Effect of high-fat diets on exercise performance

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In dietary intervention studies, lasting 3–5 d, the prevailing concept is that endurance performance after consuming a carbohydrate-rich diet is superior to that when a fat-rich diet is consumed. Thus, in the classical study by Christensen & Hansen (1939) three trained subjects consumed either a fat-rich diet (containing only 5 % energy as carbohydrate) or a carbohydrate-rich diet (90 % energy as carbohydrate) for 3–5 d. Exercise to exhaustion at approximately 65–70 % maximal O_2 uptake (V_{O_2max}) revealed an average endurance time on the carbohydrate diet of 210 min, which was markedly longer than that on the fat diet (90 min). Also, when intermittent exercise (30 min running followed by 10 min rest) at 70 % V_{O_2max} was performed in trained men, endurance performance time to exhaustion was significantly impaired after consuming a fat-rich diet (76 % energy as fat, 13·5 % energy as protein) for 4 d (62 (SE 6) min) compared with a carbohydrate-rich diet (77 % energy as carbohydrate, 13·5 % energy as protein) for 4 d (106 (SE 5) min; Galbo *et al.* 1979). Also, the short-term studies by Bergström *et al.* (1967) and Karlsson & Saltin (1971) suggested that 3–7 d on a fat-rich diet were detrimental to exercise performance. Thus, it is evident from these short-term dietary manipulations that 'fat-loading' reduces endurance performance.

Longer-term adaptation to fat-rich diets, on the other hand, may induce skeletal-muscle adaptations, metabolic and/or morphological, which in turn could influence exercise performance. It has been known for a long time that endurance training induces several adaptations in skeletal muscle, such as increased capillarization, increased mitochondrial density, increased activity of several oxidative enzymes (Saltin & Gollnick, 1983) and, as shown recently, an increased content of fatty acid-binding protein in the sarcolemma (Kiens *et al.* 1997); all variables suggested to play a significant role in enhancing lipid oxidation. It might be possible, therefore, to influence the fat oxidative system further by increasing the substrate flux of fatty acids through the system, which could be achieved by increasing the fat content of the diet. This might result in further adaptations in the fat oxidative capacity, providing possibilities for increased fat oxidation, sparing of carbohydrates and increasing endurance performance.

In the study by Lambert *et al.* (1994) five endurance-trained cyclists consumed, in a random order, either a diet containing 74 % energy as carbohydrate or a diet with 76 % energy as fat for 14 d, separated by 2 weeks on an *ad libitum* or normal diet. They continued their normal training throughout the experimental period. The study revealed that maximal power output (862 (SE 94) W *v.* 804 (SE 65) W for the high-fat and high-carbohydrate diets respectively) and high-intensity bicycle exercise to exhaustion at approximately 90 % V_{O_2max} (8·3 (SE 2) *v.* 12·5 (SE 4) min for the high-fat and high-carbohydrate diets respectively) was not impaired after the high-fat diet compared with the high-carbohydrate diet. Moreover, during a subsequent prolonged submaximal-exercise test at approximately 60 % V_{O_2max}, endurance performance was significantly enhanced on the high-fat diet compared with the high-carbohydrate diet. This improvement in submaximal endurance capacity occurred despite an initial muscle glycogen content which was twofold lower (32 (SE 6) mmol/kg wet weight) than that in the carbohydrate-adapted trial (78 (SE 5) mmol/kg wet weight). However, the subjects performed three consecutive tests on the same day only separated by short rest intervals and the submaximal endurance test to exhaustion was always performed as the last test. This design confounds the interpretation of dietary effects on endurance performance.

In contrast, in the study by Pruett (1970) relatively well-trained subjects performed intermittent exercise tests (45 min bouts followed each time by a 15 min rest period) until exhaustion after consuming either a standard diet (% energy; 31 fat, 59 carbohydrate, 10 protein), a high-fat diet (% energy; 64 fat, 26 carbohydrate, 10 protein) or a high-carbohydrate diet (% energy; 8 fat, 82 carbohydrate, 9 protein) for at least 14 d. Nine subjects participated in the study and each subject was placed on one of the three different diets, four of the subjects consumed all three diets. The exercise experiments were performed with 2-week intervals at workloads equal to 70 % V_{O_2max}. The subjects maintained their training throughout the 2 months required to complete the experiments. It was reported that exercise time to exhaustion was not different between the standard (175 (SE 15) min) and the high-fat diet (164 (SE 19) min),

Abbreviations: V_{O_2max}, maximal O_2 uptake.

