Perspective: The Application of A Priori Diet Quality Scores to Cardiovascular Disease Risk—A Critical Evaluation of Current Scoring Systems

Ghadeer S Aljuraiban,[1,2] Rachel Gibson,[2,3] Linda M Oude Griep,[2,4] Nagako Okuda,[5] Lyn M Steffen,[6] Linda Van Horn,[7] and Queenie Chan[2]

[1] Department of Community Health Sciences, College of Applied Medical Sciences, King Saud University, Riyadh, Kingdom of Saudi Arabia; [2] Department of Epidemiology and Biostatistics, School of Public Health, Imperial College London, London, United Kingdom; [3] Department of Nutritional Sciences, King's College London, London, United Kingdom; [4] NIHR Biomedical Research Centre, Diet, Anthropometry, and Physical Activity (DAPA) Group, MRC Epidemiology Unit, University of Cambridge, Cambridge, United Kingdom; [5] Department of Health and Nutrition, University of Human Arts and Sciences, Saitama, Japan; [6] Division of Epidemiology and Community Health, School of Public Health, University of Minnesota, Minneapolis, MN, USA; and [7] Department of Preventive Medicine, Northwestern University, Chicago, IL, USA

ABSTRACT

Healthy dietary habits are the cornerstone of cardiovascular disease (CVD) prevention. Numerous researchers have developed diet quality indices to help evaluate and compare diet quality across and within various populations. The availability of these new indices raises questions regarding the best selection relevant to a given population. In this perspective, we critically evaluate a priori–defined dietary indices commonly applied in epidemiological studies of CVD risk and mortality. A systematic literature search identified 59 observational studies that applied a priori–defined diet quality indices to CVD risk factors and/or CVD incidence and/or CVD mortality. Among 31 different indices, these scores were categorized as follows: *1*) those based on country-specific dietary patterns, *2*) those adapted from distinct dietary guidelines, and *3*) novel scores specific to key diet-related factors associated with CVD risk. The strengths and limitations of these indices are described according to index components, calculation methods, and the application of these indices to different population groups. Also, the importance of identifying methodological challenges faced by researchers when applying an index are considered, such as selection and weighting of food groups within a score, since food groups are not necessarily equivalent in their associations with CVD. The lack of absolute cutoff values, emphasis on increasing healthy food without limiting unhealthy food intake, and absence of validation of scores with biomarkers or other objective diet assessment methods further complicate decisions regarding the best indices to use. Future research should address these limitations, consider cross-cultural and other differences between population groups, and identify translational challenges inherent in attempting to apply a relevant diet quality index for use in CVD prevention at a population level. *Adv Nutr* 2019;00:1–15.

Keywords: cardiovascular disease, CVD risk factors, blood pressure, diet quality score, diet index, dietary patterns

Introduction

Cardiovascular disease (CVD), the major cause of death worldwide, is multifactorial and influenced largely by environmental factors, including dietary habits and other lifestyle behaviors (1). Unhealthy dietary behaviors are associated with about a third of global mortality (2).

In 1908, Alexander Ingatowski reported a link between high cholesterol intake and atherosclerosis in rabbits (3). Over the second half of the 20th century, the landmark Seven Countries Study demonstrated undesirable associations of dietary lipids with CVD based on this large-scale cohort study that was among the first to describe food patterns relative to CVD outcomes (4). Numerous later cohort studies investigated the role of single nutrients associated with CVD and its risk factors (5–7). These early investigations provided essential results demonstrating a nutritional relation with CVD, but the presence of highly correlated nutrients may attenuate effects, especially if nutrient adjustment methods are not properly applied (8). More recently developed dietary guidelines encompass both nutrients and food groups known to act synergistically and shown to provide protective benefit against development of CVD, while accounting for previous limitations (9, 10). The translation of such dietary patterns to public health guidelines was likewise applied to the 2015–2020 Dietary Guidelines for Americans (11).

The term "diet quality" refers to the nutrient adequacy or nutritional value of a dietary pattern as a whole (12). To assess diet quality, Patterson and colleagues first developed a "diet quality index score" in 1994 (13). The 2 main methods used to determine diet quality of a population are a priori and a posteriori. An a priori diet quality index score is based on predefined algorithms to quantify food and nutrient intake relative to nutritional recommendations (14). Each food or nutrient is assigned a score, and a total score is then calculated. The higher the score, the greater the adherence to the predefined diet pattern. A posteriori scores are derived from statistical techniques such as factor, cluster, or principle component analysis and are therefore specific to the population they are calculated from (15). Here we focus on a priori scores as these are applied across different cohorts.

A crude search on PubMed for publications containing a reference to a form of dietary score ("diet", or "food" or "nutrient" AND "index" or "score" or "quality" or "pattern" AND "CVD") illustrates that publication of cohort studies applying a dietary score or index to determine associations with CVD outcomes has increased exponentially, with a steady rise from an average of 302 publications per y between 2000 to 2004 to an average of 765 per year over the last 5 y (**Figure 1**).

The plethora of new diet quality indices has raised questions among researchers regarding the optimal choice for studies of CVD prevention. Understanding what the different scores measure and how they are calculated is essential for interpretation of their relations with CVD outcomes and their application to research studies. This narrative review was designed to 1) identify current a priori dietary scores reported in relation to CVD outcomes and risk factors in cohort studies, 2) evaluate the application of the most frequently used scores in the study of diet and CVD, and 3) consider the strengths and limitations of these scores based on calculation methods and their

application to different population groups. We also provide recommendations for considering the potential application of predefined diet quality scores to CVD outcomes, based on our findings.

Methods to Identify Current A Priori Dietary Scores

Study design
As the aims of this review were to identify and describe the current scores used in nutritional epidemiological studies of dietary patterns and CVD, we first systematically searched the recent published literature to identify the scores, and then we synthesized our findings in a critical narrative review. As we did not aim for an exhaustive search or quantification of evidence, the study design we adopted differs from a systematic review where formal quality assessment procedures are followed.

