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Associations between dietary patterns and metabolic syndrome in older adults in New Zealand: the REACH study

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Conflicts of interest

The authors decline no conflict of interests.

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Dietary patterns and metabolic syndrome

Abbreviations

FFQ, food frequency questionnaire

KMO, Kaiser-Meyer-Olkin

REACH, Researching Eating, Activity, and Cognitive Health

Abstract

Metabolic syndrome is common in older adults and may be modified by the diet. The aim of this study was to examine associations between *a posteriori* dietary patterns and metabolic syndrome in an older New Zealand population.

The REACH study (Researching Eating, Activity, and Cognitive Health) included 366 participants (65-74 years, 36% male) living independently in Auckland, New Zealand. Dietary data were collected using a 109-item food frequency questionnaire with demonstrated validity and reproducibility for assessing dietary patterns using principal component analysis. Metabolic syndrome was defined by the National Cholesterol Education Program Adult Treatment Panel III. Associations between dietary patterns and metabolic syndrome, adjusted for age, sex, index of multiple deprivation, physical activity, and energy intake were analysed using logistic regression analysis.

Three dietary patterns explained 18% of dietary intake variation – 'Mediterranean style' (salad/leafy cruciferous/other vegetables, avocados/olives, alliums, nuts/seeds, shellfish and white/oily fish, berries), 'prudent' (dried/fresh/frozen legumes, soy-based foods, whole grains, carrots), and 'Western' (processed meat/fish, sauces/condiments, cakes/biscuits/puddings, meat pies/hot chips). No associations were seen between 'Mediterranean style' [OR=0.75 (95% CI 0.53, 1.06), *P*=0.11] or 'prudent' [OR=1.17 (95% CI 0.83, 1.59), *P*=0.35] patterns and metabolic syndrome after co-variate adjustment. The 'Western' pattern was positively associated with metabolic syndrome [OR=1.67 (95% CI 1.08, 2.63), *P*=0.02]. There was also a small association between an index of multiple deprivation [OR=1.04 (95% CI 1.02, 1.06), *P*<0.001] and metabolic syndrome.

This cross-sectional study provides further support for a Western dietary pattern being a risk factor for metabolic syndrome in an older population.

Keywords: Mediterranean dietary pattern, Western dietary pattern, principal component analysis, metabolic syndrome, healthy ageing, metabolic syndrome prevalence, socio-economic status, index of multiple deprivation

Introduction

Metabolic syndrome is a cluster of interrelated symptoms including insulin resistance, central adiposity, hypertension, dyslipidaemia, and hyperglycaemia[(1)]. These metabolic abnormalities are associated with an increased risk of developing type 2 diabetes mellitus[(2)], and poorer cardiovascular disease outcomes[(3, 4)]. An association between metabolic syndrome and cognitive decline has also been suggested although the evidence supporting this is weaker[(5)]. The global prevalence of metabolic syndrome is estimated to be three times that of type 2 diabetes mellitus, with one billion people estimated to have metabolic syndrome[(6)].

Age is one risk factor for metabolic syndrome[(7-17)]. There is also a graded association between area-based deprivation and poorer health outcomes[(18)] including metabolic syndrome and its components[(19)]. More modifiable risk factors include diet and physical activity[(1, 20)]. The impact of dietary intake on the risk of non-communicable disease is well known. Accordingly, a low intake of whole grains, nuts and seeds, and fruit is one of the main dietary risk factors to which non-communicable disease in the Australasian region may be attributed[(21)]. Specifically, evidence also points to a diet high in fibre, and monounsaturated and polyunsaturated fats, being protective against metabolic syndrome[(22, 23)]. However, diets contain combinations of foods and a dietary pattern approach can identify additive or synergistic effects of foods and nutrients on health outcomes in a way that a measurement of a single food or nutrient cannot[(24)].

Several meta-analyses have explored associations between *a posteriori* dietary patterns (determined using factor or cluster analysis, or reduced rank regression) and metabolic syndrome. These meta-analyses had slightly different selection criteria but consistently found *a posteriori* dietary patterns containing food groups that would be considered unhealthy, had a pooled odds ratio for metabolic syndrome between 1.18 [95% CI 1.08, 1.30] and 1.28 (95% CI 1.17, 1.40) in cross-sectional studies[(20, 25)] or a relative risk of 1.29 (95% CI 1.09, 1.52), representing moderate quality evidence, in cohort studies[(26)]. While associations between *a posteriori* dietary patterns containing healthy food groups and metabolic syndrome reported a pooled odds ratio for metabolic syndrome between 0.83 (95% CI 0.76, 0.90) and 0.86 (95% CI 0.79, 0.91) in cross-sectional studies[(20, 25)], the pooled evidence in cohort studies had a relative risk of 0.76 (95% CI 0.50, 1.15) but was graded as low quality[(26)]. Meta-analyses further stratifying the data by geography and sex did not find associations between dietary patterns containing healthy food groups and metabolic syndrome in Western cultures[(20, 25)] or in males[(20)].

