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Accepted manuscript

Nutrient Patterns are Associated with Discordant Apolipoprotein B and Low-Density Lipoproteins: A Population-Based Analysis

Mohsen Mazidi[1], Richard J Webb[2] , Elena S George[3], Niloofar Shekoohi[4], Julie A Lovegrove[5], Ian G Davies[6]

[1]Department of Twin Research & Genetic Epidemiology, Kings College London, 4th Floor, South Wing St Thomas', St Thomas', London, SE1 7EH, United Kingdom; [2]Faculty of Science, Liverpool Hope University, Hope Park Campus, Taggart Avenue, Liverpool, L16 9JD, United Kingdom; [3]Institute for Physical Activity and Nutrition, School of Exercise and Nutrition Sciences, Deakin University, Geelong, Australia; [4]Niloofar Shekoohi. Department of Cellular and Molecular Nutrition, School of Nutritional Sciences and Dietetics, Tehran University of Medical Sciences, Tehran, Iran; [5]Hugh Sinclair Unit of Human Nutrition and Institute for Cardiovascular and Metabolic Research, Harry Nursten Building, University of Reading, Pepper Lane Reading, RG6 6DZ, United Kingdom; [6]School of Sports and Exercise Sciences, Faculty of Science, Liverpool John Moores University, IM Marsh Campus, Barkhill Road, Liverpool L17 6AF, United Kingdom.

Corresponding authors: Dr Richard Webb, Faculty of Science, Liverpool Hope University, Hope Park Campus, Taggart Avenue, Liverpool, L16 9JD, United Kingdom. Tel: 44(0)151 291 3177, Email: webbr1@hope.ac.uk. Dr Ian G. Davies, School of Sports and Exercise Sciences, Faculty of Science, Liverpool John Moores University, IM Marsh Campus, Barkhill Road, Liverpool L17 6AF, United Kingdom. Tel: 44(0)151 231 5290, Email: i.g.davies@ljmu.ac.uk.

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Abstract:

Individuals with discordantly high ApoB to LDL-C levels carry a higher risk of atherosclerotic cardiovascular disease compared to those with average or discordantly low ApoB to LDL-C. We aimed to determine associations between ApoB and LDL-C discordance in relation to nutrient patterns (NPs) using National Health and Nutrition Examination Survey data. Participants were grouped by established LDL-C and ApoB cut-offs (Group 1: Low ApoB/Low LDL-C, Group 2: Low ApoB/High LDL-C, Group 3: High ApoB/Low LDL-C, Group 4: High ApoB/High LDL-C). Principle component analysis was used to define NPs. Machine learning (ML) and structural equation models were applied to assess associations of nutrient intake with ApoB/LDL-C discordance using the combined effects of ApoB and LDL-C. Three NPs explained 63.2% of variance in nutrient consumption. These consisted of NP1 rich in saturated fatty acids, carbohydrate and vitamins, NP2 high in fibre, minerals, vitamins and PUFA and NP3 rich in dietary cholesterol, protein, and sodium. The discordantly high ApoB to LDL-C group had the highest consumption of the NP1 and the lowest consumption of the NP2. ML showed nutrients which had the greatest unfavourable dietary contribution to individuals with discordantly high ApoB to LDL-C were total fat, saturated fatty acids and thiamine and the greatest favourable contributions were MUFA, folate, fibre and selenium. Individuals with discordantly high ApoB in relation to LDL-C had greater adherence to NP1, whereas those with lower levels of ApoB, irrespective of LDL-C, are more likely to consume NP3.

Keywords: ApoB, LDL-C, lipoprotein, nutrition, diet, discordance, nutrient pattern, NHANES

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Introduction

A high concentration of fasted serum low density lipoprotein cholesterol (LDL-C) is an independent causal risk factor for atherosclerotic cardiovascular disease (ASCVD) [(1)]. A reduction in this, with a concordant reduction in LDL particle number (or apolipoprotein B (ApoB) concentration) has been shown to reduce the risk of ASCVD [(1)]. However, a considerable proportion of patients with ASCVD show normal/low LDL-C levels and, despite achieving significant LDL-C reduction with lipid-lowering agents, many still encounter ASCVD events (residual risk) [(2, 3)]. A phenomenon which may be associated with the presence of an increased number of circulating small dense LDL particles, which are more atherogenic [(4)]. Coversely, others may have higher LDL-C and lower ApoB, a profile indicative of a smaller number of LDL particles that are larger in size, which result in a reduced ASCVD risk [(3)]. In this regard, it has been shown that the size of atherogenic lipoprotein particles is more discriminatory, as smaller particles more readily penetrate the endothelial wall and have greater susceptibility to atherogenic modification than their larger counterparts; a process that initiates and drives ASCVD [(5)]. Therefore, LDL-C may not always be a reliable predictor of ASCVD.

ApoB is a component of all atherogenic particles and has been proposed as an appropriate surrogate for particle number, due to the presence of one ApoB molecule per lipoprotein particle [(6)]. Epidemiologic studies show that the rate of plaque progression and occurrence of ASCVD events is associated with the level and duration of exposure to ApoB lipoproteins [(7, 8)]. Furthermore, the application of Mendelian randomisation has shown ApoB to be the predominant trait responsible for the relationship between lipoproteins and the progression of the ASCVD [(9)]. Moreover, the risk of ASCVD is more strongly associated with the number of ApoB particles rather than their cholesterol content [(10-14)]. This risk is also increased by the presence of additional molecules bound to the ApoB-containing lipoprotein complex; for example, oxidised phospholipids, which have been shown to have major proatherogenic and proinflammatory roles [(15)]. Therefore, ApoB is arguably a superior risk marker for ASCVD than LDL-C [(16)]. Furthermore, it is important to note that a Western dietary pattern, typically rich in saturated fatty acids and refined carbohydrates, has also been shown to further intensify this atherogenic milieu, as well as exacerbating other associated risk factors, such as dysregulating glucose homeostatsis and unfavourable body composition [(17)].

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The application of machine learning (ML) for the evaluation of nutrient patterns (NPs) offer advantages compared to traditional techniques, including the identification of novel trends and patterns derived from models built and operated without human intervention or assistance, unlike traditional statistical approaches where human intervention is essential at every stage of the model-building process [18]. ML techniques also offer superior handling of multi-dimensional and large data [18]. Indeed, ML is a valuable tool for the evaluation of disease risk in nutritional epidemiology as it offers enhanced prediction of clinically meaningful risk factors and the identification of predictive patterns related to diet [18]. Structural equation models (SEMs) offer an improved ability to determine complex networks (magnitude of associations), as well as benefitting from multicollinearity and other features not possible with traditional statistical models [19].

