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# Serum concentrations of cholesterol, apolipoprotein A-I, and apolipoprotein B in a total of 1 694 meat-eaters, fish-eaters, vegetarians, and vegans

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## Abstract

**BACKGROUND—**The objective of this study was to describe serum lipid concentrations, including apolipoproteins A-I and B, in different diet groups.

**METHODS—**A cross-sectional analysis of a sample of 424 meat-eaters, 425 fish-eaters, 423 vegetarians, and 422 vegans, matched on sex and age, from the European Prospective Investigation into Cancer and Nutrition (EPIC)-Oxford cohort. Serum concentrations of total, and HDL cholesterol, as well as apolipoproteins A-I and B were measured, and serum non-HDL cholesterol was calculated.

**RESULTS—**Vegans had the lowest BMI, and the highest and lowest intakes of polyunsaturated and saturated fat, respectively. After adjustment for age, alcohol and physical activity, compared to meat-eaters, fish-eaters and vegetarians, serum concentrations of total and non-HDL cholesterol, and apolipoprotein B were significantly lower in vegans. Serum apolipoprotein A-I concentrations did not differ between the diet groups. In males, the mean serum total cholesterol concentration was 0.87 nmol/L lower in vegans than in meat-eaters; after further adjustment for BMI this difference was 0.76 nmol/L. In females, the difference in total cholesterol between these two groups was 0.60 nmol/L, and after further adjustment for BMI was 0.55 nmol/L.

**CONCLUSIONS—**In this study, which included a large number of vegans, serum total cholesterol and apolipoprotein B concentrations were lower in vegans compared to meat-eaters, fish-eaters and vegetarians. A small proportion of the observed differences in serum lipid concentrations was explained by differences in BMI, but a large proportion is most likely due to diet.

### Keywords

lipids; cholesterol; apolipoproteins; vegetarian diet; vegan diet

## INTRODUCTION

Serum concentrations of total cholesterol and non-HDL cholesterol are well-established risk factors for cardiovascular disease.[1] Apolipoprotein A-I and apolipoprotein B represent the



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number of circulating anti-atherogenic and atherogenic particles, respectively. Serum concentrations of these apolipoproteins have also been associated with the risk of cardiovascular disease,[2] and may provide some additional, physiologically-relevant, information to aid in the prediction of cardiovascular disease risk.[3, 4]

A comparison of serum lipid profiles in different diet groups, for example vegetarians and omnivores, can provide insight into the net effect of habitual diets that have distinctly different compositions. Previous studies have generally shown that vegetarians have relatively low serum concentrations of total cholesterol and LDL cholesterol,[5, 6] but differences in serum concentrations of apolipoproteins A-I and B between diet groups are not well characterised. In addition, previous studies have only included a small number of vegans, and relatively little is known about the serum lipid profiles of vegans – who exclude all animal products from their diet.

The objective of this study is to describe serum concentrations of lipids and apolipoproteins A-I and B, in a representative sample of meat-eaters, fish-eaters, vegetarians, and vegans participating in the European Prospective Investigation into Cancer and Nutrition (EPIC)-Oxford cohort.

## MATERIALS AND METHODS

The EPIC-Oxford cohort is a prospective study of 65 411 men and women aged 20 years or older. The study has been described in detail elsewhere.[7] Briefly, the study was designed to investigate diet, lifestyle and risk of cancer and other chronic diseases in people with different dietary habits, and thus the aim was to recruit a large number of vegetarians and vegans. Recruitment was carried out between 1993 and 2001. Eleven percent of participants, mainly non-vegetarians, were recruited through general practice surgeries. Postal methods were used to recruit all other participants, including a large number of vegetarians and vegans. The study was approved by a Multicenter Research Ethics Committee, and all participants gave written informed consent.

In the baseline questionnaire, participants were asked if they ate meat, fish, dairy products and eggs, and were classified accordingly into meat-eaters (reported consuming meat), fish-eaters (reported consuming fish but no meat), vegetarians (reported consuming dairy products and/or eggs but no meat or fish), and vegans (reported no consumption of meat, fish, dairy products, or eggs). The recruitment questionnaire also included a 130-item semi-quantitative Food Frequency Questionnaire (FFQ). Food intakes were calculated by multiplying the reported frequency of consumption of food items by standard portion sizes. Data from the fifth edition of *McCance and Widdowson's The Composition of Food* and its supplements [8-17] were used to estimate nutrient intakes.