There has been only one study exploring dietary patterns and metabolic syndrome in adults in the Australasia region - in Australia (*n* 2415, aged 45+ years)[27]. A ‘healthy’ (whole grains, fresh and dried fruit, low-fat dairy; and low in fried potatoes, alcohol, and soft drinks) dietary pattern was positively associated with a metabolically healthy profile [OR = 1.16 (95% CI 1.04, 1.29)][27]. No associations were seen for ‘red meat and vegetable’ [OR = 0.99 (95% CI 0.89, 1.10)] or ‘refined and processed’ [OR = 0.92 (95% CI 0.81, 1.04)] dietary patterns and metabolic syndrome[27].

Moreover, few studies internationally have been undertaken that were specific to the higher risk, older population. Studies have been conducted with adults older than 50 years (China, *n* 1006)[28] and populations with a mean age greater than 60 years[10, 29, 30]. These studies reported inverse associations between dietary patterns with healthy food groups and metabolic syndrome. For example, a pattern containing red dates, gouji berries, dried fruit, nuts, and grains in a Chinese population (Urumqi cohort, *n* 4265) was protective[29], as was one high in fruit and vegetables and low in red and processed meats in a German cohort (*n* 853)[30]. In contrast, metabolic syndrome was positively associated with dietary patterns containing milk tea but not yoghurt in the Urumqi cohort[29]; legumes, beef, processed meat, and bouillon in a German population (*n* 905)[10]; and a ‘Western’ cluster (*n* 343) compared with a ‘healthy’ cluster (*n* 353) in an older Chinese population[28].

A posteriori dietary patterns are unique to a particular population. While dietary patterns have been identified in a representative sample of New Zealand adults[31, 32], research is also needed to explore dietary patterns within specific sub-groups of the population. Older adults living in New Zealand are likely to have different dietary patterns than younger adults due to cohort effects[31] but will also differ from older adults in other countries due to the unique food supply and cultural elements of New Zealand. Moreover, it is necessary to examine associations between dietary patterns and diet-related health outcomes particularly as the risk of metabolic syndrome increases with age. This study aims to examine associations between *a posteriori* dietary patterns and metabolic syndrome in an older New Zealand population.

Methods

Study design and participants

This cross-sectional study includes participants from the REACH study (Researching Eating, Activity, and Cognitive Health) where the primary aim was to explore associations between dietary patterns and cognitive function[33]. This secondary outcome explores the associations between those same dietary patterns and metabolic syndrome in the older adult. A protocol and methods describing the REACH study methodology was published earlier[34, 35]. A convenience sample of community-dwelling adults (aged 65-74 years) throughout the wider Auckland region, New Zealand, were invited to participate. Exclusions were based on the primary outcome of the REACH study i.e., any factors affecting cognitive function[34]. In addition, people were excluded if they came from the household of another REACH participant or had experienced any event in the past two years which had a substantial impact on dietary intake or cognitive function, e.g., death or illness of a family member.

Signing of informed consent forms and data collection took place at the Human Nutrition Research Unit, Massey University, Auckland, New Zealand, from April 2018 to February 2019. During a single study visit, researchers collected health, demographic, lifestyle, physical activity, blood pressure, and anthropometric data, and a fasted blood sample. A food frequency questionnaire (FFQ) was completed by participants at this visit[36]. The sample size of *n* 367 was based on the primary REACH outcome of cognitive function and not specifically a metabolic syndrome outcome[33]. Funding was provided by the Health Research Council of New Zealand, Grant 17/566. Ethical approval was granted by Massey University Human Ethics Committee: Southern A, Application 17/69.

Anthropometric data and blood pressure

For the height, weight, and hip and waist circumference measurements participants wore light clothing and no shoes. Height and weight were measured using a calibrated stadiometer and Tanita Electronic Scales. Waist and hip circumference were measured using a Lufkin W600PM flexible steel tape measure. Two measurements were taken for hip and waist. The mean value was used unless the second measurement differed by 1 cm or more from the first measurement. In this instance, a third measurement was taken and the median value used. The International Society for the Advancement of Kinanthropometry (ISAK) methods[37] were followed. Blood pressure was measured using a Digital Automatic Blood Pressure Monitor (Omron HEM-907). Participants rested quietly (seated) for five minutes before the first measurement and there was a one-minute rest period before the second measurement. The mean blood pressure measurement was used unless either systolic or diastolic measurements differed by more than 5 mmHg from the first measurement. In this instance, a third measurement was taken, and the median value used. A whole-body scan using a Dual-emission X-ray absorptiometry (Hologic, Discovery QDR series), calibrated daily, measured muscle and fat mass, and calculated body fat %[38].

Blood sampling and analysis

A qualified phlebotomist drew a fasted blood sample at the research facility. Whole blood was used to measure fasting blood glucose (HemoCue Glucose 201RT), lipid profile (total cholesterol, triglycerides, HDL-cholesterol) and HbA1c (both using Cobas b101 system[39]).

Health, demographic, and physical activity data

Health, demographic, lifestyle, and physical activity information were obtained by written questionnaires during the study visit. Data were checked for completeness and plausibility. Any queries were followed up on the research day or within a few days by phone or email. Demographic data included age, sex, ethnicity, education (secondary, post-secondary, university), living situation (with others, alone), first language, and residential address (for index of multiple deprivation score). Health data included past and current disease (acute, chronic), medication (list), and daytime sleepiness (how often are you excessively sleepy during the day? [never, rarely, frequently, often])[40]. Lifestyle data included physical activity level, smoking history (no, yes [current, past]), and supplement use (list).

