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Randomized controlled trial of changes in dietary carbohydrate/fat ratio and simple *vs* complex carbohydrates on body weight and blood lipids: the CARMEN study

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OBJECTIVE: To investigate the long-term effects of changes in dietary carbohydrate/fat ratio and simple *vs* complex carbohydrates.
DESIGN: Randomized controlled multicentre trial (CARMEN), in which subjects were allocated for 6 months either to a seasonal control group (no intervention) or to one of three experimental groups: a control diet group (dietary intervention typical of the average national intake); a low-fat high simple carbohydrate group; or a low-fat high complex carbohydrate group.
SUBJECTS: Three hundred and ninety eight moderately obese adults.
MEASUREMENTS: The change in body weight was the primary outcome; changes in body composition and blood lipids were secondary outcomes.
RESULTS: Body weight loss in the low-fat high simple carbohydrate and low-fat high complex carbohydrate groups was 0.9 kg ($P < 0.05$) and 1.8 kg ($P < 0.001$), while the control diet and seasonal control groups gained weight (0.8 and 0.1 kg, NS). Fat mass changed by -1.3 kg ($P < 0.01$), -1.8 kg ($P < 0.001$) and $+0.6$ kg (NS) in the low-fat high simple carbohydrate, low-fat high complex carbohydrate and control diet groups, respectively. Changes in blood lipids did not differ significantly between the dietary treatment groups.
CONCLUSION: Our findings suggest that reduction of fat intake results in a modest but significant reduction in body weight and body fatness. The concomitant increase in either simple or complex carbohydrates did not indicate significant differences in weight change. No adverse effects on blood lipids were observed. These findings underline the importance of this dietary change and its potential impact on the public health implications of obesity.
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Keywords: obesity; dietary carbohydrate/fat ratio; simple and complex carbohydrates; body weight; blood lipids; randomized controlled trial.

Introduction

The prevalence of overweight has risen dramatically over the past three decades and is threatening to become a global epidemic.[1] A substantial proportion of adults are at increased risk of morbidity and mortality as a result of increased body weight. As a consequence, total costs of obesity-associated diseases have been estimated to be 4–7% of all health care expenditures in several developed countries. Efforts to reduce the prevalence of obesity have focused on the fat content of the diet. High-fat diets are energy dense and usually lead to an increase in energy intake.[2] This, together with the prevalence of low levels of physical activity, means a positive energy balance and weight gain is inevitable. However, the scientific evidence for the relation between dietary fat content and obesity has recently been challenged. Katan *et al*[3] have questioned the importance of low-fat diets in the prevention and treatment of obesity. Randomized controlled trials show only very limited weight reduction and the so-called 'fat paradox' can be seen in several countries where there is a poor association between dietary fat intake and percentage of the population that is overweight. Also a direct relation between dietary fat and energy density has been questioned on the basis that many low-fat foods currently available are claimed to be based on sugar or highly refined carbohydrates, leading to energy density values similar to those of their high-fat counterparts.[4]

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In controlled feeding studies in which body weight was maintained, low-fat diets were commonly associated with decreases in HDL-cholesterol and increases in triacylglycerol.[5] Both are risk factors for coronary vascular disease. In contrast to these effects in well-controlled feeding studies, there is a body of evidence from dietary intervention studies conducted in free-living populations where low-fat diets are associated with improvement of lipid profile.[6] The interpretation of these findings is complicated by the lack of dietary control plus compliance in large-scale long-term, free-living population studies when compared with well-controlled, smaller and mainly short-term feeding studies. Moreover previous research on low-fat diets may be confounded by the type of carbohydrate, including fibre intake. In addition, the number of randomized well-controlled intervention trials which have focused on the carbohydrate/fat ratio of the diet in overweight individuals is very limited.

The Carbohydrate Ratio Management in European National diets (acronym CARMEN) trial was a multicentre, randomized *ad libitum* feeding trial that tested the effects of altering the ratio of fat to carbohydrate, as well as simple to complex carbohydrate *per se*, on body weight and blood lipids in overweight individuals. A shop system where study foods were provided was used in the trial to maximize dietary compliance in an otherwise community-based population.

Methods

Study population

Five European research centres participated in CARMEN. Each research centre was required to enrol 80 subjects (40 male, 40 female) to the study. Recruitment criteria were 20–55 y of age; body mass index (BMI) between 26 and 35 kg/m^2; and free of endocrine, liver, kidney or haematological disease assessed by medical history and clinical blood and urine biochemistry. Exclusion criteria were: alcoholic excess (>28 drinks weekly for men, >21 for women); high-intensity exercise for more than 7 h weekly; use of prescribed or slimming diets; weight loss of more than 5 kg in the preceding 6 months; pregnancy; and lactation. Ethical committees at each centre approved the trial protocol; subjects signed an informed-consent form.

