International Journal of Obesity (1997) 21, 637–643
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Effect of dietary fish oil on body fat mass and basal fat oxidation in healthy adults

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OBJECTIVE: To investigate whether the substitution of fish oil for visible fats in a control diet (52% carbohydrates, 16% protein, 32% fat; P:S 0.2) influences body fat mass and substrate oxidation in healthy adults.
DESIGN: Six volunteers (5 men; 23 ± 2 y; BMI: 21.9 ± 1.6) were fed a control diet (C) ad libitum during a period of three weeks and, 10–12 weeks later, the same diet where 6 g/d of visible fat were replaced by 6 g/d of fish oil (FO) for another three weeks.
RESULTS: Energy intakes (IKA-calorimeter) were unchanged. Body fat mass (Dual-energy X-ray absorptiometry) decreased with FO (−0.88 ± 0.16 *vs* −0.3 ± 0.34 kg; FO *vs* C; $P < 0.05$). When adjusted for lean body mass (Ancova), resting metabolic rate (indirect calorimetry) was unchanged. Basal respiratory quotient decreased with FO (0.815 ± 0.02 *vs* 0.834 ± 0.02; $P < 0.05$) and basal lipid oxidation increased with FO (1.06 ± 0.17 *vs* 0.87 ± 0.13 mg kg^{-1} min^{-1}; $P < 0.05$).
CONCLUSION: Dietary FO reduces body fat mass and stimulates lipid oxidation in healthy adults.

Keywords: n-3 long-chain polyunsaturated fatty acids; fish oil; energy metabolism; body composition; resting metabolic rate; human.

Introduction

Feeding rodents with a diet containing fish oil reduces body weight gain,[1–4] body fat mass[5,6] and/or limits the abdominal and epididymal adipose tissue hypertrophy.[7–9] Such changes in body weight and/or body composition with fish oil occur in association with constant[1,6,9] or even increased energy intakes.[2] Only two other studies show a reduction in energy intake with fish oil.[3,5] These data suggest that dietary fatty acids of the n-3 series could modulate to some extent the partitioning of fat between oxidation and storage.

Because of their beneficial health effects, n-3 fatty acids are nowadays introduced as fish oil in the human diet. However, their potential effects on body composition and energy metabolism in humans have received very little attention. In the present study, energy intake, resting metabolic rate, basal substrate oxidation and body composition were monitored in six healthy adults fed first without then with 6 g/d of fish oil in replacement of 6 g/d of visible fat during two distinct periods of three consecutive weeks each.

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Received 25 November 1996; revised 21 March 1997; accepted 25 March 1997

Subjects and methods

Subjects
Written informed consent was obtained from six healthy young adults (5 men, 1 woman; age 23 ± 2 y; body mass index 21.9 ± 1.6; mean ± s.d.) in accordance with the experimental protocol approved by the Human Investigation Ethics Committee of our institution. Their good health was assessed from a detailed medical history, a thorough physical examination, routine biochemical screening of blood samples, an electrocardiogram, and an oral glucose tolerance test (75 g). Subjects with spontaneous selective diets (vegetarian or vegan) or food-fad diets and with daily alcohol consumption above 10 g/d were not included in the study. All subjects were without medication. One man smoked 5–8 cigarettes/d. Five subjects were sedentary and one (subject #4) was moderately active (1 h of tennis per week and a half hour cycling in the city per day). Except for meals, ingested under supervision in our metabolic unit during the study, the subjects led their normal lifes. They were asked to avoid other food/snacks and alcohol during the experimental periods and to maintain their usual level of physical activity throughout the study. The subjects were paid for their participation in the study.

Experimental protocol
The design of the study was an intervention trial where energy intake was measured over three weeks

while the subjects consumed a control diet ad libitum. Ten to 12 weeks later, they were fed the same diet ad libitum with the substitution of 6 g/d of visible fat by 6 g/d of fish oil. Because of the very prolonged effects of fish oil on membrane fatty acid composition (18 weeks),[10] it was decided to start the study with the control period. A washout period was introduced between the control and the fish oil experimental periods to compensate for any possible changes in membrane lipid composition due to the transition between the habitual and the control diets. Five subjects (#1 and 3–6) were studied between November and March and one subject (#2) was studied between April and mid-July. Two weeks prior to each experimental period, the subjects were individually screened for physical activity by anamnesis and dietary intake by 7 d dietary recall to confirm the absence of any differences prior to the experimental diets. In addition, physical activity was checked weekly by interview during each experimental period. The subjects were invited to report any unusual feeling and symptoms that might have occurred during each period.

