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Polyunsaturated fatty acid status of Dutch vegans and omnivores

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Summary We compared the polyunsaturated fatty acid (PUFA) status of Dutch vegans and omnivores to investigate whether disparities can be explained by different diets and long chain PUFA (LCP) synthesis rates. Dietary intakes and fatty acid compositions of erythrocytes (RBC), platelets (PLT), plasma cholesterol esters (CE) and plasma triglycerides (TG) of 12 strict vegans and 15 age- and sex-matched omnivores were determined. Vegans had higher ω6 (CE, TG), 18:2ω6 (RBC, CE, TG), 18:3ω6 (TG), 20:3ω6 (TG), 22:4ω6 (TG), 22:5ω3 (RBC, PLT), 22:5ω3/22:6ω3 (RBC, PLT) and 22:5ω6/22:6ω3 (RBC, PLT), and lower 22:4ω6 (RBC, PLT), 22:4ω6/22:5ω6 (RBC, PLT), ω3 (CE), LCPω3 (CE, TG), 20:5ω3 (RBC, PLT, CE), 22:5ω3 (TG) and 22:6ω3 (all compartments). Vegans had lower 20:4ω6 (TG) after normalization of PUFA to 100%, and normalization of eicosanoid precursors to 100% revealed similar 20:4ω6 (all), higher 20:3ω6 (TG) and lower 20:5ω3 (all). High ω6 (notably 18:2ω6) and low ω3 (notably 20:5ω3, 22:6ω3) status in Dutch vegans derives from low dietary LCPω3 and 18:3ω3/18:2ω6 ratio. Higher 18:3ω6 and 20:3ω6 in their TG may reflect higher hepatic 20:4ω6 production rate, whereas higher 20:4ω6 and 22:4ω6 in omnivores indicates 20:4ω6 intake from meat. © 2000 Harcourt Publishers Ltd

INTRODUCTION

Vegans do not consume animal products and lead a more health-conscious lifestyle than omnivores. Epidemiological studies indicate that their dietary regimen together with higher education, lower body mass index and associated life style factors such as less smoking, regular physical activity and sufficient sleep, causes decreased mortality from cardiovascular disease, diabetes, colon cancer and all causes combined.[1–3]

The vegan diet provides high intakes of grains, vegetables, vegetable oils and nuts. Vegans have consequently high intakes of the parent essential fatty acids linoleic (18:2ω6) and α-linolenic (18:3ω3) acids, and low intakes of their desaturation and chain-elongation products, collectively named long-chain polyunsaturated fatty acids (LCP; i.e. PUFA with 20 or more carbon atoms and with three or more methylene-interrupted *cis*-double bonds). More specifically, it implies low intakes of arachidonic acid (20:4ω6), which comes notably from meat, and eicosapentaenoic (20:5ω3) and docosahexaenoic (22:6ω3) acids, which derive notably from fish. LCP are important structural components of membrane phospholipids (PL) and precursors of functionally important eicosanoids (prostaglandins, prostacyclines, thromboxanes and leukotrienes). Vegans are, in contrast to omnivores, almost fully dependent on LCP synthesis from 18:2ω6 and 18:3ω3. These parent essential fatty acids compete for the same chain-elongation and desaturation enzymes.[4] Consumption of oils with low 18:3ω3/18:2ω6 ratios, such as safflower, sunflower and corn oils, may therefore, in combination with low LCPω3 intake, cause low LCPω3 status. Dietary LCP intake by omnivores may on the other hand exert negative feed back inhibition on the conversion of the parent essential fatty acids to LCP and consequently cause low levels of LCP intermediates, such as dihomo-γ-linolenic acid (20:3ω6).

We determined dietary intakes and fatty acid compositions of erythrocytes (RBC), platelets (PLT), plasma cholesterol esters (CE) and plasma triglycerides (TG) of 12 apparently healthy Dutch vegans. The data were

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compared with those of 15 age- and sex-matched omnivorous controls. We were particularly interested to see whether their PUFA differences could be explained by their different diets and by different LCP synthesis rates.

SUBJECTS AND METHODS

Study group

Healthy subjects aged 20–60 years were eligible to participate in this study. Vegans were recruited by advertisement in the periodicals of the Dutch Vegan Association and the Groningen University Hospital. Omnivores were recruited from hospital employees and students of the Pharmacy Department of the Groningen University. The final study population was composed of 12 vegans and 15 omnivores. Their characteristics are depicted in Table 1. The vegan participants reported to have taken a vegan diet for 2 years or more (median: 4 years, range: 2–20). The study protocol was approved by the medical ethical committee of the Groningen University Hospital and was in agreement with local ethical standards and the Helsinki declaration of 1975, as revised in 1989.

