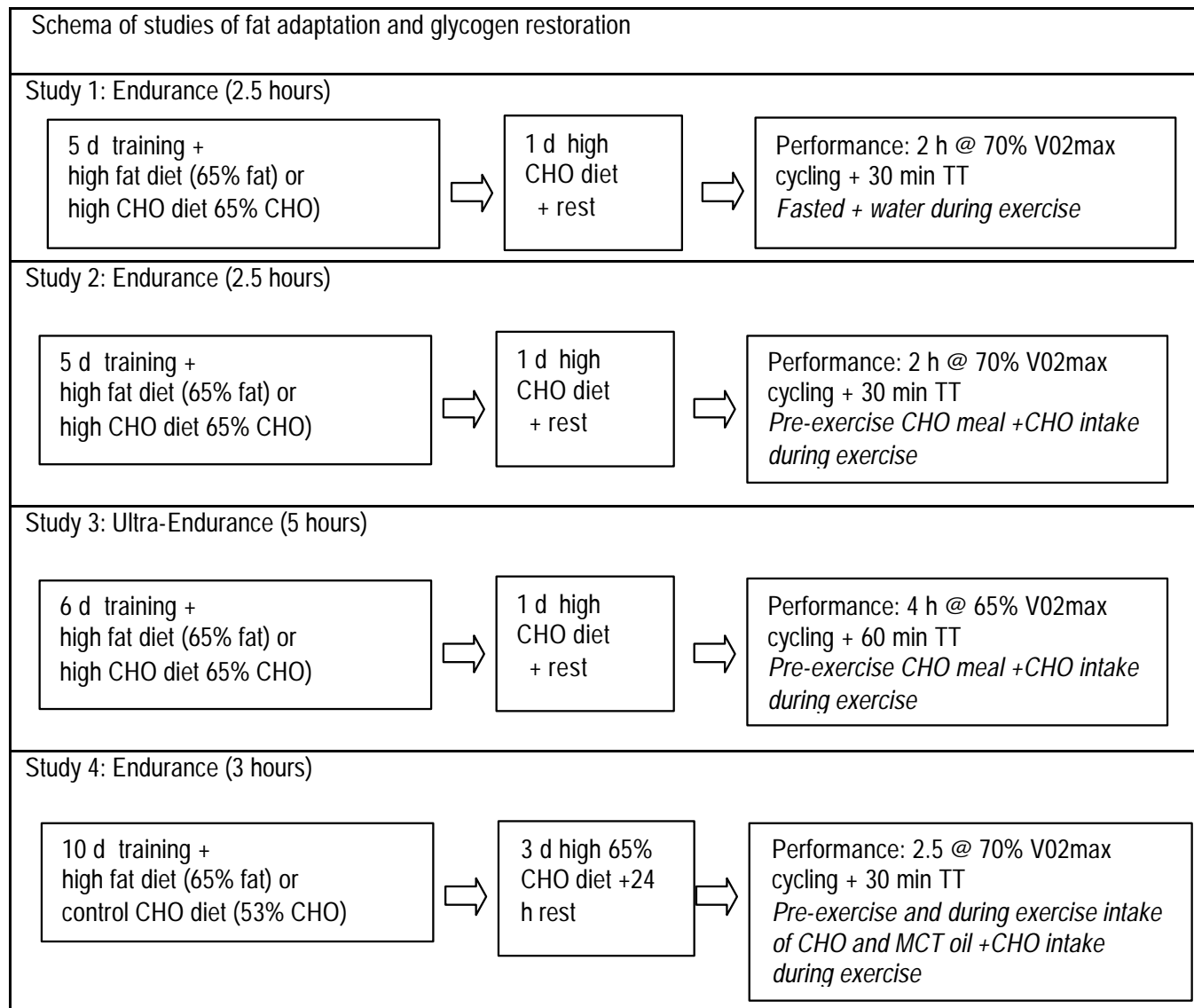
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Fig 1



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INTRODUCTION: Carbohydrate (CHO) stores in the blood and muscle are only sufficient to fuel 1-2 hours of submaximal exercise, and the depletion of these stores is associated with fatigue and impairment of exercise capacity. Typically, the nutritional strategies aimed at optimising the performance of endurance and ultra-endurance sports and exercise activities focus on increasing the availability of these limited fuel substrates. Strategies such as CHO loading, consuming a CHO-rich meal in the hours prior to exercise, and consuming CHO throughout an event have been shown to enhance endurance and performance when they are able to maintain or increase CHO availability during exercise (1). However, these strategies essentially provide an additional fuel source for the muscle rather than alter the depletion of the critically important muscle glycogen levels. An alternative angle for performance enhancement would be to find a fuel source to replace glycogen and slow its rate of use during exercise.