Inclusion criteria
Inclusion criteria in the present narrative review were 1) observational study design, 2) investigation on diet quality indices and CVD risk factors and/or CVD incidence and/or CVD mortality in adults, 3) publication between 1 January 2015 to 31 October 2018, and 4) full-text, peer-reviewed, and in English. All studies in the present review met these inclusion criteria; studies featuring a priori diet quality index scores that quantified food and nutrient intake using predefined algorithms were also included if they met the inclusion criteria.

Search strategy
A systematic article search was carried out between October and November of 2018 (see **Supplemental Table 1** for search criteria). During manuscript preparation, a weekly search was maintained to capture new publications; however, none were identified. The following databases were searched: NCBI Pubmed, Web of Science, the Cochrane Library, and SpringerLink. The search terms used were the following: "diet" OR "food" OR "nutrient" AND "pattern" OR "index" OR "indices" OR "score" OR "quality" OR "adherence" OR "adequacy" AND "cardiovascular disease" OR "coronary disease" OR "myocardial infarction" OR "stroke" OR "peripheral vascular diseases" OR "arterial disease" OR "peripheral arterial disease" OR (hypertension OR blood pressure) OR (cholesterol AND HDL) OR (cholesterol AND LDL). Retrieved articles were imported into Mendeley reference management software (Glyph and Cog, LLC). **Figure 2** presents a flow chart of the systematic search.

Overall, the search found 3072 citations; 20 articles were eliminated as duplicates and 2929 due to irrelevancy or to not being full-text peer-reviewed research articles. Two independent reviewers (GSA and RG) assessed abstracts of the remaining 170 articles; 111 failed to meet the inclusion criteria. Studies were excluded if they were not CVD specific, were feeding trials, did not include a diet quality index score, were not on adults, or a combination of any of
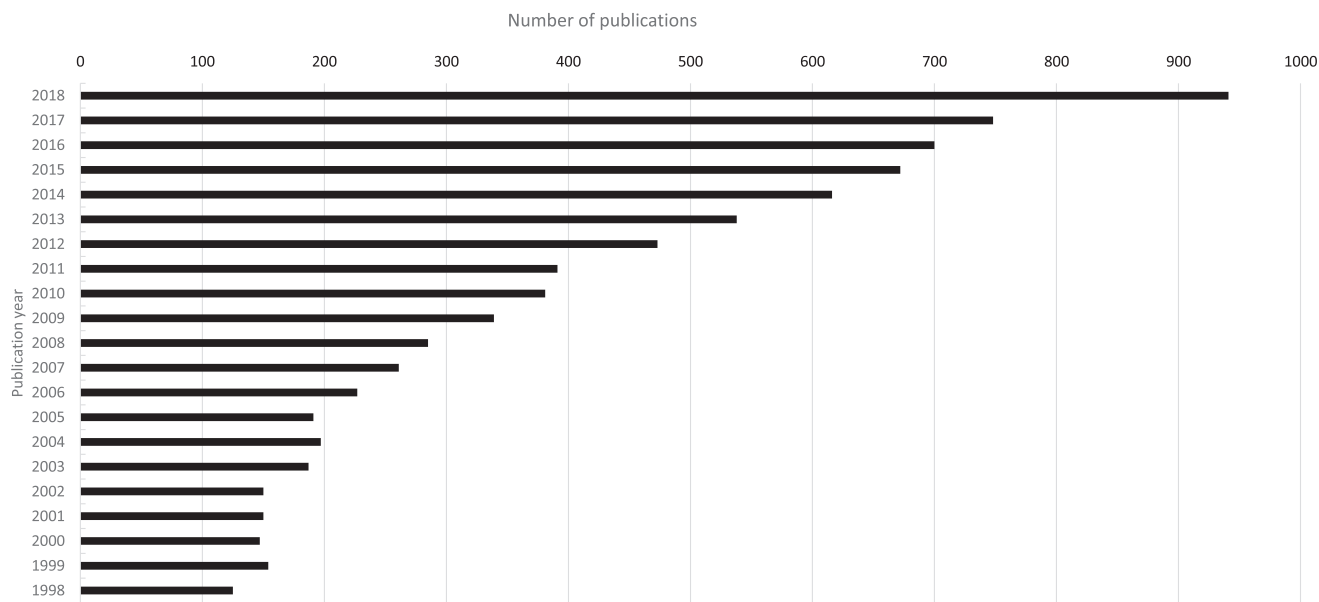
FIGURE 1 Number of publications per year listed in PubMed that contained reference to diet/food/nutrient score/index/pattern and cardiovascular disease up to 31 October 2018 (data extracted 12 December 2018).

these. Both reviewers thoroughly assessed the remaining 59 articles in full text. All were included in the review. The review identified 31 different dietary scores (Figure 2). **Supplemental Table 2** summarizes the main characteristics of the included studies and **Table 1** the main findings, including observational studies (16–74).

The indices were categorized as follows: *1*) country-specific dietary patterns, like the Mediterranean Diet Score (MDS) (75), the Dietary Approaches to Stop Hypertension (DASH) score (76), and the Nordic Food Index (NFI) (77); *2*) adaptations from recommended dietary guidelines, like the Healthy Eating Index (HEI) (78) and the UK Nutrient Profile Score (NPS) (54); and *3*) novel empirically derived scores focusing on specific properties or components, like the Dietary Inflammatory Index (DII) (79) as they may influence health outcomes. A narrative synthesis of studies is shown in **Supplemental Table 3**, where we present the number and percentage of studies that report a null or protective relation between CVD outcomes and each diet quality score reviewed. Additionally, we constructed a Venn diagram (**Figure 3**) using 4 diet scores: the 2 most commonly applied country-specific (DASH and MDS) and the 2 most commonly applied guideline intake scores (HEI and NPS) to identify and illustrate common components across a sample of scores.

Country-Specific Dietary Patterns and Associations with CVD

The most commonly applied score was MDS (Figure 1), but it is essential to recognize that there is no one or standard definition of the Mediterranean diet. The term generally refers to the diet typically consumed among people living in various countries surrounding the Mediterranean Basin as observed by Ancel Keys in the 1960s (80). For example, based on the traditional Greek diet, Trichopoulou and colleagues initially developed an MDS (81) using 9 foods and nutrients, others calculated MDS using up to 15 foods and nutrients (33, 49). Thus, calculation of the score is relative, based on the distribution of intakes observed within the population being studied, e.g., as quartiles or tertiles of intake. Each category is given a point, with equal weights assigned to each category, and the final score is the sum of total points. Most components included in the MDS are rich in antioxidants, but some have minimal or no known protective benefits, such as high intakes of refined grains and cereals, shown to have an adverse effect on CVD (82).