Dietary assessment

Dietary intake of omnivores was assessed by an unassisted semi-quantitative food frequency questionnaire (FFQ), called the Fat-express, which is designed to measure intake of total fat and fatty acids.[5] Dietary intake of vegans was assessed by an unassisted semi-quantitative FFQ, called the FFQ-ALA, which is based on the Fat-express. This FFQ provides specific information on the intakes of total fat, saturated (SAFA), monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids, and also of 18:2ω6 and 18:3ω3. Both questionnaires were processed by the nutritional software package KOMEET®. Dietary intakes of the vegans were compared with those of the omnivores and with those of a representative group of Dutch males and females of the same age group, who participated in the 1997–1998 Dutch National Food Consumption Survey.[6]

Analytical methods

EDTA-anticoagulated blood samples were collected by puncture of the cubital vein in the fasting state and separated by centrifugation into an RBC pellet, a PLT pellet and EDTA-plasma. RBC and PLT were washed with physiological saline. CE and TG were isolated from EDTA-plasma by solid-phase extraction according to our previously described method.[7] Fatty acids in RBC, PLT, CE and TG were transmethylated to fatty acid methyl esters in methanol/HCl and subsequently determined by capillary gas chromatography with flame ionization detection.[7]

Data evaluation and statistics

Fatty acid compositions were expressed in mol%. PUFA of the ω3 and ω6 series in TG and RBC were normalized to 100%, to concentrate on PUFA distribution differences between vegans and omnivores independent from other fatty acids. To focus on eicosanoid precursor distribution

Table 1 Anthropometrics and dietary fat intakes of Dutch vegans, omnivores and the general population

	Females			Males		
	Vegans (*n*=4)	Omnivores (*n*=6)	Population (*n*=1472)	Vegans (*n*=8)	Omnivores (*n*=9)	Population (*n*=1252)
Age (years)	40 ± 12	28 ± 6		37 ± 13	40 ± 11	
Age range (years)	29–55	23–40	22–50	25–57	23–51	22–50
Weight (kg)	60.3 ± 5.5	61.8 ± 4.4	69.9	66.2 ± 6.9	78.6 ± 8.2	81.8
Length (m)	1.71 ± 0.04	1.74 ± 0.04	1.69	1.79 ± 0.07	1.82 ± 0.08	1.82
BMI (kg/m^2)	20.6 ± 1.7	20.4 ± 1.9	24.6	20.6 ± 2.3	23.8 ± 2.4	24.8
Total fat (en%)	40.0 ± 4.8	38.5 ± 2.8	37.0 ± 6.8	29.9 ± 10.9	40.1 ± 4.9*	36.5 ± 6.5
SAFA (en%)	13.3 ± 4.3	14.8 ± 0.4	14.6 ± 3.4	9.5 ± 4.5	14.9 ± 2.5*	14.2 ± 3.1
MUFA (en%)	13.3 ± 2.9	15.0 ± 1.4	13.2 ± 3.0	10.3 ± 4.7	15.4 ± 3.1*	12.9 ± 2.9
PUFA (en%)	11.3 ± 4.6	7.0 ± 1.5*	6.8 ± 2.3	8.1 ± 3.8	8.1 ± 1.2	6.9 ± 2.2
PUFA/SAFA (g/g)	0.97 ± 0.56	0.47 ± 0.11*	0.47[1]	1.10 ± 0.64	0.58 ± 0.11*	0.49[1]
18:2ω6 (g)	20.9 ± 12.9		13.0 ± 6.0	23.6 ± 9.3		18.0 ± 8.0
18:2ω6 (en%)	10.0 ± 4.2		5.7 ± 2.2	7.5 ± 3.3		5.9 ± 2.1
18:3ω3 (g)	1.54 ± 0.68			2.05 ± 1.01		
18:3ω3 (en%)	1.0 ± 0.0			0.6 ± 0.5		
18:2ω6/18:3ω3 (g/g)	13.3 ± 3.8			12.8 ± 4.1		

Data represent mean ± SD. Data for the entire population derive from the Dutch National Food Consumption Survey 1997–1998 (6).
[1] as calculated from the means.
* significantly different from vegans at $P < 0.05$.

differences between vegans and omnivores we also normalized 20:3ω6, 20:4ω6 and 20:5ω3 in RBC, PLT, CE and TG to 100%. Between-group differences in fatty acid compositions of RBC, PLT, CE and TG were tested with the Mann–Whitney *U*-test. $P < 0.05$ was considered significant.

RESULTS

Table 1 shows the study group characteristics and dietary fat intakes. Available data of age-controlled counterparts who participated in the 1997–1998 Dutch National Food Consumption Survey are given as a reference. Compared with the omnivores and the Dutch population, the vegans consumed less total fat (males), SAFA (males), MUFA (males) and higher PUFA (females). The vegan diet had a higher PUFA/SAFA ratio and provided a higher energy intake from 18:2ω6 compared with the general population.