There is a lack of evidence regarding the dietary intake of individuals stratified according to the extent of concordance/discordance of ApoB and LDL-C concentrations. Research addressing this would therefore advance dietary recommendations towards precision/personalised nutrition, especially for individuals with discordantly high levels of ApoB in relation to LDL-C. Accordingly, in this population based study we aimed to determine, for the first time, the associations between LDL-C and ApoB discordance in relation to NPs by employing principle component analysis, and a ML approach in conjunction with SEMs. We hypothesised that discordantly high ApoB compared to LDL-C will be associated with a poorer overall NP.

Methods:

Population:

The National Health and Nutrition Examination Survey (NHANES) is an ongoing, repeated set of cross-sectional surveys conducted by the National Center for Health Statistics (NCHS). NHANES uses a multistage probabilistic sampling strategy that oversamples certain segments of the population, including African-Americans, Mexican-Americans, and those of lower socioeconomic status. Approximately 5000 subjects are recruited into NHANES each year, and the data are publicly available in 2-year cycles. The present study used data pertaining to two 2-year NHANES survey cycles between 2005 and 2012, restricted to participants aged ≥ 18 years. Demographic, dietary, and behavioural information are gathered through in-home questionnaires, while anthropometric, and biomarker data are collected by trained staff using mobile examination units. The NCHS Research Ethics Review Board approved the underlying protocol, and written informed consent was obtained from all

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subjects. The interview consists of questions on socio-demographic characteristics and previously diagnosed medical conditions. More detailed information on the NHANES survey design and questionnaires is reported elsewhere [20]. A blood sample was drawn from the participants' antecubital vein. Details of anthropometry procedures and laboratory procedures for collection, storage, calibration and quality control of blood samples are available elsewhere [21-24]. Blood samples are analysed for a large number of markers in NHANES; however, only those pertaining to glucose, insulin and lipid parameters were used in the present analysis.

Dietary Assessment:

Dietary intake was assessed using 24-h recall, and was obtained by a trained interviewer during the mobile examination center (MEC) visit with the use of a computer-assisted dietary interview system with standardised probes, i.e., the USDA's Automated Multiple-Pass Method (AMPM), as described previously [25, 26]. Briefly, the type and quantity of all foods and beverages consumed in a single 24-h period before the dietary interview (from midnight to midnight) at the MEC were collected with the use of AMPM. AMPM is designed to enhance complete and accurate data collection while reducing the respondent burden [26, 27].

Statistical analysis:

Participants were stratified by established LDL-C and ApoB cut-offs (130 mg/dL and 160 mg/dL for ApoB and LDL-C respectively) into four discordant groups (Group 1: Low ApoB, Low LDL-C; Group 2: Low ApoB, High LDL-C; Group 3: High ApoB, Low LDL-C; Group 4: High ApoB, High LDL-C) [28]. We then conducted further analyses according to the guidelines published by the Centres for Disease Control for analysis of complex NHANES dataset accounting for the masked variance and using the proposed weighting methodology [29]. The energy intake of the whole group of participants was adjusted using the residuals method and any individuals with an energy intake above or below 2SD of the mean energy intake were excluded from the analysis. Factor analysis with orthogonal transformation (varimax procedure) was applied. This was used to derive NPs based upon the nutrients consumed by participants, as opposed to food items which are often used in dietary pattern analysis. We used factor analysis with Varimax orthogonal transformation to generate principle components (PCs) representative of NPs based on the highest correlation coefficients between the nutrients constructing each PC [30]. All the necessary prerequisites of PC analysis including linearity, Kaiser–Meyer–Olkin measure of 0.88, and the significant Bartlett's test of sphericity (p <0.001) were met. We then used regression methods to

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calculate the factor scores of each NP for each study participant [30]. Higher score means greater adherence to particular NPs. Factors were retained for further analysis based on their natural interpretation and eigenvalues on the Scree test [31, 32]. We computed the factor score for each NP by summing up intakes of nutrients weighted by their factor loadings [31, 32]. Each participant received a factor score for each identified pattern [33]. A cut-off value for absolute factor scores of ≤0.25 was adhered to because it has been demonstrated as the optimum value for ensuring the best model fit [34] and has been successfully used previously [35, 36]. Continuous and categorical demographic variables were compared across ApoB and LDL-C discordant groups using analysis of variance (ANOVA) and Chi-square tests, respectively. We computed adjusted mean intakes of NPs and nutrients using analysis of co-variance (ANCOVA) with a Bonferroni correction with two different levels of adjustment [Model 1: Adjusted for age, sex and ethnicity; Model 2: Adjusted for age, sex, ethnicity, poverty to income ratio, alcohol intake, smoking, BMI, physical activity, fasting blood glucose, systolic and diastolic blood pressure, hypertension (diagnosed in individuals with systolic blood pressure ≥ 140 mmHg, a diastolic blood pressure ≥ 90 mmHg or in those on antihypertensive drugs) and diabetes mellitus (self-reported history of DM or fasting plasma glucose ≥ 126 mg/dl)]. ANCOVA allowed us to estimate the mean of our interested variable whilst adjusting for potential covariates.

Machine learning (ML)

We used ML to assess the most important dietary variables for our outcomes; a composite score of LDL-C and ApoB discordance, which is referred to as 'joined effect'. We hypothesised that each dietary variable may have a different effect on the joined effect of ApoB and LDL-C. Therefore, we implemented our model for each of the four groups separately to reveal predictors of the outcomes (the joined effect of ApoB and LDL-C was calculated using the dimension reduction method, principal component analysis). A random forest (RF) model was applied with cross validation. This method fits many classification trees to a data set, then combines the predictions from all trees to present a final predictive model that ranks variables by their predictive power. For the evaluation of our models we have used R^2 and Q^2 (an estimate of the predictive ability of the model calculated by cross-validation). A negative Q^2 means the model is not at all predictive. Model performance was confirmed by permutation analysis (n = 1000).