Study design

Subjects were randomly allocated on a 1–3 basis to either a seasonal control group or to an experimental group. The groups were stratified by age, sex and BMI. Subjects in the seasonal control group were weighed before and after the study and served only as a control for seasonal variation in body weight. During a 5 week run-in period, subjects in the experimental group were provided with a selection of commercially available food products, of typical macronutrient composition for each country, using a validated laboratory shop system.[7] After the run-in period, subjects were randomly assigned to one of the three experimental groups, stratified by age, sex, tertile of simple to complex carbohydrate and fat intake, as measured during the last week of the run-in. Throughout the intervention period of 6 months, subjects in the control diet group continued to be provided with a variety of products of typical macronutrient content. Subjects in the low-fat high simple carbohydrate group and the low-fat high complex carbohydrate group were provided with a variety of fat-reduced products and products with a high respectively low ratio of simple to complex carbohydrates, in order to reduce fat intake by 10 energy% and, at the same time, to increase either simple or complex carbohydrate intake from a ratio of 1.0 to 1.5 and 0.5, respectively.

Laboratory shop system

In each research centre a small shop was installed to provide subjects with a known and recorded choice of 100–150 food items. Selection of food products was based on the manufacturer's food composition, national food composition tables and food intake data, and was intended to achieve 70% coverage of total fat intake and 50% of total carbohydrate intake from the shop. A computer program was developed which ensured selection of the appropriate food items by means of a barcode scanner system. Intake was required to be between 75 and 125% of predicted daily energy requirements, based on predicted basal metabolic rate[8] and physical activity level as determined using an activity questionnaire.[9] As a number of products (eg bread, fresh fruit, fresh vegetables and fresh meat) were not provided by the laboratory shop, subjects were allowed to purchase additional foods in conventional supermarkets.

Subjects who did not attend the laboratory shop for more than 2 weeks without prior notice were excluded as non-compliers. During holiday absence (maximum 2 weeks) subjects were given instructions on the selection of a diet. Subjects with an absence or illness greater than two weeks were excluded.

Measurements

Total food intake, ie consumption of food items provided via the laboratory shop and consumption of food items bought in conventional supermarkets, was recorded at base-line, at the end of the run-in period, and after 1, 2, 4 and 6 month(s) of intervention, using 3-day or 7-day weighed dietary records. Energy and macronutrient intakes were calculated using computerized national food composition tables.

Body weight and body composition were measured at screening (body weight only), and at 0, 2, 4 and 6 months of intervention. Both measurements were assessed with subjects lightly clad, after an overnight fast. Body composition was determined by means of single frequency (50 kHz) bio-electrical impedance. Fat-free mass was calculated using linear regression equations;[10] fat mass was calculated as body weight minus fat-free mass.

Fasting venous blood samples were taken at screening, and at 0, 2, 4 and 6 months of intervention. Serum levels of total cholesterol, HDL-cholesterol and triacylglycerol were measured by enzymatic procedures.[11] LDL-cholesterol concentration was calculated according to Friedewald *et al*.[12] Plasma concentration of glucose was determined using enzymatic assays automated on a Cobas Bio centrifugal analyser at 340 nm, using standard kits (Roche Diagnostics, Hoffman-La Roche, Basel, Switzerland). Plasma levels of insulin and leptin were measured as described earlier.[13] All samples were shipped to Maastricht and analysed.

Statistical analysis

Power calculations indicated that, with a drop-out rate of 20%, power of 90% and confidence of 95%, a difference of 0.5 kg in the change of body weight between the low-fat groups and the control diet group could be detected.

The change in body weight was the primary outcome; changes in body composition and blood lipids were secondary outcomes. Logarithmic transformations of the variables were performed as required to improve normality.

Analysis of variance was used as a global test for differences in the degree of change from run-in values among groups. When analysis of variance indicated significant differences between the groups ($P < 0.05$), *post hoc* comparisons were made, with Bonferroni adjustment of significance levels for three possible pairwise comparisons, at the 5% level of significance, in two-tailed tests.

Results

After base-line measurements subjects were allocated to seasonal control ($n = 99$) or experimental ($n = 299$) groups. In the seasonal control group 17 subjects did not attend for the body weight measurement at the start of the intervention and were excluded from the study. During the run-in period nine subjects were excluded for non-compliance (failure to participate in the shop system) or dropped out for personal reasons. The remaining 290 subjects (140 male, 150 female) were then allocated to one of the three dietary intervention groups. During the 6 month intervention period the drop-out rate was 18.6% ($n = 54$) in the experimental groups and 2.4% ($n = 2$) in the seasonal control group. Hence 316 subjects completed the intervention and were included in the statistical analysis.

Subject characteristics of each intervention group at base-line are shown in Table 1. There were no significant differences between the four intervention groups. The 56 subjects who did not complete the study were significantly younger and had a higher BMI than the completers.

