International Journal of Obesity (2003) 27, 728–734
 0307-0565/03 $25.00
www.nature.com/ijo

PAPER

Diet and body mass index in 38 000 EPIC-Oxford meat-eaters, fish-eaters, vegetarians and vegans

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OBJECTIVE: To compare body mass index (BMI) in four diet groups (meat-eaters, fish-eaters, vegetarians and vegans) in the Oxford cohort of the European Prospective Investigation into Cancer and Nutrition (EPIC-Oxford) and to investigate lifestyle and dietary factors associated with any observed differences.
DESIGN: Cross-sectional analysis of self-reported dietary, anthropometric and lifestyle data.
PARTICIPANTS: A total of 37 875 healthy men and women aged 20–97 y participating in EPIC-Oxford.
RESULTS: Age-adjusted mean BMI was significantly different between the four diet groups, being highest in the meat-eaters (24.41 kg/m^2 in men, 23.52 kg/m^2 in women) and lowest in the vegans (22.49 kg/m^2 in men, 21.98 kg/m^2 in women). Fish-eaters and vegetarians had similar, intermediate mean BMI. Differences in lifestyle factors including smoking, physical activity and education level accounted for less than 5% of the difference in mean age-adjusted BMI between meat-eaters and vegans, whereas differences in macronutrient intake accounted for about half of the difference. High protein (as percent energy) and low fibre intakes were the dietary factors most strongly and consistently associated with increasing BMI both between and within the diet groups.
CONCLUSIONS: Fish-eaters, vegetarians and especially vegans had lower BMI than meat-eaters. Differences in macronutrient intakes accounted for about half the difference in mean BMI between vegans and meat-eaters. High protein and low fibre intakes were the factors most strongly associated with increasing BMI.
International Journal of Obesity (2003) **27,** 728–734. doi:10.1038/sj.ijo.0802300

Keywords: body mass index; diet; vegetarian; vegan

Introduction

Body mass index (BMI) has received considerable attention as a risk factor for mortality and a number of conditions including diabetes, heart disease and some cancers. Obesity, typically categorised as BMI > 30 kg/m^2,[1] is responsible for substantial morbidity and early mortality[2] and relatively low body weights have also been associated with increased mortality.[3,4] Previous studies have shown considerable differences in BMI and nutrient intakes between meat-eaters and vegetarians.[5–7] The Oxford cohort of the European Prospective Investigation into Cancer and Nutrition (EPIC-Oxford) intentionally recruited a high proportion of non-meat-eaters, including a large number of vegans.[8] In this study, we assessed differences in BMI between different diet groups in EPIC-Oxford and evaluated the contribution of major dietary and lifestyle factors to these differences.

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Received 8 April 2002; revised 4 October 2002; accepted 28 January 2003

Participants and methods

Between 1993 and 1999, 57 498 participants in EPIC-Oxford completed a validated semiquantitative food frequency questionnaire with additional questions on lifestyle.[8] Self-reported height was recorded to the nearest centimetre, and self-reported weight was recorded to the nearest 0.1 kg. Participants reporting a previous diagnosis of any of the following conditions were excluded from this analysis: myocardial infarction, angina, stroke, high blood pressure, high cholesterol, diabetes, gallstones, polyps or cancer (13 980 exclusions). Exclusion criteria were applied to anthropometric data as follows: data missing (843 exclusions); data measured rather than self-reported (2199 exclusions); for men, reported height under 100 cm or over 213 cm, or weight under 30 kg; for women, reported height under 100 cm or over 198 cm, or weight under 20 kg (338 men and 782 women excluded). BMI was calculated as weight in kilograms divided by the square of height in metres; for both men and women, participants with

self-reported values giving a BMI under 15 kg/m^2 or over 60 kg/m^2 were excluded (five exclusions).

Nutrient intakes were estimated from the dietary data using a computer program based on McCance and Widdowson's food composition tables.[9–18] To eliminate extreme values because of incorrect completion of questionnaires, we excluded participants in the top and bottom 1% of the ratio energy intake:estimated energy requirement, where estimated energy requirement = basal metabolic rate (BMR) × 1.4, using the equations of Schofield *et al* to calculate BMR[19] (101 exclusions). Participants were also excluded if more than 70% of the food frequency questions were unanswered (95 exclusions).

