



SYSTEMATIC REVIEWS AND META-ANALYSES

The association of dietary patterns and carotid intima-media thickness: A synthesis of current evidence



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DASH diet;
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Abstract *Aims:* Dietary pattern (DP) analysis has emerged as a holistic method to understand the effects of food intake on health outcomes. Though dietary intake has been associated with cardiovascular disease, the association of DPs and carotid intima-media thickness (CIMT), a robust early marker of cardiovascular disease progression has not been comprehensively investigated. This study systematically explores the association of *a posteriori* and *a priori* DPs and CIMT.

Data synthesis: Through a systematic search of MEDLINE, CINAHL, and Web of Science, twenty studies that derived DPs using *a posteriori* or *a priori* methods with CIMT as an outcome were included. Four cross-sectional studies and 1 cohort paper reported a statistically significant association between increased consumption of 'unhealthy' foods (i.e. processed meat, soda drinks and refined grain) and increased CIMT. While four cross-sectional studies reported a statistically significant association of DPs characterized by increased consumption of 'healthy' foods (i.e. fruit and vegetables, fish) and decreased CIMT. DPs derived from each study varied depending on derivation method, study design and use of dietary data collection method.

Conclusion: Findings from this review are generally supportive of a trend between DPs with higher consumption of 'healthy' foods and lower consumption of 'unhealthy' foods and decreased CIMT; however, the association was largely not statistically significant. Evidence was overwhelmingly heterogeneous due to differences seen in DPs based on location and culture, sample characteristics and adjustment for confounders. Long-term prospective observational and interventional studies with standardized sample selection and dietary data collection are needed to significantly establish the role of DPs on CIMT.

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Introduction

Cardiovascular disease (CVD) is the leading cause of death worldwide [1,2]. Ischemic heart disease, neonatal

disorders, stroke and COPD accounted for more than 1 million deaths each worldwide in 2017 [3]. By 2040, ischemic heart disease followed by stroke are predicted to be the leading causes of death with the global burden of

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cardiovascular disease increasing from 11.1% to 14.7% by 2020 [4,5]. CVD is projected to remain the single leading cause of death, unless healthy lifestyles are adopted; particularly healthy eating [1,6,7]. Many approaches have been used to examine the influence of nutrition on atherosclerosis; particularly cross population comparisons, nutritional questionnaires and interventional studies. While some of these approaches are very informative about individual nutrients, the methodological problems in nutrition studies may sometimes account for the variability in results reported in the literature [8].

Until recently, the study of the relationship between food or nutrient intakes, particularly single nutrients, and health have been the dominant approach of study in nutritional epidemiology. This approach is effective if the development of a disease is causally related to the intake of the food component in question. However, the effect of a food component on health can vary depending on its interaction with food constituents, the cooking methods used, and the types of foods consumed [9].

To better understand the benefits of healthy eating on future cardiovascular health, numerous studies have shifted from single nutrient analysis to dietary pattern (DP) analysis [10]. This methodological shift led to the introduction of healthy dietary patterns into national dietary guidelines. The 2015–2020 United States Dietary Guidelines included the Healthy Mediterranean-Style Eating Pattern and Healthy Vegetarian Eating Pattern, which were developed by modifying the Healthy U.S. Style Eating Pattern. Similar to the Healthy U.S.-Style Eating Pattern, these patterns were designed to consider the types and proportions of foods Americans typically consume, resulting in eating patterns that are attainable and relevant in the U.S. population [11].

For example, the DASH (Dietary Approaches to Stop Hypertension) [12] and the PREDIMED (Prevención con Dieta Mediterránea) [13] trials have provided strong evidence supporting the role of specific dietary patterns in the primary prevention of hypertension through adherence to the DASH dietary pattern and the Mediterranean-style dietary pattern respectively. Different methods such as dietary indices have emerged to study DPs in epidemiological studies. *A priori* dietary patterns are derived from individual food components that are scored and ranked from maximum adherence to minimum adherence of consumption [9,14–17]. Though this approach may not enable the investigator to study dietary behavior or identify new dietary patterns related to disease risk, it can be used to test the validity of dietary recommendations as well as provide a holistic view of the effects of diet on health [9,18].

On the other hand, *a posteriori* methods such as principal component analysis/factor analysis (PCA/FA), and cluster analysis (CA) are statistical techniques that aggregate dietary variables from food frequency questionnaires or food diaries into factors that represent the broad eating patterns of the population being studied. With this approach, associations between dietary patterns and the risk of chronic disease notably, renal, gastric, and colorectal cancers and coronary heart disease have been observed. Reduced Rank Regression (RRR), on the other

hand, identifies DPs that are weighted linear combinations of food intake that explain the maximum variation in a set of biomarkers such as inflammatory biomarkers, that are hypothesised to be on the pathway between food intake and the outcome of interest [9,10,19]. The combination of analyses of food components, foods and dietary patterns is likely to provide most insight into the relationship between diet and disease risk [9].

Carotid intima-media thickness (CIMT) is an established surrogate marker of preclinical atherosclerosis and is being increasingly used as an end point in clinical studies [20,21] and to predict cardiovascular morbidity and mortality [22]. To date, there has only been one review that provided a brief overview of the association between individual dietary components and dietary patterns with CIMT [23]. It highlighted the inconsistency in studies investigating dietary patterns and their association with CIMT due to differences in the range and measurement of nutrients and covariates. In line with the methodological shift in nutritional epidemiology to better understand the relationship between nutrition and cardiovascular disease through dietary pattern analysis, we seek to comprehensively and systematically analyse current literature to determine the differences between a *priori* and a *posteriori* dietary patterns and their association with CIMT.

Methods

Data sources

The methodology of this review is conceived according to the PRISMA statement [24]. English-language literature was searched in MEDLINE, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and Web of Science databases up to January 2019. The search strategy consisted of two parts: (1) terms specifying dietary patterns using a combination of “diet”, “food”, “eat” and “pattern”, “habit”, “index”, and “score” combined with MeSH terms “Food Habits” and “Mediterranean” and “DASH diet” and (2) keywords that specified CIMT by a combination of “IMT”, “intima media thickness,” “carotid” and the MeSH term “Carotid Intima-Media Thickness” (Appendix A). We also manually searched reference lists from the included articles and of recent reviews to complete the data bank. We assessed the relevance of studies via a hierarchical approach based on title, abstract and the full manuscript. The search terms and criteria were verified by I.K.

Study selection

Two independent reviewers (S.B. and G.M.) conducted the search and assessed study eligibility and inclusion. Reviewers agreed to include studies that were either: (1) observational studies (cross-sectional, case-control and cohort studies) or randomized control trials (RCTs), (2) studied adults (≥ 18 years) who were healthy or at elevated risk of cardiovascular disease including those with metabolic syndrome, smokers or with type 2 diabetes only if present as a subset of the study population, (3) derived

dietary patterns using Principal Component Analysis/Factor Analysis or Reduced Rank Regression, a priori indices (MedDiet and DASH diet) or where investigators defined DPs based on a standardized diet collection method (FFQ, 24 h recall or food diaries) and (4) included CIMT of the common carotid artery (CCA) as one of the outcomes. Studies were excluded if they were in-vitro studies, examined single-nutrients or specific food habits such as street food or whole-grains, and omitted CCA IMT measures from their outcome.