Missing data for variables were distributed evenly among the intervention groups; no more than five individuals within each group had missing data for any given variable.

Diets

Analysis of variance revealed a significantly lower energy intake at base-line compared with run-in (Table 2). Energy% from protein and alcohol was higher while energy% from total and simple carbohydrates as well as the energy density of the diet were lower at baseline.

Energy intake decreased significantly in the low-fat high complex carbohydrate group compared with the low-fat high simple carbohydrate and control diet groups. Both low-fat high simple carbohydrate and low-fat high complex carbohydrate groups decreased energy% from fat significantly (10.2 and 7.9% respectively). There was no difference in unsaturated fatty acid, only in energy% saturated fatty acid in the low-fat high simple carbohydrate group, which was

Table 1 Characteristics at randomization of subjects completing the 6 month intervention and drop-outs, according to study group[a]

	All subjects					
Characteristics	*Completers* ($n = 316$)	*Drop-outs* ($n = 56$)	*Seasonal control group* ($n = 80$)	*Low-fat high simple carbohydrate group* ($n = 76$)	*Low-fat high complex carbohydrate group* ($n = 83$)	*Control diet group* ($n = 77$)
Female sex (%)	50.9	53.5	51.2	52.6	48.2	51.9
Age (y)	39 ± 9	36 ± 9*	39 ± 9	41 ± 9	38 ± 9	38 ± 9
Height (m)	1.71 ± 0.10	1.72 ± 0.10	1.71 ± 0.09	1.71 ± 0.10	1.71 ± 0.10	1.70 ± 0.10
Weight (kg)	89.0 ± 12.4	92.6 ± 11.9	86.1 ± 12.0	90.7 ± 12.7	87.9 ± 11.6	89.6 ± 13.0
BMI (kg/m^2)	30.4 ± 2.7	31.4 ± 3.0*	30.0 ± 2.7	30.9 ± 2.8	30.2 ± 2.8	30.4 ± 2.6

[a]Values are expressed as means ± s.d.
*$P < 0.05$ for the comparison with completers group.

Table 2 Base-line and run-in values for variables related to the diet and changes over the 6 month intervention period compared with run-in values, according to study group[a]

			Change over 6 months compared with run-in			
Variable	*Base-line value (n = 236)*	*Run-in value (n = 236)*	*Low-fat high simple carbohydrate group (n = 76)*	*Low-fat high complex carbohydrate group (n = 83)*	*Control diet group (n = 77)*	*P-value*[b]
Energy intake (MJ/day)	10.4 ± 3.1§§§	11.1 ± 3.6	− 0.7 ± 2.1¶¶	− 1.8 ± 2.4*	− 0.8 ± 2.4	0.0031
Protein (g/day)	93.6 ± 30.0	92.8 ± 27.3	+ 3.5 ± 18.7	+ 6.0 ± 24.1	− 1.4 ± 20.2	0.0864
Protein (energy%)	15.3 ± 3.2§§§	14.3 ± 2.3	+ 1.5 ± 2.0¶¶¶	+ 3.6 ± 2.5***	+ 0.9 ± 2.4	0.0001
Total fat (g/day)	99.7 ± 37.6§§	106.4 ± 42.0	− 34.8 ± 26.1***	− 38.3 ± 28.9***	− 6.3 ± 28.2	0.0001
Total fat (energy%)	35.8 ± 6.8	35.7 ± 5.8	− 10.2 ± 5.1¶***	− 7.9 ± 4.6***	+ 0.8 ± 4.4	0.0001
Saturated fatty acids (g/day)	36.4 ± 15.6§§	39.4 ± 17.9	− 15.7 ± 11.4***	− 15.4 ± 13.9***	− 4.1 ± 14.8	0.0001
Saturated fatty acids (energy%)	13.0 ± 3.3	13.0 ± 2.9	− 4.4 ± 3.0¶***	− 3.1 ± 2.8***	− 0.3 ± 3.2	0.0001
Monounsaturated fatty acids (g/day)	36.2 ± 16.1	37.6 ± 17.1	− 13.9 ± 13.5***	− 15.1 ± 13.6***	− 3.7 ± 12.8	0.0001
Monounsaturated fatty acids (energy%)	12.9 ± 3.8§	12.4 ± 3.3	− 3.9 ± 4.5***	− 3.1 ± 3.2***	− 0.2 ± 3.2	0.0001
Polyunsaturated fatty acids (g/day)	15.5 ± 7.8	16.2 ± 7.9	− 4.3 ± 6.9	− 4.8 ± 7.2*	− 1.6 ± 7.9	0.0195
Polyunsaturated fatty acids (energy%)	5.6 ± 2.4	5.4 ± 2.0	− 1.2 ± 2.2**	− 0.8 ± 2.3	0.0 ± 2.1	0.0084
Total carbohydrates (g/day)	274.4 ± 85.7§§§	311.7 ± 108.5	+ 32.3 ± 75.7¶¶¶***	− 22.1 ± 74.1	− 33.2 ± 77.8	0.0001
Total carbohydrates (energy%)	44.4 ± 7.3§§§	47.1 ± 6.4	+ 8.4 ± 5.5¶¶¶***	+ 4.7 ± 4.8***	− 1.6 ± 4.8	0.0001
Simple carbohydrates (g/day)	123.3 ± 56.0§§§	150.2 ± 70.5	+ 32.8 ± 54.1¶¶¶***	− 44.5 ± 52.2**	− 17.7 ± 51.2	0.0001
Simple carbohydrates (energy%)	19.7 ± 6.5§§§	22.3 ± 5.9	+ 7.2 ± 5.7¶¶¶***	− 3.5 ± 5.4**	− 0.9 ± 4.5	0.0001
Complex carbohydrates (g/day)	150.2 ± 51.3§	158.1 ± 55.4	0.0 ± 37.7¶¶	+ 23.7 ± 46.3***	− 13.8 ± 41.7	0.0001
Complex carbohydrates (energy%)	24.5 ± 6.5	24.3 ± 5.8	+ 1.2 ± 4.0¶¶¶	+ 8.3 ± 4.9***	− 0.5 ± 4.7	0.0001
Alcohol (g/day)	17.1 ± 20.3§§§	11.8 ± 14.2	+ 0.5 ± 9.6¶	− 4.1 ± 10.2	− 0.4 ± 9.5	0.0087
Alcohol (energy%)	4.5 ± 5.0§§§	3.0 ± 3.5	+ 0.3 ± 2.6	− 0.5 ± 2.4	0.0 ± 2.5	0.1503
Fibre (g/day)	19.5 ± 7.6	19.0 ± 7.1	− 0.5 ± 5.7	+ 1.3 ± 6.3	− 0.1 ± 4.5	0.0991
Energy density (kJ/g)	3.79 ± 0.82§§§	4.10 ± 0.94	− 0.42 ± 0.71¶*	− 0.74 ± 0.68***	− 0.27 ± 0.68	0.0001