Structural equation modeling (SEM):

We used structural equation modeling (SEM) to test the overall model fit and relationships between sets of variables which were selected from machine learning to

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understand the underlying relationship of the composite score of ApoB and LDL-C (for each group separately). SEMs are able to test the fit of the defined model based on the observed covariance between the variables. We fitted our model under a maximum likelihood framework using covariance matrices [37]. All continuous variables were standardised by rank-normal transformed (mean 0, SD 1) by age, energy and sex (and by medication history). Relative model fit was assessed using the comparative fit index (CFI); a model with a 'good' fit typically requires indices to exceed 0.95. Absolute fit was assessed using the root mean square error of approximation (RMSEA). This ranges from 0 to 1, with 0 indicating a perfect fit [37]. A poorly fitting model is typically defined by RMSEA > 0.06 [38]. CFI and RMSEA were not used to formally determine adequacy of fit, as their use in this context is controversial and there is limited consensus on appropriate cut-off values because each index is affected differently by degrees of freedom, model complexity and sample size; however, it is standard practice to report these along with the χ^2. Statistical analysis was performed in the R environment for statistical computing v 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/). A two-sided $p < 0.05$ was used to characterise significant results.

Results:

General Characteristics:

Participants were stratified by established LDL-C and ApoB cut-offs into four discordant groups, as shown in **Table 1** [28]. Subjects in Group 3, high ApoB and low LDL-C, had a significantly higher waist circumference (106.0 ± 2.00 cm), fasting blood glucose (117.7 ± 10.3 mg/dL), fasting blood insulin (16.8 ± 1.7 µU/mL) and HOMA-IR (5.2 ± 0.9) compared with Group 4, high ApoB and high LDL-C (all $p < 0.001$).

Generation of principle components:

Using the PC method, we reduced the dietary intake from 29 macronutrients and micronutrients into three NPs that together explained 63.2 % of the variance of NP consumption. Loading factors and scree plot are shown in **Supplementary Table 1 and Supplementary Figure 1**. The first NP (NP1) was characterised by being high in saturated fatty acids, carbohydrate and low in most vitamins, the second pattern (NP2) contained high amounts of fibre, minerals vitamins, MUFA and PUFA and the third NP was high in cholesterol, protein and sodium (NP3).

As shown in **Table 2**, there was a significant difference between the adjusted mean score of the NP1 and NP2 (both $p = <0.001$). In the model adjusted for age, sex and ethnicity,

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regarding NP1 and NP2, Group 3 (High ApoB, Low LDL-C) consumed diets containing predominantly saturated fatty acids and carbohydrate (mean score = 2965 ± 22), and cholesterol, protein and sodium (mean score = 129 ± 20). Conversely, Group 1 (Low ApoB, Low LDL-C) consumed the lowest amounts of the NP1 (mean score = 2237 ± 27) and NP3 (mean score = 115 ± 10). However, NP2, which was high in fibre, minerals, vitamins and PUFA, was consumed predominantly by Group 1 (mean score = 3626 ± 40) and Group 2 (mean score = 3656 ± 40). Whereas Group 3 was shown to consume this NP the least (mean score = 2969 ± 31), as shown in **Table 2**. Similar findings were observed with the fully adjusted Model 2 as shown in **Table 2**.

Machine Learning and Structural Equation Model Approach:

We used ML to assess which dietary variables (**Supplemental Table 1**) influenced ApoB and LDL-C discordance using the joined effect of ApoB and LDL-C (composite score) as a response for each discordant group separately. Since we hypothesise that each independent factor might have a varied effect on the level of ApoB and LDL-C, we implemented our model for each of the four groups separately to reveal the predictors of LDL discordance based on ApoB and LDL-C.

The most important variables for Group 1 were PUFA, MUFA, total carbohydrate, copper, vitamin C and riboflavin (model performance: 0.86) and for Group 2 the variables of main importance were total sugars, total fat, fibre, saturated fatty acids, cholesterol, vitamin A and vitamin E (model performance: 0.69). For Group 3, the most prominent variables were MUFA, total fat, saturated fatty acids, fibre, selenium, folate vitamin B12 and thiamine (model performance: 0.71), whereas for Group 4 they were total carbohydrate, protein, cholesterol, vitamin C, vitamin K, phosphorus and magnesium (model performance: 0.56). Furthermore, we also performed this analysis on the whole population, which revealed that total sugars, saturated fatty acids, fibre, total fat, cholesterol, vitamin A, vitamin C, and magnesium were the most important variables (model performance: 0.62).

To understand the magnitude of each nutrient with our outcome (joined effect of ApoB and LDL-C), SEMs were implemented for each group separately, as shown in **Table 3**. Regarding Group 1 (Low ApoB, Low LDL-C), our findings showed that PUFA (b = -0.174, p <0.001), MUFA (b = -0.104, p <0.001) and total carbohydrate (b = 0.116, p <0.001) were the only variables which had an interdependent significant association with our outcome ($\chi 2$:22.0, CFI:0.97, RMSEA: 0.07). Total sugars (b = 0.172, p <0.001), total fat (b = 0.019, p <0.001), saturated fatty acids (b = 0.400, p <0.001), vitamin A (b = 0.137, p = 0.012) and

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fibre intake (b = -0.585, $p < 0.001$) had a significant independent link with our outcome in Group 2 (Low ApoB, High LDL-C) ($\chi 2$:20.1, CFI: 0.98, RMSEA: 0.06). SEMs revealed that MUFA (b = -0.766, $p < 0.001$), total fat (b = 0.721, $p < 0.001$), saturated fatty acid intake (b = 0.242, $p < 0.001$), fibre (b = -0.411, $p < 0.001$), folate (b = -0.198, $p = 0.031$), selenium (b = -0.133, $p = 0.046$) and thiamine (b = 0.146, $p = 0.041$) had a significant association with our outcome in Group 3 (High ApoB, Low LDL-C) ($\chi 2$:12.3, CFI:0.98, RMSEA: 0.04). In Group 4 (High ApoB, High LDL-C), SEMs revealed that total carbohydrate (b = 0.442, $p < 0.001$), protein (b = 0.296, $p < 0.001$) and cholesterol (b = 0.294, $p < 0.001$) had a significant association with our outcome ($\chi 2$:20.2, CFI:0.97, RMSEA: 0.05). On the scale of the whole population, total sugars (b = 0.296, $p < 0.001$), saturated fatty acids (b = 0.282, $p < 0.001$), fibre (b = -0.423, $p < 0.001$), cholesterol (b = 0.139, $p < 0.001$), and magnesium (b = 0.114, $p < 0.001$) were significantly associated with our outcome ($\chi 2$:16.6, CFI:0.95, RMSEA: 0.07).