The New Zealand Indices of Multiple Deprivation and participant's residential address determined the area deprivation score based on seven domains[18]. Polypharmacy was considered as five or more daily medicines[41]. The International Physical Activity Questionnaire - short form[42] was used to assess physical activity levels. A physical activity score was calculated using Metabolic equivalent of a task (MET-minutes) where one minute of activity is 3.3, 4.0 or 8.0 METs depending on an exercise level of walking, moderate or vigorous activity, respectively. One MET is equivalent to the rate of energy expended while at rest[42].

Metabolic syndrome

The National Cholesterol Education Program Adult Treatment Panel III (NCEP-ATP III)[43, 44] definition determined metabolic syndrome within the REACH population. Based on this definition, metabolic syndrome was present where three of the following five criteria were met: waist circumference ≥88 cm for women and ≥102 cm for men; a triglyceride level of ≥1.7 mmol/L; HDL-cholesterol level of <1.03 mmol/L in men or <1.3 mmol/L in women; blood pressure ≥ 130/85 mmHg; fasting blood glucose ≥5.6 mmol/L or where medication was taken to control blood pressure, elevated triglycerides, or low HDL-cholesterol[43].

Collection of dietary data

An online, validated 109-item FFQ[36] collected frequency and serving size data for foods eaten during the previous month. The FFQ had ten food categories and ten frequency response options ranging from "I never eat this food" to "6 plus times per day". For each participant and for each food item, a daily consumption quantity (g/d) was calculated. Missing values (<1% of all FFQ items) were imputed using the multiple imputation chained equations method and the *mice* package[45] with five imputations and 20 iterations (dietary pattern scores from each imputation were checked for robustness i.e., z-scores within 0.1 standard deviation, five imputed data sets were averaged for final dietary data set). Predictors used in the multiple imputation chained equations method were food items, age, sex, education and living situation. Each FFQ food item had a representative food allocated so energy intake could be calculated using the New Zealand FOODfiles 2016 food composition database[46]. Average daily energy intake was considered implausible if <2100 kJ or >14 700 kJ for women and <3360 kJ or >16 800 kJ for men[47]. While data on supplement use were collected it was not included in the data for dietary patterns.

Construction of dietary patterns

The food items from the FFQ were reduced to fifty-seven groups based on similarity of foods, culinary usage and a possible association to the primary outcome of the REACH study (i.e., cognition[33] (Supplementary Table 1). The Bartlett's test of sphericity measured the presence of relationships within the data (*P*<0.001) and the Kaiser-Meyer-Olkin (KMO) measured the sampling adequacy (KMO = 0.66). Both demonstrated the dietary dataset was suitable for principal component analysis which reduces the diet components based on their correlations with one another while retaining as much variation within the diet as possible[48].

Using R, version 3.6.1[49], the *psych* package[50] and varimax rotation, the data matrix of food groups (g/d, *n* 57) was analysed. Three dietary patterns (factors) were retained based on the scree plot, eigenvalue (>1) and interpretability of the factors. Factor loadings measure the relative contribution (correlation) of a food group to a dietary pattern. Positive loadings contribute to a dietary pattern while negative loadings have an inverse association to the dietary pattern. Food groups with factor loadings ≥0.30 or ≤-0.30 are considered significant contributors to a pattern from a sample size of 300[51]. A standardised dietary pattern score was calculated per participant per dietary pattern using the regression method. Labelling of dietary patterns was based on highly correlated food groups and the type of dietary pattern those food groups characterised.

Statistical analysis

Statistical analysis was performed using R Studio[52], R version 3.6.1[49], and *tidyverse*[53]. No data were transformed prior to statistical analysis.

Participant data, with a roughly symmetric distribution, were described with mean and standard deviation for continuous data or frequency summary statistics for categorical data. The Welch two-sample t-test or Pearson chi-squared test was used to examine differences between the sexes and between participants with and without metabolic syndrome for characteristic variables. Where categorical variables did not have adequate samples in each category, the Fisher Exact test was applied. BMI and body fat % were categorised as follows: BMI (normal = 18.5-24.9, overweight = 25.0-30.0, obese >30.0 kg/m^2)[54] and body fat % (obese is ≥30% males, ≥42% females)[55].

Logistic regression analysis was used to examine the association between each dietary pattern score (independent variable) and the prevalence of metabolic syndrome (dependent binary variable) while considering key confounding factors: age, sex, physical activity, index of multiple deprivation, and energy intake. With an older population, an Index of Multiple Deprivation was considered a better option to represent socio-economic status than income or education. The REACH population was homogenous in terms of ethnicity (primarily European) and this variable was excluded from further analysis. The first model was unadjusted and contained metabolic syndrome and the dietary pattern scores (Model 0). A second model included the confounding variables: age, sex, physical activity level, index of multiple deprivation, energy intake and other dietary pattern scores (Model 1). Odds ratios and 95% confidence intervals were calculated. Variables in the final regression model were checked for collinearity using the variance inflation factor[56]. The model showed no multicollinearity as no variables were above 5.0 (range 1.0 to 2.6).

