Eating, Drinking, and Cycling. A Controlled Tour de France Simulation Study, Part II. Effect of Diet Manipulation*

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Abstract

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Field studies during the Tour de France indicated that cyclists consume 30% of daily energy intake as liquid carbohydrate (CHO)-enriched nutrition with the goal of maintaining energy and CHO balance. The aim of the present investigation was to study the effect of such dietary manipulation during 2 days of long-lasting exhausting cycling on food and fluid intake, energy balance, nitrogen balance, and nutrient oxidation.

Thirteen highly trained cyclists were divided into two subgroups receiving ad libitum either a primarily maltodextrin-based beverage (Mf) (20% w/v, 85% maltodextrin, 15% fructose) or a 50/50% composed fructose-maltodextrin (FM) beverage in addition to their normal diet. The study was performed during a 7-day stay in a respiration chamber (2 preparation days, 1 standardized resting day, 2 cycling days, 1.5 standardized recovery days), allowing for continuous gas analysis, weighed food and fluid intake procedure, and collection of excretes. The data of this study were compared with data from the same subjects receiving a normal CHO-rich diet (N) (60 En%) in a separate experiment.

The results showed that the cyclists receiving Mf were able to maintain EB during sustained exercise days in contrast to when receiving N and to subjects receiving FM. With Mf treatment CHO intake increased, up to 80 En% ($17.5 \pm 1.0\ g \cdot kg^{-1}$ BW) and carbohydrate balance remained positive. The subjects receiving FM had the largest CHO oxidation, calculated from R. Protein oxidation significantly increased in N and FM as a result of exercise but not in Mf. The latter subjects were in slighly negative nitrogen balance at a protein intake level of $1.4\ g \cdot kg^{-1}$ BW.

The results show that supplementation with maltodextrin beverages is an adequate measure to maintain EB and CHO balance and furthermore that increased CHO intake induces protein sparing. The protein requirement while being in energy and carbohydrate balance during days of sustained exhausting cycling was in the range of $1.5–1.8\ g \cdot kg^{-1}$ BW.

Key words

Food intake, fluid intake, diet manipulation, energy balance, nitrogen balance, nutrient oxidation, cycling

Introduction

Whenever energy requirement in athletes increases to levels above 20 MJ/day, the athlete is faced with the problem of how to ingest and digest such a large quantity of food when long-lasting exercise has to be executed at the same time. Kirsch (16) described a spontaneous nibbling eating pattern of athletes who, in such circumstances, tend to eat more or less continuously throughout the day. Practical experience shows that especially foods and liquids are selected that are sweet in taste, high in energy, and convenient. Consequently, it is found that in-between meals composed of such foods and drinks may make up more than 30% of total energy intake (6, 25, 29). One of the main problems of athletes during competition days seems to be the intolerance of the gastrointestinal tract to take up and digest large amounts of food whenever intensive exercise is executed at the same time. Apart from the exercise-induced changes in appetite (4), it has clearly been indicated from practice that athletes must rely on easily digestible and energy-dense foods that are low in dietary fiber, for the following reasons:

- The amount of feces produced from a normal diet would require the cyclist to defecate several times during the day and consequently to interrupt exercise.
- Large volumes of food may interfere with fluid intake which in itself may be exceptionally high during hot days [more than 10 l/day, (25)]

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As a result the athlete will either undereat when only a conventional diet is available during such competition days (6) or will maintain energy balance when a combination of normal foods and carbohydrate (CHO)-rich liquids is supplied as was observed during the Tour de France (25). To investigate more specifically the influence of such dietary practices on food and fluid intake, energy balance, fluid status, and nutrient utilization during repeated exhausting cycling, it was decided to do a controlled laboratory study in which the effects of a normal CHO-rich diet (N) (6) were compared with those of the same diet, but supplemented with a concentrated liquid CHO beverage.

The reason for CHO supplementation as diet intervention was twofold:

1. Depletion of CHO stores in the body is related to physical exhaustion (2, 3, 24, 26) while increased CHO intake may delay exhaustion (8, 10, 15).

2. A survey among professional cyclists competing in the Tour de France showed that liquid CHO supplements had the largest relative contribution to total CHO intake (25).

Experimental Design, Analyses, and Statistics

The experimental setup used during the diet manipulation trial has been described elsewhere (6). The same holds for the analysis of samples and the statistics used to analyze the data. Therefore, only the differences due to diet manipulation, not described before, will be outlined here.