After exclusions owing to ineligibility, recording error, missing or extreme values as defined above, data were available for 8871 men and 29 004 women. Participants were categorised into one of four diet groups: meat-eaters; fish-eaters (who eat fish but no meat); vegetarians (who eat no meat or fish); and vegans (who eat no meat, fish, eggs or dairy products). Data were analysed separately for men and women. Participants were also categorised by age (20–29, 30–39, 40–49, 50–59, 60–69, 70+ y), smoking (never smoker, ex-smoker, currently smoking 1–10 cigarettes/day, currently smoking 10+ cigarettes/day), physical activity (low, medium low, medium high, high) based on an index devised by researchers at EPIC-Norfolk (Jakes, R. personal communication), education level (degree, HNC/A level/Scottish Highers, GCE/CSE, no qualifications), marital status (married, separated/divorced/widowed, single), ethnic group (white, other) and, among women, parity (no children, 1 child, 2 children, 3 or more children).

We estimated intakes of energy and the nutrients protein, total fat, saturated fat, polyunsaturated fat, carbohydrate, total sugars, fibre and alcohol. The percentage energy provided by each of protein, total fat and fat subtypes, carbohydrate and total sugars was calculated using Atwater conversion factors, and these factors are referred to as % protein, % fat, % saturated fat, % polyunsaturated fat, % carbohydrate and % sugars, respectively. Fibre was defined as nonstarch polysaccharides (Englyst fibre). Energy and nutrient intakes were grouped into fifths using sex-specific quintiles.

Analysis of variance was used to examine how BMI varied according to nutrient intake and nondietary lifestyle factors. F-tests were used to assess the statistical significance of the heterogeneity in mean BMI across categories. Statistical significance was defined as $P<0.01$, and $P<0.0001$ is referred to as highly statistically significant. Statistical analyses were performed using the Stata statistical package (Version 7).[20]

Results

The overall mean BMI was 23.81 kg/m^2 for men and 23.05 kg/m^2 for women. In all, 8% of men were underweight (BMI< 20 kg/m^2), 61% were of normal weight (BMI: 20–24.9 kg/m^2), 27% were overweight (BMI: 25–29.9 kg/m^2) and 4% were obese (BMI: 30+ kg/m^2). In women, 16% were underweight, 63% were of normal weight, 17% were overweight and 5% were obese.

Characteristics of the participants by sex and by diet group are shown in Table 1. Mean (unadjusted) BMI was highest among meat-eaters at 24.49 kg/m^2 in men and 23.69 kg/m^2 in women and lowest among vegans at 22.34 kg/m^2 in men and 21.75 kg/m^2 in women. Age ranged from 20 to 97 y in both sexes, with a median of 43 y in men and 40 y in women. In almost every reported characteristic, a gradient was evident with meat-eaters and vegans at the extremes and fish-eaters and vegetarians demonstrating intermediate values. Age varied considerably between the diet groups, with median age in men ranging from 48 in the meat-eaters to 35 y in the vegans, and median age in women ranging from 45 y in the meat-eaters to 32 y in the vegans. Energy intakes and intakes of all nutrients were highly significantly different between the diet groups, and patterns across the diet groups were similar for men and women. In both men and women, meat-eaters had the highest intakes of energy, protein, total fat, saturated fat and monounsaturated fat, and vegans had the highest intakes of fibre and polyunsaturated fat. Fish-eaters had the highest alcohol intake. In men, vegans were least likely to smoke and most likely to have never smoked, but in women, smoking habits were very similar across the diet groups. Vegans tended to report higher levels of physical activity; there were no clear patterns for education level across the diet groups; vegans were least likely and meat-eaters most likely to be married and almost the whole cohort reported ethnicity as white. Nulliparity was most common in the vegan women and least common in meat-eaters, with meat-eaters tending to have a greater number of children than the other diet groups. Some of these differences in lifestyle factors between the diet groups are likely to result from the disparity in median ages.

Differences in BMI between the diet groups

Figure 1 shows mean BMI by age in the four diet groups for men and for women. In both men and women, meat-eaters had the highest mean BMI at all age groups and vegans had the lowest, with fish-eaters and vegetarians having intermediate and similar values.