To check for effect modifiers, interactions between dietary pattern scores (sex specific tertiles where appropriate) and sex, index of multiple deprivation, BMI, body fat % and energy intake; and between sex and index of multiple deprivation, BMI, body fat % and energy intake were tested.

Results

Participant characteristics

The REACH study recruited 371 participants. Figure describes the flow of participants through the study. All participants had plausible energy intakes. Five participants were removed from the analysis due to no dietary data (n 4) or no blood data (n 1). The characteristics of the remaining 366 participants are presented in Table 1. The prevalence of metabolic syndrome was 15% and not different between the sexes (males 14%, females 16%, P=0.64). Those with metabolic syndrome (n 56) had a higher BMI, a higher percentage of body fat, a higher level of deprivation, a lower 'Mediterranean style' dietary pattern score, a lower education (secondary level) and were more likely to take five or more medications per day than participants without metabolic syndrome (Table 1). Differences between the sexes in participants with metabolic syndrome were apparent. In those with metabolic syndrome, females (when compared with males) had a higher percentage of body fat (mean (SD) %, females 39 (4), males 28 (3), $P<0.001$), though not a higher BMI (mean (SD) kg/m^2, females 30 (5), males 31 (3), $P=0.55$), were more likely to live alone (females 39%, males 6%, $P=0.02$) and had a lower 'Western' dietary pattern score ($P=0.007$). Overall, 16% (*n* 57) were considered obese by BMI categories (>30 kg/m^2) and 11% (*n* 41) by body fat % categories (≥30% body fat [males] or ≥42% body fat [females]) (Table 1).

Of the 56 participants with metabolic syndrome, 55 participants were identified based on physical criteria and one participant was identified based on medication to control lipids and a high waist circumference. All five metabolic syndrome criteria were seen in five participants, four criteria in 18 and three criteria in 33 participants. The most prevalent metabolic criterion was high waist circumference (96%), followed by high blood pressure (91%), high triglycerides (74%), low HDL-cholesterol (63%), and high fasting blood glucose (26%).

Dietary patterns

Three dietary patterns were derived from the 109-item FFQ which explained 18% of the variation in dietary intake. Supplementary Table 2 displays the dietary pattern loadings, range of dietary pattern scores, eigenvalues and the variance explained by each dietary pattern.

Dietary pattern 1, named 'Mediterranean style', was characterised by salad vegetables; leafy cruciferous vegetables; other vegetables; avocados and olives; alliums; nuts and seeds; white fish and shellfish; oily fish; berries; water; salad dressings; cruciferous vegetables; eggs;

cheese; tomatoes; and all other fruit. The 'Mediterranean style' dietary pattern scores were associated with higher beta-carotene equivalents, vitamin E and folate intake (all P<0.001, all $R^2 \geq 0.26$)[35].

Dietary pattern 2, named 'prudent', was characterised by dried legumes; soy-based foods; fresh and frozen legumes; wholegrains; carrots; and spices. The 'prudent' dietary pattern scores were associated with higher fibre and carbohydrate intake (both P<0.001, both R^2 ≥,0.25)[35].

Dietary pattern 3, named 'Western', was characterised by processed meats; sauces and condiments; cakes, biscuits, and puddings; meat pies and chips; processed fish; confectionery; vegetable oils; beer; chocolate; salad dressings; cheese; and sweetened cereal. The 'Western' dietary pattern scores were associated with higher daily energy intake (P<0.001, $R^2 = 0.43$)[35].

These dietary patterns have been validated with a subset of the REACH study participants (*n* 294)[36]. The dietary pattern loadings obtained from the validation study subset were comparable to the full REACH cohort reported here. Tucker's congruence coefficient (phi) between the loadings of the FFQ derived dietary patterns (REACH validation subset v REACH full cohort) were 0.96, 0.91 and 0.88 for 'Mediterranean style', 'Western' and 'prudent' patterns respectively.

Metabolic syndrome and dietary pattern associations

No interactions between dietary patterns scores and sex, index of multiple deprivation, BMI, body fat %, and energy intake; and between sex and index of multiple deprivation, BMI, body fat % and energy intake were observed. In the base model (logistic regression analysis, model 0), metabolic syndrome was inversely associated with the 'Mediterranean style' pattern score [OR = 0.71 (95% CI 0.51, 0.96), P=0.03], not associated with the 'prudent' pattern [OR = 1.08 (95% CI 0.80, 1.40), P=0.59] and positively associated with the 'Western' pattern score [OR = 1.32 (95% CI 1.00, 1.73), P=0.05] (Table 2).

Model 1 included age, sex, physical activity, multiple deprivation, and energy intake as confounders. The inverse association (Model 0) between the 'Mediterranean style' pattern and metabolic syndrome was attenuated in Model 1 (P=0.11). On further examination, this association was attenuated when either the multiple deprivation score or energy intake was added independently into model 1. The 'prudent' dietary pattern was not associated with metabolic syndrome in Model 1. However, the positive association between the 'Western' pattern and metabolic syndrome strengthened [OR = 1.67 (95% CI 1.08, 2.63), P=0.02]. Model 1 showed a higher deprivation predicted metabolic syndrome although the association was small [OR = 1.04 (95% CI 1.02, 1.06), P<0.001] (Table 2).