The total group of 13 subjects receiving the normal diet (N), was divided into two subgroups for diet manipulation. Six subjects were supplemented with an experimental high-maltodextrin, low-fructose beverage (Perform®, Wander Ltd) (Mf). The seven other subjects were supplemented with another experimental beverage, composed of 50% free fructose and 50% maltodextrin (FM). The subjects were randomly selected for either Mf of FM treatment as was the order of treatment (normal diet or manipulated diet). The composition of the beverages used is presented in Table 1.

Results

Energy

The data on energy intake (EI) and energy expenditure (EE) are presented in Table 2. When the values of diet manipulation were compared with those of N (each subject was his own control) there were large statistically significant differences for EI, whereas there were no differences in EE between the treatment groups. In Mf, mean EI was always greater than mean EE, despite the fact that EE increased to levels far above 20 MJ on both exhausting exercise days. In contrast to this, in cyclists with FM treatment EI was smaller than EE on both exercise days. EI was significantly higher ($P < 0.05$) in Mf compared with FM on the first exercise exhaustion day but not on the second exercise day.

As a result of the increased EI in Mf, the subjects of this group remained in energy balance (EB), whereas in the FM treatment subjects did not. In this group (EB) was

Table 1 Composition of beverages

Beverage	Malto dextrin ($g.l^{-1}$)	Fructose ($g.l^{-1}$)	K+ (mmol)	Osmolality (mosm)	pH	Energy content ($kJ.l^{-1}$)
Placebo	0	0	8.5	106	4.38	-
Mf	150	33	8.5	390	4.45	3158
FM	90	93	8.5	788	4.52	3158

Placebo drink was supplied during N treatment in equal quantities and at the same times as the beverages in Mf and FM treatment. The placebo was flavored with citrus powder, sweetened with saccharin and cyclamate, and artificially colored. In all beverages the same vitamin-mineral mix was added.

Table 2 Energy intake (EI) and expenditure (EE)

Day / Treatment	3	4	5	6
EI Mf	23.5 ± 1.0	29.2 ± 70.9*	27.0 ± 1.0**	20.3 ± 1.6
EE Mf	16.5 ± 0.4	26.6 ± 1.1	25.8 ± 1.2	16.2 ± 0.5
EI FM	22.2 ± 1.4**	26,3 ± 0.9**	25.3 ± 1.5**	18.9 ± 1.6
EE FM	16.1 ± 0.5	26.9 ± 1.0	26.3 ± 1.1	16.0 ± 0.6

Mean values ± SEM are given in MJ. For Mf group $n = 6$, for FM group $n = 7$. For composition of the beverages see Table 1. EI was determined by weighed food intake, EE was determined by indirect calorimetry. Asterisks indicate a significant difference with respect to values obtained with conventional diet (N). Each subject was his own control. For N values see Table 2, Chapter 2. * = $P < 0.05$; ** = $P < 0.01$.

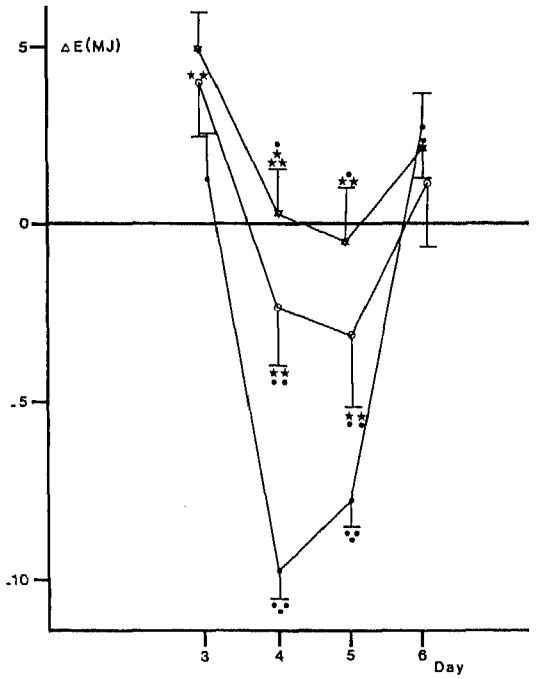

Fig. 1 Mean daily energy balance (ΔE) derived from total energy intake minus total energy expenditure. Corrections were made for energy losses in urine, feces, blood, and sweat. Days 3 and 6 were resting days, 4 and 5 were exercise days. Bars indicate mean ± 1 SEM. –·– = conventional food group (N); $n = 13$, –*– = Mf group ($n = 6$), –o– = FM group ($n = 7$). Dots indicate statistical significance of differences compared with the initial volue on day 3; · = $P < 0.05$; ·· = $P < 0.01$; ··· = $P < 0.001$. *Indicates a statistically significant difference with respect to comparative data of groups N (each subject was his own control). ** = $P < 0.01$; *** = $P < 0.001$.