Data extraction

Methodological characteristics, dietary pattern assessment and derivation, and clinical outcome were extracted from each study and organized according to dietary pattern (Table 1). The variables for methodological characteristics include study design, country, sample size studied after drop outs, gender and mean age of the sample according to dietary groups and follow-up period for RCTs and cohort studies. The variables for dietary patterns extracted were the dietary assessment tool, dietary pattern derivation method, and the dietary patterns identified along with highly consumed food components of each pattern. Studies modelled dietary patterns continuously and/or categorically in quintiles or tertiles. Where both models are provided, only the continuous model is reported. Lastly, the variables characterizing the clinical outcome; CIMT, include the IMT effect with confidence intervals or standard error, the statistical significance of the association (P-value), and the fully adjusted confounding variables. For the purpose of this study, only the IMT of the CCA is reported and where CCA IMT is not reported separately, the mean IMT of CCA and internal common artery (ICA) combined is reported.

Results

Characteristics of included studies

As illustrated in Fig. 1, the search yielded 231 unique papers (excluding 152 duplicates) of which 20 papers met the inclusion criteria (15 cross-sectional studies [25–39], 2 cohort studies [40,41], 2 RCTs [42,43] and 1 case control study [44]). Sixteen studies included men and women in similar numbers [25,27–37,39–44], two studies included only women [26,38], and two studies included only men [25,39]. The mean age ranged from 30 years to 67 years, where the studies conducted in Europe and USA tended to have higher age groups except for one [34] and one study studied postmenopausal women [26].

All studies measured CIMT using ultrasound B sonography, the standard method of measurement; however, there was variation in the anatomical locations of measurement included in the CIMT outcome. For the purpose of this review, mean IMT of the CCA excluding ICA was the outcome of interest; however, two papers reported mean CCA and ICA IMT [28,39]. Thirteen papers collected dietary data via food-frequency questionnaires [25–29,32,33,35,36,41–44]

where 7 papers derived dietary patterns using *a posteriori* methods (PCA/FA/RRR) [30,33,34,36,40,41,45], 10 studies used *a priori* methods based on standardized scores [26,28,29,31,32,35,37,42–44] and the last 3 papers studied vegetarian diets based on investigator-defined criteria [25,38,39]. The three papers that studied vegetarian diets were included to investigate the relationship of vegetarian diets with CIMT, which is a well-defined dietary pattern.

A summary of all the dietary patterns identified through the studies included in this review and the statistical significance (P-value) of the association are reported in Table 1.

The Mediterranean diet and CIMT

The Mediterranean diet (MedDiet) has been widely studied and shown to be robustly atheroprotective [46–48]. Although the Mediterranean Diet is a traditional dietary pattern that happens to be associated with positive health outcomes, adherence to the diet has been quantified by the Mediterranean Diet Score which is the summation of scores based on components of the traditional Mediterranean diet namely high intake of fruit, vegetables, bread and other cereals, olive oil, moderate intake of dairy products, fish and poultry and low intake of red meat [14].

Gardener et al. showed a slight decrease ($r = -0.000357$) in CIMT per 1 SD increase in the continuous MeDi score; however, the relationship was not statistically significant ($P = 0.80$) [28]. Similar results were seen in the PREDIMED trial [42] a large randomized control trial where 187 symptom-free patients at risk for CVD were randomized into three diet groups: MedDiet with supplemental nuts, MedDiet with supplemental extra virgin olive oil, and a control diet (low-fat). Starting with similar baseline IMT values between all the three groups, Murie-Fernandez et al. reported a reduction in mean IMT after one year. However, this within-group reduction was only statistically significant for the second group (MedDiet + nuts: -0.031 mm (95% CI: -0.055 to -0.007)). When the sample was stratified according to baseline IMT (cut-off: 0.9 mm), they noticed significant reductions in IMT for both intervention groups among participants with a baseline IMT greater than 0.9 mm.

Mateo et al. found no significant association between MedDiet adherence and mean or maximum IMT. Compared with individuals in the lowest quartile, participants with the highest MedDiet scores were, on average, older, less likely to be current smokers, had higher levels of HDL cholesterol and lower concentration of CRP, and were more physically active.

A 2-year RCT [43] randomized participants to low-fat, Mediterranean, or low-carbohydrate diets groups as weight loss interventions. The mean IMT at baseline was 0.817 ± 0.17 mm and 2 years after intervention, CIMT changed by -1.1% to 0.808 mm ($P = 0.18$), with no significant difference between diet groups ($P = 0.91$).

Overall, there was no convincing evidence that may suggest an association between the Mediterranean diet and CIMT progression based on the studies to date.

Vegetarian diet and CIMT

In a systematic review and meta-analysis, Dinu et al. [49] recently reported that vegetarian diets are effective in improving CV risk markers including CIMT [50] and thus people consuming vegetarian diets had a lower probability of developing CVD. Yang et al. [39] presented notable protective effects of the Chinese vegetarian diet compared to the omnivore on CIMT. They demonstrated significantly lower IMT as well as reduced triglycerides, LDL and diastolic BP in vegetarian men compared to the omnivores (0.59 ± 0.16 cm and 0.63 ± 0.10 cm respectively, $P = 0.014$) [39]. Vegetarians were also divided according to duration of vegetarian diet (<6 yrs, 6 to \leq 11 yrs, >11 yrs) where those in the first (<6 yrs) and second tertiles (6 to \leq 11 yrs) showed lower IMT compared to the omnivores. Thus, they concluded that IMT is dependent on duration of vegetarian diet; however, the effects on reduction of IMT were not significant in those whose duration was beyond 11 years, possibly due to nutritional deficiency that may emerge in long-term vegetarians.

Acosta-Navarro et al. [25] found that individuals who consumed a vegetarian diet (mean duration 17.8 SD

12.5 yrs) had lower CIMT value than those who consumed an omnivore diet ($P = 0.003$). These differences persisted after adjustment for age, SBP and BMI. Their findings confirmed Yang et al.'s conclusions [39] that suggest a vegetarian DP (consumption void of meat, fish and poultry) is independently associated with improved CIMT. Though, Taiwanese vegetarian women were seen to have lower levels of fasting serum glucose, HDL-C and LDL-C, Su et al. [38] found no significant difference in CCA IMT between postmenopausal Taiwanese women who consumed a vegetarian and omnivorous diet.

Overall, there was convincing evidence that may suggest the Vegetarian diet in Asian samples have a protective effect on CIMT progression based on the studies to date.