Height and weight were self-reported in the baseline questionnaire. In a sub-sample of the cohort, height and weight were measured ($n$ = 4 808); measured and self-reported values showed excellent agreement ($r > 0.90$).[18] Measured (where available) or self-reported height and weight were used to calculate BMI (kg/m$^2$). The baseline questionnaire collected information on occupational and leisure activities. This information was combined into a physical activity index, and participants were categorised into one of four groups: inactive, or low, moderate, or high level of activity. This index has been shown to rank participants according to objectively measured physical activity energy expenditure.[19, 20]

The present study consists of a sub-sample drawn from participants younger than 90 years who provided a blood sample at recruitment to the EPIC-Oxford cohort between 1993 and 1998. In addition, to be eligible for the current study, participants had to have: responded to

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at least 80% of the relevant questions in the FFQ (in total, 130 relevant questions for meat-eaters and fish-eaters, and 113 relevant questions for vegetarians and vegans) and have a daily energy intake between 3.3 and 16.7 MJ (800 and 4000 kcal) for men or between 2.1 and 14.7 MJ (500 and 3500 kcal) for women [21]; information on smoking and diet group; follow-up data; no self-reported or prevalent malignant cancer at recruitment; no self-reported history of MI, stroke, or angina at recruitment, or missing information for these variables; and, not been receiving treatment for a long-term illness at recruitment or missing information for this variable. In addition, women who were pregnant or using oral contraceptives or hormone replacement therapy at recruitment were excluded from the present study. In order to include a wide range of dietary exposures in this cross-sectional analysis, eligible participants were stratified by sex and 10-year age categories and approximately equal numbers of participants in each of the four diet groups were randomly selected within each strata. The final sample includes 424 meat-eaters (168 men, 256 women), 425 fish-eaters (168 men, 257 women), 423 vegetarians (168 men, 255 women), and 422 vegans (167 men and 255 women in total).

At recruitment or shortly after, participants attended their local general practice surgeries where a blood sample was taken. Participants were not required to fast prior to the blood sample. Blood was transported overnight to a laboratory in Norfolk by mail at ambient temperature, where samples were centrifuged and serum was aliquoted into 0.5 mL plastic straws. These were heat-sealed at both ends and stored in liquid nitrogen (−196°C) until 2010-2011 and subsequently in electric freezers (−80°C) until analysis later in 2011. Beckman Synchron CX autoanalyzers (Beckman Coulter, High Wycombe, UK) were used to measure apolipoprotein A-I and B by immunoturbimetric assay, HDL cholesterol was measured directly, and total cholesterol was measured by enzymatic assay. Pooled serum samples ($n$ = 196) were included in each run; the laboratory technicians were blinded to the diet groups and to the pooled samples. The coefficients of variation were 1.9% for total cholesterol, 1.9% for HDL cholesterol, 2.8% for apolipoprotein A-I, and 2.6% for apolipoprotein B.

STATA Statistical software, release 12 (StataCorp LP; College Station, USA), was used for all statistical analyses. All analyses were conducted for males and females separately. Participant characteristics and dietary intakes were compared between diet groups. Chi-squared tests were used to test for differences in proportions between diet groups, and for continuous variables ANOVA was used to test for differences in means between diet groups.

Multiple linear regression was used to calculate the mean serum lipid concentrations in the four diet groups. In the basic model age (as a continuous variable), alcohol consumption (continuous), and physical activity (categorical: inactive, low activity, moderate activity, or high level of activity) were included as covariates; in the second model BMI (continuous) was also included as a covariate. If there was significant heterogeneity between the four diet groups, post-hoc pairwise comparisons were used to test for significant differences in serum lipid concentrations between each of the diet groups, using the Bonferroni adjustment for multiple comparisons. All $p$ values were two-sided and $p < 0.05$ was considered statistically significant.

## RESULTS

Selected characteristics and dietary intakes of male and female participants in each diet group are shown in Table 1 and Table 2. In both males and females, mean BMI differed significantly between diet groups ($p < 0.001$, for both). Compared to the other diet groups, vegans had a lower mean BMI and a much higher proportion of vegans had a BMI of less than 20 kg/m$^2$ ($p$ for difference between diet groups < 0.001, for all). The distribution of physical activity differed significantly between diet groups in males ($p = 0.015$), but not in females ($p = 0.168$). In males, a higher proportion of vegans was considered to be very active (28.1%) compared to meat-eaters (22.0%), fish-eaters (17.3%) and vegetarians (17.3%), whereas the proportion of males who were inactive was similar in vegans (19.2%) and meat-eaters (19.6%), and lower in fish-eaters (11.9%) and vegetarians (12.5%). In both males and females, compared to the other diet groups, vegans had a lower energy and alcohol intake, and a lower proportion of energy from saturated fat ($p$ for difference between diet groups < 0.001, for all). Vegans had a higher fiber intake, and a higher proportion of energy from carbohydrate and polyunsaturated fat ($p$ for difference < 0.001, for all). Ninety-six percent of participants were of white European origin.