Table 2 shows the fatty acid compositions of RBC, PLT, plasma CE and plasma TG for the 12 vegans and the 15 omnivores.

SAFA

Vegans had lower SAFA (CE, TG), 14:0 (CE) 16:0 (CE, TG), 20:0 (PLT) and 22:0 (RBC, PLT), but higher 18:0 (RBC) and 26:0 (RBC).

Table 2 Fatty acid compositions of Dutch vegans and omnivores

Fatty acids	RBC		PLT		CE		TG	
	Vegans (*n*=12)	Omnivores (*n*=15)	Vegans (*n*=12)	Omnivores (*n*=15)	Vegans (*n*=12)	Omnivores (*n*=15)	Vegans (*n*=12)	Omnivores (*n*=15)
14:0	0.38 ± 0.16	0.38 ± 0.07	0.51 ± 0.35	0.49 ± 0.16	0.57 ± 0.33	0.85 ± 0.25*	1.46 ± 0.69	1.94 ± 0.74
16:0	21.08 ± 6.72	23.51 ± 0.59	19.78 ± 2.73	20.84 ± 2.06	11.83 ± 2.52	13.83 ± 1.12**	19.68 ± 3.64	28.33 ± 2.35***
18:0	17.46 ± 1.50	16.38 ± 0.67*	22.41 ± 5.15	19.38 ± 1.07	1.76 ± 0.55	1.77 ± 0.47	4.10 ± 0.73	3.97 ± 1.03
20:0	0.42 ± 0.07	0.43 ± 0.04	1.40 ± 0.12	1.58 ± 0.13**	—	—	0.34 ± 0.85	0.08 ± 0.04
22:0	1.78 ± 0.31	1.94 ± 0.14*	2.91 ± 0.38	3.48 ± 0.32***	—	—	0.36 ± 0.59	0.24 ± 0.17
24:0	4.79 ± 0.69	4.89 ± 0.25	1.82 ± 0.33	1.70 ± 0.28	—	—	—	—
26:0	0.29 ± 0.04	0.25 ± 0.03**	0.06 ± 0.03	0.05 ± 0.05	—	—	—	—
SAFA	46.21 ± 4.52	47.78 ± 0.59	48.89 ± 7.38	47.53 ± 3.36	14.17 ± 3.18	16.45 ± 1.21**	25.94 ± 4.26	34.57 ± 2.88***
18:3ω3	0.13 ± 0.11	0.17 ± 0.06	0.19 ± 0.10	0.20 ± 0.10	0.37 ± 0.23	0.22 ± 0.25	1.47 ± 0.70	1.20 ± 0.38
20:5ω3	0.22 ± 0.20	0.55 ± 0.23***	0.05 ± 0.13	0.31 ± 0.22**	0.37 ± 0.20	0.72 ± 0.42**	0.14 ± 0.10	0.25 ± 0.15
22:5ω3	3.74 ± 0.76	2.02 ± 0.27***	1.95 ± 0.64	1.13 ± 0.26***	—	—	0.32 ± 0.39	0.40 ± 0.16*
22:6ω3	2.04 ± 0.87	3.90 ± 1.06***	0.72 ± 0.30	1.43 ± 0.46***	0.32 ± 0.14	0.77 ± 0.29***	0.25 ± 0.17	0.72 ± 0.44***
ω3	6.13 ± 1.04	6.64 ± 1.22	2.92 ± 0.81	3.07 ± 0.73	1.06 ± 0.34	1.71 ± 0.61***	2.17 ± 0.90	2.57 ± 0.67
LCPω3	6.00 ± 0.97	6.47 ± 1.26	2.72 ± 0.81	2.87 ± 0.72	0.68 ± 0.31	1.49 ± 0.66***	0.71 ± 0.49	1.37 ± 0.60**
18:2ω6	11.61 ± 1.67	9.78 ± 1.48**	8.40 ± 2.33	8.22 ± 1.47	56.34 ± 7.43	52.20 ± 4.79*	26.85 ± 4.17	18.55 ± 2.83***
18:3ω6	0.05 ± 0.04	0.04 ± 0.05	0.12 ± 0.08	0.14 ± 0.12	0.93 ± 0.41	0.78 ± 0.38	0.59 ± 0.16	0.37 ± 0.18**
20:2ω6	0.42 ± 0.13	0.26 ± 0.04**	0.43 ± 0.08	0.31 ± 0.13**	—	—	0.44 ± 0.27	0.28 ± 0.09
20:3ω6	1.60 ± 0.84	1.67 ± 0.29	1.26 ± 0.30	1.38 ± 0.30	0.74 ± 0.14	0.85 ± 0.19	1.08 ± 1.81	0.37 ± 0.10***
20:4ω6	14.24 ± 1.09	13.76 ± 1.19	19.26 ± 3.22	19.76 ± 2.63	6.16 ± 1.50	6.81 ± 1.61	1.41 ± 0.29	1.47 ± 0.62