Table 2 shows mean age-adjusted BMI in the four diet groups. Vegans had the lowest mean age-adjusted BMI and meat-eaters the highest. The difference in mean BMI between vegans and meat-eaters was 1.92 kg/m^2 in men and 1.54 kg/m^2 in women. Mean age-adjusted BMI in both fish-eaters and vegetarians was significantly less than mean age-adjusted BMI in meat-eaters, but significantly greater than mean age-adjusted BMI in vegans. For both men and women, there was no significant difference in mean age-adjusted BMI between fish-eaters and vegetarians. Age-adjusted prevalence of obesity (BMI > 30 kg/m^2) was lowest in vegans at 1.9% in men and 1.8% in women and highest in meat-eaters at 5.0% in men and 5.7% in women. The

Table 1 Characteristics by sex and diet group

	Men				*Women*			
Variable	*Meat-eater (n = 4318)*	*Fish-eater (n = 1095)*	*Vegetarian (n = 2888)*	*Vegan (n = 570)*	*Meat-eater (n = 13506)*	*Fish-eater (n = 5096)*	*Vegetarian (n = 9419)*	*Vegan (n = 983)*
Median age at recruitment (y)	48	41	38	35	45	38	34	32
Mean body mass index (kg/m^2)	24.49	23.29	23.28	22.34	23.69	22.60	22.51	21.75
Mean nutrient intake/day								
Energy (kJ)	9344	9011	8872	8232	8039	7782	7632	7034
Protein (% energy)	15.8	13.9	13.0	12.9	17.1	14.8	13.8	13.4
Fat (% energy)	32.4	31.4	31.2	28.5	31.6	30.8	30.4	27.9
Saturated fat[a] (% energy)	10.9	9.6	9.4	5.1	10.4	9.4	9.4	5.1
Polyunsaturated fat[a] (% energy)	5.2	5.7	5.7	7.7	5.1	5.4	5.3	7.2
Monounsaturated fat[a] (% energy)	10.0	9.0	8.7	8.2	9.5	8.7	8.4	7.8
Carbohydrate (% energy)	46.7	49.4	51.1	54.3	48.3	51.0	52.8	56.1
Total sugars (% energy)	23.1	23.3	23.7	23.3	24.5	25.2	25.8	25.0
Fibre (g)	18.7	22.2	22.7	28.1	19.0	21.4	21.8	26.5
Alcohol (g)	16.3	16.7	14.6	12.6	8.3	9.0	8.0	6.5
Nondietary factors								
Smoking[b]								
Never smoker	51%	56%	58%	62%	62%	61%	65%	64%
Ex-smoker	33%	29%	29%	28%	26%	29%	25%	24%
Currently 1–10 cigarettes/day	5%	6%	5%	5%	6%	6%	6%	8%
Currently 10+ cigarettes/day	12%	8%	7%	5%	6%	4%	4%	4%
Physical activity[b]								
Low	22%	16%	17%	16%	24%	18%	20%	21%
Medium low	37%	34%	36%	30%	44%	42%	41%	36%
Medium high	22%	27%	24%	20%	20%	22%	23%	23%
High	19%	23%	23%	34%	12%	17%	16%	20%
Education level[b]								
Degree	45%	59%	52%	47%	32%	46%	42%	43%
HNC/Alevel	22%	19%	23%	24%	25%	24%	27%	26%
GCE/CSE	19%	15%	18%	19%	28%	23%	25%	23%
No qualifications	14%	7%	7%	10%	14%	7%	6%	8%
Marital status[b]								
Married	75%	67%	66%	50%	72%	63%	62%	50%
Separated/divorced/widowed	9%	9%	8%	8%	14%	13%	10%	12%
Single	15%	24%	27%	42%	14%	23%	28%	38%
Ethnic group[b]								
White	98%	96%	96%	97%	98%	98%	98%	97%
Other	2%	4%	4%	3%	2%	2%	2%	3%
No. of children[b]								
None					23%	41%	52%	64%
1					14%	16%	15%	13%
2					39%	29%	22%	13%
3+					23%	15%	12%	10%

[a]Data on fatty acid fractions were not available for all foods.
[b]Data unavailable for some subjects (maximum 7%). Percentages relate to subjects for whom data are available.

age-adjusted prevalence of obesity in fish-eaters and vegetarians was about 3% for both men and women.