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Background to "Fat loading": The immediate effect of short-term (1-3 day) exposure to a high-fat, low CHO diet is to lower resting muscle glycogen stores, which impairs an athlete's ability to perform prolonged exercise by causing premature depletion of this critical fuel (2). However, longer periods (> 7 days) on such a diet cause metabolic adaptations that enhance fat oxidation during exercise, and compensate for the reduced CHO availability. In fact, it has been suggested that "fat loading" strategies might enhance the performance of endurance and ultra-endurance athletes by making them better able to "tap into body fat stores".

Despite the publicity for "fat loading" theories, there are few studies in which it has been tested in trained subjects, and most investigations of performance changes are clouded by problems of flaws in the study design. In the best known study by Phinney et al., 5 well-trained cyclists cycled to exhaustion at a workrate eliciting 60% VO_{2max} before and after 4-weeks of adaptation to a high-fat (70% of energy), low-CHO (< 20g/d) diet (3). Although this study is widely cited in support of fat loading strategies, in fact, the cyclists achieved similar endurance times in both trials. However, the group results were skewed by an unusually large improvement in the performance of one cyclist, while the remaining subjects showed a neutral or negative reaction to the treatment. Furthermore, it should be noted that the treatment was applied with an order effect – all subjects were tested with their normal carbohydrate diet, followed by the high-fat treatment, allowing for the possibility of systematic changes in training status.

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stores following a period of fat loading might offer the athlete an opportunity to take better advantage of both fat and CHO substrates. A number of studies have considered the possibility of “dietary periodisation” in well-trained athletes. In this model, muscle fat utilisation is optimised with the minimal necessary exposure to a high-fat diet, then followed by a period of high CHO intake, to restore muscle glycogen concentrations without allowing a “washing out” of the enhanced capacity for fat oxidation. This paper will discuss 4 studies recently undertaken on this theme; including 3 studies conducted at the Australian Institute of Sport (6,7,8,)

METHODS USED IN DIETARY PERIODISATION STUDIES: FAT LOADING AND GLYCOGEN RESTORATION:

Figure 1 provides an overview of 4 studies undertaken on endurance and ultra-endurance athletes using a dietary periodisation protocol, each designed to investigate metabolic changes during exercise as well as a measurement of performance (6,7,8,9). In each study, highly-trained athletes were recruited to participate in a cross-over designed investigation, and considerable rigour was applied in ensuring compliance to the designated high-fat or high-CHO diets.

In the first 3 studies, a five- or six-day period of fat adaptation was undertaken, followed by a 24 hour period of carbohydrate restoration (6,7,8). Subjects were supervised to follow an identical training program of 15-22 hours per week of cycling on each treatment. Biopsy-determined measurements of muscle glycogen concentrations showed that the high fat diet lead to a depletion of muscle CHO stores, whereas subjects were able to maintain glycogen stores while undertaking the same training program on the high CHO diet. At the end of the 5-6 days of training and dietary treatment, a subsequent day of rest and high CHO eating was found to restore – in fact, supercompensate - muscle glycogen concentrations, regardless of the preceding diet. This loading day enabled subjects to start the performance trial with equally elevated glycogen stores despite their previous dietary treatment. The separate aims of each of the studies is summarised below:

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Ultra-endurance study 3 (8). To investigate whether a longer exercise protocol, providing a greater risk of performance limitations from depleted muscle glycogen stores, would benefit from glycogen sparing.

In a fourth study (9), undertaken at the University of Cape Town, subjects followed a 10- day control diet or high fat diet in randomised cross-over order, followed by a 3 day high CHO phase designed to load muscle glycogen stores.

RESULTS AND DISCUSSION: A common feature of these dietary periodisation studies was the reporting of symptoms of lethargy, mild headaches and fatigue during the high-fat treatment. During the studies incorporating supervised training protocols, all subjects had trouble in completing at least one of their programmed training sessions – complaining of either an increased perception of effort, or difficulty in maintaining the desired training pace. These generalised symptoms appeared to decrease as the week progressed, but may be an important consideration in the completion of training programs based on perception of effort.

Performance was measured in all studies at the end of each treatment using a two-part model: 1) An initial portion in which the athletes rode at a steady-state pace indicative of the typical workload of their event, and 2) The immediate completion of a self-paced time-trial in subjects finished a certain volume of riding as quickly as possible. In this way, scientists endeavoured to monitor the metabolic responses to a standard exercise task, as well as have athlete “compete” in a performance protocol that mimics the demands of a real-life sporting event.