Table 3 Relative contribution of nutrients to energy intake

Food component	Diet group N	Mf	FM
CHO			
Day 3	61.8 ± 1.7	66.8 ± 2.7	68.0 ± 1.9*
Day 4	62.9 ± 1.3	80.5 ± 1.5**..	75.6 ± 2.0***..
Day 5	62.4 ± 1.6	79.7 ± 1.3**.	77.9 ± 2.2**...
Day 6	62.7 ± 1.6	67.5 ± 2.6	66.9 ± 2.7
Fat			
Day 3	25.7 ± 1.3	22.7 ± 2.1	21.9 ± 1.5*
Day 4	24.7 ± 1.0	13.2 ± 1.0**..	16.7 ± 1.4***..
Day 5	25.6 ± 1.3	17.0 ± 0.9**.	14.9 ± 1.7**...
Day 6	24.5 ± 1.2	21.2 ± 1.9	21.2 ± 1.9
Protein			
Day 3	12.5 ± 0.6	10.5 ± 0.8	10.3 ± 0.4*
Day 4	12.3 ± 0.6	6.3 ± 0.4..	7.4 ± 0.5***..
Day 5	12.1 ± 0.7	8.3 ± 0.6*.	7.4 ± 0.6*..
Day 6	12.8 ± 0.4	1.3 ± 1.0	10.3 ± 0.9***

Mean values ± SEM are given in En%. N = normal diet ($n = 13$). Mf = diet supplemented with high-maltodextrin (85%)/low-fructose (15%) beverage ($n = 6$). FM = diet supplemented with fructose (50%)/maltodextrin (50%) beverage ($n = 7$). Days 3 and 6 were resting days; days 4 and 5 were exercise days. Statistical significance with respect to the corresponding initial values on day 3 is indicated by . = $P < 0.05$; .. = $P < 0.01$; ... = $P < 0.001$. Statistical significance of groups Mf and FM with respect to corresponding data of group N (each subject was his own control) is indicated by * = $P < 0.005$; ** = $P < 0.01$; *** = $P < 0.001$.

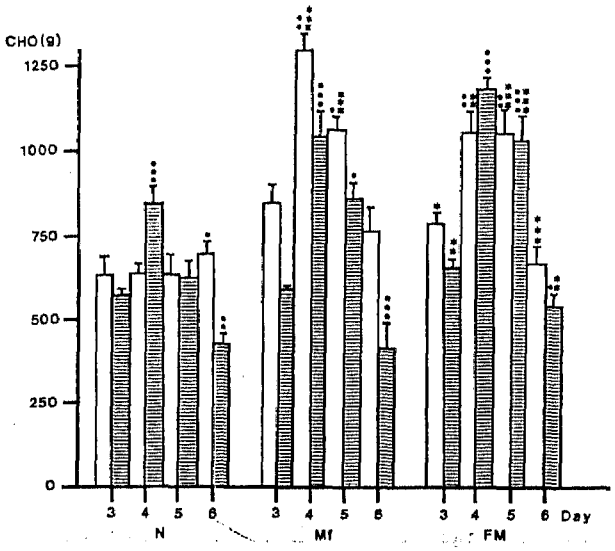

Fig. 2. Mean daily CHO intake (□, g) and CHO oxidized □, g). The amount of CHO oxidized was calculated from nonprotein R. Bars represent mean ± 1 SEM. For the N treatment group $n = 13$, for the Mf treatment group $n = 6$, for the FM treatment group $n = 7$. Statistical significance with respect to the initial values on day 3 is indicated by · = $P < 0.05$; ·· = $P < 0.01$. Statistical significance of groups Mf and FM with respect to comparative data of group N (each subject was his own control) is indicated by * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

negative during the sustained cycling days, however, to a lesser extent than during N (Fig. 1).

Nutrient Intake

In contrast to N, dietary manipulation caused a significant shift in the relative contribution of macronutrients to total energy intake. During the exhausting exercise days, CHO intake increased significantly to a mean level of 80 En% in Mf and 77 En% in FM, respectively.