Influence of dietary and lifestyle factors on the differences in BMI between the diet groups

Table 2 also shows mean BMI in the four diet groups adjusted for age plus lifestyle factors and further adjusted for dietary factors. Nondietary lifestyle factors such as smoking accounted for only a very small proportion (3–4%) of the difference in mean BMI between meat-eaters and vegans. In contrast, dietary factors accounted for about half the difference in mean BMI between meat-eaters and vegans. When all lifestyle and dietary factors were included in the model, the difference in mean BMI between meat-eaters and vegans was reduced to 0.95 kg/m^2 in men and 0.68 kg/m^2 in women, although the differences in mean BMI between the diet groups were still statistically significant.

Of the factors in the full model for men, diet group, age, energy, % protein, fibre, smoking, education level, physical activity and marital status were each highly statistically significantly associated with BMI. In women, the same factors with the exception of marital status were each highly statistically significantly associated with BMI. Higher energy intake, higher % protein intake, lower

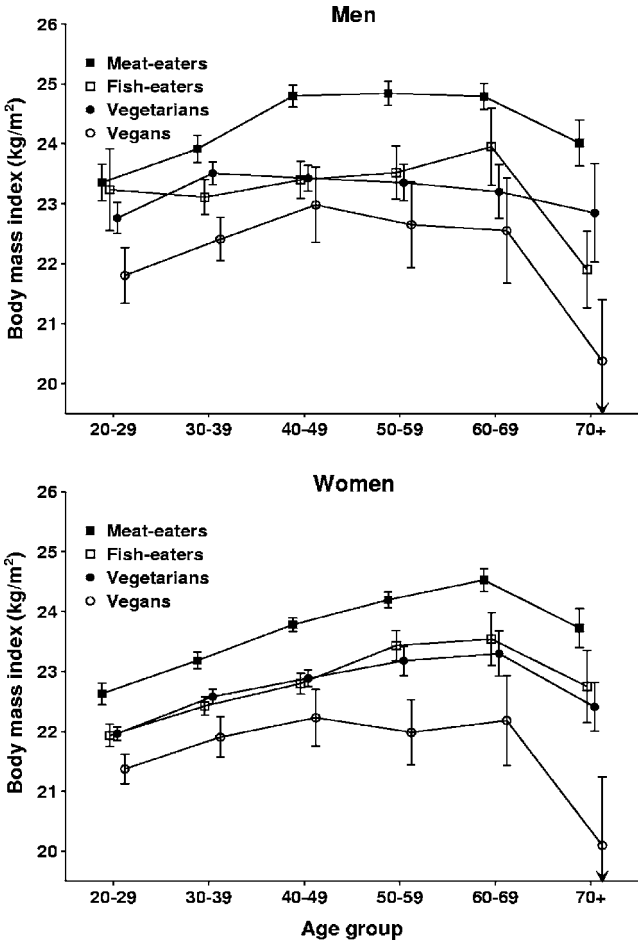

Figure 1 Mean BMI by age in four diet groups, showing 95% confidence intervals.

fibre intake, past smoking, lower education level and lower physical activity levels were associated with higher BMI in men and women. In men, being married was associated with higher BMI.

Table 3 shows the difference in mean BMI between meat-eaters and vegans, firstly adjusted for age and lifestyle factors, then further adjusted for energy and each nutrient in turn. In men and women, % protein, % polyunsaturated fat and fibre accounted for the greatest reduction in the difference in mean BMI between meat-eaters and vegans.

Within diet groups there was a significant positive association between % protein and BMI and a significant negative association between fibre and BMI among meat-eaters, fish-eaters and vegetarians, but not among vegans, for both men and women. In contrast, there were no significant positive associations between % polyunsaturated fat and BMI within any diet group. In age-adjusted correlations, the partial correlation coefficient between BMI and % protein was higher than for any other dietary factor, consistently in all four diet groups for both men and women.