Trichopoulou et al. reported that adherence to MDS in a sample of 182 elderly Greeks was significantly associated with a 17% increased survival (81). Further development of MDS, studied in small- (83–85) and large-scale observational studies (53, 75, 84), demonstrated inverse relations between variations of MDS and all-cause mortality and cardiovascular events. Data from the European Prospective Investigation into Cancer and Nutrition (EPIC), including 22,043 Greeks, showed that higher conformity to MDS was inversely related to mortality from coronary artery disease (CAD) (75). Numerous meta-analyses of the relation between adherence to MDS and CVD incidence and mortality have found inverse associations (86–90); however, these meta-analyses suffered from methodological issues, such as incomplete literature searches, lack of sensitivity analyses, different selection of food groups for MDS among studies, and lack of
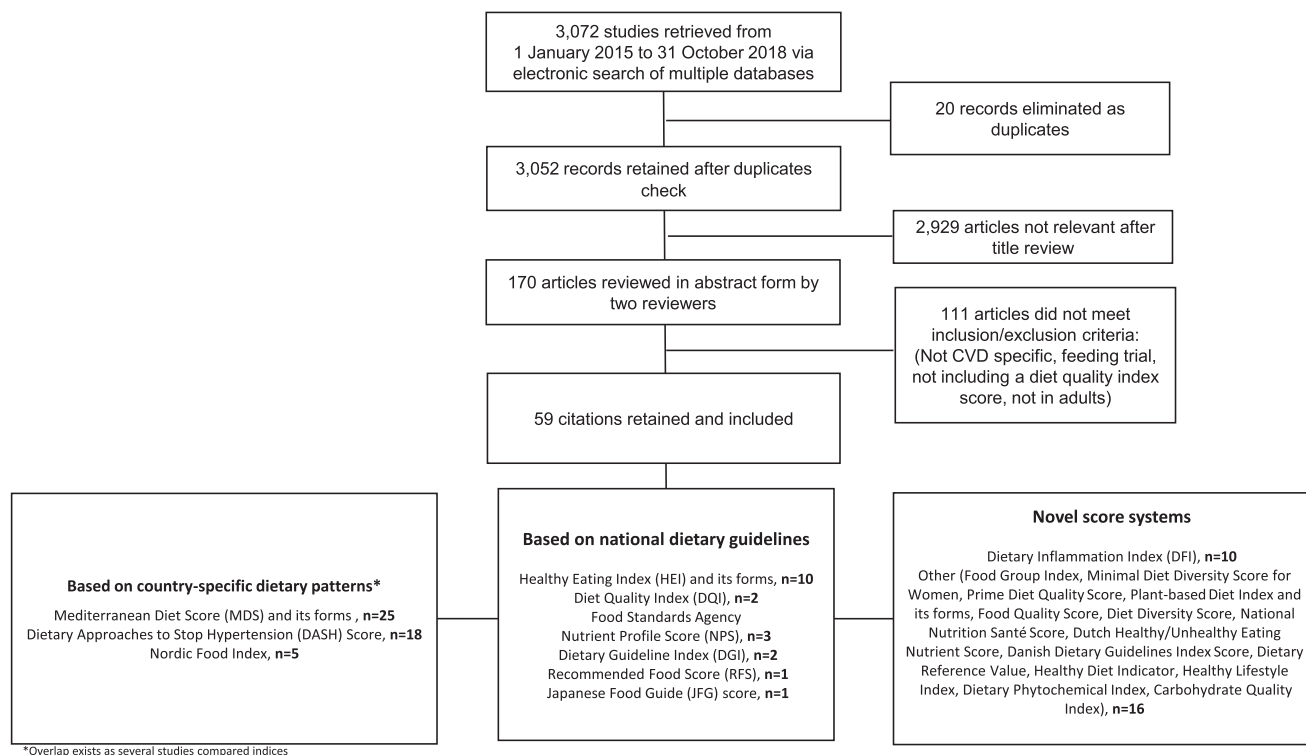
FIGURE 2 Search flow diagram of literature review process for studies investigating dietary patterns and CVD risk factors and/or CVD incidence and/or mortality. CVD, cardiovascular disease.

differentiation between types of CVD. Rosato and colleagues addressed these limitations in a recent meta-analysis of observational studies and demonstrated a 20–25% reduction in CAD and/or acute myocardial infarction (MI) with high adherence to MDS, showing stronger associations among participants residing in the Mediterranean region versus elsewhere (91).

Although some of the methodological limitations of previous systematic reviews were addressed in these analyses—others were not, such as applying MDS to populations outside the Mediterranean Basin where foods like olive oil are limited. In China, a high MDS was an independent predictor for low systolic blood pressure (BP) variability (35), but in the Czech Republic, Poland, and the Russian Federation, a significant but weak association between adherence to MDS and CVD mortality was reported (25). In Germany, MDS was also weakly associated with severity of CAD (36), and in Iran MDS was not associated with C-reactive protein (CRP), an inflammatory biomarker related to CVD (37). Other unaddressed methodological issues include lack of an agreed-upon definition of MDS identifying foods included or excluded and absence of any cutoff values (29, 47) (Supplemental Table 3).

The DASH score, developed by Dixon et al. in 2007, was based on food groups and nutrients encouraged or limited in the DASH diet (92). Score components range between 6 and 8 foods and nutrients (17, 55). Similar to MDS, the DASH

scoring system is relative—based on quantiles of sex-specific intakes, with equal weights assigned to each component; the overall score is the sum of all individual scores.