In the basic model adjusted for age, alcohol intake, and physical activity, in both males and females, compared to meat-eaters, fish-eaters and vegetarians the mean serum concentrations of total cholesterol, non-HDL cholesterol, and apolipoprotein B were each lower in vegans ($p$ for pairwise comparison < 0.001, for all) (Tables 3 and 4). In men, compared to meat-eaters, vegans had a 0.87 mmol/L lower mean total cholesterol concentration, a 0.85 mmol/L lower mean non-HDL cholesterol concentration, and an 18 mg/dL lower mean apolipoprotein B concentration. In women, compared to meat-eaters, vegans had a 0.60 mmol/L lower mean total cholesterol concentration, a 0.49 mmol/L lower mean non-HDL cholesterol concentration, and an 11 mg/dL lower mean apolipoprotein B concentration. In women, compared to meat-eaters and fish-eaters, mean HDL cholesterol was lower in vegans ($p$ for pairwise comparison = 0.001 for meat-eaters vs vegans, and $p$ = 0.014 for fish-eaters vs vegans). In the basic model, there were no statistically significant differences in the mean apolipoprotein A-I concentration between diet groups in men ($p$ for difference = 0.690) or women ($p = 0.092$). In men, there were significant differences in the ratio of total:HDL cholesterol and in the ratio of apolipoprotein B:apolipoprotein A-I between the diet groups; in both cases compared to meat-eaters the ratio was lower in the vegans ($p$ for pairwise comparison < 0.001 for both). In women, there was no statistically significant difference in the ratio of total:HDL cholesterol between the diet groups ($p$ for difference = 0.053). However, compared to meat-eaters, the ratio of apolipoprotein B:apolipoprotein A-I was lower in vegans ($p$ for pairwise comparison < 0.001).

After further adjustment for BMI the differences in serum lipid concentrations between the diet groups were, in most cases, slightly attenuated (Tables 3 and 4). In men, compared to meat-eaters, vegans had a 0.76 nmol/L lower mean total cholesterol concentration, a 0.68 nmol/L lower mean non-HDL cholesterol concentration, and a 14 mg/dL lower mean apolipoprotein B concentration ($p$ for pairwise comparison < 0.001, for all). In women, compared to meat-eaters, vegans had a 0.55 nmol/L lower mean total cholesterol concentration, a 0.40 nmol/L lower mean non-HDL cholesterol concentration, and a 9 mg/dL lower mean apolipoprotein B concentration ($p$ for pairwise comparison < 0.001, for all). However, the non-significant association between diet group and mean apolipoprotein A-I concentration in women became significant after further adjustment for BMI ($p$ for heterogeneity = 0.092 before and $p = 0.003$ after adjustment for BMI).

## DISCUSSION

In this cross-sectional study, which included a large number of vegetarians and vegans, serum concentrations of total cholesterol, non-HDL cholesterol, and apolipoprotein B were significantly lower in vegans compared to meat-eaters, fish-eaters and vegetarians. In women, compared to meat-eaters and fish-eaters, the mean HDL cholesterol concentration was lower in vegans. In men, there were no significant differences in apolipoprotein A-I concentrations between the diet groups. In women, after additional adjustment for BMI, there were significant differences in apolipoprotein A-I concentrations between the diet groups; vegans had a lower mean apolipoprotein A-I concentration than meat-eaters.

Previous studies have also documented lower total cholesterol concentrations in vegetarians compared to omnivores.[5, 6, 22-30] Five studies that included vegans as a separate diet group observed the lowest total cholesterol concentrations in this diet group, although the number of vegans in these studies (ranging from 8 to 114) was much smaller than in the present study (n = 422).[6, 22, 24, 29-30]

In accordance with our findings on non-HDL cholesterol – the majority of which is LDL cholesterol – in the Oxford Vegetarian Study serum LDL cholesterol concentrations were shown to be highest in meat-eaters ($n$ = 1 198), followed by fish-eaters ($n$ = 415), vegetarians ($n$ = 1 550), and vegans ($n$ = 114).[6] Other much smaller cross-sectional studies carried out in Hong Kong[5], Brazil[26, 28-29], Taiwan[27], and Australia[30] also observed higher LDL cholesterol concentrations in omnivores compared to vegetarians.