The CHO intake is shown in Fig. 2. As a result of the diet manipulation, CHO intake increased significantly on all days, reaching a mean maximum value of 1300 g and 1060 g in Mf and FM, respectively. As a consequence, fat intake dropped significantly to 15 En% and protein intake to 7.5 EN% in both supplemented groups (Table 3).

The protein intake per kg body weight is presented in Fig. 3. Although there was a significant reduction in the relative contribution of protein intake to total energy intake, it can be seen that the quantitative protein intake remained more or less constant during the different treatments.

The largest intake occurred during N whereas the supplemented groups had lower intakes, but still markedly above the RDA (2) of 0.8g·kg^{-1} BW (mean lowest value 1.4 g.kg^{-1} on day 4 in Mf), and above the pre-set minimal intake of 1.2 g·kg^{-1} BW. There were no differences in intake in the different treatments between the first and last standardized rest day. However, when N was compared with the supplemented diets, it became apparent that fat and protein intake during the rest days was larger in N.

Nutrient Oxidation

The absolute amounts of CHO, fat, and protein oxidized are also graphically presented in Figs. 2 and 3. With respect to CHO, it can be seen that when oxidation is compared with intake, Mf treatment resulted in a positive CHO balance during the entire experiment. This is in contrast to N and FM which resulted in negative CHO balance due to increased CHO oxidation. The calculated relative contribution of the nutrients to total daily energy metabolism is presented in Fig. 4.

In contrast to N the relative contribution from fat to energy metabolism in the supplemented groups decreased during the first exercise day, followed by a gradual increase during the second exercise day and following recovery day, however, at a lower level than in N. Consequently, the oxidized fraction of CHO in both groups was larger. The lowest contribution from fat to energy metabolism, together with the highest CHO contribution, occurred in the "high" fructose group, during both rest and exercise days. Compared with N this was highly significant on all days.

Protein oxidation remained constant in Mf, despite sustained exercise. This is in contrast to N which showed a large significant increase during exercise and recovery days. In FM the amount of protein oxidized tended to increase during the first exercise day, then increased significantly during the second exercise day, and almost returned to

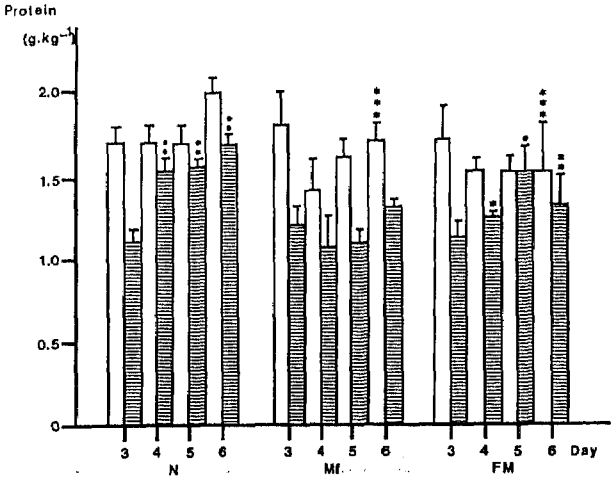

Fig. 3 Mean daily protein intake (□, $g.kg^{-1}$) and protein oxidized (□, $g.kg^{-1}$). The amount of protein oxidized was calculated from nitrogen excretion in urine and sweat. Bars indicate mean ± 1 SEM. N = conventional diet ($n = 13$); Mf = diet supplemented with high-maltodextrin/low-fructose beverage ($n = <6$); FM = diet supplemented with "high" fructose/maltodextrin beverage ($n = 7$). For exact composition of diets and beverages see text. Days 3 and 6 were resting days, 4 and 5 were exercise days. Statistical significance with respect to the initial values on day 3 is indicated by · = $P < 0.05$; ·· = $P < 0.01$; ··· = $P < 0.001$. Statistical significance of groups Mf and FM with respect to comparative data of group N (each subject was his own control) is indicated by * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