DASH diet and CIMT

The Dietary Approaches to Stop Hypertension (DASH) diet, characterized by high proportions of fruit, vegetables, low-fat dairy products, whole-grain foods and low in saturated fat and refined sugar, was specifically designed to lower blood pressure in an American population and has been associated with various cardioprotective effects. One study

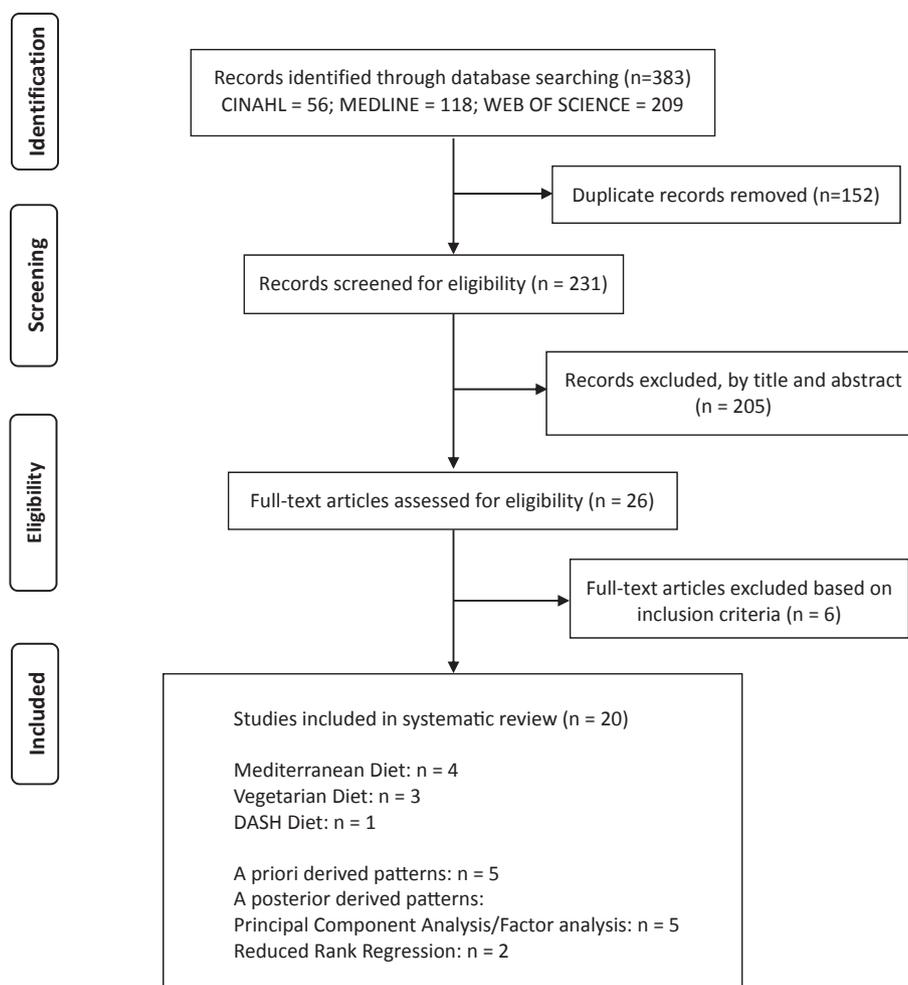


Figure 1 Flow Summary of literature search. Adapted from The PRISMA Group (2009) [47].

Table 1 Characteristics and CIMT effect of all included studies (N = 20) stratified according to a priori or a posteriori dietary pattern derivation method.

First Author (Year of Publication), Country, study design, follow-up duration (years)	Sample Size (n), % men, mean age (years)	Diet Assessment Tool, Dietary Pattern Derivation Method (modelling method)	Dietary Patterns Identified (highly consumed food components)	IMT section measured	Mean IMT (mm, unless otherwise specified) ± SE or (95% CI), P-Value	Adjusted Confounders (multivariate model)
Mediterranean Diet						
Gardener (2014), USA, cross sectional	1374, 40%, 66 ± 9	FFQ, MeDi Diet Score (continuous; higher score indicates greater adherence)	Mediterranean Diet (dairy, meat including poultry, fruits, fruit juices and nuts, vegetables excluding potatoes, legumes, cereals, grains, and fish)	Mean IMT of near and far walls of CCA, bifurcation IMT, ICA	Beta coefficient per 1 SD increase: −0.000357, P = 0.80	Age, sex, ethnicity, education, smoking status, physical activity, total daily calories, blood sugar, blood pressure (systolic/diastolic), LDL/HDL, BMI, medications (cardiac and anti-hypertensive, diabetic, cholesterol-lowering), prescribed diet, previous cardiac disease.
Mateo-Gallego (2017), Spain, cross sectional	2523, 95.7%, Q1: 50.9 ± 4.03; Q2: 51.3 ± 3.87; Q3: 51.3 ± 3.87; Q4: 51.7 ± 3.72	FFQ, Alternative MEDiterranean score (aMED) (quartiles; higher scores reflect higher MedDiet adherence)	higher intakes of vegetables, fruits, legumes, cereals, whole-grain cereals, and olive oil.	Mean and maximum IMT of left and right CCA	N = 2396 Mean IMT: Q1: 0.69 ± 0.12; Q2: 0.69 ± 0.12; Q3: 0.68 ± 0.12; Q4: 0.69 ± 0.11 P = 0.329	Age, sex, energy intake, education, BMI, smoking status, physical activity, blood pressure (systolic/diastolic), LDL/HDL, diabetes mellitus, C-reactive protein, and lipoprotein(a)
Murie-Fernandez (2011), Spain, RCT, 1y	187, 79%, 67 ± 6	FFQ, MedDiet score	MedDiet with Extra Virgin Olive Oil; MedDiet with nuts (walnuts, hazelnuts, and almonds); Control diet (low fat diet)	Mean IMT of far walls of right and left CCA	IMT Difference: MedDiet + EVOO: −0.012 (−0.035, 0.011) MedDiet + Nuts: −0.031 (−0.055, −0.007) Control: −0.007 (−0.031, 0.017) P = 0.33	Age, sex, hyperlipidaemia at baseline
Shai (2010), Israel, RCT, 2y	140, 88%, 51.43 (SD 6.15)	FFQ and Food Diaries	Low-fat diet Low-Carbohydrate Diet (fat, protein, cholesterol, urinary ketone) Mediterranean Diet	Mean IMT of far wall of CCA	At baseline: 0.817 ± 0.17, P = 0.18 At follow-up: 0.808, P = 0.91 No significant difference between diet groups	Age, sex, dietary group, baseline CIMT, weight, SBP, ApoA1, total homocysteine
Vegetarian Diet						
Acosta-Navarro (2017), Brazil, cross sectional	88, 100%, VEG: 45.5 ± 7.8, OMN: 46.8 ± 9.6	24 h Dietary Recall, FFQ	VEG (vegetarian diet void of meat, fish, and poultry for at least 4 years (could be lacto-ovo-vegetarians (consuming egg and milk and dairy products) or vegans (consuming no eggs or milk and dairy products)) OMN (omnivore diet consumption of any type of meat at least five or more servings by week)	Right CCA	c-IMT (µm) VEG: 593 ± 94; OMN: 661 ± 128 P = 0.003	Age, blood pressure (systolic), and BMI.