Most previous studies have found no difference in serum HDL cholesterol concentrations between omnivores and vegetarians.[26-29] The study of Hong Kong Chinese by Lee *et al.*[5] found lower HDL cholesterol concentrations in vegetarians (1.20 mmol/L) compared to omnivores (1.32 mmol/L, $p < 0.05$). The Oxford Vegetarian Study found significant differences in HDL cholesterol concentrations between diet groups; HDL cholesterol concentrations were similar in meat-eaters (1.49 mmol/L), vegetarians (1.50 mmol/L) and vegans (1.49 mmol/L), but higher in fish-eaters (1.56 mmol/L, $p$ for difference between diet groups < 0.01).[6] Although in our study there were only small differences in HDL cholesterol concentrations between the diet groups, in males the ratio of total to HDL cholesterol was lower in vegans compared with meat-eaters and vegetarians, owing to the very low mean total cholesterol concentration in vegans relative to the other diet groups. In females, the differences in the ratio of total to HDL cholesterol concentrations between the diet groups were not statistically significant. Although the ratio of total to HDL cholesterol has been shown to predict cardiovascular disease risk[1], a recent Mendelian randomisation study has brought into question the view that HDL is causally related to risk of cardiovascular disease.[31] In this Mendelian randomisation study, genetic variants that give rise to a high HDL concentration were not associated with a reduced risk of myocardial infarction.[31]

In our study, vegans had a lower BMI than meat-eaters, and there is good evidence that BMI is positively related to serum non-HDL cholesterol concentrations.[32] However, adjustment for BMI only slightly attenuated the difference in serum lipid concentrations between the diet groups, indicating that differences in BMI explained only a small proportion of the differences between the diet groups. However, BMI is not a perfect measure of body composition, and future studies should include more comprehensive measures of body composition such as body fat percentage. In our study, vegans had the lowest saturated fat intakes and the highest polyunsaturated fat intakes. Evidence from metabolic ward studies[33] and dietary intervention trials[34] demonstrates that isocaloric replacement of carbohydrate with saturated fat increases serum total and LDL cholesterol concentrations, whereas isocaloric replacement of carbohydrate with polyunsaturated fat has the opposite effect. In addition, vegans had a higher mean daily fiber intake than meat-eaters, and fiber may have a modest cholesterol lowering effect.[35] Taken together, these findings strongly suggest that a large proportion of the difference in serum lipid concentrations between diet groups is explained by differences in the nutrient composition of the diets, especially differences in saturated and polyunsaturated fat intakes.

We have recently reported a 32% lower risk of hospital admission or death from ischaemic heart disease (IHD) in vegetarians and vegans combined, compared to meat-eaters and fish-eaters combined.[36] The reduced risk of ischaemic heart disease among vegetarians and vegans combined was shown in both men and women.[36] Using the serum lipid concentrations of meat-eaters and vegans in our study we are able to predict the difference in IHD mortality between these two distinct diet groups. Data from the Prospective Studies Collaboration[1] indicates that in males, a 0.85 mmol/L difference in non-HDL cholesterol concentrations (observed between male meat-eaters and vegans in our study) would be associated with an approximately 37% lower risk of IHD mortality, and in females a 0.49 mmol/L difference in non-HDL cholesterol concentrations (observed between female meat-eaters and vegans in our study) would be associated with an approximately 25% lower risk of IHD mortality.

The strengths of this study include the large number of participants, especially vegan participants, and the inclusion of the apolipoproteins A-I and B in the analysis of lipid profiles. The sample used in this analysis was randomly selected from the larger EPIC-Oxford cohort, but the EPIC-Oxford cohort was recruited mainly through postal recruitment targeted toward vegetarians, the health-conscious public and their friends and family members. We have previously established that the meat-eaters participating in EPIC-Oxford are healthier than the general British population (most of whom are meat-eaters) [37], but it is difficult to judge whether our fish-eaters, vegetarians, and vegans are generally representative of these diet groups in Britain. Nearly all (96%) of the participants in this analysis were of white European origin, and our findings may not apply to diet groups of other ethnicities, for example Indian vegetarians. This study was cross-sectional and therefore we cannot infer causality; however our findings are consistent with meta-analyses of controlled dietary studies on the effects of saturated and polyunsaturated fats on serum cholesterol concentrations. We did not directly measure LDL cholesterol, instead we report non-HDL cholesterol. However, the majority of non-HDL cholesterol is LDL, and non-HDL cholesterol is an established risk factor for ischaemic heart disease mortality[1]. We collected non-fasting blood samples and therefore we did not measure triglycerides.