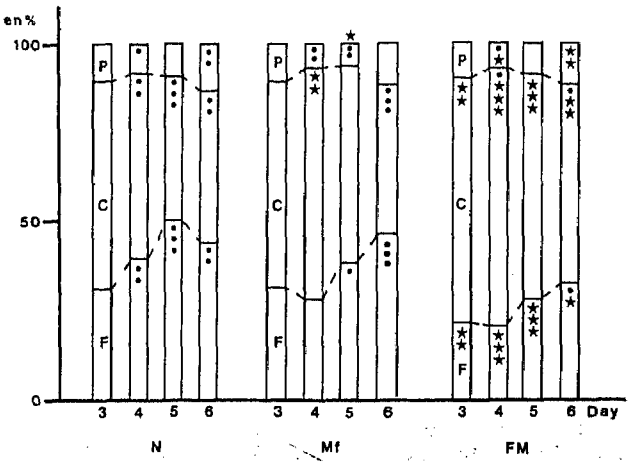

Fig. 4 Mean relative contribution of CHO, fat, and protein to total energy expenditure as calculated from nonprotein R and nitrogen excretion. C = carbohydrate; F = fat; P = protein. The amount of C and F oxidized was calculated from nonprotein R. The amount of protein oxidized was calculated from nitrogen excretion in urine and sweat. Bars indicate mean ± 1 SEM. Statistical significance with respect to the initial values on day 3 is indicated by · = $P < 0.05$; ·· = $P < 0.01$; ··· = $P < 0.001$. Statistical significance of groups Mf and FM with respect to comparative data of group N (each subject was his own control) is indicated by * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

Table 4 Fluid intake and loss in Mf (a) and FM (b) treatment

Day b Condition	3		4		5		6	
Mf	Intake	Loss	Intake	Loss	Intake	Loss	Intake	Loss
Rest	4.08 ± 0.17		3.34 ± 0.50		3.12 ± 0.44		4.08 ± 0.26	
Urine		1.82 ± 0.11		2.03 ± 0.17		1.85 ± 0.25		1.88 ± 0.14
Feces		0.15*		0.15*		0.15*		0.15*
Resp.water		0.40*		0.32*		0.32*		0.40*
Sweat		0.50*		0.40*		0.40*		0.50*
Exercise			3.15 ± 0.41		3.47 ± 0.41			
Sweat		–		3.99 ± 0.51		4.07 ± 0.35		–
Resp.water		–		0.56 ± 0.03		0.53 ± 0.04		–
Mean total	4.08	2.87	6.49	7.45	6.59	7.31	4.08	2.93
Day a Condition	3		4		5		6	
FM	Intake	Loss	Intake	Loss	Intake	Loss	Intake	Loss
Rest	3.60 ± 0.24		3.72 ± 0.51		2.55 ± 0.26		3.70 ± 0.37	
Urine		1.74 ± 0.17		2.69 ± 0.42		2.35 ± 0.42		1.46 ± 0.16
Feces		0.15*		0.15*		0.15*		0.15*
Resp.water		0.40*		0.32*		0.32*		0.40*
Sweat		0.50*		0.40*		0.40*		0.50*
Exercise			3.03 ± 0.31		3.53 ± 0.24			
Sweat		–		3.40 ± 0.51		3.54 ± 0.60		–
Resp.water		–		0.56 ± 0.02		0.56 ± 0.04		–
Mean total	3.60	2.79	6.75	7.52	6.09	7.32	3.70	2.51

Mean values ± 1 SEM (I; Mf $n = 6$; FM $n = 7$)
*Mean daily loss in resting conditions, taken from Weitzman (28).

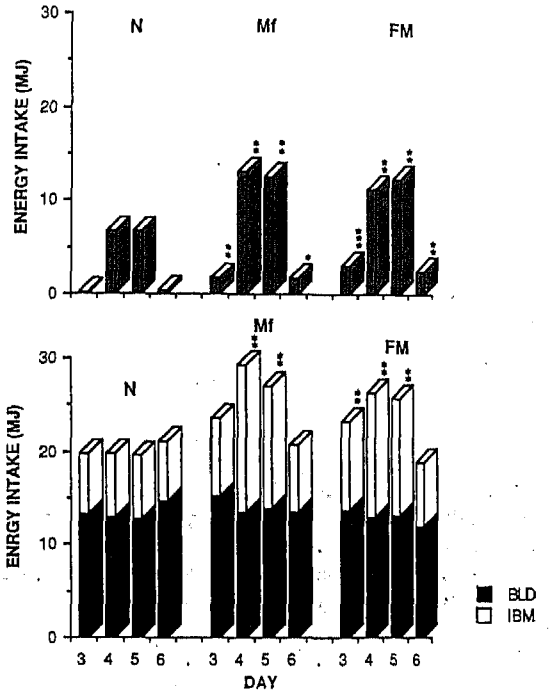

Fig. 5 Bottom, relative contribution of main meals and in-between meals to total daily energy intake. BLD = breakfast, lunch, dinner; Top, energy intake during exercise. Statistical significance of groups Mf and FM with respect to comparative data of group N (each subject was his own control) is indicated by * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