Energy intake: All meals were ingested in the metabolic unit between 7:30 and 8:00 am, 12:00 and 1:30 pm, and 7:00 and 8:00 pm. The meals were prepared individually from conventional French food, cooked and weighed (1 g) by a dietitian. Leftover food was weighed (1 g) item by item and was taken into account in the calculations of food intake. A sample of each food item was weighed (1 g), frozen at $-80°C$ and the gross energy content of each food item ($n = 119$) was measured using an IKA-Calorimeter C 700T (IKA-Analysentechnik GmbH, D-7843 Heitersheim, Germany). Butter, olive oil, sunflower oil and peanut oil were used as visible fat. Each portion of visible fat was prepared for each meal (0.1 g) and added to the meal just before eating by a dietitian. Fish oil was given as eight caps of 750 mg each (two caps at breakfast, three caps at lunch and three caps at dinner, namely 1.1 g/d of 20:5n-3 and 0.7 g/d of 22:6n-3). Except for butter served with breakfast, the subjects were unaware of oils used in the diet. A daily weighed takeout snack was prepared by the dietitian in the unit and given to three subjects (#2, 4 and 5) as part of their regular dietary habits (‘French goûter’). The amounts and contents of these snacks were recorded and taken into account in the final calculation of energy intake. The composition of the diet was assessed using a French nutrient database.[11] Net energy intake was calculated from gross energy content corrected for digestibility according to Black *et al*.[12]

Resting metabolic rate: RMR was measured at the end of each period using a ventilated hood connected to an open-circuit indirect calorimeter (Magnetopneumatic O_2 analyzer Magnos 4G and infrared CO_2 gas analyzer Uras 3G, Hartmann & Braun, Metz, France). The apparatus and the calibration procedure have been previously described.[13] The subjects were admitted in the Metabolic Unit between 07.00 and 08.00 am after a 11 h overnight fast. After voiding, they were placed in a bed and maintained in the supine position throughout the experiment.

Respiratory gas exchange measurements were started after 90 min rest and lasted for 45 min. O_2 and CO_2 were calculated using the classical equations.[13] Urines were collected on HCl during the night before respiratory gas exchange measurements from bedtime (11:00–00:00 pm) to the time of admission in the metabolic unit (7:00–8:00 am). Thus, urinary collection mainly corresponds to the sleeping time. The volumes were recorded and samples were frozen at $-80°C$ for further measurement of total urinary nitrogen (Kjeldahl method) and catecholamines (HPLC). Resting metabolic rate, net carbohydrate and lipid oxidation were calculated from O_2 consumption, CO_2 production and protein oxidation using the equations of Livesey and Elia.[14] The rate of protein oxidation was calculated from urinary nitrogen excretion using an equivalent of 6.25 g of protein per g of nitrogen and assuming a constant rate of nitrogen excretion over the urinary collection period. Although the respiratory quotient (RQ) of fish oil is 0.737,[14] namely higher than that of endogenous triglyceride stores (0.710), the formulae used for the calculation of substrate oxidation and energy expenditure on the fish oil diet were not modified. If some fatty acids of fish oil were included in the fat stores of our subjects (at most in the same proportion as in fat intake, namely 7%), the mean RQ obtained for endogenous triglycerides would be 0.712 instead of 0.71. Such small difference in mean RQ did not significantly affect calculated lipid or carbohydrate oxidation.

Body composition: Body composition was measured at the beginning and at the end of each period using dual-energy X-ray absorptiometry (Lunar DPX, No. 6097, Kontron Inst., St Quentin-sur-Yvelines, France; medium mode: software version 3.6Z). Bone and soft tissue measurements were performed in the morning after an overnight fast in subjects wearing only underwear and after voiding. The trained technician who positioned the subjects and performed all the scans was unaware of the purpose of the study and unaware of the dietary manipulation. A calibration block provided by the manufacturer and containing three bone equivalent chambers was used for calibration. An aluminium spine phantom was also used for calibration. Before the beginning of the study, *in vivo* precision of DXA was evaluated in eight subjects scanned twice, 2 h apart on the same day. Within-day precision of double measurements was $\leq 1.16\%$, $\leq 3.61\%$, $\leq 3.5\%$, and $\leq 0.82\%$ for bone mineral mass, percentage of fat, fat mass and fat free soft tissue mass respectively. The subjects were weighed

(1 g) using an electronic scale (Mettler Toledo KC120, Viroflay, France) in the fasting state, without clothes and after voiding. Weights were recorded at the beginning and at the end of each period.