In conclusion, this study compares the serum lipid concentrations of British meat-eaters, fish-eaters, vegetarians, and vegans, and finds lower serum concentrations of total and non-HDL cholesterol in vegans. Vegans also had very low saturated fat intakes, and higher intakes of polyunsaturated fat and fiber. Variation in the intake of these dietary components most likely explains a large proportion of the difference in serum lipid concentrations between diet groups. To the best of our knowledge, this is the first time that serum concentrations of apolipoproteins A-I and B have been reported for a large number of vegans. Our results show that vegans had the lowest apolipoprotein B concentrations. In men, there were no significant differences in apolipoprotein A-I concentrations between the diet groups. In women, after further adjustment for BMI, apolipoprotein A-I concentrations were lower in vegans compared to meat-eaters. The serum lipid profile of vegans in our study would be expected to confer a much lower risk of IHD mortality compared with meat-eaters.

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## Table 1

Characteristics of male participants by diet group

| | Diet group | | | | |
|---|---|---|---|---|---|
| | Meat-eaters | Fish-eaters | Vegetarians | Vegans | |
| | *n* = 168 | *n* = 168 | *n* = 168 | *n* = 167 | *p* value[1] |
| Age category (years) | | | | | |
| 20 to 29 | 11 (6.6) | 10 (6.0) | 11 (6.6) | 10 (6.0) | |
| 30 to 39 | 48 (28.6) | 48 (28.6) | 48 (28.6) | 48 (28.7) | |
| 40 to 49 | 63 (37.5) | 63 (37.5) | 63 (37.5) | 62 (37.1) | 1.00 |
| 50 to 59 | 22 (13.1) | 23 (13.7) | 23 (13.7) | 23 (13.8) | |
| 60 + | 24 (14.3) | 24 (14.3) | 23 (13.7) | 24 (14.4) | |
| BMI (kg/m$^2$) | | | | | |
| Mean (SD) | 24.9 (3.1) | 23.2 (2.9) | 23.3 (2.6) | 22.4 (3.2) | < 0.001 |
| < 20 | 4 (2.4) | 16 (9.5) | 9 (5.4) | 28 (16.8) | |
| 20 to 22.5 | 34 (20.2) | 51 (30.4) | 61 (36.3) | 64 (38.3) | |
| 22.5 to 25 | 50 (29.8) | 56 (33.3) | 49 (29.2) | 49 (29.3) | < 0.001 |
| 25 to 27.5 | 47 (28.0) | 24 (14.3) | 27 (16.1) | 16 (9.6) | |
| 27.5+ | 33 (19.6) | 21 (12.5) | 22 (13.1) | 10 (6.0) | |
| Physical activity | | | | | |
| Inactive | 33 (19.6) | 20 (11.9) | 21 (12.5) | 32 (19.2) | |
| Low activity | 53 (31.6) | 72 (42.9) | 61 (36.3) | 39 (23.4) | |
| | | | | | 0.015 |
| Moderate activity | 32 (19.1) | 36 (21.4) | 46 (27.4) | 37 (22.2) | |
| Very active | 37 (22.0) | 29 (17.3) | 29 (17.3) | 47 (28.1) | |
| Daily dietary intakes[2] | | | | | |
| Energy (MJ) | 9.25 (2.35) | 9.04 (2.32) | 9.11 (2.37) | 8.00 (2.34) | < 0.001 |
| Protein (% of energy) | 16 (2) | 14 (2) | 13 (2) | 13 (2) | < 0.001 |
| Carbohydrate (% of energy) | 48 (6) | 50 (7) | 51 (7) | 54 (7) | < 0.001 |
| Fat (% of energy) | 32 (6) | 31 (6) | 31 (6) | 29 (7) | 0.003 |
| Saturated | 12 (3) | 11 (3) | 11 (3) | 6 (2) | < 0.001 |
| Monounsaturated | 11 (2) | 10 (2) | 10 (2) | 10 (3) | 0.003 |
| Polyunsaturated | 6 (2) | 7 (2) | 7 (2) | 10 (3) | < 0.001 |
| Polyunsaturated:saturated[3] | 0.57 (0.26) | 0.73 (0.34) | 0.73 (0.33) | 1.56 (0.39) | < 0.001 |
| Fiber (g) | 19 (7) | 23 (8) | 23 (7) | 27 (9) | < 0.001 |
| Alcohol (g) | | | | | |
| < 1 | 15 (8.9) | 21 (12.5) | 25 (14.9) | 52 (31.1) | |
| 1 to 7 | 55 (32.7) | 59 (35.1) | 48 (28.6) | 56 (33.5) | |
| | | | | | < 0.001 |
| 8 to 15 | 46 (27.4) | 34 (20.2) | 43 (25.6) | 25 (15.0) | |
| 16+ | 52 (31.0) | 54 (32.1) | 52 (31.0) | 34 (20.4) | |