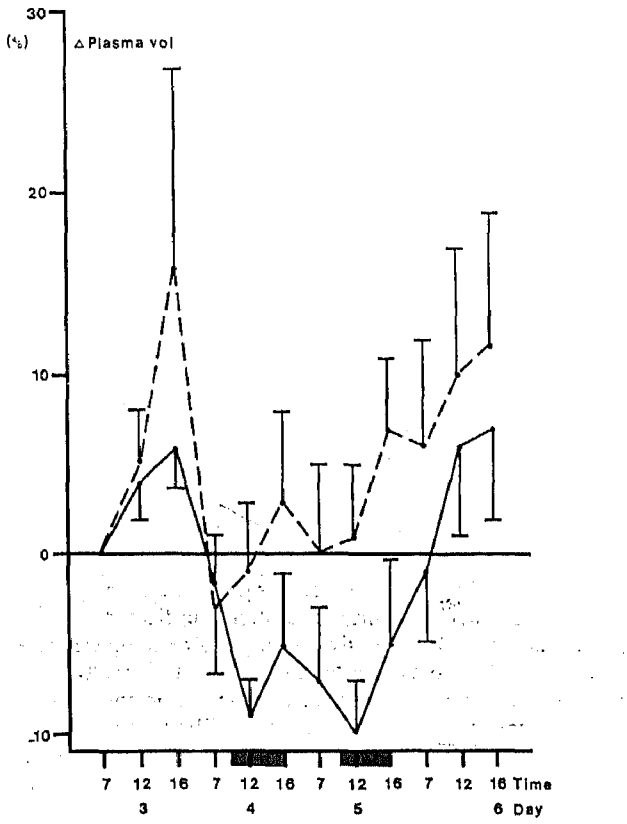

Fig. 6 Relative changes in plasma volume at rest (days 3 and 6) and during exhaustive exercise (days 4 and 5). - - - = Mf treatment group; -·- = FM treatment group. Vertical barx indicate 1 SEM. There was no statistically significant difference between the treatment groups.

the initial level during the recovery day. Compared with N, exercise caused less protein degradation probably as a result of diet manipulation, which became significant in FM and tended toward significancy in Mf. The relative contribution of protein to overall energy metabolism as calculated from nitrogen losses in sweat and urine decreased significantly during both exercise days in Mf, but in FM only during the first exercise day. Compared with N the relative contribution was smaller, except on the first rest day. During the recovery day all three treatment groups showed an increased protein oxidation compared with the pre-exercise rest day. However, this increase was only significant in N. Compared with N, FM had a significantly lower value on this day while Mf tended to be significantly lower ($P < 0.07$).

Food Consumption Pattern

The food consumption pattern presented in Fig. 5 shows that the supplementation of CHO-rich beverages during exercise caused a significant increase in energy intake, being almost entirely responsible for the increased total energy intake compared with N. In general, energy intake derived from the three main meals remained constant.

Table 5 Body weights over 4 days

Day Time		3	4	5	6
7 AM	Mf	75.5 ± 0.4	75.7 ± 0.4	75.3 ± 0.4*	75.3 ± 0.3
	FM	71.7 ± 0.3	71.4 ± 0.2	70.6 ± 0.2*.	70.7 ± 0.2
4 PM	Mf	75.5 ± 0.4	74.7 ± 0.4*.	74.7 ± 0.4	75.3 ± 0.4
	FM	71.4 ± 0.2	70.9 ± 0.2	70.2 ± 0.2.	70.9 ± 0.2
9 PM	Mf	76.1 ± 0.4*	75.8 ± 0.4	76.0 ± 0.4*	76.0 ± 0.4
	FM	72.1 ± 0.2*	71.7 ± 0.2	71.5 ± 0.2	71.6 ± 0.2

Mean values ± SEM (kg); Mf $n = 6$; FM $n = 7$).
Changes with respect to initial values on day 3 are indicated by dots. . = $P < 0.05$. Significance of changes with repect to values found when on a normal diet are indicated by asterisks * = $P < 0.05$.