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Table 1 (continued)

First Author (Year of Publication), Country, study design, follow-up duration (years)	Sample Size (n), % men, mean age (years)	Diet Assessment Tool, Dietary Pattern Derivation Method (modelling method)	Dietary Patterns Identified (highly consumed food components)	IMT section measured	Mean IMT (mm, unless otherwise specified) \pm SE or (95% CI), P-Value	Adjusted Confounders (multivariate model)
Su (2006), Taiwan, cross sectional	118, 0%, VEG: 59.2 \pm 6.4, OMN: 57.5 \pm 5.1	Structured Questionnaire	Exclusive consumption of a diet void of meat, fish, and poultry for at least 5 years.	Maximal right and left CCA IMT	VEG: 0.773 \pm 0.187 OMN: 0.739 \pm 0.132 P = 0.421	Age, BMI, LDL-C, and fasting blood glucose
Yang (2011), China, cross sectional	179, 100%, Vegetarians: 32.6 \pm 12.7; Omnivores: 34.2 \pm 6.0	24 h Dietary Recall, Average of daily consumption of energy and nutrients (categorical; vegetarians classified in tertiles according to age started and duration of vegetarian diet)	Chinese vegetarian Diet (vegetables, fruits, seeds, nuts, dairy products, and eggs) Omnivore Diet	Mean IMT of right and left CCA, bifurcation, ICA	Age of starting vegetarian diet: Q1 (<17yrs): 0.57 (0.55, 0.60) Q2 (17–22yrs): 0.57 (0.54, 0.59) Q3 (>22yrs): 0.58 (0.55, 0.60) Omnivores: 0.62 (0.60, 0.64) P = 0.016 Duration of vegetarian diet: Q1 (0–6yrs): 0.57 (0.55, 0.59) Q2 (6–11yrs): 0.57 (0.55, 0.59) Q3 (\geq 12yrs): 0.60 (0.57, 0.62) Omnivores: 0.62 (0.60, 0.64) P = 0.047	Age, smoking status, drinking, duration of vegetarian diet, history of diabetes, hypertension, and hyperlipidaemia
DASH Diet						
Maddock (2018), UK, cross-sectional	1298, 48%, 60–64 years	5-day estimated food diaries, DASH-type diet score (sex-specific quintiles (Q1–Q5) which higher quintiles representing higher consumption of food components)	DASH: high intake of fruits (including pure fruit juice), vegetables (excluding potatoes), nuts and legumes	Mean IMT of right and left CCA	Correlation Coefficient Q1: Ref; Q2: –0.06 (–0.26, 0.14); Q3: –0.10 (–0.29, 0.09); Q4: –0.10 (–0.29, 0.09); Q5: –0.24 (–0.44, –0.04) P = 0.02	Socioeconomic position, BMI, smoking and physical activity
A Priori derived DPs						
Bondonno (2017), Australia, cross sectional	1010, 0%, 75	FFQ, Dietary Inflammatory Index (DII) score (continuous; higher score associated with higher intake of pro-inflammatory diet)	fruits, vegetables, whole grain foods linked with lower circulating concentrations of inflammatory biomarkers (C-reactive protein, IL1 β , IL4, IL6, IL10 and TNF- α)	Mean IMT and maximum IMT of CCA	Mean (per 1SD): Beta-coefficient: 0.013 (0.002, 0.023), P = 0.016	Age, smoking status (current or previous smoker), BMI, energy intake, energy expended in physical activity, SES, use of low-dose aspirin, antihypertensive medication, statins, prevalent ASVD and treatment
Luedemann (2002), Germany, cross sectional	1633, 47%, 57.7 (SD 6.93)	FFQ, German Society of Nutrition Food Groups (categorical; according to tertiles)	Unfavourable (meat, sausages, chocolate, cakes, salted snack) Normal (fish, vegetables, salad, fresh fruit, whole grain bread, oats) Optimal (potatoes, pasta, rice, salad, vegetables, fresh fruit, oats, whole grains)	Mean IMT of far wall of right and left CCA	Non-Smoker Unfavourable: 0.750; Normal: 0.735; Optimal: 0.723 P \leq 0.05 Smoker Unfavourable: 0.771; Normal: 0.763; Optimal: 0.778 P \geq 0.05	Age and sex

Mokbel Alissa (2018), Saudi Arabia, case-control	105, 27%, 57.8 ± 0.5	FFQ, Alternate Healthy Eating Index (AHEI) diet quality score (Good Score (>=81), Needs improvement (51-80), Poor (<=50))	Higher scores represent higher intake of vegetables, fruit, whole grains, nuts and legumes, long-chain omega-3 fats, polyunsaturated fatty acids	Mean IMT of near and fall wall of CCA	Good Score (>=81): CIMT ≥0.82 mm Needs improvement (51-80): CIMT ≥0.85 mm Poor (<=50): CIMT ≥0.90 mm P ≥ 0.05	
Nettleton (2008), USA, cross sectional	5042, 47%, Q1: 59.6 ± 0.3; Q2: 60.8 ± 0.3; Q3: 62.2 ± 0.3; Q4: 62.2 ± 0.3; Q5: 63.9 ± 0.3	FFQ, A priori scores (categorical; according to quintiles)	Comprehensive healthy dietary pattern (dairy, poultry, fruits and nuts, vegetables fried potatoes), legumes and avocados, cereals, grains, and fish)	Mean IMT of far walls of right CCA	Q1: 0.84 (0.83, 0.85); Q2: 0.84 (0.83, 0.85); Q3: 0.84 (0.83, 0.84); Q4: 0.84 (0.83, 0.84); Q5: 0.84 (0.83, 0.85) P = 0.09	Age, smoking status, physical activity, blood pressure (systolic), ethnicity, study centre, education school, energy intake, systolic blood pressure, supplement use, height, weight, pulse rate, waist circumference
Recio-Rodriguez (2017), Spain, cross sectional	500, 54.4%, 60.3 ± 8.4 yrs	Short diet quality screening questionnaire, Diet Quality Index (DQI) (increased consumption of healthy food components, higher score)	Bread, vegetables, fruit, yoghurt/milk, pasta/rice, olive oil, alcohol and weekly consumption of fish, legumes and nuts	Mean IMT of near and fall wall of CCA	Regression Coefficient -0.001 (-0.003, 0.002) P = 0.690	Age, sex, level of education, smoking, physical activity, medications (antihypertensive, antidiabetics and lipid lowering)
A Posteriori derived DPs: Principal Component Analysis/Factor Analysis						
Buscemi (2013), Italy, cross sectional, 1y	929, 35%, MedDiet Group: 53 ± 13; Intermediate Group: 48 ± 14; Unhealthy Group: 44 ± 15	FFQ, PCA (dietary clusters)	Unhealthy (soft drinks, fried foods, seed oils, cured meats, butter, red meat and sweets) Mediterranean Diet (fruit, milk and cheese, olive oil, vegetables, pasta and bread) Intermediate habits (between the unhealthy and the Mediterranean patterns)	Mean IMT of far wall of right and left CCA	Unhealthy: 0.65 ± 0.01 Intermediate: 0.65 ± 0.01 Mediterranean: 0.64 ± 0.01 P = 0.63	Age
Kesse-Guyot (2010), France, cohort, 7.5y	1026, 52%, 52.5 ± 4.7	24 h Dietary Recall, PCA (categorical; score according to tertiles)	Pattern 1 (meat, poultry, processed meat, alcoholic beverages, wine) Pattern 2 (vegetables, vegetable oil, fish, seafood, fat-free/low-fat sauces, reduced-fat products, fruits) Pattern 3 (bread, crisps, butter, cheese) Pattern 4 (starch, sweetening products, butter)	Mean IMT of far wall of CCA	Pattern 1 Q1: 0.702 ± 0.004; Q2: 0.705 ± 0.004; Q3: 0.696 ± 0.004 P = 0.36 Pattern 2 Q1: 0.701 ± 0.004; Q2: 0.699 ± 0.004; Q3: 0.704 ± 0.004 P = 0.66 Pattern 3 Q1: 0.700 ± 0.004; Q2: 0.703 ± 0.004; Q3: 0.701 ± 0.004 P = 0.84 Pattern 4 Q1: 0.699 ± 0.004; Q2: 0.700 ± 0.004; Q3: 0.704 ± 0.004 P = 0.40	Age, sex, smoking status, level of education, BMI, mean arterial pressure, medications (lipid lowering, anti-hypertensive, antidiabetic), and heart rate.