Values are number (%) unless otherwise stated

[1] ANOVA was used to test for differences in means for continuous variables, and $\chi 2$ tests were used to test for differences in proportions for categorical variables

[2] Daily dietary intakes are mean (SD), except for categories of alcohol consumption which are number (%)

[3] Ratio of polyunsaturated fat to saturated fat intake

**Table 2**

Characteristics of female participants by diet group

| | Diet group | | | | |
|---|---|---|---|---|---|
| | **Meat-eaters** | **Fish-eaters** | **Vegetarians** | **Vegans** | |
| | ***n* = 256** | ***n* = 257** | ***n* = 255** | ***n* = 255** | ***p* value**[1] |
| Age category (years) | | | | | |
| 20 to 29 | 49 (19.1) | 50 (19.5) | 49 (19.2) | 49 (19.2) | |
| 30 to 39 | 95 (37.1) | 95 (37.0) | 96 (37.7) | 95 (37.3) | |
| 40 to 49 | 57 (22.3) | 57 (22.2) | 56 (22.0) | 56 (22.0) | 1.00 |
| 50 to 59 | 33 (12.9) | 33 (12.8) | 32 (12.6) | 33 (12.9) | |
| 60 + | 22 (8.6) | 22 (8.6) | 22 (8.6) | 22 (8.6) | |
| BMI (kg/m$^2$) | | | | | |
| Mean (SD) | 23.7 (3.6) | 22.3 (2.7) | 22.8 (3.8) | 21.8 (2.9) | < 0.001 |
| < 20 | 22 (8.6) | 40 (15.6) | 48 (18.8) | 76 (29.8) | |
| 20 to 22.5 | 93 (36.3) | 112 (43.6) | 99 (38.8) | 84 (32.9) | |
| 22.5 to 25 | 67 (26.2) | 57 (22.2) | 57 (22.4) | 70 (27.5) | < 0.001 |
| 25 to 27.5 | 34 (13.3) | 24 (9.3) | 21 (8.2) | 10 (3.9) | |
| 27.5+ | 40 (15.6) | 24 (9.3) | 30 (11.8) | 15 (5.9) | |
| Physical activity | | | | | |
| Inactive | 31 (12.1) | 31 (12.1) | 46 (18.0) | 48 (18.8) | |
| Low activity | 118 (46.1) | 113 (44.0) | 113 (44.3) | 98 (38.4) | |
| | | | | | 0.168 |
| Moderate activity | 42 (16.4) | 56 (21.8) | 50 (19.6) | 49 (19.2) | |
| Very active | 35 (13.7) | 36 (14.0) | 31 (12.2) | 34 (13.3) | |
| Daily dietary intakes[2] | | | | | |
| Energy (MJ) | 8.14 (2.06) | 7.60 (2.08) | 7.94 (2.12) | 7.08 (2.10) | < 0.001 |
| Protein (% of energy) | 17 (3) | 15 (2) | 14 (2) | 13 (2) | < 0.001 |
| Carbohydrate (% of energy) | 49 (6) | 52 (6) | 53 (6) | 55 (7) | < 0.001 |
| Fat (% of energy) | 31 (6) | 30 (6) | 30 (6) | 29 (7) | 0.001 |
| Saturated | 11 (3) | 10 (3) | 10 (3) | 7 (2) | < 0.001 |
| Monounsaturated | 11 (2) | 10 (2) | 10 (2) | 10 (3) | < 0.001 |
| Polyunsaturated | 6 (2) | 7 (2) | 7 (2) | 10 (3) | < 0.001 |
| Polyunsaturated:saturated[3] | 0.61 (0.24) | 0.72 (0.31) | 0.72 (0.32) | 1.47 (0.42) | < 0.001 |
| Fiber (g) | 20 (7) | 22 (8) | 23 (8) | 26 (9) | < 0.001 |
| Alcohol (g) | | | | | |
| < 1 | 38 (14.8) | 30 (11.7) | 52 (20.4) | 89 (34.9) | |
| 1 to 7 | 126 (49.2) | 118 (45.9) | 121 (47.5) | 109 (42.8) | |
| | | | | | < 0.001 |
| 8 to 15 | 64 (25.0) | 69 (26.9) | 48 (18.8) | 35 (13.7) | |
| 16+ | 28 (10.9) | 40 (15.6) | 34 (13.3) | 22 (8.6) | |