Discussion:

The impact of diet upon ApoB and LDL-C discordance is currently unknown. Therefore, the aim of the present study was to apply two methods of determining NPs to data derived from NHANES to reveal, for the first time, the association between our outcome (i.e. the joined effect of ApoB and LDL-C) and nutrient intake between four groups stratified by ApoB and LDL-C. Even after accounting for a large range of confounding variables, individuals with high ApoB, irrespective of LDL-C, had the highest consumption of NP1, which was high in saturated fatty acids and carbohydrates and low in vitamins and minerals and is characteristic of a 'Western dietary pattern'. Furthermore, those with discordantly high levels of ApoB in relation to LDL-C had the greatest consumption of NP3 (i.e. high in dietary cholesterol, protein and sodium) and the lowest adherence to a healthier dietary pattern rich in fibre, minerals vitamins, MUFA and PUFA (i.e. NP2), which has characteristics of a Mediterranean-style diet.

In addition to using a traditional statistical approach, (i.e. PCA), for extracting patterns, we also implemented a novel ML approach in conjunction with SEMs. The advantages of employing ML is that it can better explain intra-relationships and enable more accurate predictions to be made based upon the classification ability of the technique. SEMs were then used to elucidate the magnitude of the resulting relationships, allowing us to determine nutrient predicators relating to the concordance/discordance of ApoB and LDL-C. Our findings revealed that the groups with increased ApoB concentrations were positively

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associated with a range of nutrients, including dietary carbohydrate, saturated fatty acids, protein and cholesterol and negatively associated with other nutrients, such as MUFA and fibre; a finding also reflected in our analysis across the spectrum of the whole population. In agreement with these results, a previous analysis of dietary patterns in 140 healthy men demonstrated that switching dietary intake from a moderate carbohydrate/high fat diet to a high carbohydrate/low fat diet was associated with an increase in plasma ApoB lipoprotein concentration [(39)]. The effect of these dietary changes on plasma ApoB concentration was reported to be mediated via an increased flux of carbohydrate to the liver, which led to upregulated de-novo lipogenesis and the subsequent production of ApoB lipoproteins [(40)]. Moreover, refined carbohydrate in particular has also been shown to result in increased visceral adiposity, decreased insulin sensitivity, and the upregulation of hepatic de novo lipogenesis [(41)]. This consequently decreases HDL-C levels and raises ApoB and LDL-C; in particular the small, dense LDL subclass, a particularly atherogenic lipoprotein, which is considered a key risk factor for ASCVD [(41)]. This constellation of lipid abnormalities, which also include raised circulating triacylglycerol concentrations are often referred to as atherogenic dyslipidaemia and is the result of neutral lipid exchange [(42)]. Therefore, the combination of a high intake of refined carbohydrates, free sugars and dietary fats such as saturated fatty acids and trans fats, can be regarded as dietary components principally implicated in the the development of atherosclerosis. The presence of some of these elements in the nutrient pattern predominantly consumed by those with raised ApoB, although somewhat unsurprising, should still be acknowledged.

Similarly, our ML analysis, followed by SEMs, revealed a strong, positive and significant association between those with High ApoB, Low LDL-C and total dietary fat, whereas MUFA had a strong and significant negative association. A significant, yet weak positive relationship regarding SFA was also reported within this group. These findings are in contrast to previous studies which have observed different associations between saturated and unsaturated fatty acids and ApoB [(43)]. For example, it has been reported that a diet high in SFA compared to a diet rich in n-6 PUFA contributed towards higher plasma proprotein convertase subtilisin/kexin type 9 (PCSK9) concentrations [(44)], leading to a decrease in the catabolic rate of ApoB [(45)]. It has also been suggested that unsaturated trans fatty acids, such as elaidic acid and conjugated linoleic acid, may increase the hepatic secretion of ApoB containing lipoproteins, mainly consisting of the small, dense LDL subclass [(46, 47)]. Despite these findings, the weak positive relationship found between SFA and our outcome (i.e. the

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joined effect of ApoB and LDL-C) in our study may be an indicator that the impact of SFA may be less than that inferred by unsaturated fatty acids upon atherogenic lipoproteins. Incidentally, a Mediterranean-style dietary pattern which typically contains lower levels of SFA, together with higher levels of MUFA and PUFA, has been associated with a beneficial increased clearance of ApoB particles [45], facilitated by a higher LDL receptor activity. Furthermore, this dietary pattern is effective for reducing endpoint ASCVD [48-50].

With respect to those with Low ApoB, Low LDL-C (Group 1), the highest association observed was consumption of NP2, which contains elements often found in a 'Mediterranean-style diet' (for example, higher fibre, minerals, vitamins and PUFA). It is noteworthy that Group 2 (Low ApoB, High LDL-C) was also associated with consumption of this NP, despite having raised LDL-C. This is important since the benefits of a Mediterranean-style diet (which contains these key nutrients) and the positive effect on ApoB has been well established [43]. For example, randomised controlled trials have shown that adherence to a Mediterranean diet for three months resulted in significant reductions in ApoB [51, 52]. Similarly, two prospective intervention studies demonstrated the favourable impact of the Mediterranean diet upon plasma ApoB [45, 53]. These improvements in ApoB are likely to be the result of an increased consumption of pulses, vegetables and fruits, fish, contributing to an increase in unsaturated fatty acids, soluble fibre and polyphenols, as well as a decrease in SFA [51]. Moreover, favourable effects on ApoB have been attributed to the diet being rich in extra virgin olive oil which, along with its phenolic compounds, has also been shown to influence mRNA and protein expression of lipoproteins, resulting in the reduced production of very low density lipoproteins (VLDL) and their conversion to LDL lipoproteins, in tandem with a subsequent increase in the rate of LDL catabolism [51, 54]. That said, it has previously been shown in the NHANES cohort the consumption of extra virgin olive oil is not high and it is therefore questionable whether this nutritional aspect was responsible for the differences in ApoB observed in this analyses [55]. Nonethless, regardless of the food items consumed a nutrient profile containing elements which are characteristic of a Mediterranean dietary pattern were found in the group with the lowest ASCVD profile in terms of ApoB, which corresponds with the existing literature [51].