A recent systematic review and meta-analysis of prospective cohort studies totaling 260,011 men and women showed that, compared with the lowest compliance to the DASH diet, the highest compliance was associated with a 20% reduction in the risk of CVD (93). Another form of the score, the Modified DASH score, which does not account for sodium intake, also showed inverse associations with incidence of CAD (17). Fung and colleagues also found beneficial effects of adhering to the DASH diet in reducing inflammation at the 24-y follow-up in women from the Nurses' Health Study, with no previous history of CVD (76). The recent systematic review and meta-analysis of randomized controlled trials by Soltani et al. confirmed findings by Fung and colleagues: the beneficial effects of the DASH diet are due not only to reductions in BP but also to improvements in inflammatory biomarkers, which are suggested to reduce CVD events (94). Based on these findings, the American Heart Association recommended the DASH diet in their Guidelines on Lifestyle Management to Reduce Cardiovascular Risk, with a strong level of evidence for reducing CVD risk (95).

However, the cardioprotective effects of the DASH diet were more prominent in hypertensive than in normotensive individuals (96) and in individuals from ethnic minority backgrounds than in Caucasians (97). Moreover, the asso-

TABLE 1 Summary of main findings of observational studies investigating the relation between CVD and CVD risk factors and dietary scores[1]

Study (reference)	Country	Dietary score	Main findings
USA			
Aigner et al, 2018 (16)	USA	HEI, AHEI, DASH	All scores: low-quality diet associated with ↑ risk of stroke mortality (4.6-y follow-up); HEI-2010 was strongest predictor. Associations varied by ethnicity
Dijousse et al, 2018 (17)	USA	Modified DASH	↑ Modified DASH score associated with ↓ CAD
Fung et al, 2018 (18)	USA	FGI, MDDS for women, PDQS	FGI not associated with total IHD in any cohort (26-y follow-up)
			PDQS ↓ IHD in all 3 cohorts
			MDDS ↓ IHD in 2 of 3 cohorts
Satija et al, 2017 (19)	USA	PDI, hPDI, uPDI	↑ PDI independently associated with ↓ CAD
			↑ hPDI independently associated with ↓ CAD
			↑ uPDI associated with ↑ CAD
Shivappa et al, 2017 (20)	USA	DII	DII (proinflammatory diet tertile 3 vs. tertile 1) ↑ associations for CVD mortality
Fung et al, 2016 (21)	USA	FQS	Comparing top to bottom deciles, ↓ total CAD (26-y follow-up), independent of established risk factors (body weight, physical activity, smoking)
Li et al, 2016 (22)	USA	DASH, AHEI, AMD	AHEI, AMDS, DASH ↓ risk of hypertension (18.5-y follow-up). Comparing the extreme quartiles (highest and lowest) AMDS largest effect size
Mattei et al, 2016 (23)	USA	AHEI	↓ MetS (modified by ethnic background), ↓ waist circumference, BP, and glucose (Mexicans and Puerto Ricans) and with ↓ TAG (Mexicans) ↑ HDL cholesterol (Puerto Ricans and Central Americans)
Frazier-Wood et al, 2015 (24)	USA	HEI	Women: HEI score not associated with any CVD risk factors
			Men: HEI score associated with ↓ fasting insulin, ↓ HOMA-IR, ↓ HDL-C, ↓ TAG and ↓ CRP (not significant post adjustment for BMI)
Sotos-Prieto et al, 2015 (25)	USA	HEI, AHEI, modified MDS, DASH	Compared diet stability in each 4-y period, ↑ diet quality scores associated with ↓ CVD risk in the subsequent 4-y period
Tsivgoulis et al, 2015 (26)	USA	MDS	MDS ↓ incident ischemic stroke no association with incident hemorrhagic stroke (6.5-y follow-up)
Southern Europe			
Shivappa et al, 2018 (27)	Italy	DII	DII (proinflammatory diet tertile 3 vs. 1) ↑ CVD mortality
Verde et al, 2018 (28)	Italy	MDS	↑ MDS associated with ↓ hypertension
Vitale et al, 2018 (29)	Italy	Relative-MDS	↑ R-MDS associated with ↓ plasma lipids, BP, and BMI
Bendinelli et al, 2018 (30)	Italy	HEI, DASH, MDS, IMI	IMI, DASH, and HEI were significantly and inversely associated with SBP and DBP. Strongest association between IMI and both SBP and DBP
			Women: ↓ association between IMI, SBP, and DBP
			Men: ↓ association between DASH and DBP
			MDS not associated with SBP or DBP
Bonaccio et al, 2017 (31)	Italy	MDS, Diet Diversity Score	2-point increase in MDS associated ↓ CVD risk (4.3-y follow-up). Stronger association in high income groups
Alvarez-Alvarez et al, 2018 (32)	Spain	MDS (4 versions), DASH	Compared with the lowest category of adherence to the 3 of the 4 MDS (MEDAS no significant association), higher adherence associated with ↓ CVD (10.4-y follow-up)
			DASH: no significant associations across extreme score categories, ↓ linear trend
Aleman et al, 2016 (33)	Spain	MDS	Lower MSD associated with ↑ prevalence of hypertension
Eguaras et al, 2015 (34)	Spain	MDS	↑ Risk of CVD across categories of BMI with ↓ adherence to MDS
Garcia-Arellano et al, 2015 (35)	Spain	DII	Risk ↑ across the quartiles (increasing inflammatory potential) incidence CVD (4.8-y follow-up)
Ramallal et al, 2015 (36)	Spain	DII	DII (proinflammatory diet highest vs. lowest quartile) ↑ CVD event (8.9-y follow-up)
Georgousopoulou et al, 2016 (37)	Greece	DII	Higher DII (anti-inflammatory diet): borderline association with ↓ 10-y CVD incidence

(Continued)

TABLE 1 (*Continued*)