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Table 1 (continued)

First Author (Year of Publication), Country, study design, follow-up duration (years)	Sample Size (n), % men, mean age (years)	Diet Assessment Tool, Dietary Pattern Derivation Method (modelling method)	Dietary Patterns Identified (highly consumed food components)	IMT section measured	Mean IMT (mm, unless otherwise specified) \pm SE or (95% CI), P-Value	Adjusted Confounders (multivariate model)
McClintock (2016), Bangladesh, cross sectional	1149, 38%, 45.5	FFQ, PCA (continuous; effect estimate per 1 SD increase in diet adherence)	Balanced pattern (rice, red meat, fish, fruit and vegetables) Animal protein diet (eggs, milk, red meat, poultry, bread and vegetables) Gourd/root vegetables diet (gourds, radishes, pumpkin, sweet potato and spinach)	Mean IMT of near and far walls of right and left CCA	Difference in IMT: Balanced: -0.00495 ($-0.00978, -0.00011$), $P = 0.045$ Animal Protein: 0.00203 ($-0.00320, 0.00726$), $P = 0.45$ Gourd Root Vegetables: 0.00774 ($0.00286, 0.01262$), $P \leq 0.01$	Age, sex, daily energy intake, smoking status, BMI, Systolic BP, current diabetes diagnosis
Mikkila (2009), Finland, cross sectional, 21y	785, 46%, 30.3 (24–39)	48 h Dietary Recall, PCA (continuous; increasing score signifies greater adherence to pattern)	Traditional dietary pattern (intakes of rye, potatoes, milk, butter, sausages, coffee) Health-conscious dietary pattern (vegetables, legumes and nuts, rye, tea, cheese, other dairy products, alcoholic beverages)	Maximal IMT of far walls of right and left CCA	Beta coefficient per 1 SD increase: Traditional: W 0.003 ± 0.007 , $P = 0.66$ M 0.019 ± 0.006 , $P \leq 0.01$ Health-conscious: W 0.006 ± 0.006 , $P = 0.26$ M -0.002 ± 0.005 , $P = 0.76$	Age, total energy, smoking status, physical activity, education, systolic blood pressure, LDL/cholesterol, BMI
Nettleton (2007), USA, cross sectional	5089, 47%, PCA Q1: 63.6 ± 0.3 ; PCA Q3: 61.6 ± 0.3 ; PCA Q5: 59.5 ± 0.3 ; RRR Q1: 60.9 ± 0.3 ; RRR Q3: 62.1 ± 0.3 ; RRR Q5: 62.1 ± 0.3	FFQ, PCA; RRR with CRP, IL-6, fibrinogen, homocysteine as response variables (categorical; according to quintiles)	PCA factor 1 (fats and oils, processed meats, fried potatoes, desserts) RRR Factor 1 (fats and oils, processed meats, fried potatoes, desserts, non-diet sodas)	Mean IMT of far walls of right CCA	PCA Factor 1 Q1: 0.84 ($0.83, 0.85$); Q2: 0.84 ($0.83, 0.85$); Q3: 0.85 ($0.84, 0.86$); Q4: 0.85 ($0.84, 0.86$); Q5: 0.86 ($0.84, 0.87$) $P = 0.13$ RRR Factor 1: Q1: 0.84 ($0.83, 0.85$); Q2: 0.85 ($0.84, 0.86$); Q3: 0.85 ($0.84, 0.86$); Q4: 0.85 ($0.84, 0.86$); Q5: 0.86 ($0.85, 0.87$) $P = 0.006$	Age, smoking status energy, study centre, ethnicity, education level, active/inactive leisure activity, dietary supplement use.

A Posteriori derived DPs: Reduced Rank Regression	
<p>Liese (2010), USA, cohort; 5.2y</p> <p>802, 44%; Q1: 54.9 (SD 8.7); Q2: 55.2 (SD 8.2); Q3: 54.5 (SD 8.4); Q4: 53.9 (SD 8.4)</p> <p>RRR with PAI-1, fibrinogen as response variables (categorical); increasing quartiles signifies increasing intake of less healthful food groups)</p>	<p>More healthful food groups to less healthful food groups (low-fibre bread and cereal, red and processed meat, cottage cheese, tomato foods, regular soft drinks and sweetened beverages)</p> <p>High B-Vitamin DP: strongly and positively correlated with dietary folate and dietary VB12 (high intake of vegetables, fruit, and low fibre breakfast cereals low intakes of processed meat, white bread and, sugar)</p>
<p>Maddock (2018), UK, cross-sectional</p> <p>1562, 48%, 60–64 yrs</p> <p>5-day estimated diet diary, RRR with plasma Hcy, dietary folate and dietary vitamin B12 as response variables (DP z-score; higher quintile is associated with higher consumption of food components)</p>	<p>Mean IMT of Left DP Q1 REF; DP Q2: -0.09 and right CCA (-0.29, 0.10); DP Q3: -0.22 (-0.41, -0.03); DP Q4: -0.19 (-0.38, 0.01); DP Q5: -0.14 (-0.33, 0.06)</p> <p>P = 0.16</p>
<p>Age, sex, smoking status, ethnicity, clinic location, blood pressure (systolic/diastolic), glucose tolerance status at baseline, BMI, total and HDL cholesterol</p>	<p>Smoking status, physical activity, dietary misreporting, socioeconomic status, BMI, diabetes.</p>
<p>IMT Difference (µm): Q1 0.02; Q2 0.02; Q3 0.07; Q4 0.06</p> <p>P = 0.0017</p>	

showed that participants in higher quintiles of long-term DASH-type diet had lower CIMT than those in the lowest quintile after adjustment for socioeconomic profile. The association remained statistically significant following adjustment for BMI, smoking and physical activity. However, the association between greater adherence to the DASH diet at 36 and 43 years when assessments were conducted and CIMT was stronger than any other time point, suggesting that consuming a DASH-type diet earlier in adulthood may be important to influence CIMT [31].