Values are number (%) unless otherwise stated

[1]ANOVA was used to test for differences in means for continuous variables, and $\chi 2$ tests were used to test for differences in proportions for categorical variables

[2]Daily dietary intakes are mean (SD), except for categories of alcohol consumption which are number (%)

[3]Ratio of polyunsaturated fat to saturated fat intake

### Table 3

Serum lipid profiles of male participants by diet group

| | Diet group | | | | |
|---|---|---|---|---|---|
| | Meat-eaters | Fish-eaters | Vegetarians | Vegans | |
| | *n* = 168 | *n* = 168 | *n* = 168 | *n* = 167 | *p* value[1] |
| Serum lipid concentrations (basic model[1]) | | | | | |
| Total cholesterol (mmol/L) | 5.28 (5.15 to 5.41)[a] | 5.07 (4.94 to 5.21)[a,b] | 4.87 (4.73 to 5.00)[b] | 4.41 (4.28 to 4.55)[c] | < 0.001 |
| Non-HDL cholesterol (mmol/L) | 4.11 (3.98 to 4.25)[a] | 3.85 (3.71 to 3.98)[b] | 3.71 (3.58 to 3.85)[b] | 3.26 (3.13 to 3.49)[c] | < 0.001 |
| HDL cholesterol (mmol/L) | 1.16 (1.12 to 1.21)[a] | 1.23 (1.18 to 1.27)[a] | 1.15 (1.11 to 1.20)[a] | 1.15 (1.11 to 1.19)[a] | 0.044 |
| Total to HDL cholesterol ratio | 4.79 (4.60 to 4.98)[a] | 4.34 (4.15 to 4.53)[b,c] | 4.46 (4.27 to 4.65)[a,b] | 3.99 (3.80 to 4.18)[c] | < 0.001 |
| Apo A-I (mg/dL) | 148 (145 to 151) | 151 (147 to 154) | 149 (146 to 153) | 148 (145 to 152) | 0.690 |
| Apo B (mg/dL) | 100 (96 to 103)[a] | 93 (90 to 96)[b] | 89 (85 to 92)[b,c] | 82 (78 to 85)[d] | < 0.001 |
| Apo B to Apo A-I ratio | 0.69 (0.66 to 0.71)[a] | 0.64 (0.61 to 0.66)[a,b] | 0.61 (0.58 to 0.63)[b,c] | 0.57 (0.54 to 0.59)[c] | < 0.001 |
| Serum lipid concentrations (BMI model[2]) | | | | | |
| Total cholesterol (mmol/L) | 5.23 (5.09 to 5.37)[a] | 5.08 (4.94 to 5.22)[a,b] | 4.88 (4.74 to 5.02)[b] | 4.47 (4.34 to 4.61)[c] | < 0.001 |
| Non-HDL cholesterol (mmol/L) | 4.03 (3.90 to 4.17)[a] | 3.85 (3.72 to 3.99)[a,b] | 3.73 (3.60 to 3.87)[b] | 3.35 (3.21 to 3.48)[c] | < 0.001 |
| HDL cholesterol (mmol/L) | 1.19 (1.15 to 1.24)[a,b] | 1.23 (1.18 to 1.27)[a] | 1.15 (1.11 to 1.19)[a,b] | 1.13 (1.08 to 1.17)[b] | 0.005 |
| Total to HDL cholesterol ratio | 4.60 (4.42 to 4.78)[a] | 4.35 (4.17 to 4.53)[a,b] | 4.50 (4.32 to 4.68)[a] | 4.15 (3.97 to 4.33)[b,c] | 0.005 |
| Apo A-I (mg/dL) | 150 (146 to 153) | 151 (147 to 154) | 149 (145 to 153) | 146 (143 to 150) | 0.415 |
| Apo B (mg/dL) | 98 (94 to 101)[a] | 93 (90 to 96)[a,b] | 89 (86 to 92)[b,c] | 84 (81 to 87)[c] | < 0.001 |
| Apo B to Apo A-I ratio | 0.66 (0.64 to 0.69)[a] | 0.64 (0.61 to 0.66)[a,b] | 0.61 (0.58 to 0.64)[a,b] | 0.59 (0.56 to 0.61)[b,c] | 0.001 |