Key strengths of our study include the large and nationally representative sample, which is adequately powered to determine associations [56]. Furthermore, the novel combination of ML and SEMS approaches provide statistical metrics of magnitude and significance, which allow for inferences to be made regarding input variables and outcomes

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(i.e. joined effect of ApoB and LDL-C) [18]. This is not the case when using ML methods alone, which often impedes the interpretation of findings [18]. In addition to this, our novel method for describing food intakes and nutrient patterns has also facilitated the elucidation of unique relationships and the quantification of novel NPs, which would not otherwise have been possible. Despite these strengths, our study has some limitations. The dietary recall methods used can be prone to bias, particularly with regards to misreporting, which when present has been shown to affect all food groups [57]. Furthermore, associations do not imply causality and are acknowledged as a limitation of all observational studies and should be considered when evaluating our findings [58]. Despite best efforts, residual confounding from a range of lifestyle and socioeconomic factors, along with bias may also limit the generalisability of our findings [59]. Similarly, there is the possibility of reverse causaility in observational studies and even when taking precautions, such as excluding individuals with pre-existing illness, its influence cannot be entirely negated [60]. For example, it has been previously shown that the relationship between dietary and serum cholesterol can be confounded by reverse causality based upon education level and employment status [61].

In conclusion, we have shown that those individuals with discordantly high levels of ApoB in relation to LDL-C consume diets containing elements which may possibly represent a 'Western' dietary pattern. This includes high dietary SFA and refined carbohydrates and a low intake of fibre and minerals. These findings will be useful for personalised nutrition strategies in populations stratified by LDL-C and ApoB concentrations. Furthermore, we have also demonstrated that those with lower levels of ApoB were more likely to consume diets containing elements of a 'Mediterranean-style' dietary pattern, despite high LDL-C concentrations.

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Conflict of Interest: None.

Authors' Contributions: MM, RW and ID formulated the research question, MM, RW and ID designed the study, MM carried out the study and analysed the data, MM, RW, NS, EG, JL and ID interpreted the findings and MM, RW, NS, JL and ID wrote the article. All authors have read and approved the final manuscript.

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References:

1. Ference BA, Ginsberg HN, Graham I *et al.* (2017) Low-density lipoproteins cause atherosclerotic cardiovascular disease. 1. Evidence from genetic, epidemiologic, and clinical studies. A consensus statement from the European Atherosclerosis Society Consensus Panel. *Eur Heart J* 38, 2459-2472.
2. Lieb W, Enserro DM, Larson MG *et al.* (2018) Residual cardiovascular risk in individuals on lipid-lowering treatment: quantifying absolute and relative risk in the community. *Open Heart* 5.
3. Otvos JD, Mora S, Shalaurova I *et al.* (2011) Clinical Implications of Discordance Between LDL Cholesterol and LDL Particle Number. *J Clin Lipidol* 5, 105-113.
4. Sniderman AD, Thanassoulis G, Glavinovic T *et al.* (2019) Apolipoprotein B Particles and Cardiovascular Disease: A Narrative Review. *JAMA Cardiol* 4, 1287-1295.
5. Ivanova EA, Myasoedova VA, Melnichenko AA *et al.* (2017) Small Dense Low-Density Lipoprotein as Biomarker for Atherosclerotic Diseases. *Oxid Med Cell Longev* 2017.
6. Cromwell WC & Barringer TA (2009) Low-density lipoprotein and apolipoprotein B: clinical use in patients with coronary heart disease. *Curr Cardiol Rep* 11, 468-475.
7. Fernández-Friera L, Fuster V, López-Melgar B *et al.* (2017) Normal LDL-cholesterol levels are associated with subclinical atherosclerosis in the absence of risk factors. *J Am Coll Cardiol* 70, 2979-2991.
8. Navar-Boggan AM, Peterson ED, D'Agostino Sr RB *et al.* (2015) Hyperlipidemia in early adulthood increases long-term risk of coronary heart disease. *Circulation* 131, 451-458.
9. Richardson TG, Sanderson E, Palmer TM *et al.* (2020) Evaluating the relationship between circulating lipoprotein lipids and apolipoproteins with risk of coronary heart disease: A multivariable Mendelian randomisation analysis. *PLoS Med* 17, e1003062.
10. Sniderman AD, St-Pierre AC, Cantin B *et al.* (2003) Concordance/discordance between plasma apolipoprotein B levels and the cholesterol indexes of atherosclerotic risk. *The American journal of cardiology* 91, 1173-1177.
11. Cromwell WC, Otvos JD, Keyes MJ *et al.* (2007) LDL particle number and risk of future cardiovascular disease in the Framingham Offspring Study—implications for LDL management. *J Clin Lipidol* 1, 583-592.
12. Lawler PR, Akinkuolie AO, Ridker PM *et al.* (2017) Discordance between circulating atherogenic cholesterol mass and lipoprotein particle concentration in relation to future coronary events in women. *Clinical chemistry* 63, 870-879.