A priori defined dietary patterns and CIMT

Apart from the Mediterranean Diet-Style Score and DASH diet, various other predefined indices of overall diet quality have been proposed and validated by relating the index score to health outcome. The Comprehensive Healthy Dietary Pattern (HDP), categorised food groups as positive (anticipated to favourably affect CVD outcomes), neutral (anticipated to neither favourably nor adversely affect CVD outcomes), and negative (anticipated to adversely affect CVD outcomes). CCA IMT measures differed significantly across quintiles of the HDP after multivariable adjustment (P = 0.007, results not shown); however, this association did not withstand adjustment for waist circumference (P = 0.09) [35].

Luedemann et al. [29] categorized participants into optimal lifestyle, normal lifestyle and unfavourable lifestyle based on the level of physical activity and dietary consumption. CIMT of non-smoker participants in the optimal dietary pattern (P < 0.05) characterized by increased consumption of pasta, rice, salad or vegetables, fresh fruit, whole grains and oats was significantly lower than those consuming the normal (increased consumption of fish, vegetables, potatoes, pasta and rice, and oats) or unfavourable dietary pattern (increased consumption of meat, sausages, chocolate, cakes, salted snacks).

The Alternate Healthy Eating Index (AHEI) is characterized by high consumption in vegetables, fruit, whole grains, seafood, and legumes; one that would contain carotenoids, ascorbic acids, phytochemicals, dietary fibres, omega-3 fatty acids and other nutrients well known to have cardioprotective effects [51]. The AHEI was not significantly different across AHEI categories and CIMT values (P > 0.05) in an overweight Arab population. However, after adjustment for age and energy intake, a significant inverse relationship was seen between mean AHEI score and CIMT (r = -0.197, P < 0.01) [44].

Previous studies have shown that diets rich in fruits, vegetables and whole-grain foods are linked with lower circulating inflammatory biomarkers (C-reactive protein, IL1, IL4, IL6, IL10 and TNF-alpha), and thus are associated with decreased risk of chronic disease such as CVD [52–56]. The Dietary Inflammatory Index (DII), created to assess the overall inflammatory potential of an individuals' diet, was linearly associated with mean and maximum CCA IMT in age and multivariable-adjusted models in post-menopausal women. Participants with a DII score greater than 1.721 (top quartile) had a significantly higher CCA

IMT than participants with a DII score less than 1.370 (bottom quartile) after multivariable adjustment for baseline risk factors [26].

The Diet Quality Indices (DQI) [37] are calculated by a combination of foods and/or nutrients that represent a dietary pattern. The best values in these indices have been associated with positive changes in weight and inverse relationship with inflammatory response markers associated with vascular health. Higher DQI score suggests a higher diet quality (score ≥ 40) characterized by increased daily consumption of bread, vegetables/salad, fruits, yoghurt, pasta/rice, and olive oil and was not significantly associated with mean CIMT in the fully adjusted model ($P = 0.690$) in a primarily hypertensive and dyslipidaemic sample. Logistic regression analysis also did not show any significant relation between DQI and CIMT > 0.9 mm ($P = 0.890$).

In summary, a priori defined dietary patterns characterized by increased consumption of fruits, vegetables and whole-grain foods (Comprehensive HDP, AHEI, DII) were generally associated with decreased CIMT. The DQI pattern did not show any significant relation with CIMT in a hypertensive and dyslipidaemic sample.

A posteriori derived dietary patterns and CIMT

Principal component analysis/Factor analysis

Five studies included in this review used derived DPs using Principal Component Analysis/Factor Analysis (PCA/FA). Mikkila et al. [34] identified two dietary patterns: the health-conscious dietary pattern (similar to the MedDiet characterized by high consumption of vegetables and legumes, nuts, low consumption of dairy products, tea and some alcoholic drinks) and the traditional dietary pattern (correlated with increased intake of rye, potatoes, milk, butter, sausages and coffee), both of which had no significant association with CCA IMT in all adjusted models. However, they did notice a significant positive correlation between CCA IMT and the traditional dietary pattern only in men after adjusting for covariates.

Buscemi et al. [27] identified dietary patterns via factor analysis using the MedDiet as the baseline criteria and identified 3 patterns: unhealthy (high consumption of soft drinks, fried foods, seed oils, cured meats, butter, red meat and sweets); a pattern that resembled the MedDiet (high intakes of fruit, milk and cheese, olive oil, vegetables, pasta and bread); and intermediate (between the unhealthy pattern and the MedDiet). There was a slight decrease in CIMT in the intermediate diet group (0.64 ± 0.01 mm) compared to the unhealthy diet pattern group (0.65 ± 0.01 mm) and MedDiet group (0.65 ± 0.01 mm), but the association was not statistically significant ($p = 0.63$). Overall, there was no significant protective effect of the MedDiet-like pattern and CIMT. Kesse-Guyot et al. [40] identified four dietary patterns using PCA, all of which did not have significant associations with CIMT, in age, sex, energy intake adjusted or full multivariate models.

McClintock et al. [33] reported interesting associations between dietary patterns identified using PCA and CIMT, contrary to the studies seen so far. They identified three

patterns categorized by quartile of increasing adherence: balanced pattern (comprised of steamed rice, red meat, fish, fruit and vegetables); animal protein diet (heavily weighted towards eggs, milk, red meat, poultry, bread and vegetables); and gourd and root vegetables (relied on gourds, radishes, pumpkin, sweet potato and spinach) in a South Asian population. The balanced diet was associated with lower CIMT in the fully adjusted model where each 1 SD increase in diet adherence was associated with a $4.95 \mu\text{m}$ decrease in CIMT ($P = 0.045$). While each 1 SD increase in adherence to the animal protein diet was associated with an increase of $7.70 \mu\text{m}$ in CIMT ($P < 0.01$); however, this association did not persist in the fully adjusted model ($P = 0.45$). In all models, the gourd and root vegetable diet was strongly associated with increased CIMT, particularly in participants in the second, third, and fourth quartile ($7.74 \mu\text{m}$ increase in model 3, $P < 0.01$). They suggest this association may be due to nutritional deficiencies particularly in vitamin B12 and n-3 fatty acids, which are obtained solely through consumption of animal products and thus lacks in a predominant vegetable-based diet. The gourd and root vegetable diet was also most highly associated with carbohydrate intake, which is seen to lead to increased atherosclerosis risk [57].

Nettleton et al. [36] investigated whether using RRR incorporating inflammatory intermediates specifically CRP, IL-6, fibrinogen and homocysteine, would produce dietary patterns more strongly associated with CIMT than those derived by PCA. The PCA derived DP was characterized by increased consumption of fats and processed meats, fried potatoes and desserts and the RRR derived DP was similar to the PCA DP and included high consumption of diet sodas, and low consumption of soy foods, dark-yellow cruciferous vegetables. The PCA DP was not significantly associated with CCA IMT after adjusting for demographic and lifestyle confounders. Increasing quintiles of RRR DP was marginally associated with high CCA IMT after adjustment for demographic and lifestyle factors since the range of values over quintiles was rather narrow (about a 2% increase in CCA IMT). Thus, the dietary pattern based on variation in CRP, IL-6, fibrinogen and homocysteine (RRR1) was significantly associated with IMT while the PCA dietary pattern based on variation in food groups was not.