Sensitivity analysis

One outlying participant following the 'prudent' pattern had a standardised dietary pattern score of 8.31 ('prudent' score range of -2.49 to 8.31 [Supplementary Table 2]). This participant consumed significant servings of carrots, peas, canned beans, brown rice, and couscous each day but remained within our energy intake boundaries. A sensitivity analysis recalculated the odds ratio of the association between metabolic syndrome and the dietary patterns after removing this one participant. This had no effect on model 0 or model 1.

Discussion

A cross-sectional study of healthy, older (65-74 years), community-dwelling adults in Auckland, New Zealand, identified three *a posteriori* dietary patterns and explored their associations with metabolic syndrome. The three valid [36] dietary patterns explained 18% of the variation in the diet of the REACH cohort – 'Mediterranean style', 'prudent', and 'Western'. The 'Mediterranean style' dietary pattern was inversely associated with metabolic syndrome, but the association was no longer significant when confounders (age, sex, index of multiple deprivation, energy intake and physical activity) were added in Model 1. The 'prudent' pattern was not associated with metabolic syndrome in any statistical models. The 'Western' dietary pattern was positively associated with metabolic syndrome, with age, sex, index of multiple deprivation, energy intake, and physical activity included as possible confounders (Model 1). Having a higher level of deprivation was positively associated with metabolic syndrome.

The 'Mediterranean style' pattern shared similar components with the traditional Mediterranean diet, with foods such as vegetables, avocados, olives, tomatoes, nuts, seeds, oily fish, white fish, shellfish, and berries[57]. The word 'style' was included in the name because New Zealand is not a Mediterranean country and not all elements of a Mediterranean diet are represented in this one pattern e.g., olive oil is included in the food group 'vegetable oils' because of its similar culinary uses to other vegetable oils. The 'Mediterranean style' pattern was also similar to 'healthy' dietary patterns (consisting of vegetables, fruit, fish, poultry, and whole grains) identified in recent meta-analyses[20, 25]. Mixed results, in both cross-sectional and cohort studies, are reported when it comes to associations between dietary patterns with these components, and metabolic syndrome[20, 25, 26]. The current study suggested that an increase of one standard deviation in the ‘Mediterranean style’ dietary pattern score, decreased the odds of having metabolic syndrome by 29%. However, the effects of multiple deprivation and energy intake independently attenuated the dietary pattern’s association in model 1 and it was difficult to separate the interplay between these variables and the ‘Mediterranean style’ pattern. This weak ‘Mediterranean style’ dietary pattern finding is still of value as it directs focus to associations between metabolic syndrome, higher deprivation, higher energy intake (diet quantity) and the ‘Mediterranean style’ pattern (diet quality). Further observational studies should consider these variables.

Interestingly, the ‘prudent’ dietary pattern had no association with metabolic syndrome, even though it shared components of the ‘healthy’ dietary patterns covered by meta-analyses e.g., vegetables and whole grains, though it lacked fruits, fish, and poultry[20, 25]. This was surprising considering the high levels of fibre associated with this pattern and the protective effects of fibre on metabolic syndrome[22, 58]. However, this ‘prudent’ pattern did contain only a limited range of foods (legumes, carrots, whole grains, and spices), and some of these food groups included processed foods such as canned baked beans, refried beans (dried legumes food group) and vegetarian sausages and burgers (soy-based foods food group) which may have blunted the beneficial effects of these food groups on health outcomes.

This study’s ‘Western’ pattern showed similarities to the ‘Western’ dietary patterns in other studies[20, 25] with common components such as processed meats, confectionery, chocolate, puddings, and refined grains, though it also contained vegetable oils which may have been used for cooking e.g., frying red and processed meat. Unlike the ‘Mediterranean style’ dietary pattern, the ‘Western’ pattern maintained an association with metabolic syndrome even when multiple deprivation and energy intake were held constant (Model 1).

Cross-sectional and cohort studies support a positive association between a dietary pattern with components of unhealthy food groups and metabolic syndrome[20, 25, 26]. In this current study, an increase of one standard deviation in the ‘Western’ dietary pattern score increased the odds of metabolic syndrome by 67%. Of note was the wide confidence interval which is consistent with an association as small as 8% or as large as 163%.

Other studies in older populations have found associations between dietary patterns and metabolic syndrome. In a German population (*n* 853, mean age = 61 years), a ‘SELONOP’ dietary pattern (containing fruit, vegetables, and antioxidant beverages) was inversely associated with metabolic syndrome [OR = 0.54 (95% CI 0.40, 0.73)][30]. 'Traditional' (containing rice, beans and oils)[59], and 'legumes, beef, processed meat and bouillon'[10] dietary patterns were positively associated with metabolic syndrome in Puerto Rican (*n* 1165, mean age ~60 years, [OR = 1.70 (95% CI 1.04, 2.70)]) and German (*n* 905, mean age = 61 years, [OR = 1.71 (95% CI 1.04, 2.79)]) populations, respectively.