Blood parameters: Blood samples were drawn at the beginning and at the end of each three week period for the determination of the fatty acid composition of platelet phospholipids. Thyroid hormones, basal glucose and insulin concentrations were also determined at the end of each period. Platelet concentrate was obtained by differential centrifugation and washed three times using calcium-free Hanks 1X solution (Eurobio, Les Ulis, France). Lipid extraction was performed as previously described.[15] Phospholipids were purified by silica-gel thin-layer chromatography (type linear-K6, Whatman, Mardstone, UK). Fatty acids were transmethylated and analyzed by capillary gas chromatography (Carlo Erba, type GC 6000 Vega) using an on-column injector under conditions already described.[15] Thyroid hormones were measured by radio-immunological methods (TSH: ELSA-TSH, CIS, Biointernational, France; Free T_3: Amerlex, Free-T_3, Amersham, France, Free T_4: CA-555A, Sorin, France; reverse T_3: reverse T_3 kit, Biodata France). Plasma glucose was measured with the glucose oxidase method using a Beckman Glucose Analyzer II (Beckman Instruments, Gagny, France). Plasma immunoreactive insulin was measured by RIA (INSIK 5, CIS Bio, Germany).

Statistical analysis: Results are expressed as mean $\pm$ s.d. Statistical analysis was performed using Statview II®, (Abacus Concepts Inc., Berkley, CA, USA). Student paired *t*-tests were used to explore the statistical significance of the differences observed between the two periods Difference in RMR was sought by analysis of covariance with FFM as a covariate. Correlations were explored using conventional linear regression analysis where appropriate. Differences and correlations were considered as significant if $P < 0.05$.

Table 1 Body weight and body composition in six young healthy volunteers with and without fish oil intake (6 g/d) over three consecutive weeks

	With fish oil			*Without fish oil*		
	Before	*After*	Δ^a	*Before*	*After*	Δ^a
Body weight (kg)						
#1	61.68	60.54	−1.14	60.34	60.29	−0.05
#2	67.85	66.25	−1.60	68.52	67.47	−1.04
#3	71.93	71.23	−0.69	69.70	69.51	−0.19
#4	70.14	69.45	−0.69	70.84	69.54	−1.30
#5	70.58	70.55	−0.03	71.24	70.77	−0.48
#6	55.02	55.00	−0.02	55.31	55.13	−0.18
mean	66.20	65.50	−0.70	66.00	65.45	−0.54
s.d.	6.57	6.47	0.62	6.59	6.30	0.52
Calcium mass (kg)						
#1	2.71	2.64	−0.07	2.69	2.70	0.01
#2	3.24	3.24	0.00	3.22	3.24	0.02
#3	3.41	3.40	−0.01	3.36	3.30	−0.06
#4	3.16	3.15	−0.01	3.04	3.09	0.05
#5	2.94	3.00	0.06	2.98	3.04	0.06
#6	2.94	2.92	−0.02	2.96	2.94	−0.02
mean	3.07	3.06	−0.01	3.04	3.05	0.01
s.d.	0.25	0.27	0.04	0.23	0.22	0.04
Fat mass (kg)						
#1	13.08	12.05	−1.03	11.95	12.06	0.11
#2	7.29	6.49	−0.79	7.88	7.29	−0.59
#3	8.49	7.91	−0.58	8.15	7.85	−0.30
#4	16.13	15.21	−0.92	16.08	15.51	−0.57
#5	15.87	14.89	−0.98	16.53	16.63	0.10
#6	13.64	12.70	−0.94	14.88	14.30	−0.58
mean	12.42	11.54	−0.88*	12.58	12.27	−0.30
s.d.	3.73	3.60	0.16	3.88	3.95	0.34
Fat free mass (kg)						
#1	45.89	45.85	−0.04	45.70	45.53	−0.17
#2	57.28	56.51	−0.77	57.42	56.94	−0.48
#3	60.03	59.93	−0.11	58.18	58.35	0.17
#4	50.85	51.09	0.24	51.71	50.97	−0.74
#5	51.73	52.69	0.95	51.73	51.10	−0.64
#6	38.44	39.37	0.94	37.47	37.89	0.42
mean	50.70	50.91	0.20	50.37	50.13	−0.24
s.d.	7.81	7.41	0.66	7.77	7.57	0.46

$^a\Delta$ = final value − initial value.
*P = 0.02, with *vs* without fish oil.