Apo A-I: Apolipoprotein A-I; Apo B: Apolipoprotein B

Values are mean (95% CI). Values in the same row that do not share a common superscript letter are significantly different

[1]The basic model included age (continuous), alcohol (continuous), and physical activity (categorical) as covariates

[2]The BMI model, age (continuous), alcohol (continuous), physical activity (categorical), and BMI (continuous) as covariates

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### Table 4

Dietary intakes and serum lipid profiles of female participants by diet group

| | Diet group | | | | |
|---|---|---|---|---|---|
| | Meat-eaters | Fish-eaters | Vegetarians | Vegans | |
| | *n* = 256 | *n* = 257 | *n* = 255 | *n* = 255 | *p* value[1] |
| Serum lipid concentrations (basic model[1]) | | | | | |
| Total cholesterol (mmol/L) | 5.05 (4.95 to 5.15)[a] | 4.86 (4.76 to 4.96)[a,b] | 4.76 (4.66 to 4.86)[b] | 4.45 (4.36 to 4.55) | < 0.001 |
| Non-HDL cholesterol (mmol/L) | 3.56 (3.47 to 3.66)[a] | 3.40 (3.30 to 3.49)[a,b] | 3.35 (3.25 to 3.44)[b] | 3.07 (2.98 to 3.17)[c] | < 0.001 |
| HDL cholesterol (mmol/L) | 1.48 (1.45 to 1.52)[a] | 1.46 (1.43 to 1.50)[a] | 1.42 (1.38 to 1.45)[a,b] | 1.38 (1.34 to 1.42)[b,c] | < 0.001 |
| Total to HDL cholesterol ratio | 3.52 (3.42 to 3.63) | 3.44 (3.33 to 3.54) | 3.49 (3.39 to 3.59) | 3.33 (3.23 to 3.43) | 0.053 |
| Apo A-I (mg/dL) | 163 (160 to 166) | 162 (159 to 165) | 162 (159 to 165) | 158 (155 to 161) | 0.092 |
| Apo B (mg/dL) | 87 (85 to 89)[a] | 82 (80 to 85)[b] | 81 (78 to 83)[b] | 76 (74 to 78)[c] | < 0.001 |
| Apo B to Apo A-I ratio | 0.54 (0.52 to 0.56)[a] | 0.52 (0.50 to 0.53)[a,b] | 0.51 (0.49 to 0.53)[a,b] | 0.49 (0.47 to 0.51)[b] | < 0.001 |
| Serum lipid concentrations (BMI model[2]) | | | | | |
| Total cholesterol (mmol/L) | 5.03 (4.92 to 5.13)[a] | 4.87 (4.77 to 4.97)[a,b] | 4.76 (4.66 to 4.86)[b] | 4.48 (4.38 to 4.58)[c] | < 0.001 |
| Non-HDL cholesterol (mmol/L) | 3.52 (3.42 to 3.61)[a] | 3.42 (3.32 to 3.51)[a] | 3.34 (3.25 to 3.44)[a] | 3.12 (3.02 to 3.21)[b] | < 0.001 |
| HDL cholesterol (mmol/L) | 1.51 (1.47 to 1.55)[a] | 1.45 (1.41 to 1.48)[a,b] | 1.42 (1.38 to 1.45)[b,c] | 1.36 (1.32 to 1.39)[c] | < 0.001 |
| Total to HDL cholesterol ratio | 3.43 (3.34 to 3.53) | 3.48 (3.38 to 3.57) | 3.48 (3.38 to 3.57) | 3.41 (3.31 to 3.50) | 0.667 |
| Apo A-I (mg/dL) | 165 (162 to 168)[a] | 161 (158 to 164)[a,b] | 162 (159 to 165)[a,b] | 157 (154 to 160)[b] | 0.003 |
| Apo B (mg/dL) | 86 (83 to 88)[a] | 83 (81 to 85)[a,b] | 81 (78 to 83)[b,c] | 77 (75 to 79)[c] | < 0.001 |
| Apo B to Apo A-I ratio | 0.53 (0.51 to 0.54) | 0.52 (0.51 to 0.54) | 0.51 (0.49 to 0.52) | 0.50 (0.48 to 0.52) | 0.054 |

Apo A-I: Apolipoprotein A-I; Apo B: Apolipoprotein B

Values are mean (95% CI). Values in the same row with different superscript letters are significantly different

[1]The basic model included age (continuous), alcohol (continuous), and physical activity (categorical) as covariates

[2]The BMI model, age (continuous), alcohol (continuous), physical activity (categorical), and BMI (continuous) as covariates