Study (reference)	Country	Dietary score	Main findings
Kastorini et al, 2016 (38)	Greece	MDS	Per 10% increase MDS ↓ CVD incidence (8.4-y follow-up)
Northern Europe			
Adriouch et al, 2017 (39)	France	FSA-NPS	↑ CVD risk with lower diet quality (12.4-y follow-up). Association stronger in overweight
Lelong et al, 2016 (40)	France	PNNS score, DASH, MDS	PNNS, DASH, and MDS ↓ associated with systolic BP (women only)
			No significant association found in men
Neufcourt et al, 2016 (41)	France	DII	DII (proinflammatory diet highest vs. lowest quartile) ↑ MI (11.4-y follow-up)
Alkerwi et al, 2015 (42)	Luxembourg	DQI-I, DASH, MDS, DII	↑ DASH score and MDS were associated with ↓ DBP
Sijtsma et al, 2015 (43)	Netherlands	DHNaFS, DUNaFS	Q5 vs. Q1 DHNaFS: 30% ↓ CVD risk
			DUNaFS not related to CVD risk
Lemming et al, 2018 (44)	Sweden	Modified MDS, Healthy NFI	MDS (mMED) and NFI high-adherence categories vs. low-adherence categories ↓ mMED showed stronger association
Boden et al, 2017 (45)	Sweden	DII	Male participants with the most proinflammatory DII scores ↑ risk of MI (6.4-y follow-up). No association found between DII and MI in women
Roswall et al, 2015 (46)	Sweden	NFI	No association between the healthy NFI and overall CVD (21.3-y follow-up)
Tektonidis et al, 2015 (47)	Sweden	Modified-MDS	↑ MDS associated with ↓ risk of MI
Galbete et al, 2018 (48)	Germany	NFI, MDS,	Nordic diet, MDS, and MedPyr not associated with incidence of MI
Waldeyer et al, 2018 (49)	Germany	MDS	↑ MDS associated with ↓ SYNTAX score
Phillips et al, 2018 (50)	Ireland	DASH score	↑ DASH score associated with ↓ BMI, tumor necrosis factor α (TNF-α), interleukin 6 (IL-6)
			Q4 of DASH score associated with lower obesity and metabolic syndrome, respectively, compared to Q1
Arentoft et al, 2018 (51)	Denmark	Danish Dietary Guidelines Index	Lower score: ↓ LDL:HDL ratio, ↑ HDL-cholesterol; Men: ↓ BMI, trunk fat, high-sensitivity C-reactive protein, HbA1c; Women: ↑ systolic BP
Hansen et al, 2018 (52)	Denmark	Danish Dietary Guidelines Index	Higher Danish Dietary Guidelines Index score ↓ total incidence stroke in men but not in women. In women, ↓ total incidence ischemic stroke
Stefler et al, 2017 (53)	Czech Republic, Poland, and the Russian Federation	MDS	One SD increase in the MDS ↓ associated with CVD mortality but not with CAD
Eriksen et al, 2018 (54)	UK	FSA-NPS, UK DRV score	2-point increase in NP score associated with ↓ total cholesterol and HbA1c
			2-point increase in DRV score associated with ↓ waist circumference, BMI, total cholesterol and HbA1c
Gibson et al, 2018 (55)	UK	DASH	Lower DASH (poor diet quality) ↑ cardiometabolic risk (metabolic syndrome)
Jones et al, 2018 (56)	UK	DASH	Compared with participants with the least DASH-accordant diets, those with the most DASH-accordant diets ↓ risk incident stroke and total incident CVD (12.4-y follow-up). No association with risk of CAD
Mytton et al, 2018 (57)	UK	FSA-NPS	No association between consumption of less-healthy food and incident CVD or CVD mortality (fully adjusted)
Maddock et al, 2018 (58)	UK	DASH	Across quintiles, higher DASH-type diet ↓ BP, TAG, PWV, ↑ HDL-cholesterol (30-y follow-up)
Tong et al, 2016 (59)	UK	MDS (4 versions: pyramid-based MDS, literature-based MDS, median MDS and tertile MDS)	All MDS ↓ incidence of the cardiovascular outcomes, MDS dietary pyramid showed strongest effect (17-y follow-up)
Lassale et al, 2016 (60)	Pan-Europe (10 countries)	NFI, MDS (3 versions), HLI, WHO HDI, DASH, DQI	All dietary scores: ↓ associations CVD mortality (12.8-y follow-up), stratified results by country showed differential associations between scores and CVD mortality)
Asia			
Bai et al, 2017 (61)	China	DASH	Stratified results reported: normal BMI, DASH-style diet and physical activity: ↓ incidence hypertension (11-y follow-up)

(Continued)

TABLE 1 (*Continued*)

Study (reference)	Country	Dietary score	Main findings
Lau et al, 2015 (62)	China	MDS	↑ MDS was an independent predictor for ↓ systolic BPV
Murakami et al, 2018 (63)	Japan	JFG score, MDS, DASH	JFG and mJFG scores ↑ LDL-cholesterol, MDS ↓ HDL cholesterol No associations of DASH score with BP
Kim et al, 2018 (64)	Korea	CQI	Highest quintile CQI ↓ prevalence of obesity and hypertension
Tiong et al, 2018 (65)	Philippines and Malaysia	Modified DASH score	Modified DASH score not significantly associated with CVD risk in the Malaysian cohort ↑ Modified DASH score associated with ↓ SBP, ↓ DBP, ↓ total cholesterol, ↓ LDL, and ↓ triglyceride in the Philippines cohort
Neelakantan et al, 2018 (66)	Singapore	AHEI, Modified-MDS, DASH, HDI	↑ diet index scores associated with a ↓ risk of CVD mortality
Australia			
Hodge et al, 2018 (67)	Australia	DII, MDS	MDS and DII (less inflammatory) diets ↓ total, CVD, and CAD mortality. No difference in effect size between DII and MDS with CVD mortality
Livingstone et al, 2018 (68)	Australia	DGI	DGI associated with ↓ glucose, BMI, waist circumference
Livingstone et al, 2016 (69)	Australia	DGI, RFS	DGI and RFS (highest vs. lowest tertile) ↓ hypertension (DGI stronger effect size, and stronger in obese) in men not women
Vissers et al, 2016 (70)	Australia	DII	DII (proinflammatory diet) ↑ risk of myocardial infarction (no association fully adjusted models), no association found for total CVD, IHD, or cerebrovascular disease
Middle East			
Daneshzad et al, 2018 (71)	Iran	Modified-NFI	↑ modified-NFI associated with ↓ LDL, ↓ SBP, ↓ risk of obesity
Sakhaei et al, 2018 (72)	Iran	DASH, MDS	↑ DASH diet associated with ↓ serum CRP concentrations but not with IL-17A concentrations; ↑ MDS associated with ↓ circulating IL-17A concentrations but not with hs-CRP concentrations
Saraf-Bank et al, 2017 (73)	Iran	HEI	HEI (highest vs. lowest quartile) ↓ risk of MetS and individual risk factors
Golzarand et al, 2015 (74)	Iran	DPI	No association with systolic and diastolic blood pressure across Q categories of DPI