Results

Table 1 shows the changes in body weight and body composition during the two dietary periods of the study. Body weight decreased to a similar extent whether fish oil was introduced into the diet or not. Mean body fat mass decreased during both dietary periods. However, body fat mass was significantly more reduced ($P < 0.05$) during the fish oil period (-0.88 ± 0.16 kg) than during the control period (-0.3 ± 0.34 kg). The fat-free calcium-free mass tended to increase with fish oil and to decrease without fish oil, but the difference did not reach statistical significance.

Energy intakes were similar during both dietary periods (Table 2). Diet composition was also similar during both periods except for the amounts of eicosapentaenoic acid (20:5n-3) and docosahexaenoic acid (22:6n-3), which were increased by 1.1 and 0.7 g/d respectively during the fish oil period (Table 2). There was no nibbling and no alcohol consumption during the control and fish oil periods. Daily snacking which occurred during both periods in three subjects (#2, 4 and 5) accounted for 1.01 ± 0.63 and 0.95 ± 0.9 MJ/d for the control and fish oil periods respectively. It mainly involved carbohydrates (90.9 ± 4.2 *vs* 92.2 ± 7.2% of energy; control *vs* fish oil, respectively) and contained very small amounts of fat (1.8 ± 1.6 *vs* 3.0 ± 2.7% of energy; control *vs* fish oil, respectively).

When expressed in absolute terms (MJ/d), RMR increased significantly during fish oil replacement ($P < 0.05$; Table 3). However, when FFM was introduced in the analysis (Ancova), the effect of fish oil on RMR was not significant. Likewise, RMR expressed according to FFM did not differ between periods (147.6 ± 14.9 *vs* 144.4 ± 13.5 kJ min^{-1} kg FFM^{-1} with *vs* without fish oil; NS). RMR and FFM were significantly correlated [RMR (kJ min^{-1}) $= 2.63 + 0.048$ FFM (kg)]; $r^2 = 0.67$; $P < 0.01$). Basal respiratory quotient decreased ($P < 0.05$; Table 3). Basal substrate oxidation data are presented in Table 4. The rate of fat oxidation increased significantly with fish oil (1.06 ± 0.17 *vs* 0.87 ± 0.13 mg kg^{-1} min^{-1}; $P < 0.05$). The rate of protein oxidation (0.65 ± 0.09 *vs* 0.70 ± 0.13 mg kg^{-1} min^{-1}; NS) and of carbohydrate oxidation (1.37 ± 0.30 *vs* 1.57 ± 0.35 mg kg^{-1} min^{-1}; NS) were not significantly different between periods.

Table 2 Detailed dietary intake of six healthy volunteers with and without fish oil intake (6 g/d) over three consecutive weeks (±s.d.)

	Fish oil	
	With	*Without*
Energy intake (MJ/d)	10.3±1.2	10.4±0.7
Protein (% energy)	15.6±0.7	15.5±0.5
Carbohydrates (% energy)	52.5±3.3	52.4±2.5
Fat (% energy)	31.9±2.7	32.1±2.1
Saturated (% fat)	52.5±0.3	54.5±0.3
Monounsaturated (% fat)	36.9±0.4	34.1±0.2
Polyunsaturated (% fat)	10.6±0.5	11.4±0.5
P/S ratio	0.2±0.0	0.2±0.0
Fatty acids (% fat)		
C14:0	7.4±0.5	8.0±0.2
C16:0	23.9±1.2	25.4±0.5
C18:0	8.9±0.3	9.7±0.2
C16:1	3.1±0.7	2.8±0.1
C18:1	26.9±0.8	26.6±0.4
C18:2	7.6±1.1	8.7±1.0
C18:3	1.0±0.1	1.0±0.0
Others	21.2±3.4[a]	17.6±0.4

[a]Including 1.3±0.04% of C22:5ω3 and 0.8±0.03% of C22:6ω3.