Fluids

Fluid intakes and losses in Mf and FM are represented in Table 4. As in N, fluid intakes were larger than the calculated fluid losses during both rest days. During both sustained cycling days losses via urine, sweat, and respiratory water loss exceeded fluid intake by approximately one liter. Urine losses increased during exercise days and were not

different from N. Respiratory water loss during exercise was remarkably constant reaching a mean level of around 550 ml or approximately 110 ml/h. In general plasma volume (Fig. 6) showed a similar response pattern to food and fluid intake and to exercise as described for N (6).

Although Mf subjects tended to have decreased plasma volumes below the initial level on exercise days compared with N treatment, this was not statistically significant. Body weight remained markedly stable during the experiment in both Mf and FM. This is in contrast to N where a significant body weight reduction occurred which was not corrected during the recovery period. Although in FM as well as in Mf body weight decreased at the same measuring points during exercise, there was a tendency to significantly smaller weight changes than those measured during N. In contrast to N the subjects in Mf and FM restored their individual weight on a daily basis, by 9:00 PM (Table 5).

Discussion

The present study was designed to analyze the effect of diet manipulation on nutritional indices during repeated days of highly intensive cycling and to compare these effects with those present after a supply of a normally composed CHO-rich diet (N). The diet manipulation consisted of ad libitum supplementation of liquid CHO concentrates, along with the normal CHO-rich diet. The parameters specifically of interest were energy intake, expenditure, and balance, nutrient utilization, and fluid status.

The results of this study showed that the supplemented subjects (Mf and FM) increased their daily EI significantly more during days of intensive cycling than under N treatment. However, only the Mf group was able to maintain EB. FM subjects did not increase their intakes sufficiently to bridge the deficit caused by exercise. The fact that Mf subjects were able to increase their EI was clearly the result of the ad libitum supplementation with a beverage high in maltodextrin and low in fructose. The same subjects were not able to maintain EB when using a conventional CHO-rich diet. Furthermore, the FM group showed that a beverage high in fructose led to lower mean intakes compared with one with a small fructose fraction. This can partially be explained by the fact that a 20% (w/v) FM solution was not always tolerated by the subjects. A high osmolality (788 mosm) together with the extreme sweetness of the drink, due to fructose, caused gastric distress and impalatability. Although a reduction of the CHO concentration to 10% during exercise in some subjects increased palatability, this did not necessarily lead to the intake of larger volumes to compensate for the reduced EI.

As a result of the supplementation, total CHO intake increased significantly, on the first exercise day somewhat more in Mf (mean max. intake 1302 ± 549 g equal to 17.5 ± 1.0 $g \cdot kg^{-1}$ BW) than in FM (1059 ± 609 g equal to 14.9 ± 1.0 $g \cdot kg^{-1}$ BW). Despite these high CHO intakes, none of the cyclists reacted with (osmotic) diarrhea caused by malabsorption. This was especially surprising in FM since it has been described that solutions containing free fructose and introducing more than 50 g of fructose into the gastrointestinal tract cause diarrhea and gastric distress (1, 5, 9) also during exercise (19). During the day of the highest CHO intake, the FM subjects derived 566 ± 29 g from the supplement, half of which was free fructose. The discrepancy with data from the literature may be caused by the additional presence of glucose or by differences in training status.

The relative contribution of CHO intake to total EI, 80 EN% and 77 En% in Mf and FM, respectively, was far above intakes normally advised (50–65 En%). Some studies showed that CHO intake leading to elevated blood glucose levels stimulates CHO metabolism and inhibits fat metabolism, finally resulting in increased degradation rates of endogenous CHO stores (13, 14, 22). With respect to this, the question has been raised whether or not CHO supply can match the increased utilization of CHO induced by it. In the present study, it has been shown that Mf subjects were able to remain in positive CHO balance. CHO intakes were always larger than the calculated CHO oxidation, which must have led to sparing of endogenous CHO stores. This is in contrast to N where CHO balance was negative [muscle glycogen values are presented elsewhere (7)].

Although FM subjects also significantly increased their CHO intake, they were not able to compensate completely for the increased oxidation. Surprisingly, the treatment with the high fructose moiety in the drink showed the largest increase in CHO oxidation and decrease in fat oxidation, as calculated from nonprotein R. Although fructose is insulin-independent and may therefore have a smaller effect on lipolytic activity than mainly glucose, allowing for a larger energy exchange from fat, we did not observe such an effect with the drink given. This observation is supported by the recent work of Tappy et al. (27) and contradicts the general belief that fructose may lead to a sparing of endogenous CHO by enhancing fat oxidation. The additional maltodextrin moiety will also have influenced the metabolic effect of FM.