[1] Direction of associations based on headline results reported in the study between dietary score exposure and cardiovascular outcomes. ↑ denotes increase/direct and ↓ decrease/inverse. AHEI, alternative HEI; AMDS, alternative MDS; BMI, body mass index; BP, blood pressure; CAD, coronary artery disease; CQI, carbohydrate quality index; CVD, cardiovascular disease; DASH, Dietary Approaches to Stop Hypertension Trial; DBP, diastolic blood pressure; DGI, Dietary Guideline Index; DII, Dietary Inflammation Index; DPI, Dietary Phytochemical Index; DQI-I, Diet Quality Index-International; DRV, dietary reference value; DHNaFS, Dutch Healthy Nutrient and Food Score; DUNaFS, Dutch Undesirable Nutrient and Food Score; FSA-NPS, Food Standards Agency nutrient profile score; hPDI, healthful PDI; HbA1c, glycated hemoglobin; HEI, Healthy Eating Index; IHD, ischemic heart disease; IMI, Italian Mediterranean Index; JFG, Japanese Food Guide; MDDS, minimal diet diversity score; MEDAS, Mediterranean Diet Adherence Screener; MDS, Mediterranean Diet Score; MetS, metabolic syndrome; NFI, Nordic Food Index; mMED, modified Mediterranean Diet score; PDQS, prime diet quality score; PNNS, Program National Nutrition Santé; Q, quartile of score; RFS, Recommended Food Score; SBP, systolic blood pressure; TAG, triacylglycerol; uPDI, unhealthful Plant-based Diet Index.

ciation of DASH score with CVD risk factors differed by country in which it was applied (65). The DASH dietary score does not apply a cutoff value for maximum intake, which may overestimate the final score. In addition, the score does not differentiate between types of dietary fat nor account for intake of other foods associated with CVD risk, like fish (98). The DASH diet was initially based on dietary factors that were shown to lower BP, including reduced intake of sodium, alcohol, and red and processed meat and higher intake of fruits, vegetables, and low-fat dairy foods (96), thereby supporting cardiometabolic health. Basing the DASH diet score on an FFQ raises concerns, especially for quantifying sodium intake. For large-scale cohort studies, an alternative approach for measuring sodium intake used

a salt-based questionnaire that improved accuracy by 7–13% (99).

The NFI, less commonly used, is based on frequently consumed foods in the Nordic countries (the Scandinavian region), such as whole grains, fruits, low-fat dairy products, fatty fish such as salmon, and cabbage and root vegetables, with a focus on the intake of organic foods and healthy fat (100). The number of components included in the score range between 6 and 9 (48, 71). The Nordic scoring system is relative and is based on distribution of intake above and below median consumption, with equal weights assigned to each category, and without applying a cutoff value for maximum intake. The overall score is the sum of individual scores.
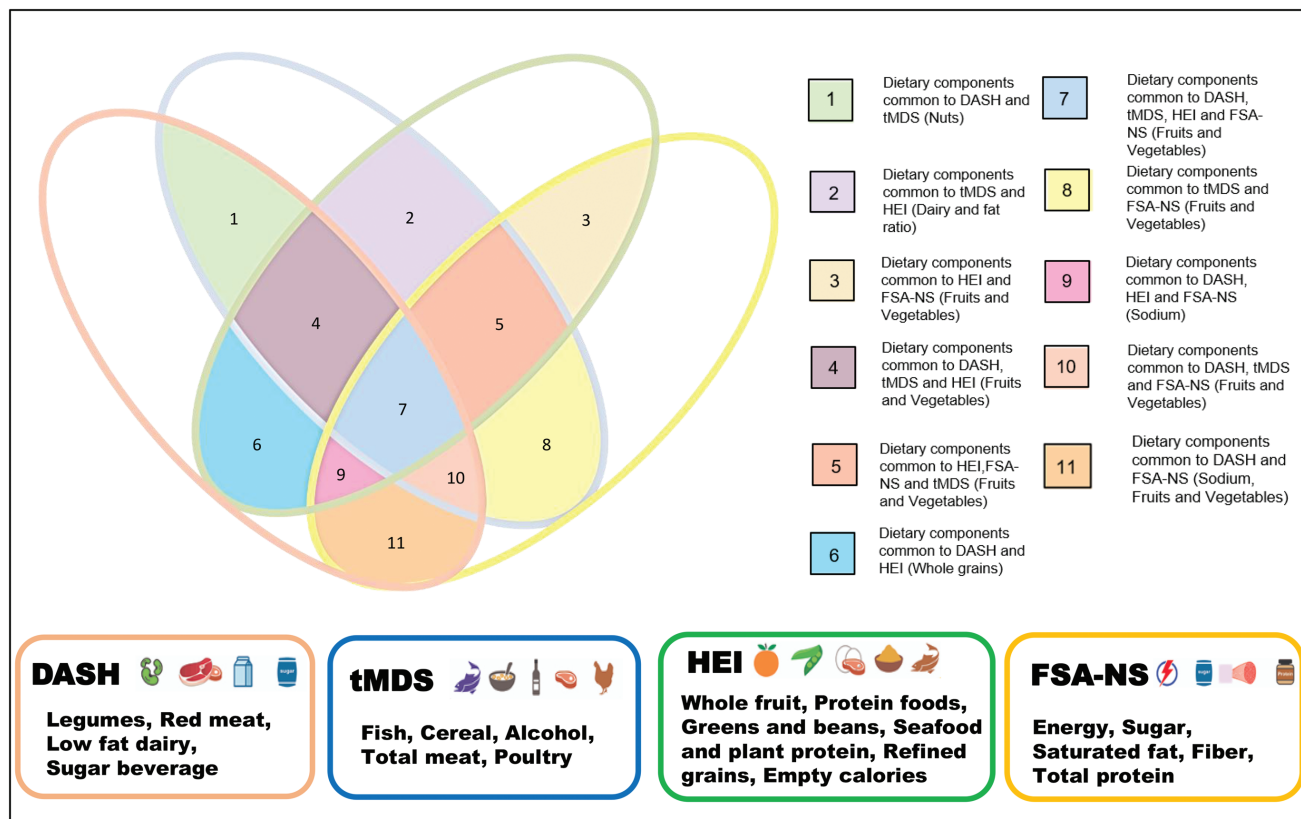
FIGURE 3 Venn Diagram illustrating unique and shared food and nutrient groups of 4 predominantly food-based scores: DASH, Dietary Approaches to Stop Hypertension Trial; FSA-NP, Food Standards Agency Nutrient Profile; HEI, Healthy Eating Index; tMDS, Traditional Mediterranean Diet Score. Across the 4 scores there were 13 duplicate and 20 unique dietary components or grouping of components.