Table 3 Resting energy expenditure and resting respiratory quotient (RQ) from six healthy volunteers with and without fish oil intake (6 g/d) over three consecutive weeks

	Fish oil		*P*
	With	*Without*	
Resting energy expenditure (MJ/d)			
#1	6.88	6.31	
#2	7.70	7.64	
#3	7.84	7.63	
#4	8.18	7.68	
#5	7.32	7.37	
#6	6.66	6.36	
mean±s.d.	7.43±0.58	7.16±0.65	0.045
Resting RQ			
#1	0.781	0.806	
#2	0.820	0.829	
#3	0.809	0.821	
#4	0.813	0.857	
#5	0.841	0.837	
#6	0.826	0.853	
mean±s.d.	0.815±0.020	0.834±0.019	0.041

Table 4 Basal substrate oxidation rates (mg kg^{-1}) from six healthy volunteers with and without fish oil intake (6 g/d) over three consecutive weeks

	Fish oil		*P*
	With	*Without*	
Fat oxidation			
#1	1.30	0.99	
#2	1.02	0.94	
#3	1.09	1.02	
#4	1.12	0.72	
#5	0.77	0.75	
#6	1.07	0.80	
mean±s.d.	1.06±0.17	0.87±0.13	0.03
Carbohydrate oxidation			
#1	0.83	1.06	
#2	1.43	1.57	
#3	1.30	1.50	
#4	1.41	1.95	
#5	1.58	1.44	
#6	1.68	2.00	
mean±s.d.	1.37±0.30	1.59±0.35	
Protein oxidation			
#1	0.64	0.75	
#2	0.78	0.71	
#3	0.53	0.49	
#4	0.64	0.71	
#5	0;71	0.88	
#6	0.62	0.69	
mean±s.d.	0.65±0.09	0.70±0.13	

There was no significant change in the EPA and DHA content of platelet phospholipids over time in the absence of fish oil whereas a significant increase was observed during fish oil consumption (EPA: $1.55 \pm 1.17\%$; $P < 0.05$; DHA: $0.61 \pm 0.07\%$; $P < 0.01$). Neither basal thyroid hormone concentrations (Free-T4: 21.3 ± 4.3 *vs* 22.6 ± 4.9 pM; NS; free-T3: 5.1 ± 1.3 *vs* 5.2 ± 0.9 pM; NS; reverse-T3: 317.5 ± 54 *vs* 306.7 ± 83.1 pM; NS; with *vs* without fish oil respectively) nor TSH concentrations (1.71 ± 1 *vs* 1.54 ± 0.74 mU l^{-1}; NS; with *vs* without fish oil respectively) changed with fish oil intake. Urinary dopamine excretion (849 ± 296 *vs* 724 ± 223 nmol; with *vs* without fish oil, NS) and adrenaline + noradrenaline excretion (73 ± 20 *vs* 49 ± 14 nmol; with *vs* without fish oil, NS) were not modified by fish oil intake. Basal blood glucose concentration increased (from 4.67 ± 0.19 to 4.98 ± 0.14 mmol/l, $P < 0.05$) and basal insulinaemia decreased (from 10.5 ± 2.6 to 5.3 ± 1.3 μU/ml, $P < 0.05$) with fish oil intake.

Discussion

According to the model of nutrient balance proposed by Flatt,[16] the metabolic handling of fat energy is likely to induce a positive energy balance mainly because of the inability of dietary fat to promote fat oxidation.[17,18] Although fat intake[19,20] and genotype[21,22] interact to regulate fat deposition, there are both *in vitro*[1,23] and *in vivo*[24,25] data which suggest that dietary fatty acid composition modulates to some extent the partitioning of fat between oxidation and storage.

Although body weight was not reduced by fish oil in the present study, a significant decrease in fat mass was observed when the subjects consumed the diet high in n-3 LC-PUFAs. This result is in agreement with previous observations in rodents showing that n-3 LC-PUFAs either reduce total body fat mass[5,6] or limit abdominal and epididymal adipose tissue hypertrophy when fed a high fat diet[7–9] without any significant decrease in body weight.[5–7,9] One study did not show any decrease in fat mass and body weight in rats receiving 14% of their energy intake as fish oil over four weeks.[26]

The decrease in fat mass with n-3 LC-PUFAs together with a similar lipid intake during both periods suggest a facilitation of the mobilisation[27] and/or the oxidation[28] of lipids. The increase in lipid oxidation is supported by the lower basal respiratory quotient observed in the present study at the end of the fish oil period as well as the 20% increase in basal lipid oxidation. Such a difference in lipid oxidation would lead to a loss of 370 g of fat over the 21 d period, namely 0.497 kg of adipose tissue (assuming 75% of fat in adipose tissue). Furthermore, a 35% increase in the cumulated net lipid oxidation has been previously reported in five of these six subjects during the 6 h following a fructose and a glucose load (1 g kg^{-1} body weight).[29] The reduced basal (present study) and postprandial plasma insulin concentrations[29] might contribute to the facilitation of lipid oxidation during the fish oil period. In addition, fish oil has been shown to enhance carnitine palmitoyltransferase I activity in rats,[30] mice[31] and Syrian hamsters,[32] and to decrease the sensitivity of carnitine palmitoyltransferase I to malonyl-CoA inhibition in liver mitochondria[33] even in rats fed fish oil at a level as low as 0.2% of the diet.[1] It should be noted that any increase in the carnitine palmitoyltransferase I activity and/or reduction in its malonyl-CoA inhibition renders fatty acids more available for the β-oxidative pathway. Whether fish oil can affect carnitine palmitoyltransferase activity or lipid oxidation in tissues other than liver is not known.