13. Wilkins JT, Li RC, Sniderman A *et al.* (2016) Discordance between apolipoprotein B and LDL-cholesterol in young adults predicts coronary artery calcification: the CARDIA study. *Journal of the American College of Cardiology* 67, 193-201.
14. Pencina MJ, D'Agostino RB, Zdrojewski T *et al.* (2015) Apolipoprotein B improves risk assessment of future coronary heart disease in the Framingham Heart Study beyond LDL-C and non-HDL-C. *European journal of preventive cardiology* 22, 1321-1327.
15. Que X, Hung M-Y, Yeang C *et al.* (2018) Oxidized phospholipids are proinflammatory and proatherogenic in hypercholesterolaemic mice. *Nature* 558, 301-306.
16. Sniderman AD, Bergeron J Frohlich J (2001) Apolipoprotein B versus lipoprotein lipids: vital lessons from the AFCAPS/TexCAPS trial. *CMAJ* 164, 44-47.
17. Walsh EI, Jacka FN, Butterworth P *et al.* (2017) The association between Western and Prudent dietary patterns and fasting blood glucose levels in type 2 diabetes and normal glucose metabolism in older Australian adults. *Heliyon* 3, e00315-e00315.
18. Panaretos D, Koloverou E, Dimopoulos AC *et al.* (2018) A comparison of statistical and machine-learning techniques in evaluating the association between dietary patterns and 10-year cardiometabolic risk (2002-2012): the ATTICA study. *The British Journal of Nutrition* 120, 326-334.
19. Khodarahmi M, Asghari-Jafarabadi M Abbasalizad Farhangi M (2019) A structural equation modeling approach for the association of a healthy eating index with metabolic syndrome and cardio-metabolic risk factors among obese individuals. *PLoS One* 14, e0219193.
20. Klein-Platat C, Drai J, Oujaa M *et al.* (2005) Plasma fatty acid composition is associated with the metabolic syndrome and low-grade inflammation in overweight adolescents. *Am J Clin Nutr* 82, 1178-1184.
21. http://www.cdc.gov/NCHS/data/nhanes/nhanes_09_10/CRP_F_met.pdf ([accessed 19.08.13]).
22. Remer T (2001) Influence of nutrition on acid-base balance--metabolic aspects. *Eur J Nutr* 40, 214-220.
23. Engberink MF, Bakker SJ, Brink EJ *et al.* (2012) Dietary acid load and risk of hypertension: the Rotterdam Study. *Am J Clin Nutr* 95, 1438-1444.
24. CDC (2011) National Health and Nutrition Survey - Laboratory Procedures Manual [CDC, editor].
25. Ahluwalia N, Andreeva VA, Kesse-Guyot E *et al.* (2013) Dietary patterns, inflammation and the metabolic syndrome. *Diabetes Metab* 39, 99-110.

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26. Ahluwalia N, Dwyer J, Terry A *et al.* (2016) Update on NHANES Dietary Data: Focus on Collection, Release, Analytical Considerations, and Uses to Inform Public Policy. *Adv Nutr* 7, 121-134.
27. Moshfegh AJ, Rhodes DG, Baer DJ *et al.* (2008) The US Department of Agriculture Automated Multiple-Pass Method reduces bias in the collection of energy intakes. *Am J Clin Nutr* 88, 324-332.
28. Grundy SM, Stone NJ, Bailey AL *et al.* (2019) 2018 AHA/ACC/AACVPR/AAPA/ABC/ACPM/ADA/AGS/APhA/ASPC/NLA/PCNA Guideline on the Management of Blood Cholesterol: Executive Summary: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *J Am Coll Cardiol* 73, 3168-3209.
29. Statistics. NCfH (http://www.cdc.gov/nchs/data/nhanes/ nhanes 03 04/nhanes analytic guidelines dec 2005.pdf.) ANALYTIC AND REPORTING GUIDELINES
30. Liu RX, Kuang J, Gong Q *et al.* (2003) Principal component regression analysis with SPSS. *Computer methods and programs in biomedicine* 71, 141-147.
31. Stanhope KL (2012) Role of fructose-containing sugars in the epidemics of obesity and metabolic syndrome. *Annu Rev Med* 63, 329-343.
32. Khayyatzadeh SS, Moohebati M, Mazidi M *et al.* (2016) Nutrient patterns and their relationship to metabolic syndrome in Iranian adults. *Eur J Clin Invest* 46, 840-852.
33. W W (2013) Nutritional epidemiology. . *Oxford University Press, Oxford*.
34. Castro MAd, Baltar VT, Selem SSAdC *et al.* (2015) Empirically derived dietary patterns: interpretability and construct validity according to different factor rotation methods. *Cad Saude Publica* 31, 298-310.
35. Flynn AC, Seed PT, Patel N *et al.* (2016) Dietary patterns in obese pregnant women; influence of a behavioral intervention of diet and physical activity in the UPBEAT randomized controlled trial. *International Journal of Behavioral Nutrition and Physical Activity* 13, 124.
36. Roberts K, Cade J, Dawson J *et al.* (2018) Empirically Derived Dietary Patterns in UK Adults Are Associated with Sociodemographic Characteristics, Lifestyle, and Diet Quality. *Nutrients* 10, 177.
37. Bentler PM (1990) Comparative fit indexes in structural models. *Psychol Bull* 107, 238-246.
38. Tucker LR & Lewis C (1973) A reliability coefficient for maximum likelihood factor analysis. *Psychometrika* 38, 1-10.

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39. Shin M-J, Blanche PJ, Rawlings RS *et al.* (2007) Increased plasma concentrations of lipoprotein (a) during a low-fat, high-carbohydrate diet are associated with increased plasma concentrations of apolipoprotein C-III bound to apolipoprotein B–containing lipoproteins. *The American journal of clinical nutrition* 85, 1527-1532.
40. Parks EJ & Hellerstein MK (2000) Carbohydrate-induced hypertriacylglycerolemia: historical perspective and review of biological mechanisms. *The American journal of clinical nutrition* 71, 412-433.
41. Stanhope KL, Schwarz JM, Keim NL *et al.* (2009) Consuming fructose-sweetened, not glucose-sweetened, beverages increases visceral adiposity and lipids and decreases insulin sensitivity in overweight/obese humans. *The Journal of clinical investigation* 119, 1322-1334.
42. Lechner K, McKenzie AL, Kränkel N *et al.* (2020) High-Risk Atherosclerosis and Metabolic Phenotype: The Roles of Ectopic Adiposity, Atherogenic Dyslipidemia, and Inflammation. *Metab Syndr Relat Disord* 18, 176-185.
43. Lamantia V, Sniderman A Faraj M (2016) Nutritional management of hyperapoB. *Nutr Res Rev* 29, 202–233.
44. Bjermo H, Iggman D, Kullberg J *et al.* (2012) Effects of n-6 PUFAs compared with SFAs on liver fat, lipoproteins, and inflammation in abdominal obesity: a randomized controlled trial. *The American journal of clinical nutrition* 95, 1003-1012.
45. Richard C, Couture P, Ooi EM *et al.* (2014) Effect of Mediterranean diet with and without weight loss on apolipoprotein B100 metabolism in men with metabolic syndrome. *Arterioscler Thromb Vasc Biol* 34, 433-438.
46. Mitmesser SH & Carr TP (2005) Trans fatty acids alter the lipid composition and size of apoB-100-containing lipoproteins secreted by HepG2 cells. *J Nutr Biochem* 16, 178-183.
47. Mozaffarian D & Clarke R (2009) Quantitative effects on cardiovascular risk factors and coronary heart disease risk of replacing partially hydrogenated vegetable oils with other fats and oils. *Eur J Clin Nutr* 63, S22-S33.
48. Daumerie CM, Woollett LA Dietschy JM (1992) Fatty acids regulate hepatic low density lipoprotein receptor activity through redistribution of intracellular cholesterol pools. *Proceedings of the National Academy of Sciences* 89, 10797-10801.
49. Hitoshi K, Kozo H, Shingu T *et al.* (1995) Opposite effects on cholesterol metabolism and their mechanisms induced by dietary oleic acid and palmitic acid in hamsters. *Biochimica et Biophysica Acta (BBA)-Lipids and Lipid Metabolism* 1258, 251-256.