Overall, there is mixed evidence on the association between dietary patterns derived using principal component analysis/factor analysis and CIMT measures, which is influenced by the sample characteristics.

Reduced rank regression

Reduced Rank Regression (RRR) identifies patterns among food groups by identifying a set of response variables, ideally biomarkers, that have known associations with the disease of interest. As seen previously, Nettleton et al. [36] illustrated that the RRR DP based on variation in CRP, IL-6, fibrinogen and homocysteine was positively associated with CCA IMT compared to the PCA derived dietary pattern. Liese et al. [41] used RRR to derive a simplified dietary pattern based on inflammatory markers PAI-1 and fibrinogen. With increasing quartile of the dietary pattern score, the intake of less healthful food groups increased

(low-fibre bread and cereal, red and processed meat, cheese, tomato food, soft and sweetened drinks), while the intake of more healthful foods decreased. Mean CCA IMT at follow-up increased significantly across quartile of food pattern score ($P = 0.0032$) independent of covariates and baseline CCA IMT. Compared to individuals in the lowest quartile (where the CCA IMT decreased slightly over 5 years, difference = $-0.02 \mu\text{m}$), those in the highest quartile experienced a $0.06 \mu\text{m}$ increase in CCA wall thickness.

On the other hand, Maddock et al. [30] derived RRR dietary patterns based on variation of dietary folate, dietary vitamin B12 and plasma homocysteine; biomarkers known to be associated with increased CVD risk [58–60]. This high B-vitamin DP was characterized by high intakes of vegetables, fruit and low fibre breakfast cereal, and low intakes of processed meat, white bread, sugar and preserves. Compared with the bottom fifth, participants in the higher average DP groups had lower CIMT scores; however, the association attenuated following adjustment for lifestyle factors. The only significant trend was seen in DP distribution at 36 years where participants in the top fifth of the DP distribution had lower CIMT compared with those in the bottom fifth ($P = 0.09$). However, this association too attenuated following adjustment for lifestyle factors. Interestingly, they found an association between the high B-vitamin DP and CRP suggesting that the effect of diet on CVD may be mediated by inflammation which in turn can promote endothelial dysfunction and atherogenesis and consequently CVD.

There is convincing evidence supporting the association between dietary patterns derived using reduced rank regression and CIMT; however, the strength of the association varied depending on the response variables, dietary quartile and age.

Discussion

The primary prevention of CVD has become a public health priority. Various dietary patterns particularly the DASH diet and the Mediterranean Diet have shown to have cardio-protective effects via mechanisms that are yet to be fully understood [15,61,62]. Dietary recommendations on fruit and vegetable intake are not univocal among countries but there is general consensus that increasing their consumption improves general health and decreases risk of chronic disease [63]. Diet rich in fibre, vitamins and polyphenols are seen to be prevalent in foods considered ‘healthy’ and have been shown to have beneficial effects on cardiovascular health [64,65]. Since CIMT is established as a robust surrogate marker of the progression of atherosclerosis and consequently a predictor of future CVD, it is beneficial to investigate how CIMT is affected with varying dietary patterns. This review builds on the findings by Petersen et al. [23] and provides a comprehensive view of the different methods used to derive a priori and a posteriori dietary patterns and their association with CIMT.

Table 2 Summary of relative consumption of food components that characterize each dietary pattern identified and its CIMT effect.

Dietary Pattern (Citation)	Food Components*										CIMT Effect ⁶
	← Healthful groups					→ Unhealthful groups					
	Fruits and Nuts ¹	Vegetables ²	Legumes	Cereals and Grains ³	Fish	Dairy (milk, butter, cream) ⁴	Yogurt and cottage cheese	Meat ⁵	Sugary/non-diet drinks	Alcoholic drinks	
Mediterranean Diet											
MedDiet [28]	↑	↑	↑	↑	↑	↑	↑	↓		↓	↓ (NS)
aMED [32]	↑	↑	↑	↑	↑	↑	↑	↓		↓	↓ (NS)
MedDiet + EVOO [42]	↑	↑	↑	↑	↑	↑	↑	↓		↓	↓ (NS)
MedDiet + Nuts [42]	↑	↑	↑	↑	↑	↑	↑	↓		↓	↓ (NS)
Low-Fat Diet [43]	↑	↑	↑	↑	↑	↓	↓	↓			
Low-Carb Diet [43]	↑	↑	↑	↓	↑	↑	↑	↑			↓ (NS)
MedDiet [43]	↑	↑	↑	↑	↑	↑	↑	↓		↓	
Vegetarian Diet											
VEG [25]	↑	↑	↑		–	↑	↑	–			↓ (S)
OMN [25]	↑	↑	↑		↑	↑		↑			
VEG [38]	↑	↑	↑		–	↑	↑	–			↓ (NS)
OMN [38]	↑	↑	↑		↑	↑		↑			
VEG [39]	↑	↑	↑		–	↑	↑	–			↓ (S)
OMN [39]	↑	↑	↑		↑	↑		↑			
DASH Diet											
DASH [30]	↑	↑	↑	↑		↑		↓	↓		↓ (S)
A Priori Indices											
Diet Inflammatory Index [26]				↑		↑	↑	↑	↑		↑ (S)
Unfavourable [29]	↓	↓	↓	↓	↑			↑	↑		
Normal [29]	↑	↑	↑	↑	↑			↑	↓		↓ (S)#
Optional [29]	↑	↑	↑	↑	↓			↓	↓		
AHEI [44]	↑	↑	↑	↑				↓	↓	~	↓ (NS)

(continued on next page)

This review pooled 30 unique dietary patterns and their effect on CCA IMT, presented in Table 2. Though, there is a lack of statistically significant associations between DPs and CIMT, a general trend between increased adherence to DPs characterized by healthy food groups notably vegetables, legumes, minimally processed foods (i.e. whole grain foods) and decreased CIMT was noticed. While conducting this review, incredible heterogeneity was noticed among participant characteristics and sample selection, CIMT measurement techniques, diet retrieval methods and study design that we hypothesize led to the differences in CIMT effect seen.

Study population

An important limitation across studies was the difference in participant characteristics. The PREDIMED study [42] included elderly subjects, community-dwelling men and women at high risk of CVD due to presence of type II diabetes mellitus while Mateo-Gallego et al. studied the MedDiet in healthy participants with no CVD risk factors

[32]. Presence of CVD risk factors would predispose the participants to higher baseline CIMT values, leading to overestimation of CIMT values based on the DP.