[a]Values are expressed as mean ± s.d.
[b]*P*-values were derived by analysis of variance and denote the overall significance of differences among the three groups. *P*-values for comparisons between groups have been adjusted for three pair-wise comparisons (Bonferroni's adjustment).
§$P < 0.05$; §§ $P < 0.01$; §§§ $P < 0.001$ for the comparison with the run-in value.
*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ for the comparison with the control diet group.
¶$P < 0.05$; ¶¶ $P < 0.01$; ¶¶¶ $P < 0.001$ for the comparison with the low-fat high complex carbohydrate group.

significantly reduced compared with the low-fat high complex carbohydrate group. Energy% from protein, and also from total carbohydrates, increased significantly in both low-fat groups compared with the control diet group. The low-fat high simple carbohydrate group increased total and simple carbohydrates energy% above the low-fat high complex carbohydrate group. In the low-fat high complex carbohydrate group energy% from complex carbohydrates was significantly higher and energy% from simple carbohydrates significantly lower compared with the low-fat high simple carbohydrate and control diet groups. Finally, energy density decreased significantly in the low-fat groups compared with the control diet group. The decrease in the low-fat high complex carbohydrate group was significantly greater than the low-fat high simple carbohydrate group.

Energy% fat remained constant in the control diet group over the 6 month intervention period (Figure 1). In the low-fat groups a significant ($P < 0.001$) and stable decrease was observed. Energy from total carbohydrate increased by 2.7% during the run-in compared with base-line values ($P < 0.001$). During the intervention period intake values slightly decreased by 1.6 energy% for the control diet group, in contrast to a significant ($P < 0.001$) increase of 8.4 and 4.7 energy% for the low-fat high simple carbohydrate and low-fat high complex carbohydrate groups. Food intake coming from the laboratory shop contributed 64–68% of energy intake in the study groups (Table 3). In the low-fat high simple carbohydrate group the contribution of fat was significantly lower compared with the control diet group.

Body weight and composition

Analysis of variance revealed no significant differences among the groups for body weight and composition at the start of the intervention period (Table 4). Body weight and fat mass were then significantly reduced in the low-fat groups, compared with the control diet group after the intervention. The changes in body weight and fat mass between the low-fat groups were not significantly different. Body weight did not change in the seasonal control group over the 6 month intervention period (pre 89.1 ± 12.5 kg, post 89.2 ± 12.4 kg, $n = 80$, NS). The decrease in body weight and fat mass in the low-fat groups levelled off after 4 months of dietary intervention (Figure 2).