Rates of total fat oxidation and total CHO oxidation were calculated for the steady-state portion of each performance protocol. In each study the fat-adaptation treatment was associated with substantially higher rates of fat utilisation, and lower rates of CHO oxidation, with these differences being maintained throughout the duration of the steady-state ride. Equally, these differences were maintained even under the conditions of maximal carbohydrate availability, achieved by having the athletes consume a high CHO meal prior to cycling, and continue to consume CHO during the ride. Thus, the high fat diet caused powerful metabolic adaptations, which persisted and were independent of body CHO availability. The use of muscle biopsies, and glucose tracers enabled researchers in some studies to determine that the reduction in CHO use during exercise was almost entirely accounted for by a sparing of muscle glycogen stores (6,8). As previously noted, this should be considered to represent a true case of glycogen sparing, since muscle glycogen stores were equalised at the onset of each performance test. Other results showed that there were no differences in the rate of utilisation of blood glucose or CHO derived from drinking a sports drink throughout

the performance ride (8). The techniques used in these studies were unable to determine the source of the additional fat used as a muscle fuel.

In the first endurance study, undertaken without further intake of CHO before or during the exercise protocol, subjects showed a gradual decline in blood glucose concentrations during the ride (6). However, this decline was less severe following the fat adaptation treatment, and appeared to protect 2 subjects from developing symptoms of hypoglycemia as occurred while on the control (high CHO) treatment. The performance of the time-trial in this study showed no statistically significant benefits from the fat adaptation treatment among the group, despite all subjects started the time-trial with substantially greater muscle glycogen stores. Nevertheless the two subjects who developed hypoglycemia with CHO deprivation on the control treatment, clearly performed better on the fat adaptation trial. Of course, in the second endurance study (7) when CHO was consumed before and during exercise in accordance with recommendations and current practice, all problems of blood glucose maintenance were overcome. In this study, time-trial performances were identical between treatments. Thus, we concluded that fat-adaptation strategies were not useful for the performance of athletes who undertake events of 2-2.5 hours duration. We felt that in these events, muscle glycogen stores were not limiting, and athletes could compete optimally with the use of the recommended strategies to promote CHO availability.

It was initially predicted that the ultra-endurance scenario in which the prolonged duration of exercise draws heavily on muscle glycogen would be the only situation in which fat-adaptation/dietary periodisation could be a useful nutritional strategy. However, performance in the ultra-endurance study showed individual subject responses, without a clear group benefit from the fat-adaptation strategy (8). Overall, a 4% enhancement of TT performance was shown for the fat-adaptation treatment compared to the control trial. However, this effect was not statistically significant and the likely range of true responses ranged from a clear performance improvement (11%) to a performance decrement (-3%). Even though the subjects were highly trained and well-accustomed to riding in laboratory trials, it is possible that the reliability of time-trials undertaken at the end of such a long event is not sufficiently sensitive to detect small but real performance improvements. On the other hand, it is possible that aggressive tactics of CHO intake during ultra-endurance events (consuming sports drinks, sports gels and other CHO-rich foods) is sufficient to achieve optimal performance. Finally, this study observed in agreement with other investigations that individuals may show variability in response to fat adaptation treatments, with some being "responders" to the treatment.

Finally, in the study involving 10 days of adaptation to a high fat diet, followed by 3 days of CHO loading, subjects reported a 4% improvement in TT compared with the control trial (9). Although this study introduced other elements, such as the intake of medium chain triglyceride (MCT) oils before and during the performance ride, the overall enhancement is in agreement with the changes seen in the ultra-endurance trial (8)

Further investigations are warranted to pursue the benefits of dietary periodisation strategies to individual athletes and individual situations of prolonged exercise.

CONCLUSIONS: Despite causing substantial metabolic adaptations to fuel utilisation during exercise, fat loading or adaptation strategies are unlikely to improve the performance of endurance sports or exercise activities (90-120 min), when strategies to promote CHO availability are undertaken. Furthermore, dietary periodisation strategies fail to provide a clear benefit to ultra-endurance events. Since high-fat, low-CHO diets are difficult to construct and follow, most athletes should continue to focus on the well-supported guidelines for consuming CHO before, during and after their exercise activities. Nevertheless, studies should continue to investigate dietary periodisation strategies for prolonged events (3 hours +) with the focus on identifying situations and individuals that may benefit or "respond" to these strategies.

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Fig 1