The prevalence rate for metabolic syndrome in the current study was 15%. This is in line with an earlier New Zealand study (35-74 years) that reported a prevalence rate of 16% in an "Others" (excludes Māori and Pacific but includes New Zealand European) population[8], although another New Zealand study found the prevalence of metabolic syndrome in Europeans aged 60-79 years to be 22% for males and 31% for females[60]. Both studies used the NCEP-ATP III definition. The differences in prevalence between this current study and that of Simmons and Thompson[60] may be due to markedly different deprivation levels – Simmons and Thompson[60] based their study in South Auckland which has higher levels of deprivation[61] than North Auckland where the current study was based. This again highlights the complex interplay between deprivation and metabolic syndrome.

In the current study, the odds of metabolic syndrome increased with deprivation. In the final model, holding all other variables constant, for each 100-point increase in deprivation (score range 1 to 6181) the odds of metabolic syndrome increased between 2 and 6%. This is not surprising; deprivation and chronic diseases such as metabolic syndrome (and its components) are related[19, 62, 63] due to food insecurity, increased psychological stress[64], a healthy diet having a higher financial cost[65], and reduced access to primary medical care when cost is a barrier[66] e.g., in New Zealand primary health care is subsidised but not fully paid for by the Government. It is important to note the index of multiple deprivation did not interact with any of the dietary patterns, therefore living in an area of higher deprivation increased the risk of metabolic syndrome regardless of the dietary pattern eaten.

The current study used a multiple deprivation index, an approach that is not commonly used in other studies examining the association between *a posteriori* dietary patterns and metabolic syndrome. Sometimes a socio-economic status indicator (based on combinations of education, income, occupation, and household assets) have been included in other studies[29, 67, 68]. While associations between the dietary patterns and metabolic syndrome were reported in these studies, it is not known how the socio-economic status affected the association other than as a confounding variable. Our deprivation score is based on residential address, but this has limitations within our cohort, as several participants were living with family which may not accurately reflect their true socio-economic status.

In this current study, age, sex, physical activity, and energy intake were not significant predictors of metabolic syndrome. The narrow age range (10 years) in this study may not have provided sufficient variation to detect an association with metabolic syndrome. The prevalence of metabolic syndrome is steeper in females than males[69]. The driver behind this difference is an increase in abdominal obesity and a decrease in HDL-cholesterol levels in females after menopause[69]. Even so, there were no sex differences in the prevalence or as a predictor of metabolic syndrome in this current study. Adding energy intake to the model attenuated the association between the ‘Mediterranean style’ dietary pattern and metabolic syndrome to the point that it was no longer statistically significant. However, the association observed with the ‘Western’ pattern was retained, and in fact strengthened, suggesting that it resulted from the composition of the foods eaten, beyond just their energy content. Including energy intake as a possible confounder is important, though it is common for energy intake to be excluded from analyses[20] leaving ambiguity about any true effect of a dietary pattern itself.

Two mechanisms with dietary patterns are strongly associated with metabolic syndrome. The first acts through a persistent state of inflammation which is responsible for tissue and cell damage[70]. Evidence suggests the diet is able to influence inflammation either through a positive effect of a Mediterranean diet[71] or a negative effect of a Western dietary pattern[72]. The second mechanism is through oxidative stress[73]. Here, reactive oxygen species, a by-product of normal biochemical processes, are not neutralised due to insufficient antioxidants thus resulting in increased levels of plasma glucose, insulin and triglycerides[74]. The current study did not observe an association between the ‘Mediterranean style’ or ‘prudent’ pattern and metabolic syndrome. However, the ‘Western’ dietary pattern consisted of pro-inflammatory food groups (including processed foods), and was low in fruit and vegetables (which provide antioxidants), which could contribute to metabolic syndrome as described above.

Though BMI is recommended as an important confounder due to it being a well-defined risk factor for developing metabolic syndrome[20], BMI (and body fat %) were excluded as confounders in this study. Both BMI and body fat % were highly correlated with waist circumference which was one (of five) measure used to define metabolic syndrome and considered to be in the causal pathway[75]. In this older population, waist circumference was the most prevalent component of metabolic syndrome followed closely by hypertension, as has been reported by others[10, 60]. This can be expected as increasing central obesity and hypertension are both associated with age[76, 77].

This study has several strengths. To our knowledge, this is the first study in an older New Zealand population to explore associations between dietary patterns and metabolic syndrome. A full set of confounders was used in the analyses. Validated tools were used to collect physical activity and dietary data which produced robust dietary patterns[36] specific to our study population.

However, the findings of this current study also have limitations. First, the New Zealand has population groups with high prevalence of metabolic syndrome – 32% of Māori and 39% of Pacific people[8]. Our sampling did not capture these population groups hence our findings are not representative of the New Zealand population overall. In addition, our participants were self-selecting and more likely to be 'health motivated'. This study reports a secondary outcome of the REACH study and an *a priori* power calculation was not calculated for this outcome, therefore our findings may not have statistical power. Despite the FFQ being validated there remains inherent measurement errors associated with assessing dietary intake with any method used. It was also assumed that the current dietary data collected was the usual diet for our participants. Finally, this study is cross-sectional and while known potential confounders were adjusted for, we cannot infer a particular dietary pattern has a causal effect on metabolic syndrome.