Blood lipids and other biochemical variables

Diet-induced changes in the blood lipid values as well as glucose, insulin and leptin did not differ significantly among the groups (Table 4).

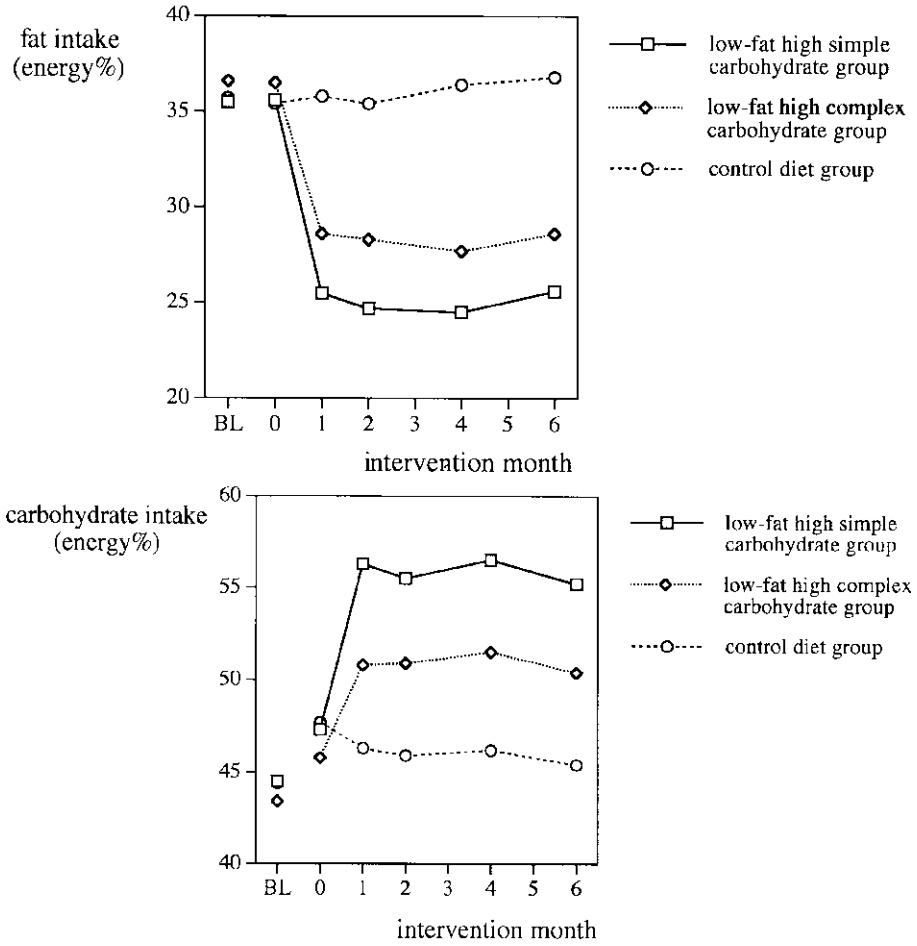

Figure 1 Energy percentage total fat and carbohydrate intake at base-line (BL), the start and at 1, 2, 4, and 6 month(s) of dietary intervention, according to study group.

Table 3 Food intake (energy, total fat, total carbohydrates, simple carbohydrates and complex carbohydrates) from the experimental shop as function of the recorded food intake during the 6 month intervention period according to study group[a]

		Mean shop intake compared with mean dietary record value(%)			
Variable	*Mean dietary* record value (*n* = *236*)	*Low-fat high simple carbohydrate group* (*n* = *76*)	*Low-fat high complex carbohydrate group* (*n* = *83*)	*Control diet group* (*n* = *77*)	*P-value*[b]
Energy intake (MJ/day)	9.9 ± 3.3	64 ± 18	67 ± 17	68 ± 19	0.3686
Protein (g/day)	95.4 ± 30.4	61 ± 22	69 ± 21*	61 ± 22	0.02
Total fat (g/day)	79.6 ± 34.5	65 ± 22**	69 ± 17	77 ± 22	0.0015
Total carbohydrates (g/day)	303.2 ± 105.8	66 ± 19	67 ± 22	65 ± 21	0.8076
Simple carbohydrates (g/day)	139.5 ± 69.2	78 ± 26¶¶¶	57 ± 19***	72 ± 29	0.0001
Complex carbohydrates (g/day)	161.5 ± 58.7	56 ± 24¶¶¶	74 ± 27***	60 ± 22	0.0001

[a]Data are means ± s.d.
[b]*P*-values were derived by analysis of variance and denote the overall significance of differences among the three groups. *P*-values for comparisons between groups have been adjusted for three pair-wise comparisons (Bonferroni's adjustment).
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ for the comparison with the control diet group.
¶¶¶ $P < 0.001$ for the comparison with the low-fat high complex carbohydrate group.