22:4ω6	1.60 ± 0.73	2.76 ± 0.51***	1.15 ± 0.48	1.77 ± 0.37**	—	—	0.30 ± 0.16	0.20 ± 0.08*
22:5ω6	0.55 ± 0.14	0.50 ± 0.14	0.25 ± 0.06	0.22 ± 0.11	—	—	—	—
ω6	30.07 ± 3.30	28.77 ± 1.64	30.87 ± 4.25	31.80 ± 2.49	64.16 ± 7.99	60.63 ± 3.79**	30.66 ± 4.94	21.33 ± 2.88***
LCPω6	17.99 ± 2.00	18.69 ± 1.61	21.92 ± 3.38	23.13 ± 2.98	6.89 ± 1.55	7.66 ± 1.72	2.79 ± 1.80	2.04 ± 0.72
16:1ω7	0.21 ± 0.13	0.25 ± 0.09	0.22 ± 0.12	0.43 ± 0.17**	1.85 ± 1.05	2.95 ± 1.31	2.40 ± 1.15	3.80 ± 1.27*
18:1ω7	1.55 ± 0.26	1.61 ± 0.15	1.13 ± 0.29	1.45 ± 0.17**	1.26 ± 0.52	1.38 ± 0.22*	2.75 ± 0.90	3.50 ± 0.89*
ω7	1.76 ± 0.32	1.86 ± 0.20	1.36 ± 0.33	1.88 ± 0.27**	3.10 ± 1.44	4.33 ± 1.38*	5.15 ± 1.66	7.30 ± 1.45**
18:1ω9	12.05 ± 0.83	10.75 ± 0.47***	13.39 ± 2.26	13.27 ± 1.03	17.45 ± 3.71	16.79 ± 1.72	36.00 ± 4.43	34.00 ± 2.40
20:1ω9	0.30 ± 0.09	0.23 ± 0.03*	0.69 ± 0.15	0.50 ± 0.14**	—	—	0.08 ± 0.15	0.34 ± 0.11**
24:1ω9	3.25 ± 1.36	3.70 ± 0.44	1.58 ± 0.46	1.65 ± 0.26	—	—	—	—
20:3ω9	0.24 ± 0.06	0.27 ± 0.08	0.30 ± 0.39	0.30 ± 0.12*	0.06 ± 0.09	0.09 ± 0.06	—	—
ω9	15.84 ± 1.25	14.94 ± 0.69*	15.96 ± 2.95	15.72 ± 1.28	17.51 ± 3.78	16.88 ± 1.74	36.08 ± 4.48	34.34 ± 2.44
MUFA	17.36 ± 1.13	16.54 ± 0.81	17.02 ± 2.92	17.31 ± 1.32	20.55 ± 4.86	21.12 ± 2.88	41.23 ± 4.48	41.63 ± 3.11
PUFA	36.44 ± 4.02	35.68 ± 0.82	34.09 ± 4.83	35.17 ± 2.60	65.28 ± 7.81	62.43 ± 3.50**	32.84 ± 4.71	23.80 ± 3.23***
PUFA/SAFA	0.81 ± 0.23	0.75 ± 0.02	0.72 ± 0.19	0.75 ± 0.10	4.87 ± 1.30	3.82 ± 0.44**	1.32 ± 0.38	0.70 ± 0.13***
ω3/ω6	0.20 ± 0.03	0.23 ± 0.06	0.09 ± 0.03	0.10 ± 0.02	0.02 ± 0.01	0.03 ± 0.01**	0.07 ± 0.04	0.12 ± 0.03***
LCPω3/LCPω6	0.33 ± 0.05	0.35 ± 0.09	0.12 ± 0.03	0.13 ± 0.03	0.10 ± 0.04	0.20 ± 0.09***	0.29 ± 0.22	0.71 ± 0.26***
18:3ω3/18:2ω6	0.01 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0.01	0.01 ± 0.01	0.00 ± 0.00	0.06 ± 0.03	0.06 ± 0.02
20:3ω9/20:4ω6	0.02 ± 0.00	0.02 ± 0.01	0.02 ± 0.02	0.02 ± 0.01	0.01 ± 0.02	0.01 ± 0.01	—	—
22:4ω6/22:5ω6	3.10 ± 1.63	5.70 ± 0.96***	4.71 ± 2.21	8.81 ± 3.47**	—	—	—	—
22:5ω3/ 22:6ω3	2.20 ± 1.04	0.56 ± 0.18***	2.93 ± 1.20	0.86 ± 0.32***	—	—	1.28 ± 0.97	0.78 ± 0.59
22:5ω6/22:6ω3	0.33 ± 0.18	0.14 ± 0.05**	0.42 ± 0.21	0.17 ± 0.13**	—	—	—	—

Data represent means ± SD in mol% or mol/mol (ratios).
RBC, erythrocytes; PLT, platelets; CE plasma cholesterol esters; TG, plasma triglycerides.
Significantly different from vegans at $P < 0.05$ (*), $P < 0.01$ (**) and $P < 0.001$ (***).