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whereas a longer work time was observed when on the high-carbohydrate diet (193 (SE 12) min) compared with the high-fat diet (164 (SE 19) min).

In the study by Phinney *et al.* (1983) submaximal endurance performance was studied in five well-trained bicyclists when fed on a balanced diet for 1 week (providing 146–209 kJ/kg per d, 1·75 g protein/kg per d and the remainder of energy as two-thirds carbohydrates and one-third fat). This was followed by 4 weeks of a ketogenic diet, isoenergetic and isonitrogenous with the balanced diet, but providing less than 20 g carbohydrates daily. The subjects continued their normal training throughout the study. Endurance time to exhaustion, at 60–65 % V_{O_2max}, was longer in three subjects (by 57, 30 and 2 %) and shorter in two subjects (by 36 and 28 %) after 4 weeks of adaptation to the ketogenic diet, resulting in no statistical difference in the mean exercise time after the two dietary trials (147 (SE 13) min for balanced diet *v.* 151 (SE 25) min for ketogenic diet). However, the big variability in performance time of the subjects makes the results difficult to interpret. A highly-significant decrease in RQ values during the endurance test was found and, in agreement with this finding, a threefold decrease in glucose oxidation and a fourfold reduction in muscle glycogen use were demonstrated.

The interaction between training and diet was studied by Helge *et al.* (1998). Fifteen initially-non-trained male subjects were randomly assigned to consume a high-fat diet (% energy; 62 fat, 21 carbohydrate, 17 protein) or a high-carbohydrate diet (% energy; 20 fat, 65 carbohydrate, 15 protein) while following a supervised training programme for 4 weeks. Training was performed four times weekly and each 60 min training session comprised alternating short- and long-duration periods of exercise at 60–85 % V_{O_2max}. After the 4-week intervention period V_{O_2max} was increased by 9 % in both dietary groups ($P < 0·05$). Endurance performance time to exhaustion, measured using a Krogh bicycle ergometer, at 72 % V_{O_2max} (same absolute work load as in the initial non-trained trial), was similarly and significantly increased in both dietary groups after both 2 and 4 weeks of training and dietary treatment. Thus, comparing the trained subjects in the high-fat group with those in the high-carbohydrate group after 4 weeks, exercising at the same relative work load (72 % V_{O_2max}), no differences in exercise time to exhaustion were found between the two dietary groups (79 (SE 8) min high-fat group *v.* 79 (SE 15) min high-carbohydrate group). Thus, it appears that adaptation to a high-fat diet in combination with training for up to 4 weeks, exercising at a submaximal workload (60–72 % V_{O_2max}), does not impair endurance performance (Phinney *et al.* 1983; Helge *et al.* 1998). However, in the study by Helge *et al.* (1996), two groups of non-trained male subjects underwent a 7-week supervised training programme while consuming either a high-fat diet (% energy; 62 fat, 21 carbohydrate, 17 protein) or a high-carbohydrate diet (% energy; 20 fat, 65 carbohydrate, 15 protein). V_{O_2max} increased similarly in the two groups by 11 % ($P < 0·05$). Time to exhaustion, exercising on the Krogh bicycle ergometer at 82 % pre-training V_{O_2max}, was significantly increased, from the mean initial value for the two groups of 35 (SE 4) min to 65 (SE 7) min in the high-fat