Discussion

In this study of nearly 38 000 healthy EPIC-Oxford participants, there were considerable differences in mean BMI between the four diet groups. The fish-eaters and vegetarians each had lower mean BMI than the meat-eaters, but had a higher mean BMI than the vegans. For a man of height 1.80 m (5 ft 11 in) the difference in mean BMI between meat-eaters and vegans represents a difference in weight of about 6 kg (about 13 lb). For a 1.68 m (5 ft 6 in) tall woman, the corresponding difference in mean BMI represents a difference in weight of about 5 kg (about 11 lb). Obesity rates were significantly lower in the vegans than the other diet groups, and significantly lower in the vegetarians and fish-eaters than the meat-eaters. This supports previous findings in the Oxford Vegetarian Study[21] and in EPIC-Oxford.[22] We previously demonstrated in a subgroup of the cohort that BMI calculated from self-reported height and weight was underestimated on average by 0.96 kg/m^2 in men and 0.72 kg/m^2 in women, and that heavier people under-reported their BMI to a greater extent than leaner people.[23] Therefore, it may be that the true associations of dietary and lifestyle factors with BMI are stronger than reported here. The cohort is regarded as being generally 'health conscious'[8] and the mean BMI, adjusted for reporting error, in participants aged 16–64 y in EPIC-Oxford is lower than that reported for this age range by the Health Survey for England 1995[24] by approximately 1 kg/m^2 in men and 2 kg/m^2 in women.

In comprising a substantial number of vegans and large numbers of vegetarians, fish-eaters and meat-eaters, with a wide range of BMI and nutrient intakes between the diet groups, the EPIC-Oxford cohort allows comparison of very different dietary patterns and their associated BMI. There was a wide range of BMI within each diet group, indicating that diet group was not the only determinant of BMI. Nutrient intakes and lifestyle factors varied across the diet groups. Nondietary lifestyle factors such as smoking and exercise explained some of the difference in BMI between diet groups; however, after adjusting for these factors, over 95% of the difference remained. Energy and macronutrient intake explained about half the difference in mean BMI between meat-eaters and vegans, suggesting that these differences are largely attributable to dietary factors. After adjusting for all lifestyle and dietary factors included in this study, statistically significant differences in mean BMI between the diet groups remained. However, the estimates of nutrient intakes from the FFQ are not very accurate and adjustment for the true nutrient intakes might account for a greater proportion of the variation in mean BMI between the diet groups.

Given the many strong associations between dietary factors, only the dietary factors that appeared to show a strong and consistent association with BMI are considered to be important here. Thus, protein (as percent of energy intake) and fibre were judged to be the most important determinants of BMI. Nutrient intakes and diet group were

Table 2 Mean BMI (kg/m^2) by sex and diet group, adjusted for age, adjusted for age+lifestyle factors[a] and adjusted for age+lifestyle factors[a]+dietary factors[b]

	Men	*Women*
Factors adjusted for	*Mean (95% CI)*	*Mean (95% CI)*
Age		
Meat-eaters	24.41 (24.31, 24.50)	23.52 (23.46, 23.58)
Fish-eaters	23.30 (23.12, 23.49)	22.66 (22.57, 22.76)
Vegetarians	23.37 (23.26, 23.49)	22.71 (22.64, 22.78)
Vegans	22.49 (22.23, 22.75)	21.98 (21.76, 22.19)
Range of mean values	1.92	1.54
Age+lifestyle factors[a]		
Meat-eaters	24.39 (24.29, 24.48)	23.49 (23.43, 23.55)
Fish-eaters	23.35 (23.17, 23.54)	22.70 (22.61, 22.80)
Vegetarians	23.38 (23.26, 23.49)	22.73 (22.65, 22.80)
Vegans	22.53 (22.27, 22.79)	22.01 (21.80, 22.23)
Range of mean values (% reduction)	1.86 (3%)	1.48 (4%)
Age+lifestyle factors +dietary factors[b]		
Meat-eaters	24.09 (23.97, 24.20)	23.24 (23.17, 23.31)
Fish-eaters	23.45 (23.27, 23.64)	22.83 (22.73, 22.92)
Vegetarians	23.67 (23.54, 23.80)	22.96 (22.88, 23.04)
Vegans	23.13 (22.83, 23.43)	22.56 (22.32, 22.79)
Range of mean values (% reduction)	0.95 (50%)	0.68 (56%)

[a]Lifestyle factors adjusted for: smoking, education level, physical activity, marital status, ethnicity and in women only, parity.
[b]Dietary factors adjusted for: energy intake, % protein, % fat, % saturated fat, % polyunsaturated fat, % carbohydrate, fibre intake, % sugars and alcohol intake.