PUFA

Vegans had higher PUFA (CE, TG), ω6 (CE, TG), 18:2ω6 (RBC, CE, TG), 18:3ω6 (TG), 20:2ω6 (RBC, PLT) and 20:3ω6 (TG). They had higher 22:4ω6 in TG, but lower 22:4ω6 in RBC and PLT. Vegans had lower ω3 (CE), LCPω3 (TG, CE), 20:5ω3 (RBC, PLT, CE) and 22:6ω3 (RBC, PLT, TG, CE). They also had lower 22:5ω3 in TG, but higher 22:5ω3 in RBC and PLT.

MUFA

Vegans had higher ω9 (RBC) and 18:1ω9 (RBC). They also had higher 20:1ω9 in RBC and PLT, but lower 20:1ω9 in TG. Vegans had lower ω7 (PLT, CE, TG), 16:1ω7 (PLT, TG) and 18:1ω7 (PLT, CE, TG).

Ratios

Vegans had lower ω3/ω6 (CE, TG), LCPω3/LCPω6 (CE, TG) and 22:4ω6/22:5ω6 (RBC, PLT). They had higher PUFA/SAFA (CE, TG), 22:5ω3/22:6ω3 (RBC, PLT; a marker of ω3 deficiency) and 22:5ω6/22:6ω3 (RBC, PLT; a marker of ω3 deficiency). Vegans and omnivores had similar 20:3ω9/20:4ω6 (a marker of EFA deficiency) ratios.

Figure 1 shows a comparison of the PUFA compositions of plasma TG and RBC for vegans and omnivores. PUFA of the ω3 and ω6 series were normalized to 100% and ordered according to their metabolic precursor-metabolite relationships. Vegans had higher 18:2ω6 (TG, RBC), 22:5ω3 (RBC) and lower 20:4ω6 (TG), 22:4ω6 (RBC), 20:5ω3 (TG, RBC), 22:5ω3 (TG), 22:6ω3 (TG, RBC). PLT exhibited the same significant differences as RBC (data not shown). PUFA of the ω3 and ω6 series in CE were not considered in this evaluation. Figure 2 shows a comparison of the eicosanoid precursor compositions in RBC, PLT, plasma CE and plasma TG for vegans and omnivores. For this we normalized 20:3ω6, 20:4ω6 and 20:5ω3 to 100%. Vegans had significantly lower 20:5ω3 levels in all compartments, and higher 20:3ω6 in plasma TG.

DISCUSSION

We compared the fatty acid compositions of RBC, PLT, plasma CE and plasma TG in Dutch vegans and omnivores (Table 2). Most importantly it was found that vegans have higher ω6 (notably 18:2ω6) and lower LCPω3 (notably 20:5ω3 and 22:6ω3), which together seems to give rise to LCPω3 marginality. Vegans seem to have higher hepatic synthesis rates of 18:2ω6 to 20:4ω6, as derived from their higher contents of the intermediates