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50. Estruch R, Ros E, Salas-Salvadó J *et al.* (2018) Primary Prevention of Cardiovascular Disease with a Mediterranean Diet Supplemented with Extra-Virgin Olive Oil or Nuts. *N Engl J Med* 378, e34.
51. Solá R, Fitó M, Estruch R *et al.* (2011) Effect of a traditional Mediterranean diet on apolipoproteins B, AI, and their ratio: a randomized, controlled trial. *Atherosclerosis* 218, 174-180.
52. Vincent-Baudry S, Defoort C, Gerber M *et al.* (2005) The Medi-RIVAGE study: reduction of cardiovascular disease risk factors after a 3-mo intervention with a Mediterranean-type diet or a low-fat diet. *Am J Clin Nutr* 82, 964-971.
53. Bédard A, Riverin M, Dodin S *et al.* (2012) Sex differences in the impact of the Mediterranean diet on cardiovascular risk profile. *Br J Nutr* 108, 1428-1434.
54. Ng TW, Watts GF, Barrett PHR *et al.* (2007) Effect of weight loss on LDL and HDL kinetics in the metabolic syndrome: associations with changes in plasma retinol-binding protein-4 and adiponectin levels. *Diabetes Care* 30, 2945-2950.
55. Taylor MK, Mahnken JD Sullivan DK (2020) NHANES 2011-2014 Reveals Cognition of US Older Adults may Benefit from Better Adaptation to the Mediterranean Diet. *Nutrients* 12, 1929.
56. Statistics NCfH (2017) About the National Health and Nutrition Examination Survey. https://www.cdc.gov/nchs/nhanes/about_nhanes.htm (accessed 11/11/20 2020)
57. Naska A, Lagiou A Lagiou P (2017) Dietary assessment methods in epidemiological research: current state of the art and future prospects. *F1000Research* 6.
58. Gianicolo EAL, Eichler M, Muensterer O *et al.* (2020) Methods for Evaluating Causality in Observational Studies. *Dtsch Arztebl Int* 116, 101-107.
59. Forouhi NG, Krauss RM, Taubes G *et al.* (2018) Dietary fat and cardiometabolic health: evidence, controversies, and consensus for guidance. *BMJ* 361.
60. Sattar N & Preiss D (2017) Reverse Causality in Cardiovascular Epidemiological Research: More Common Than Imagined? *Circulation* 135, 2369-2372.
61. Okami Y, Ueshima H, Nakamura Y *et al.* (2019) The Relationship of Dietary Cholesterol with Serum Low-Density Lipoprotein Cholesterol and Confounding by Reverse Causality: The INTERLIPID Study. *J Atheroscler Thromb* 26, 170-182.

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Tables

Table 1: Demographic and clinical characteristics of the total population grouped by apolipoprotein B and low-density lipoprotein cholesterol levels.

Characteristics		Group 1 (Low ApoB, Low LDL-C) (n=12,384)	Group 2 (Low ApoB, High LDL-C) (n=711)	Group 3 (High ApoB, Low LDL-C) (n=285)	Group 4 (High ApoB, High LDL-C) (n=885)	*p*-value
Age (Years)		48.8 ± 1.2	51.1 ± 1.9	55.6 ± 1.4	56.1 ± 1.6	<0.001
Sex (%)	**Male**	49.4	52.3	51.4	44.9	<0.001
	Female	50.6	47.7	49.6	55.1	
Anthropometric Parameters	**BMI (kg/m^2)**	28.3 ± 0.1	28.1 ± 0.5	30.9 ± 0.9	30.1 ± 0.6	<0.001
	WC (cm)	97.3 ± 0.3	96.7 ± 1.2	106.0 ± 2.0	102.6 ± 1.2	<0.001
Insulin and Glucose Parameters	**Fasting blood glucose (mg/dL)**	101.0 ± 0.7	99.2 ± 2.3	117.7 ± 10.3	112.5 ± 4.3	<0.001
	Plasma insulin (µU/mL)	13.1 ± 0.3	11.2 ± 0.6	16.8± 1.7	13.1 ± 0.9	<0.001
	HOMA-IR	3.4 ± 0.1	2.8 ± 0.2	5.2 ± 0.9	3.6 ± 0.3	<0.001
	HbA$_{1c}$ (%)	5.7 ± 0.0	5.7 ± 0.1	6.2 ± 0.3	6.2 ± 0.1	<0.001
Macronutrients	**Fat (g/day)**	78.5 ± 1.0	75.5 ± 4.2	78.6 ± 6.4	69.2 ± 3.3	<0.001
	MUFA (g/day)	29.2 ± 0.4	28.7 ± 1.7	31.3 ± 3.0	25.7 ± 1.2	<0.001
	PUFA (g/day)	17.1 ± 0.2	15.3 ± 1.0	15.7 ± 1.5	15.2 ± 0.8	<0.001
	SFA (g/day)	25.4 ± 0.4	24.7 ± 1.4	24.7 ± 1.9	22.4 ± 1.2	<0.001
	Protein	79.2 ± 0.9	77.8 ± 3.7	76.1 ± 5.8	70.4 ± 3.2	<0.00