Conclusion

In an older New Zealand population group of primarily European adults, the 'Western' dietary pattern, explaining 6% of the variation in the diet, was positively associated with metabolic syndrome. Also, of importance, was the observed positive association between higher deprivation and metabolic syndrome and future research should consider deprivation as a confounder. However, these results cannot be applied to the New Zealand population in general. Further observational studies in a larger representative sample of the New Zealand older population, including Māori and Pacific people, and those with higher deprivation may identify further associations with a dietary pattern with healthy or unhealthy food groups. The current study provides further support for a Western dietary pattern being a risk factor for metabolic syndrome in older people, an understudied population group.

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Conflict of Interest:

The authors declare no conflict of interests.

Authorship:

The authors' contributions were as follows: KLB, CAC, PRvH, BJ, CFH-R, WS, A-LMH, and JC designed research; KLB, CAC, PRvH, KDM, CS, OM conducted research; KM, KLB, JdS, BJ analysed data or performed statistical analysis or advised on analysis; KDM wrote paper; KLB, CAC, PRvH, KDM had primary responsibility for final content. All authors read and approved the final manuscript.

Figure Captions

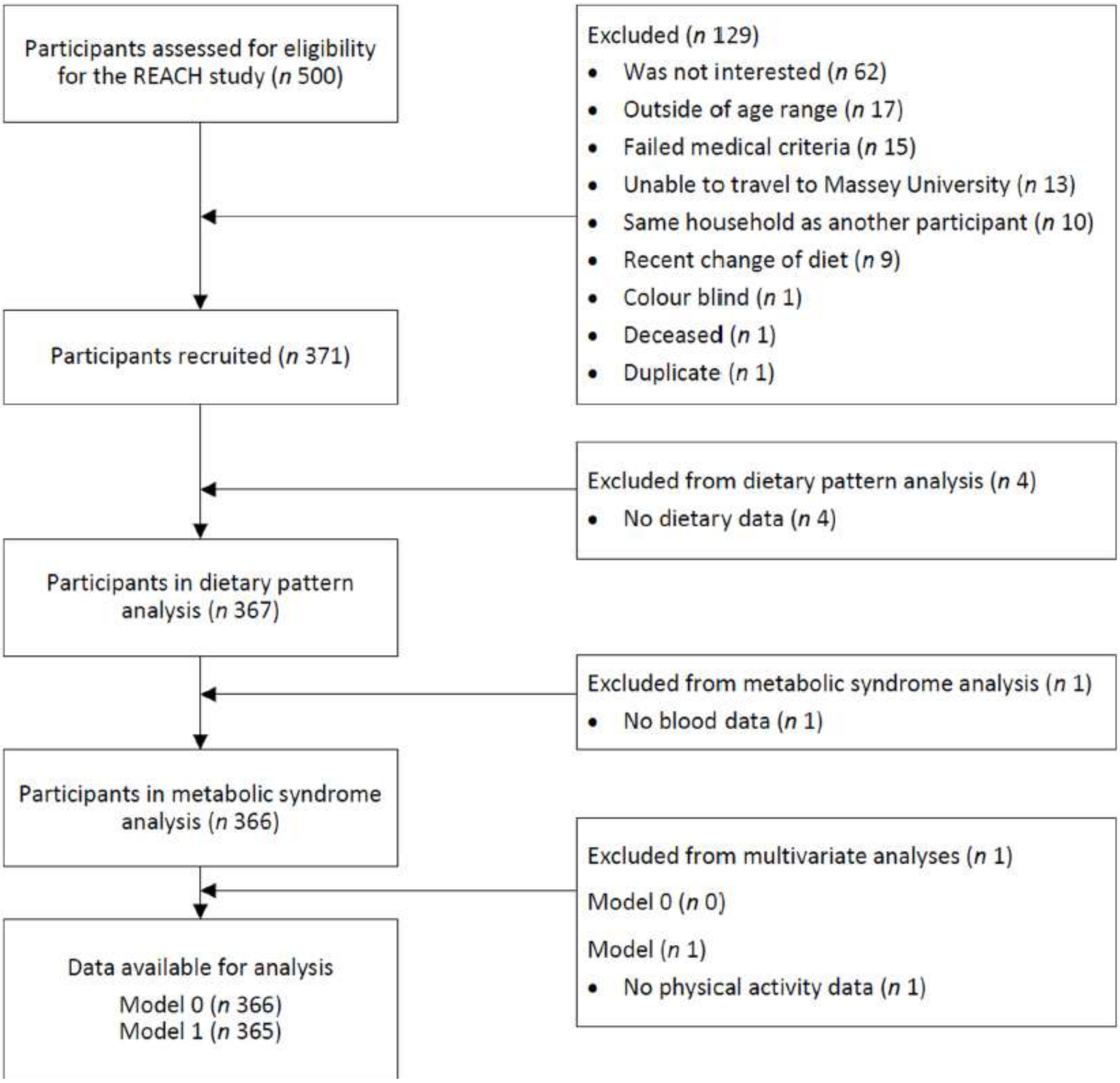

Figure 1: Flowchart of participants in the REACH (Researching Eating, Activity, and Cognitive Health) study.

Tables

Table 1: Characteristic of the REACH cohort and participants with and without metabolic syndrome including differences.