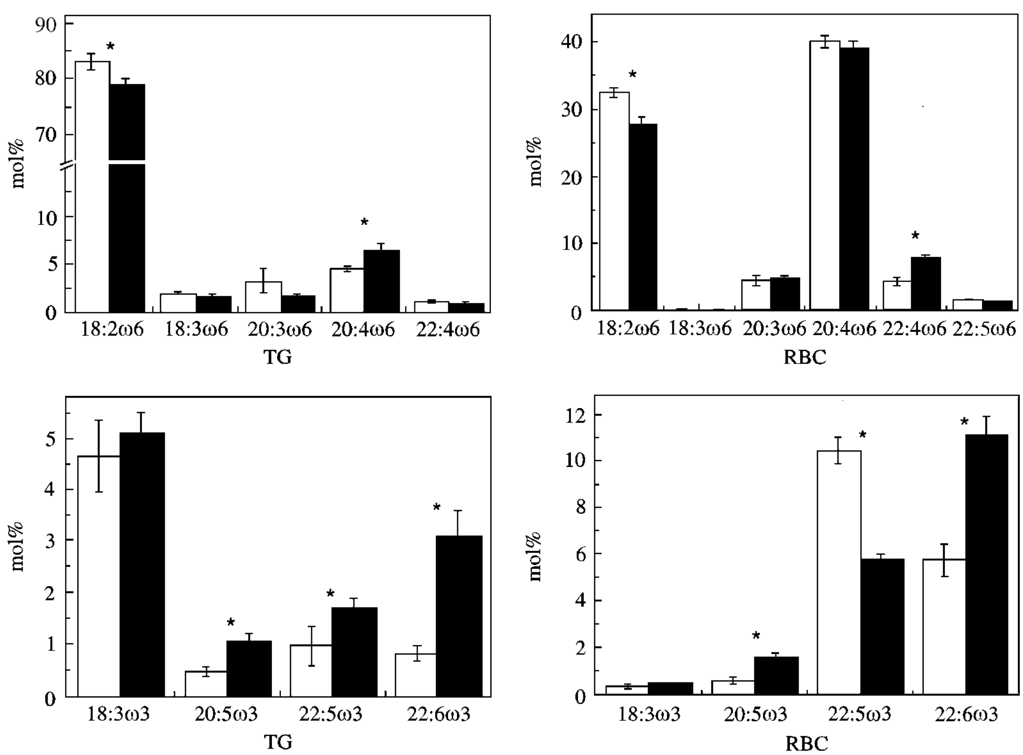

Fig. 1 Polyunsaturated fatty acid compositions of Dutch vegans (open bars) and omnivores (closed bars). PUFAω6 and PUFAω3 were normalized to 100%. Data represent means ± SEM. RBC, erythrocytes; TG plasma triglycerides. *, statistically different at $P < 0.05$ by Mann–Whitney *U*-test.

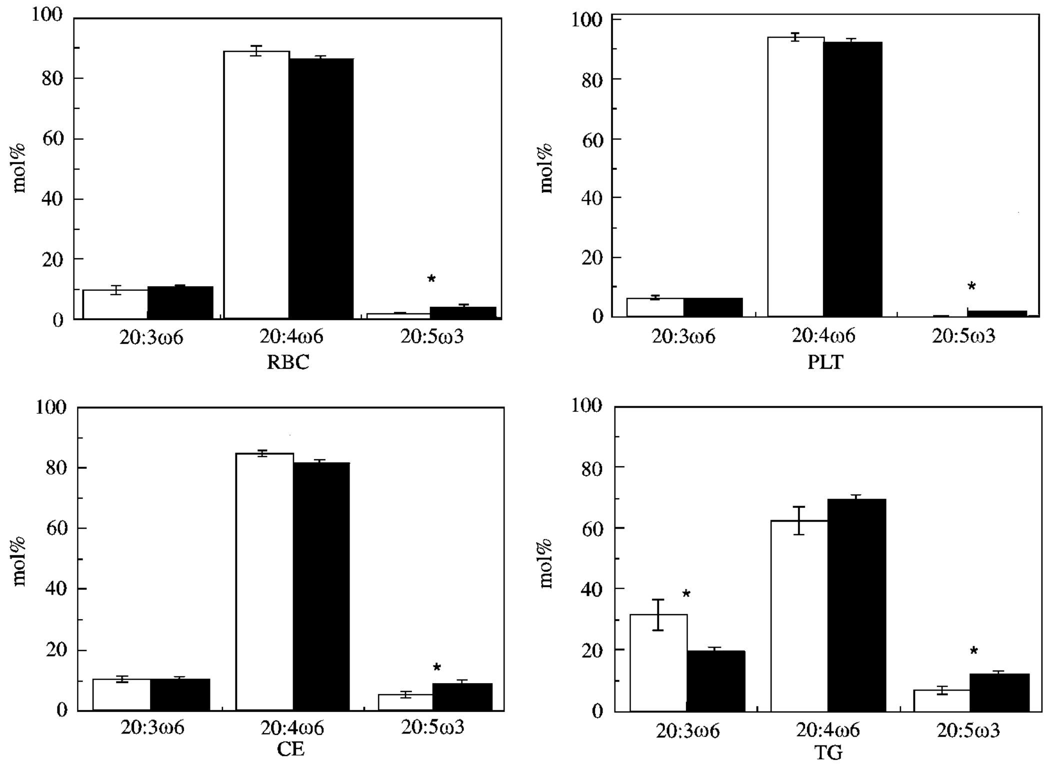

Fig. 2 Eicosanoid precursor compositions of Dutch vegans (open bars) and omnivores (closed bars). 20:3ω6, 20:4ω6 and 20:5ω3 were normalized to 100%. Data represent means $\pm$ SEM. RBC, erythrocytes; PLT, platelets; CE plasma cholesterol esters; TG plasma triglycerides. * Statistically different at $P < 0.05$ by Mann–Whitney *U*-test.

18:3ω6 and 20:3ω6 in fasting TG. Our results also suggest that omnivores have higher 20:4ω6 and 22:4ω6 as a consequence of higher 20:4ω6 intakes. These findings are discussed in more detail.