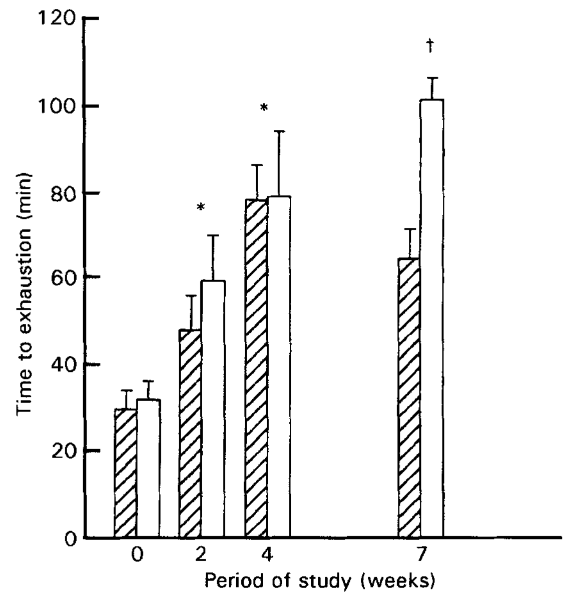

Fig. 1. Endurance performance to exhaustion measured on a Krogh bicycle ergometer before (0) and after 2, 4 and 7 weeks of endurance training when consuming a fat-rich diet (▨) or a carbohydrate-rich diet (□). Mean values were significantly different from those at week 0 for both diets: *$P < 0·05$. Mean value for the carbohydrate-rich diet was significantly different from that for the fat-rich diet at week 7: † $P < 0·05$. (Data from Helge *et al.* 1996, 1998.)

group, with a significantly higher value in the high-carbohydrate group (102 (SE 5) min). Thus, combining these findings, it is apparent that the training-induced increase in endurance performance is less when a major part of daily energy intake consists of fat for a period longer than 4 weeks compared with when carbohydrates made up the major part of daily energy intake (Fig. 1). Furthermore, when comparing the trained subjects exercising at the same relative workload, time to exhaustion after 7 weeks on a high-fat diet was found to be significantly shorter than that with a high-carbohydrate diet. Summarizing these studies it appears that a further increase in endurance performance will be impaired when a high-fat diet is continued beyond 4 weeks. It is not clear why prolonged elevated dietary fat intake reduces improvement in endurance performance in human subjects. One important aspect of the adaptation to dietary fat could be the capacity of enzymes involved in fat oxidation; a strong correlation has been demonstrated between β-hydroxyacyl-CoA dehydrogenase (*EC* 1.1.1.35) activity and fatty acid uptake and oxidation in human subjects (Kiens, 1997). In the study by Helge & Kiens (1997) the activity of β-hydroxyacyl-CoA dehydrogenase was increased by 25 % after 7 weeks of adaptation to a fat-rich diet, irrespective of whether subjects were trained or not. Furthermore, after 4 weeks of adaptation to a fat-rich diet, carnitine palmitoyl-transferase (*EC* 2.3.1.21) activity was increased by 35 % and hexokinase (*EC* 2.7.1.1) activity was decreased by 46 % (Fisher *et al.* 1983). Putman *et al.* (1993) demonstrated that the activity of the active form of pyruvate dehydrogenase (*EC* 1.2.4.1) was higher after 3 d of adaptation to a high-fat diet compared with a high-carbohydrate diet. Preliminary data from our laboratory

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(B Kiens, LB Turcotte and JFC Glatz, unpublished results) also reveal that a fat-rich diet per se, consumed for 4 weeks, induces a significant increase in the fatty acid-binding protein located in the cytosol and in the plasma membrane. Thus, allowing for the complexity of this issue, it seems fair to conclude that a fat-rich diet consumed for more than 4 weeks increases the capacity for fatty acid transport and oxidation. Despite this adaptation, training-induced increases in endurance performance are nevertheless impaired when compared with a high-carbohydrate diet. Thus, the fat oxidative capacity does not by itself seem to be decisive for endurance. Other explanations have to be found. Possible mechanisms could include an increased sympathetic activity with time when a fat rich diet is consumed, or changes in phospholipid-fatty acid membrane composition induced by dietary fat intake over a longer period (Helge *et al.* 1996). We have also demonstrated that 7 weeks of training induced a significant and similar increase in muscle insulin-sensitive glucose transporter protein GLUT4 when either a fat-rich diet or a carbohydrate-rich diet was consumed during the training period. However, during submaximal exercise at 71 % V_{O_2max}, glucose uptake, measured across the thigh, was 53 % lower with the fat-rich diet than with the carbohydrate-rich diet. This decrease in exercise-induced muscle glucose uptake might contribute to the impairment of endurance performance associated with the consumption of a fat-rich diet (JW Helge, EA Richter and B Kiens, unpublished results).

Conclusion

From the available literature, based on human studies, it seems fair to conclude that short-term ingestion of a fat-rich diet (3–5 d) leads to a deterioration of endurance performance when compared with ingestion of a carbohydrate-rich diet. Moreover, adaptation to a fat-rich diet, in combination with training, from 1–4 weeks, does not reduce endurance performance compared with a diet rich in carbohydrates, but when dietary treatment and training are continued for 7 weeks, endurance performance is markedly better when a carbohydrate-rich diet is consumed.

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