Adherence to the NFI showed inconsistent results (46, 66). In German participants, there was no significant association between higher adherence to the score and MI (48). Likewise in an Iranian population, after adjustment for dietary and lifestyle confounders, no significant association between the score and BP was observed (71). Nonadherence to the diet, especially in non–Nordic region populations, and lack of a uniform Nordic diet (46, 77) are likely confounders.

Dietary guidelines–based scores

The HEI was originally developed in 1995 to evaluate level of adherence to US dietary guidelines (78). The index was updated several times, with the most widely used version in our review being the HEI-2010, although there is now an updated 2015 version. The HEI-2010 includes 12 components of foods and nutrients, based on amounts per 1000 kcal (101). Each component has a minimum score of zero and a maximum score of 10 using weighted means, with the sum of all scores used as the final score.

An alternative version [alternative HEI (AHEI)-2010] was developed based on absolute values (102), with both scores (HEI and AHEI) used widely in relation to CVD (103). Data from a large prospective cohort study of 424,662 participants aged 50–71 y showed that the reductions in CVD mortality associated with the highest and lowest HEI

and AHEI scores were 15% and 26%, respectively (104), although the risk of CVD mortality in obese women was not reported, raising issues regarding generalizability (105). HEI-2010 includes both foods and nutrients that may overlap, such as total vegetables and plant proteins that may alter the score, especially when an FFQ was the source of intake data, including sodium.

Another dietary index, the UK Nutrient Profile Score (NPS), scores foods and nutrients as either beneficial (negative score), such as fruits and vegetables, or detrimental (positive score), like total sugar and sodium (57). This score was originally designed to identify less healthy foods in order to restrict TV advertisement to children and not to prevent CVD specifically (106). Regardless, researchers have explored the utility of this score system in CVD prevention in adult populations (54, 57), but no significant associations between consumption of less healthy food assessed using UK NPS and incident CVD were observed in the EPIC-Norfolk cohort (57). UK NPS does not account for important nutrients like mono- and polyunsaturated fats and does not differentiate between refined and whole grains. Thus, certain scoring systems may not be applicable to other diseases or population groups.

An additional score based on the UK dietary guidelines is the Dietary Reference Values index, which reflects the adherence to Public Health England dietary policy for optimal

health and prevention of CVD (54). Higher adherence to the score was inversely associated with BMI in the Airwave Health Monitoring cohort, but not with BP (54).

Novel scores

Conceptually, a dietary index or score has evolved to become more specialized as more detailed associations between certain foods/nutrients/diets and biologic outcomes or mechanisms are identified. Recently, the NHANES III follow-up study of 12,366 participants reported a positive association between a proinflammatory diet and CVD mortality (20). The DII focuses on potential inflammatory aspects of the diet thought to be associated with development of risks for a variety of diseases (79). After an extensive review of the literature, Shivappa et al. compiled the DII using data from 11 countries for the effects of 45 food components on several inflammatory biomarkers. A higher DII score correlates with a proinflammatory, less healthy dietary profile and, conversely, a lower DII score correlates with an anti-inflammatory, healthier dietary profile (79).

The DII is calculated based on intakes of foods and nutrients using standard global means for reference, where the standard mean is subtracted from the actual intake and divided by its standard deviation. Values are then converted to percentiles to minimize the effect of right skewing. Foods and nutrients are scored between −1 (maximally anti-inflammatory) and +1 (maximally proinflammatory), with each percentile score doubled, and 1 is subtracted and multiplied by its respective "overall food parameter–specific inflammatory effect score" to obtain the "food parameter–specific DII score." The overall score is the sum of all individual scores.

However, the DII is mainly based on nutrients that are difficult to estimate from dietary recording methods (e.g., use of herbs, including pepper and thyme), which adds to the complexity of index calculation. Due to this limitation, we found studies that have modified this score to include a reduced number of components (36, 41, 45) (Supplemental Table 2).

Sijtsma and colleagues developed 2 dietary scores, the Dutch Undesirable Nutrient and Food Score, including 13 food groups, and the Dutch Healthy Nutrient and Food Score, including 11 food groups, and investigated their relations to CVD mortality risk in 4837 patients with MI undergoing drug treatment (43). Calculation of the score is relative, where nonconsumers are coded 0 and consumers are divided into quartiles of intake (1 to 4), with equal weights given to each food group and no cutoffs used for maximum intake. Since a large number of components are included in the score, an overlap between foods and nutrients (e.g., processed meat and sodium) may exist, causing large variations in the scores.

In recent years, increased attention has been given to plant-based foods and CVD and its risks. Plant-based diets have previously been linked with a lower incidence of CVD than animal-based diets (107, 108). Available evidence, however, has focused mainly on the relation between vegetarian diets and CVD risk and has showed inconsistent results (109–111). Many prospective cohort studies and trials on the relation between plant-based diets and CVD (109, 110, 112–114) have limitations. Some investigations consider plant-based diets to be "vegetarian" diets; some investigations fail to distinguish between types of plant-based foods, like refined grains and sugar-sweetened beverages. To address these limitations, Satija et al. (19) created an overall, graded plant-based diet index (PDI) with positive scores for plant foods and reverse scores for animal foods, totaling 18 food groups. The authors then derived from the PDI a healthful PDI (hPDI) and an unhealthful PDI (uPDI).