In addition, the heterogenous findings of this review can also be attributed to participant recall and self-selection biases. Participants from the Young Finns Study [34] could choose to attend the CIMT follow-up appointments, introducing self-selection biases. Some of the included studies included participants from rural or deprived areas where the literacy rates are often quite low [33,35,36], leading to potentially inaccurate self-record of nutritional and dietary intake via 24-h recall diaries and FFQs. Therefore, due to the variation in participant characteristics, CIMT effect cannot be compared between the included studies leading to ungeneralizable results.

Dietary pattern analysis

As seen in this review, use of different dietary pattern derivation methods gave rise to different values of CIMT

Table 2 (continued)

CHDP [35]	↑	↑	↑	↑	↑	↓	↑	↓	↓	↑	↓ (NS)
DQI [37]	↑	↑	↑	↑	↑	↑	↑	↓	↓	↓	↓ (NS)
Unhealthy [27]								↑	↑	↑	↓ (NS)
Intermediate [27]	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	
MedDiet [27]	↑	↑	↑	↑	↑	↑	↑	↓		↓	
Principal Component Analysis											
Pattern 1 [40]								↑		↑	↓ (NS)
Pattern 2 [40]	↑	↑	↑		↑	↓					↑ (NS)
Pattern 3 [40]				↑		↑	↑				↑ (NS)
Pattern 4 [40]				↑		↑			↑		↑ (NS)
Balanced [33]	↑	↑	↑	↑	↑			↑			↓ (NS)
Animal protein [33]		↑		↑		↑	↑	↑			↑ (NS)
Gourd/Root vegetables [33]		↑	↑								↑ (S)
Traditional [34]				↑		↑		↑			W: ↑ (NS) M: ↑ (S)
Health-conscious [34]	↑	↑	↑	↑			↑			↑	W: ↑ (NS) M: ↓ (NS)
PCA 1 [36]						↑	↑	↑			↑ (NS)
Reduced Rank Regression											
RRR1 (Hcy, CRP, IL-6, fibrinogen) [36]		↓				↑	↑	↑	↑		↑ (S)
RRR (PAI-1 Fibrinogen) [41]	↓	↓	↓	↑			↑	↑	↑	↑	↑ (S)
RRR (Hcy, folate, B12) [31]	↑	↑		↑		↑	↑	↓	↓	↓	↓ (NS)

*↑ - increased consumption (Green), ↓ - decreased consumption (Red), ~ - moderate consumption, – no consumption of the particular food group. Empty cells denote no data provided.

¹Fruits and nuts does not include fruit juices

²Vegetables include all vegetables excluding potatoes

³Grains include primarily whole-grains

⁴Dairy products include low and high fat dairy

⁵Meat products include processed and unprocessed meat and poultry

⁶CIMT effect refers to the decrease (↓) or increase (↑) in IMT with respect to the dietary pattern in question. In cells where CIMT is presented for more than one dietary pattern, CIMT effect is shown as a trend between the dietary patterns in question. NS refers to not statistically significant (P value ≥ 0.05) and S refers to statistically significant value (P value <0.05)

⁷W refers women, M refers to men

#only significant in non-smokers

measure. Two out of the three studies that derived DPs using Reduced Rank Regression demonstrated a significant association between the DP and CIMT [30,36] compared to only one out of the four studies that studied PCA/FA derived DPs. The integrative nature of RRR rather than the focus on single nutrient analysis or PCA/FA, sheds light on the etiologic processes that involve pro-inflammatory and pro-thrombotic pathways that impact the development of atherosclerosis before clinical symptoms appear.

CIMT measurement

CIMT is associated with risk of stroke, myocardial infarction, and death from coronary causes in several large observational studies [21,66]. The PREDIMED study is a landmark study establishing the cardioprotective effects of the Mediterranean Diet. Although not statistically significant, there was an absolute negative association with increasing adherence to the MedDiet and decreased CIMT, which could potentially be clinically significant. A systematic review and meta-analysis of eight large population-based observational studies of CIMT and CVD risk concluded that for an absolute CIMT difference of 0.1 mm, the future risk of myocardial infarction increased by 10%–15%, and the stroke risk increased by 13%–18% [21]. In the PREDIMED trial according to Table 1, there was an IMT difference of more than 0.1 mm between the MedDiet + EVOO group and MedDiet + nuts group and the control group, which suggests that there is potentially a clinically significant association between the MedDiet and CIMT. The lack of statistical significance could be due to small sample size (carotid ultrasound was not part of the initial examination of all PREDIMED trial participants), the time it takes for IMT progression (in the PREDIMED trial, CIMT was measured after 1 year), and type of study.

Many of the studies included in this review demonstrated associations with DPs and other markers of atherosclerotic progression namely vessel wall volume, pulse wave velocity and focal plaque thickness in addition to CIMT [26,28–30,32,38,40,43]. For example, significant changes were seen between increasing quartiles of DP characterized by high consumption of meat, micro-nutrients and fibres, and higher PWV measured 7.5 years later, while no significant association was found with IMT [40]. Shai et al. [43] showed no significant 2-year change in CIMT between the intervention groups, but significant carotid VWV regression. These findings suggest that DPs may have an influence on various other components of the atherosclerotic pathway and not just CIMT. There is potential for future studies to investigate the relationship between dietary patterns and CIMT in conjunction with other cardiovascular markers that contribute to atherosclerotic risk.

Dietary data collection

Studies that used recall methods to collect dietary data are prone to recall bias [25,30,31,34,37–40]. Recorded self-

reported dietary information without use of a verified and validated method of dietary information assessment can introduce discrepancies in data and at times may not provide sufficient information on food consumption. The primary limitation of this method is that recording consumption for a single day is seldom representative of a person's usual intake due to daily variation. Furthermore, in studies [42,43] where participants were separated into experimental groups before deriving the dietary patterns, within-group would be restricted. Whether the CIMT effect was due to participant adherence to the dietary pattern or due to the specific dietary components is indistinguishable. Similar issues arise when participants are categorized based on self-report as in the studies that assessed vegetarian diets [25,38,39].

Conclusion

This synthesis of current evidence is the first review of its kind to comprehensively assess the available literature of various study types on the association between dietary patterns and CIMT. Several limitations should be acknowledged. For instance, the heterogeneity of the studies and limited number of articles found made it unfeasible to conduct a meta-analysis of the pooled association between dietary patterns and CIMT. As a consequence, more granular interpretation of data was challenging. One major conclusion from this work is that well-orchestrated research on the association between diet and CIMT is generally lacking.

To fully uncover the mechanistic links between diet and CIMT, more explanatory intervention trials with robust methods are required, and this would further develop the ability to utilise CIMT as a practical early biomarker of diet-related cardiovascular risk. Specifically, larger sample sizes must be included to ensure fair representation of the population or alternatively sufficiently weighted samples of specific at-risk populations ought to be studied in depth. CVD is complex, involving numerous biochemical pathways, which makes it unlikely that modifying the intake of a few nutrients would alter these systems and influence clinical outcomes. Given the advantages of evaluating dietary patterns versus single nutrient components, this review recommends that future RCTs test various dietary patterns in sufficiently large populations and determine the effects of derived dietary patterns on multiple CVD markers to account for interaction.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.numecd.2019.08.014>.

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