Table 3 Difference in mean BMI between meat-eaters and vegans after adjustment for individual dietary factors

	Men		*Women*	
Dietary factor adjusted for[a]	*Difference in mean BMI between meat-eaters and vegans (kg/m^2)*	*% reduction in difference*	*Difference in mean BMI between meat-eaters and vegans (kg/m^2)*	*% reduction (increase) in difference*
None	1.86	—	1.48	—
Energy	1.80	3.3	1.48	(0.5)
Energy+% protein	1.40	25.0	1.03	30.2
Energy+% fat	1.82	2.2	1.53	(3.7)
Energy+% saturated fat	1.75	5.7	1.46	1.2
Energy+% polyunsaturated fat	1.65	11.1	1.34	9.6
Energy+% carbohydrate	1.77	4.7	1.50	(1.2)
Energy+% sugars	1.80	3.1	1.48	(0.2)
Energy+fibre (g)	1.62	12.7	1.39	5.6
Energy+alcohol (g)	1.80	3.3	1.48	(0.5)

[a]All adjusted for age and lifestyle factors: smoking, physical activity, education level, marital status, ethnicity and in women only, parity

strongly associated. Characteristics of a vegan diet, including lower intakes of protein and higher intake of fibre, were also associated with lower BMI and adjusting for these factors reduced the difference in BMI between meat-eaters and vegans. However, protein and fibre intakes were significantly associated *within* all four diet groups except the vegans, suggesting that these nutrients affect BMI independently of diet group. The absence of any nutrient/BMI associations within the vegan group may reflect insufficient variation in nutrient intakes within this diet group or insufficient numbers of vegan participants. Alternatively, for protein (but not for fibre), it is possible that animal protein is responsible for the association observed in the other three diet groups, and that plant protein intake is not associated with BMI. Although significantly associated with BMI across the diet groups, % polyunsaturated fat was not significantly associated with BMI within diet groups, indicating that this nutrient may simply be a marker of diet group.

The potentially important effect of protein on BMI has recently been reported in another EPIC cohort in Greece.[25] However, previous reports of protein being associated with adiposity are few.[26,27] Putative mechanisms for protein's

influence on adiposity are not frequent in the literature, but include high protein intakes causing hormonal changes in the body which alter metabolic systems to favour abdominal adiposity deposition.[28]

Low fibre intakes have previously been associated with higher levels of adiposity[29–31] and our findings are consistent with this. Fibre has been proposed to promote maintenance of lean weight via effects on satiety,[29,32,33] insulin control[34] or by reducing fat absorption.[35]

Statistically significant differences in mean BMI between the diet groups remained after adjusting for all the lifestyle and dietary factors included in this study, which may indicate that error in measuring these factors led to inadequate adjustment for their effects. Physical activity may account for more of the variation in BMI than observed in this study as it was not ideally measured; however, differences in physical activity are unlikely to explain the associations observed between protein and BMI and fibre and BMI. Other factors that we did not measure or include in the analysis may be responsible for some of the difference in BMI between meat-eaters and vegans. The vegan diet is restricted in the range of available foods compared with the omnivorous diet, and dietary restraint may be a characteristic of many vegans, reducing the likelihood of the vegans gaining weight during adulthood. Furthermore, as an observational cross-sectional study this study cannot distinguish between cause and effect, and it is possible that leaner individuals are more likely to adopt a vegetarian or vegan diet.

In calculating nutrient intake from the FFQ, uniform portion sizes for each item were used for each participant. It is possible that participants with greater BMI consistently ate larger portions and so we did not detect a stronger effect of energy intake. Conversely, energy intakes may have been under-reported for vegans, who may eat larger portion sizes because of the lower energy density of many plant foods. Furthermore, there is some evidence that when completing this FFQ, participants selectively under-report more for fat intake than for other nutrients,[36] possibly as a result of under-reporting snack foods. If this is so, it may explain why statistically significant associations between total fat intake and BMI were not observed here. More work is needed to determine whether there is under-reporting of specific food groups and/or nutrients associated with BMI.

We have shown that vegan diets, and to a lesser extent fish-eating and vegetarian diets, are associated with lower BMI and lower levels of obesity than diets which include meat. An increase in the proportion of plant foods in the diet may help to prevent overweight and obesity.

Acknowledgements

We thank all the participants in EPIC-Oxford and all the research staff who have worked on this study. EPIC-Oxford is supported by Cancer Research UK, the Medical Research Council and the Europe Against Cancer Programme of the Commission of the European Community.

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