The present study shows a significant increase in RMR. As such, this result fits with the hypothesis of the 'leaky membrane'[34] and is in accordance with the increased metabolic rate associated with increased n-3 LC-PUFA content of tissue phospholipids reported elsewhere.[35,36] However, the increase in RMR is cancelled out when lean body mass is considered in the comparison, suggesting that FO might also stimulate RMR through an enhanced FFM. It is to be emphasized that fish oil intake increases FFM in rats.[5,6] The present study cannot separate the relative effects of changes in membrane lipid composition and body composition. Therefore, we suggest that FFM and fat mass are also measured and considered for explaining changes in energy metabolism in future trials with fish oil. Furthermore, changes in RMR were independent of either changes in plasma thyroid hormone concentrations or urinary catecholamine excretion. Although of limited magnitude ($\approx 4\%$), the significant increase in RMR observed during the fish oil period without any difference in energy intake and body weight between the two periods suggest that total energy expenditure was not increased by fish oil. Recent studies performed in rodents have shown that total energy expenditure as assessed by either respiratory gas exchange[5,9] or with the doubly-labelled water method[6] if not enhanced by a high fat-high n-3 LC-PUFA diet. Whether fish oil intake reduces other component(s) of total energy expenditure to compensate for the increased resting metabolic rate cannot be determined from the present study.

The design of the study deserves additional comments. Because of the known effect of season on body composition, each subject was studied within a period of 3.5–4 consecutive months and comparisons were made using the changes observed in body composition between the beginning and the end of each three week period. Thus, any seasonal effect on fat mass changes during the two experimental diets can be factored out. Secondly, physical activity remained unchanged during the experimental and the washout periods and dietary intakes were similar prior to each experimental

period. Thirdly, the P:S ratio of the experimental diets was controlled and set to the same value for all subjects since this ratio has been shown to influence energy substrate utilization in the human. The value of the P:S ratio (0.20) was arbitrarily chosen to be under the lowest P:S ratio seen in the volunteers (range: 0.24–0.71; mean: 0.41). Therefore, and compared to their usual P:S ratio, the change was in the same direction for all subjects and of the same magnitude for each subject during both diets. Such change was also of the same duration (three weeks) since washout period was included in the study. Whether the low P:S ratio of the experimental diets has magnified or smoothed out the response to fish oil cannot be determined from the present study. Finally, we postulated that fish oil intake would not modify food digestibility and lipid absorption. This assumption appears reasonable because of the low dose of fish oil used in our study, the similar and relatively small amounts of fat intake during both periods (≈ 85 g/d) and the absence of effect of fish oil on food digestibility in some studies performed in the rat.[4,5,9] However, fish oil increased fecal energy losses[6] and steatorrhea[3] as compared to safflower and olive oil in rats fed a high fat diet. Although gross fat malabsorption is unlikely in the present study, it may be worth measuring fecal fat excretion in further human studies performed with higher amounts of fish oil than used in the present study.

Conclusions

In summary, a 6 g/d substitution of visible fat by fish oil over three weeks in healthy adults reduces body fat-mass and increases basal lipid oxidation. These results sustain the role of long-chain fatty acids of the n-3 series as an environmental factor in the regulation of body fat mass in the human. Small individual differences in the amount of n-3 LC-PUFA consumption (a dose of 6 g/d of fish oil is equivalent to a 100–200 g/d of fish consumption depending on the species of the marine fish considered) and/or in the capacity to synthesize these long-chain fatty acids from α-linolenate (an essential fatty acid) might contribute to the diversity of the body mass index phenotype between and within populations. However, further mechanistic and clinical studies performed in healthy volunteers and obese subjects are needed before n-3 LC-PUFAs can be considered as a therapeutic adjuvant in the dietary management of human obesity.

Acknowledgements
The authors thank V Theret, M Objois, M Pinault and MA Garrigue for their technical assistance. This work was supported in part by the 'groupe Danone', Paris, France.

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