Fat and protein intake, in absolute quantities and relative to total EI, decreased as a consequence of the high CHO intake; in the N group intake was remarkably constant. The reduction in protein and fat intake was caused entirely by the intake of the protein- and fat-free energy supplement and the reduced intake of normal foodstuffs containing fat and protein, especially during the cycling hours. Interesting to note is that this reduced intake of normal foodstuffs remained present during the recovery day in contrast to the N group, where food intake increased. Probably the subjects undergoing diet intervention were less stimulated to increase food intake during recovery because the exercise-induced deficits were smaller.

A value of 7.5 En% for protein intake may sound alarming; however, this should be interpreted with respect to the level of daily energy expenditure. In fact, the mean lowest absolute daily intake within this value of 7.5 En% was still 1.4 $g \cdot kg^{-1}$ BW.

Protein utilization in energy metabolism had significantly increased in N but not in Mf. It is also known that CHO depletion leads to catabolic stress which, through a variety of biochemical changes, leads to increased protein degradation to supply precursors for gluconeogenesis (11, 12, 17, 18, 21). The response of the N subjects being in negative energy and CHO balance confirms these findings. Mf sub-

jects, remaining in positive energy and CHO balance did not show an increased protein oxidation which further confirms that the same type of exercise, performed with the same intensity, even with a significantly longer performance time during the final 90% Wmax load (7), causes less catabolism when energy intake and especially CHO intake meet the requirements.

The fact that FM subjects had a significantly increased protein oxidation on the second exercise day but not during the first may be explained as follows. The subjects under this treatment were almost in balance with respect to CHO intake and CHO oxidation. However, their energy balance was negative on both days. Initially the high CHO intake may have counterregulated the biochemical factors inducing protein degradation but when energy balance remained negative for a longer period of time, protein catabolism must have been initiated. The fact that nitrogen losses remained significantly increased during the next 36 h of recovery in N indicates that biochemical disturbance was more pronounced in these subjects in contrast to that in subjects with CHO supplementation. Recovery of a normal metabolic status may have been enhanced in this condition.

Some observations indicate that fluid intakes may have been sufficient to compensate for the losses during all days. Increased urine production during the exercise days indicates an increased drive to eliminate water from the body rather than to retain it.

The reason why this is so, while at the same time plasma volumes are decreased compared with rest days, remains obscure. One possibility may be that urine production was increased due to the potassium content of the drink. Nielsen (23) observed a diuretic and natriuretic effect of increased plasma potassium after rehydration with a high potassium drink, in spite of a low plasma volume. They could not explain this effect. An increase in ANF (atrial natriuretic factor) as a result of exercise may also be hypothesized (1a). The fact that plasma volume tends to decrease more in Mf cannot be explained by a fluid shift toward the splanchnic bed caused by the osmolality of the drink (380 mosm) since osmolality of FM was higher (788 mosm). Electrolyte influences also have to be ruled out since electrolyte content in both drinks was identical.

The fast restoration of body weight further indicates that fluid loss and substrate loss must have been minimal in Mf and FM compared with N subjects who, even after 36 h of recovery, did not regain their initial body weights. This finding together with a better maintenance of EB, CHO balance, and lower protein oxidation indicate a less pronounced catabolic state and a better recovery in the diet-manipulated situation as compared with the situation in which a normal CHO-rich diet was administered.

Summarizing the results of this study leads to the following conclusions:

- Cyclists are able to maintain energy balance when energy expenditure levels exceed 20 MJ by using concentrated CHO solutions in addition to a normal CHO-rich diet. In contrast, by using a normal CHO-rich diet alone energy balance cannot be maintained in such a situation.
- The ad libitum supply of 20% and 10% CHO solutions during cycling as described does not impair fluid intake or overall fluid status of the body compared with water intake.
- The intake of substantial amounts of a CHO solution during exercise causes an increased CHO, a decreased fat, and a decreased protein oxidation as compared with the situation in which a normal CHO-rich diet alone is used.
- The recommended level of protein intake for endurance athletes performing highly intensive sustained exercise, consuming a CHO-rich diet and being in positive energy balance, most probably is in the range of 1.5 to 1.8 $g \cdot kg^{-1}$ body weight.

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