Our results and those of others show that European vegans have high 18:2ω6 intakes,[8–12] which give rise to high 18:2ω6 levels in many compartments compared with omnivores.[13] We also found that vegans have higher 18:3ω6 and 20:3ω6 in their fasting plasma TG (Table 2), which is consistent with data of Phinney et al.[14] and Agren et al.[12] These fatty acids are intermediates in the synthesis of 20:4ω6, and their augmented contents in fasting TG may point at a higher hepatic 20:4ω6 synthesis rate. After normalization of total ω3 and ω6 fatty acids to 100%, we found that the 20:4ω6 levels of vegans were somewhat lower in fasting plasma TG compared with omnivores (Fig. 1). Higher 20:4ω6 in various compartments of omnivores, notably their plasma CE, plasma PL and PLT-PL, is supported by the findings of Sanders et al.[10] and Phinney et al.[14] It is also consistent with the study of Nelson et al.,[15,16] who showed augmented 20:4ω6 levels in PLT, RBC, plasma PL, CE, FFA, TG and total FA following daily supplementation of healthy adults with 1.7 g 20:4ω6 for 50 days. Higher dietary 20:4ω6 intake by omnivores also seems to cause higher contents of its chain-elongation product 22:4ω6 in RBC, PLT and plasma TG (Table 2, Fig. 1). This notion is supported by the increase of 22:4ω6 in PLT following controlled 20:4ω6 supplementation.[15] It has previously been suggested that tissue 22:4ω6 may via retro-conversion act as a storage form of 20:4ω6.[4]

Our data also indicate that vegans have low 20:5ω3 and 22:6ω3, compared with omnivores, which is consistent with other studies with European vegans.[9–13,17] North American vegans have, however, 20:5ω3 and 22:6ω3 levels comparable with omnivores.[14,18] The similar LCPω3 status of American vegans and omnivores is probably caused by the low intake of LCPω3 by American omnivores.[19,20] The LCPω3 status similarity between American and European vegans[12,14] indicates that the higher dietary 18:3ω3/18:2ω6 ratio of Americans, compared with Europeans,[19,20] has little effect on, notably, their 22:6ω3 status.

The low 20:5ω3 and 22:6ω3 status of European vegans seems to progress in the direction of a biochemical ω3 deficiency. This may be derived from their higher 22:5ω3 and 22:5ω6 levels, and lower 22:6ω3 and 22:4ω6 levels in RBC and PLT (Table 2, Fig. 1). Vegans have consequently higher 22:5ω3/22:6ω3 and 22:5ω6/22:6ω3, and lower

22:4ω6/22:5ω6. These ratios are markers of biochemical ω3-deficiency, since they indicate the dominance of LCPω6 over LCPω3.[4] An unfavorably low 18:3ω3/18:2ω6 ratio, and not necessarily low 18:3ω3 intake per se, may be at the basis of poor Δ6 desaturation of 18:3ω3 and 24:5ω3 (the chain elongation product of 22:5ω3[21]), causing little conversion of dietary 18:3ω3 into LCPω3, and a blockage at the level of 22:5ω3. It remains to be seen whether this blockage can be overcome by increasing their dietary 18:3ω3/18:2ω6 ratio.

As a consequence of their low dietary 18:3ω3/18:2ω6 and low LCP intake, Dutch vegans have quite different eicosanoid precursor profiles in RBC, PLT, plasma CE and plasma TG (Fig. 2). The eicosanoid precursor composition of PLT bears functional relevance since it provides insight into the potential to synthesize functionally distinct tromboxane A_2 (from 20:4ω6) and tromboxane A_3 (from 20:5ω3). Each of the above compartments show that vegans have comparably high 20:4ω6 with significantly lower 20:5ω3 and comparable 20:3ω6 (except for TG). Comparable 20:3ω6 in RBC, PLT and CE despite its higher content in TG suggests that active hepatic 20:3ω6 formation by vegans, if any, does not necessarily lead to higher 20:3ω6 levels in eicosanoid producing cells. The eicosanoids produced from 20:3ω6 and 20:5ω3 have remarkably similar function, as opposed to those deriving from 20:4ω6.[22] Consequently, a compensatory role of 20:3ω6 for the low 20:5ω3 status of vegans does not seem plausible.

In summary, Dutch vegans have higher ω6 (notably 18:2ω6) and lower ω3 (notably 20:5ω3 and 22:6ω3) status, compared with omnivores. They are in this respect comparable with their European counterparts. Dependence on 20:4ω6 synthesis in the liver may be the principal reason for the encountered higher levels of the intermediates 18:3ω6 and 20:3ω6 in fasting TG of vegans, but this higher synthesis rate, if any, does not cause higher 20:3ω6 status in other compartments. Higher 20:4ω6 and 22:4ω6 in various compartments of omnivores may on the other hand point at their dietary intake of 20:4ω6 from meat. The eicosanoid precursor profiles of vegans are dominated by 20:4ω6 because of their low 20:5ω3 and comparable 20:3ω6 contents. It remains to be seen whether their LCPω3 status can be improved by augmentation of the dietary 18:3ω3/18:2ω6 ratio.