Discussion

This randomized controlled trial demonstrates that specific changes in the macronutrient composition of the diet can favourably affect body weight and body fat mass in moderately obese adults. Specifically, an *ad libitum* diet low in fat and high in complex carbohydrates reduced body weight by 2.6 kg and fat mass by 2.4 kg relative to a moderate-fat control diet. A diet low in fat but higher in simple carbohydrates also reduced body weight and fat mass significantly compared with a control diet (1.7 and 1.9 kg, respectively).

With the publication of the clinical debate pertaining to the role that percentage of dietary fat plays in the exponential increase in the prevalence of obesity, several review articles and editorials have underlined

Table 4 Start intervention values and changes after 6 month dietary intervention for body weight and other factors related to obesity, according to the study group[a]

		Change after 6 months compared with start			
Variable	*Start intervention value (n = 236)*	*Low-fat high simple carbohydrate group (n = 76)*	*Low-fat high complex carbohydrate group (n = 83)*	*Control diet group (n = 77)*	*P-value*[b]
Body weight (kg)	89.4 ± 12.4	− 0.9 ± 3.6*	− 1.8 ± 3.2***	+ 0.8 ± 4.1	0.0001
Fat-free mass (kg)	55.4 ± 11.3	+ 0.3 ± 2.7	0.0 ± 2.7	+ 0.1 ± 3.0	0.7374
Fat mass (kg)	34.0 ± 7.4	− 1.3 ± 3.6*	− 1.8 ± 3.9***	+ 0.6 ± 4.3	0.0004
Lipids (mmol/l)					
Total cholesterol	5.66 ± 1.09	− 0.24 ± 0.62	− 0.22 ± 0.65	− 0.14 ± 0.63	0.5928
HDL-cholesterol	1.28 ± 0.34	− 0.13 ± 0.18	− 0.08 ± 0.22	− 0.07 ± 0.23	0.1894
LDL-cholesterol	3.70 ± 1.02	− 0.09 ± 0.53	− 0.02 ± 0.56	− 0.03 ± 0.65	0.7612
HDL/LDL cholesterol	0.39 ± 0.19	− 0.03 ± 0.08	− 0.03 ± 0.11	− 0.04 ± 0.15	0.8996
Triacylglycerol	1.45 ± 0.80	+ 0.01 ± 0.53	− 0.16 ± 0.61	− 0.13 ± 0.57	0.1667
Glucose (mmol/l)	5.36 ± 0.77	− 0.05 ± 0.47	− 0.17 ± 0.53	− 0.01 ± 0.52	0.1277
Insulin (mU/l)	12.16 ± 5.07	+ 0.85 ± 9.60	− 1.33 ± 4.81	+ 0.32 ± 6.02	0.1453
Leptin (ng/ml)	19.50 ± 13.49	+ 0.16 ± 5.86	− 0.24 ± 6.76	+ 1.56 ± 6.57	0.2004

[a]Data are means ± s.d.
[b]*P*-values were derived by analysis of variance and denote the overall significance of differences among the three groups. *P*-values for comparisons between groups have been adjusted for three pair-wise comparisons (Bonferroni's adjustment).
*$P < 0.05$; ***$P < 0.001$ for the comparison with the control diet group.