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	(g/day)					1
	Carbohydrate (g/day)	251.5 ± 2.7	237.5 ± 10.9	256.7 ± 13.6	223.3 ± 8.8	<0.001
	Fibre (g/day)	15.7 ± 0.2	12.6 ± 0.6	14.5 ± 1.4	14.0 ± 0.8	<0.001
	Total sugar (g/day)	113.5 ± 1.7	112.3 ± 7.1	126.1 ± 10.3	103.2 ± 5.5	<0.001
	Energy (kcal/day)	2069.6 ± 21.5	1992.4 ± 87.9	2048.2 ± 116.1	1823.1 ± 69.3	<0.001
Total cholesterol (mg/dL)		185.1 ± 0.7	250.8 ± 1.9	239.5 ± 3.0	281.3 ± 2.6	<0.001
HDL-C (mg/DL)		54.1 ± 0.3	56.3 ± 1.3	42.9 ± 1.8	51.4 ± 1.1	<0.001
LDL-C (mg/dL)		105.4 ± 0.6	170.4 ± 0.9	145.0 ± 2.9	192.1 ± 2.4	<0.001
ApoB(mg/dL)		87.0 ± 0.9	118.6 ± 0.7	137.9 ± 0.9	145.6 ± 0.6	<0.001
Triglycerides (mg/dL)		116.0 ± 1.3	117.0 ± 4.7	232.9 ± 12.9	176.6 ± 5.3	<0.001
TG/HDL ratio		2.5 ± 0.0	2.3 ± 0.1	5.9 ± 0.5	3.7 ± 0.2	<0.001
LDL-C/ApoB ratio		1.2 ± 0.0	1.5 ± 0.0	1.1 ± 0.0	1.3 ± 0.0	<0.001
Non-HDL-C		131.0 ± 0.7	194.5 ± 1.4	196.5 ± 2.9	229.9 ± 2.5	<0.001

Value expressed as a mean and SEM or percent. Continuous and categorical demographic variables were compared across the four groups using analysis of variance (ANOVA) and chi-square tests respectively.

Abbreviations: BMI, body mass index; WC, waist circumference, HOMA-IR, Homeostatic Model Assessment of Insulin Resistance, HbA_{1c}, *glycated haemoglobin; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol, ApoB, apolipoprotein B.*

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Table 2: Adjusted mean of score of nutrient patterns grouped by apolipoprotein B and low-density lipoprotein cholesterol concentrations.

Variables	**Group 1 (ApoB: L, LDL-C: L)**		**Group 2 (ApoB: L, LDL-C: H)**		**Group 3 (ApoB: H, LDL-C: L)**		**Group 4 (ApoB: H, LDL-C: H)**		***p*-value**
	Model1	**Model2**	**Model 1**	**Model2**	**Model1**	**Model2**	**Model1**	**Model2**	
Nutrient Pattern 1 (High in saturated fatty acids and carbohydrate)	2237 ± 27	2196 ± 22	2336 ± 30	2289 ± 26	2965 ± 22	2896 ± 20	2746 ± 30	2654 ± 27	Both <0.001
Nutrient Pattern 2 (High in fiber, minerals vitamins, PUFA)	3626 ± 40	3562 ± 34	3656 ± 40	3596 ± 36	2969 ± 31	2744 ± 30	3125 ± 30	2965 ± 26	Both <0.001
Nutrient Pattern 3 (High in cholesterol, protein, sodium)	115 ± 10	99 ± 9	124 ± 10	114 ± 10	129 ± 20	118 ± 19	119 ± 20	103 ± 17	Model1= 0.183 Model2=0.249

Abbreviations: ApoB, Apolipoprotein B; LDL-C, Low-density lipoprotein cholesterol, PUFA, Polyunsaturated fatty acids.

Model 1: Age, sex, and ethnicity

Model 2: Model 1 plus poverty to income ratio, alcohol intake, smoking, BMI, physical activity, fasting blood glucose, systolic and diastolic blood pressure, hypertension and diabetes mellitus.

Values expressed as estimated mean and standard error.

Dietary patterns were calculated using principle component analysis and variables were compared across the groups using analysis of co-variance (ANCOVA) test.

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Table 3: Effect estimates of associations between nutrients and the joined effect of ApoB and LDL-C.

Exposure	**Outcome**	**Beta coefficient**	**SE**	***p*-value**
Group 1 (Low ApoB, Low LDL-C)				
Copper	ApoB/LDL-C	0.022	0.509	0.136
MUFA	ApoB/LDL-C	-0.104	0.022	<0.001
PUFA	ApoB/LDL-C	-0.174	0.034	<0.001
Riboflavin	ApoB/LDL-C	0.050	0.314	0.425
Total carbohydrate	ApoB/LDL-C	0.116	0.003	<0.001
Vitamin C	ApoB/LDL-C	-0.017	0.004	0.235
Group 2 (Low ApoB, High LDL-C)				
Cholesterol	ApoB/LDL-C	0.038	0.004	0.253
Fibre	ApoB/LDL-C	-0.585	0.128	<0.001
SFA	ApoB/LDL-C	0.400	0.054	<0.001
Total fat	ApoB/LDL-C	0.264	0.019	<0.001
Total sugars	ApoB/LDL-C	0.172	0.011	<0.001
Vitamin A	ApoB/LDL-C	0.137	0.002	0.012
Vitamin E	ApoB/LDL-C	0.103	0.203	0.098
Group 3 (High ApoB, Low LDL-C)				
Fibre	ApoB/LDL-C	-0.411	0.099	<0.001
Folate	ApoB/LDL-C	-0.198	0.006	0.031
MUFA	ApoB/LDL-C	-0.766	0.046	<0.001
Selenium	ApoB/LDL-C	-0.133	0.010	0.046
SFA	ApoB/LDL-C	0.242	0.072	<0.001
Thiamine	ApoB/LDL-C	0.146	0.056	0.041
Total fat	ApoB/LDL-C	0.721	0.022	<0.001
Group 4 (High ApoB, High LDL-C)				
Cholesterol	ApoB/LDL-C	0.294	0.004	<0.001
Magnesium	ApoB/LDL-C	-0.189	0.007	0.074
Phosphorus	ApoB/LDL-C	0.142	0.002	0.163
Protein	ApoB/LDL-C	0.296	0.027	<0.001
Total carbohydrate	ApoB/LDL-C	0.442	0.010	<0.001
Vitamin C	ApoB/LDL-C	0.023	0.012	0.295
Vitamin K	ApoB/LDL-C	-0.155	0.014	0.122

To determine effects structural equation models were implemented for each group separately based upon the joined effect of ApoB and LDL-C.

Abbreviations: ApoB, Apolipoprotein B; LDL-C, Low-density lipoprotein cholesterol, PUFA, Polyunsaturated fatty acids; MUFA, Monounsaturated fatty acids; SFA, Saturated fatty acids.

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