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REFERENCES

1. Dwyer J. T. Health aspects of vegetarian diets. *Am J Clin Nutr* 1988; **48**: 712–738.
2. Chang-Claude J., Frentzel-Beyme R. Dietary and lifestyle determinants of mortality among German vegetarians. *Int J Epidemiol* 1993; **22**: 228–236.
3. Chang-Claude J., Frentzel-Beyme R., Eilber U. Mortality pattern of German vegetarians after 11 years of follow-up [see comments]. *Epidemiology* 1992; **3**: 395–401.
4. Innis S. M. Essential fatty acids in growth and development. *Prog Lipid Res* 1991; **30**: 39–103.
5. Feunekes G. I., Van Staveren W. A., De Vries J. H., Burema J., Hautvast J. G. Relative and biomarker-based validity of a food-frequency questionnaire estimating intake of fats and cholesterol. *Am J Clin Nutr* 1993; **58**: 489–496.
6. Hulshof K. F. A. M., Kistemaker C., Bouman M. Intake of energy and dietary nutrients by Dutch population groups – the national food consumption survey 1997–1998. Report no V98.805, Zeist, 1998.
7. Hoving E. B., Jansen G., Volmer M., Van Doormaal J. J., Muskiet F. A. Profiling of plasma cholesterol ester and triglyceride fatty acids as their methyl esters by capillary gas chromatography, preceded by a rapid aminopropyl-silica column chromatographic separation of lipid classes. *J Chromatogr* 1988; **434**: 395–409.
8. Abdulla M., Andersson I., Asp N. G. et al. Nutrient intake and health status of vegans. Chemical analyses of diets using the duplicate portion sampling technique. *Am J Clin Nutr* 1981; **34**: 2464–2477.
9. Sanders T. A., Younger K. M. The effect of dietary supplements of omega 3 polyunsaturated fatty acids on the fatty acid composition of platelets and plasma choline phosphoglycerides. *Br J Nutr* 1981; **45**: 613–616.
10. Sanders T. A., Roshanai F. Platelet phospholipid fatty acid composition and function in vegans compared with age- and sex-matched omnivore controls. *Eur J Clin Nutr* 1992; **46**: 823–831.
11. Reddy S., Sanders T. A., Obeid O. The influence of maternal vegetarian diet on essential fatty acid status of the newborn. *Eur J Clin Nutr* 1994; **48**: 358–368.
12. Agren J. J., Tormala M. L., Nenonen M. T., Hanninen O. O. Fatty acid composition of erythrocyte, platelet, and serum lipids in strict vegans. *Lipids* 1995; **30**: 365–369.
13. Sanders T. A., Ellis F. R., Dickerson J. W. Studies of vegans: the fatty acid composition of plasma choline phospholycerides, erythrocytes, adipose tissue, and breast milk, and some indicators of susceptibility to ischemic heart disease in vegans and omnivore controls. *Am J Clin Nutr* 1978; **31**: 805–813.
14. Phinney S. D., Odin R. S., Johnson S. B., Holman R. T. Reduced arachidonate in serum phospholipids and cholesteryl esters associated with vegetarian diets in humans. *Am J Clin Nutr* 1990; **51**: 385–392.
15. Nelson G. J., Schmidt P. C., Bartolini G., Kelley D. S., Kyle D. The effect of dietary arachidonic acid on platelet function, platelet acid composition, and blood coagulation in humans. *Lipids* 1997; **32**: 421–425.
16. Nelson G. J., Schmidt P. C., Bartolini G. et al. The effect of dietary arachidonic acid on plasma lipoprotein distributions, apoproteins, blood lipid levels, and tissue fatty acid composition in humans. *Lipids* 1997; **32**: 427–433.
17. Krajcovicova-Kudlackova M., Simoncic R., Bederova A., Klvanova J. Plasma fatty acid profile and alternative nutrition. *Ann Nutr Metab* 1997; **41**: 365–370.
18. Finley D. A., Lonnerdal B., Dewey K. G., Grivetti, L. E. Breast milk composition: fat content and fatty acid composition in vegetarians and non-vegetarians. *Am J Clin Nutr* 1985; **41**: 787–800.

19. Sanders T. A. Polyunsaturated fatty acids in the food chain in Europe. *Am J Clin Nutr* 2000; **71**: 176S–178S.
20. Kris-Etherton P. M., Taylor D. S., Yu-Poth S. et al. Polyunsaturated fatty acids in the food chain in the United States. *Am J Clin Nutr* 2000; **71**: 179S–188S.
21. Sprecher H., Luthria D. L., Mohammed B. S., Baykousheva S. P. Reevaluation of the pathways for the biosynthesis of polyunsaturated fatty acids. *J Lipid Res* 1995; **36**: 2471–2477.
22. Horrobin D. F. Gamma linolenic acid: an intermediate in essential fatty acid metabolism with potential as an ethical pharmaceutical and as a food. *Rev Contemp Pharmacother* 1990; **1**: 1–45.