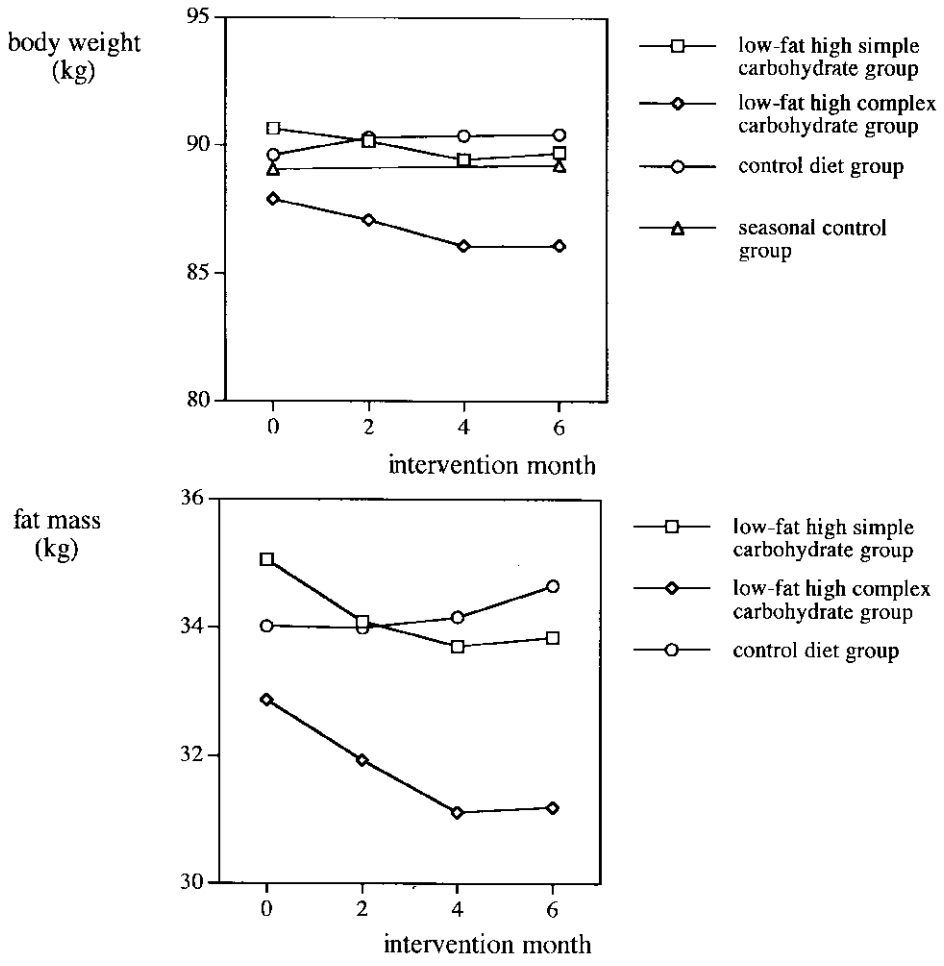

Figure 2 Mean body weight and fat mass at the start and during the 6 month dietary intervention, according to study group.

the complexity of the problem.[4,14,15] A large body of controlled animal and human experimental studies suggest that a high fat content in the diet strongly contributes to weight gain[15] whilst many epidemiology and uncontrolled community trials do not. Ecological, cross-sectional and prospective studies, all observational in nature, suffer from various biases and results are therefore far from conclusive.[14] In

particular, the observation that a substantial decline in the percentage of energy from fat consumed during the past two decades in affluent countries concomitant with a massive increase in obesity highlights the lack of consensus in this area.[4] Randomized controlled trials specifically addressing this issue are therefore needed. The major constraint for a long-term design of a nutrition randomized controlled trial is the inability to achieve and maintain compliance of food intake using only diet recommendations. Accurate information on food intake and especially fat intake is difficult to achieve in populations that have been educated to reduce fat intake. Underreporting of energy and fat intake is a well-documented phenomenon especially in obese.[16] On the other hand the ability to fully control food supply is limited; and relative to the issue of body weight regulation, is short-term (only a few weeks to a few months). The strengths of the current study include the randomized controlled trial design, the size of the cohort, the length of the dietary intervention period combined with the control on food intake that can be achieved by means of a validated shop system.[7]

In a 6 month randomized controlled trial with subjects of comparable levels of obesity it was shown that with a low-fat diet with high or normal protein level compliance to the diet was excellent using the same shop system and 24 h urinary nitrogen excretion as biomarker.[7] Although in the present study no biological markers were available for objective information about dietary intake of fat and carbohydrate, we believe that with the use of this laboratory shop system good compliance can be achieved despite the relatively long dietary intervention period. Fat intake from shop foods covered 65–77% of the total fat intake in the different groups. Carbohydrate intake from the shop provided 65–67%, with more variation in the specific carbohydrates depending on the type of intervention (simple carbohydrates: 57–78%; complex carbohydrates: 56–74%). These figures underline the effectiveness of the shop system to alter food habits in a desirable direction.

In both low-fat dietary intervention groups a significant decrease in body weight and body fatness was observed. These findings further support the opinion that *ad libitum* low-fat diets have a positive effect on body fatness. In a meta-analysis of 28 clinical trials on the effect of low-fat diets a reduction in body weight was found of 1.6 g/day for each percentage point reduction in energy from fat.[15] This result predicts a weight loss for the low-fat high simple carbohydrate and low-fat high complex carbohydrate groups of 3.0 and 2.3 kg, respectively, when compared with the observed differences of 1.7 and 2.6 kg relative to the control diet group. For the low-fat high complex carbohydrate group this prediction is in line with the observed change, whilst for the low-fat high simple carbohydrate group the reduction is about half of what could be expected.

In the search for dietary factors associated with the development of obesity, sugar intake is commonly proposed. However, epidemiological and experimental data do not support this idea.[17] From epidemiological data a clear inverse relation between intake of carbohydrates and fat is observed. In particular, the simple carbohydrates, and not the complex carbohydrates, tend to counterbalance the energy intake from fat. This phenomenon has been dubbed the 'fat–sugar see-saw'. Observational studies consistently show a strong negative association between sugar intake and indices of obesity.[18] Metabolic studies also show that simple carbohydrates do not differ from complex carbohydrates in terms of energy expenditure.[19] Although the energy content of the different types of carbohydrates is essentially the same, complex carbohydrates are obtained from food that tends to contain more fibre. In the present study, however, a 7.2 energy% increase in simple carbohydrates in the low-fat high simple carbohydrate group did not lead to a decreased fibre intake. This is probably related to the fact that intake of complex carbohydrates in the low-fat high simple carbohydrate group remained constant. In addition, a significant increase of 8.3 energy% in complex carbohydrates in the low-fat high complex carbohydrate group did not lead to a further increase in fibre intake. The absence of fresh fruit and vegetables in the selection of shop foods could explain this lack of increase in fibre.