Characteristic	Total		With metabolic syndrome		Without metabolic syndrome		*P*
n (%)	366	(100%)	56	(15%)	310	(85%)	
Age (years)*	69.7	(2.6)	69.7	(2.6)	69.6	(2.5)	0.91
Sex (% male)†	131	(36%)	18	(32%)	113	(36%)	0.53
BMI (kg/m^2)*	26.3	(4.5)	30.6	(4.3)	25.5	(4.1)	<0.001
Normal (<25 kg/m^2)[a]†	151	(41%)	2	(4%)	149	(48%)	<0.001
Overweight (25-30 kg/m^2)†	158	(43%)	26	(46%)	132	(43%)	
Obese (>30 kg/m^2)†	57	(16%)	28	(50%)	29	(9%)	<0.001
Body fat %[b]*	31.8	(7.5)	35.4	(6.2)	31.2	(7.5)	<0.001
Not obese	324	(89%)	44	(80%)	280	(90%)	0.05
Obese	41	(11%)	11	(20%)	30	(10%)	0.05
Education†							
Secondary[c]	83	(23%)	20	(36%)	63	(20%)	0.03
Post-secondary	147	(40%)	17	(30%)	130	(42%)	
University	136	(37%)	19	(34%)	117	(38%)	
Employed (paid or volunteer)†	179	(49%)	25	(45%)	154	(50%)	0.58
Ethnicity†							0.07
Asian	11	(2%)	2	(4%)	9	(3%)	
European	345	(94%)	50	(89%)	295	(95%)	
Māori/Pacific	10	(3%)	4	(7%)	6	(2%)	
Index of Multiple Deprivation[d]* [(18)]	1982	(949, 3206)	2998	(1834, 3539)	1835	(845, 3046)	<0.001

Characteristic	Total		With metabolic syndrome		Without metabolic syndrome		*P*
Food Security							
Secure	351	(96%)	53	(95%)	298	(96%)	
Moderately secure	13	(4%)	1	(2%)	12	(4%)	
Insecure	2	(0%)	2	(3%)	0	(0%)	
Living†							1.00
Alone	106	(29%)	16	(29%)	90	(29%)	
With others	260	(71%)	40	(71%)	220	(71%)	
Polypharmacy [e]†	31	(8%)	9	(16%)	22	(7%)	0.03
Physical activity [f, g] (MET minutes/week)*	3106	(1680, 5118)	2803	(1422, 3407)	3206	(1848, 5172)	0.22
Smoker†							0.80
Yes (current and 'used to')	77	(21%)	13	(23%)	64	(21%)	
No	289	(79%)	43	(77%)	246	(79%)	
Daily energy intake (MJ)*	7.6	(2.1)	7.6	(2.4)	7.6	(2.1)	0.80
Dietary pattern score*							
Mediterranean style	0.00	(1.00)	-0.27	(0.99)	0.05	(0.99)	0.03
Western	0.00	(1.00)	0.25	(1.11)	-0.05	(0.97)	0.07
Prudent	0.00	(1.00)	0.06	(1.11)	-0.01	(0.98)	0.65

REACH, Researching Eating, Activity, and Cognitive Health; MET, metabolic equivalent of task

[a] includes 3 participants (1 male, 2 female) with BMI <18.5 kg/m^2.

[b] one value missing from female participant with metabolic syndrome. Obese is body fat % ≥30% (males) and ≥42% (females)[55].

[c] for education, 'no qualification' (*n* 9) and 'secondary' (*n* 74) were aggregated, due to small numbers.

[d] low score = least deprived, study range 11 to 5636, Index of Multiple Deprivation range = 1 to

Characteristic	Total	With metabolic syndrome	Without metabolic syndrome	*P*

6181.

[e] 5 or more medicines/d[(41)].

[f] one value missing from participant without metabolic syndrome.

[g] MET minutes/week based on 3.3 MET for walking, 4.0 MET for moderate activity and 8.0 MET for vigorous activity.

* mean (standard deviation) or median (25th, 75th quartile), differences between those with and without metabolic syndrome calculated using the Welch two-sample t-test (continuous variables).

† *n* (%) differences between those with and without metabolic syndrome calculated using Pearson chi-squared test or Fisher Exact test (categorical variables).

Table 2: Results of logistic regression (odds ratio and 95% CI) examining associations between metabolic syndrome and dietary patterns

Coefficient	Model 0[a]	*P*	Model 1[b]	P
Mediterranean style	**0.71 (0.51, 0.96)**	**0.03**	0.75 (0.53, 1.06)	0.11
Prudent	1.08 (0.80, 1.40)	0.59	1.17 (0.83, 1.59)	0.35
Western	**1.32 (1.00, 1.73)**	**0.05**	**1.67 (1.08, 2.63)**	**0.02**
Age			1.03 (0.92, 1.16)	0.63
Sex				
Male (reference)				
Female			1.91 (0.94, 4.04)	0.08
Physical Activity			1.00 (0.98, 1.01)	0.55
Multiple deprivation score			**1.04 (1.02, 1.06)**	**<0.001**
Energy intake			0.99 (0.97, 1.01)	0.39

[a] *n* 366.

[b] *n* 365, adjusted for dietary pattern scores, age, sex, physical activity, deprivation, and energy intake; missing data: physical activity score (*n* 1, without metabolic syndrome).

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