Energy density has also been proposed as an important confounding factor. It has been shown that it is high-fat high-density foods that lead to weight gain, and not high-fat *per se*.[20] In foods selected at random from food tables or from the supermarket shelf, there is a strong correlation between the percentage of energy derived from fat and the energy density of the foods, with most of the remaining variance attributable to hydration differences.[2] Thus in normal life high-fat foods are generally energy-dense foods and vice versa. In both low-fat groups energy density decreased significantly compared with the control diet group. The decrease in the low-fat high simple carbohydrate group is of particular importance. It is often claimed that the replacement of fat by sugar or highly refined carbohydrates in low-fat foods does not lead to a decrease in energy density. In the present study with considerable use of low-fat alternatives this outcome was not observed.

A most critical question is whether the observed reductions in body weight and body fatness justify the recommendation to lower fat intake. The present randomized controlled trial shows that a decrease in dietary fat intake in individuals eating to appetite leads to a reduction in body weight and body fatness consistent with the data from both epidemiological and clinical studies. However, not all investigators are convinced that this moderate reduction has clinical importance. Willett[4] argued that only when the reduction is cumulative over periods of years does clinical

relevance emerge. As in most other low-fat trials, a steady state in body weight was reached in our study after 4 months, demonstrating a new equilibrium in energy intake and expenditure. Hence a further decrease is not expected over time. The observed gain in weight in long-term trials (>1 y) is probably related to the gradual deterioration of compliance.[4] Therefore, the question remains whether a body weight reduction of 2–3 kg by means of a general reduction in fat intake of about 10 energy% is of relevance in relation to the public health aspects of obesity. As in a number of other public health issues, such as average alcohol consumption and prevalence of alcohol abuse, there is a link between the average and extreme levels of body fatness within a population.[1] In the INTERSALT study comprising body weight data from 52 populations, a 4.7% increase in the prevalence of obesity was found for every unit increase in the average BMI above 23.[21] This implies that even moderate weight reductions of 2–3 kg on a population level significantly contribute to the reduction in the prevalence of obesity, and hence relative disease risk.

The greatest impact of reducing dietary fat is likely to be the prevention of weight gain rather than radical weight loss. Given the strong physiological defence mechanisms to prevent weight loss during periods of energy restriction, it is remarkable that a reduction in dietary fat in individuals eating *ad libitum* consistently leads to a modest loss of body weight. Unfortunately, there are as yet no large prospective randomized controlled trials testing the hypothesis that lower levels of dietary fat intake can prevent obesity.[22]

An important concern that has been raised by the use of low-fat diets is the deleterious effect on blood lipids. In controlled feeding studies in which body weight was maintained constant, low-fat diets were associated with a decrease in HDL-cholesterol and an increase in triacylglycerol levels, both risk factors for coronary vascular disease.[3] In contrast, in low-fat trials allowing *ad libitum* intake these negative effects were less of a concern, probably due to a concomitant decrease in body weight. This has been confirmed in a meta-analysis evaluating the effects of the American National Cholesterol Education Program on major coronary vascular disease risk factors.[6] The meta-analysis on the step 1 dietary intervention (<30 energy% fat and <10 energy% saturated fatty acid) clearly showed beneficial effects on blood lipids, most probably related to the positive interaction with weight loss. In our current study, no undesirable effects on HDL-cholesterol or triacylglycerol levels were observed in either of the low-fat groups. In all three groups a trend towards lower blood lipids was observed over the 6 month period. Seasonal effects may play a role (winter to summer), although the literature is inconclusive on this topic.[23]

In conclusion, this study provides valuable information in the debate on the importance of low-fat diets in the prevention and treatment of obesity. It adds to the large body of evidence that an *ad libitum* diet with a reduction of fat by about 10 energy% produces a modest but significant reduction in body weight and body fatness. The lack of adverse effects on blood lipids underlines the importance of this dietary change and its potential impact on the public health implications of obesity. This trial was the first long-term randomized controlled trial looking at the effect on body weight of simple *vs* complex carbohydrate intake when an *ad libitum* low-fat diet is provided to volunteers. Neither type of carbohydrate revealed significant differences in body weight loss or blood lipids. Thus the observed inverse epidemiological relationship between low-fat and high simple carbohydrate intake may be less of a concern than previously suggested.

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