Calculation of the score is based on quintiles of intake, with a score of 5 given to participants above the highest quintile of a food group and a score of 1 to those below the lowest quintile. The scoring system is inversed for reverse scores. Therefore, PDI is calculated by giving positive scores to plant foods and reverse scores to animal foods, hPDI is calculated by giving positive scores to healthy plant food groups and reverse scores to less healthy plant food groups and animal food groups, uPDI is calculated by giving positive scores to less healthy plant food groups and reverse scores to healthy plant food groups and animal food groups. The overall score is the sum of all scores. This score is unique in that it distinguishes between healthful and unhealthful plant foods. However, similar to previous scores, equal weights are assigned to each food group and no cutoffs are used for maximum intake, which may lead to an overestimation of the overall score. Moreover, an overlap may exist, with scoring of some components, like animal fat and meat, causing large variations in the scores.

Studies that compare different scores

Due to the plethora of diet quality indices, some studies compared the association between adherence to the above-mentioned indices and CVD and its risk factors (25, 42). Sotos-Prieto and colleagues compared AHEI, modified MDS, and DASH score in relation to CVD risk during the first 4-y follow-up in the Health Professionals Follow-up Study involving 29,343 men and the Nurses' Health Study including 51,195 women (25). Higher AHEI and DASH scores and a higher modified MDS were inversely associated with long-term CVD risk. Sotos-Prieto and colleagues concluded that AHEI and DASH scores have more components in common (e.g., sugar-sweetened beverages, red and processed meat, and sodium intake) than they have with modified MDS. AHEI and modified MDS both include alcohol, whereas the DASH score does not. When alcohol was removed from AHEI and modified MDS in sensitivity analysis, the association between AHEI and CVD/CAD risk was attenuated to null for the highest quintile of change in AHEI (25).

Alkerwi and colleagues also compared diet quality indices [Recommendation Compliance Index (RCI), Diet Quality Index-International (DQI-I), DASH score, MDS, and DII] in relation to CVD risk factors (42). Adherence to the diet quality indices was assessed in 1352 participants using an FFQ and results showed inverse associations with lipids.

DASH and MDS, but not RCI or DQI-I, showed inverse relations with diastolic BP (42). It is noteworthy that RCI and DQI-I treat poultry, fish, dairy, beans, and eggs as one group.

In a cross-sectional analysis of the EPIC-Norfolk, the relations of HEI-2010, DASH score, MDS, and the Italian Mediterranean Index (IMI) to BP were compared (30). IMI is similar to MDS but includes additional food groups commonly consumed in Italy, such as soft drinks, alcohol, butter, red meat, and potatoes. All dietary indices were inversely associated with both systolic and diastolic BP, with strongest associations observed between IMI and both systolic and diastolic BP in women only and between DASH score and diastolic BP in men only (30).

Perspectives

A closer examination of the components of diet quality scores reveals that protective effects against CVD stem from components such as fruit, vegetables, legumes, nuts, fish, and moderate amounts of alcohol (115, 116). Many of these scores include monounsaturated fatty acids, fiber from vegetables, fruit, cereals, and legumes and contain high amounts of antioxidants like vitamins C and E in addition to flavonoids and polyphenols (81). All nutrients and nonnutrient compounds within the food matrix work synergistically and some specific combinations may directly protect against CVD. For example, the combination of compounds found in olive oil and green leafy vegetables, a characteristic of the Mediterranean diet, modified signaling pathways related to BP control (117). Other benefits of adhering to diet quality scores may occur through improvements in CVD risk factors, such as normalization of triglyceride concentrations, total blood cholesterol, low-density lipoprotein, high-density lipoprotein, and BP (28).

We highlight 2 beneficial food groups consistently included in some of the most common score algorithms—fruit and vegetables (Figure 3). Strong and consistent evidence shows that higher fruit and vegetables intake is beneficial to cardiometabolic health (118), since these foods are rich in fiber, vitamins, and phytochemicals and low in energy density. The equal weighting given to these food groups makes it challenging to determine whether they drive the effect of diet quality scores on CVD. Some scores have specified subgroups within fruits and vegetables (NFI, dietary phytochemical index; Supplemental Table 2); use of such scores is challenging in regions with infrequent or varied intake.

Moreover, the dietary collection tool needs to capture intake of these specific components—which may be a limitation of some established predefined FFQ lists. Although detailed categorization presents challenges in assessment, clarity is needed when broad fruit and vegetable categories are reported in a score. The traditional Greek MDS includes potato (a source of potassium) in the vegetables category, a food group later excluded from alternative MDS (119) when adapted to the US population. Additionally, there are variations in the assessment of fruit and vegetables; AHEI

distinguishes whole fruit from other sources such as fruit juice (23).

Additionally, we found the majority of indices to assign equal weighting to all foods in a score, leading to an overestimation of the final score. Not all foods, however, contribute equally to a health outcome. Some indices combined certain groups; for example, the DQI-I treats poultry, fish, dairy, beans, and eggs as 1 group without differentiating their effects on CVD and its risk factors.

It is also important to understand how diet components are converted to a score. Scores can be calculated either by using absolute cutoff values (e.g., higher or lower than a predefined level, as usually applied to scores based on country-specific intake guidelines) or based on the relative distribution of intakes within a population (e.g., DASH score is based on quantiles of sex-specific intakes). Compared with relative intake score systems, absolute cutoff values can limit score overestimation and allow comparison and pooling of studies for meta-analyses. For example, the dietary profile of a high MDS in a southern European population will be quite different from a high score in a northern European population. In the original MDS study (81), the median intake cutoff value used was ∼360 g/d of fruit and nuts in a Greek population, whereas in a UK study the value used was 213 g/d (59). Moreover, the ratio of MUFA to SFA was ∼1.7 in the Greek cohort and 0.9 in the UK cohort. This example illustrates the challenge of comparing outcomes across different population groups using relative scores. An important question when interpreting the utility of the MDS in different population groups is whether intakes of the food reflect the levels typically observed in southern Mediterranean populations.

We also observed that the number of dietary components can vary greatly across different scores from the carbohydrate quality index and versions of the NFI with 4 and 6 components, respectively, to the DII with up to 45 different components. Figure 3 compares dietary components across a sample of scores reviewed. The components are often weighted as "positive" (healthy) or "negative" (unhealthy) in scores. Most scores have focused on increasing the intake of healthy foods rather than limiting unhealthy foods, resulting in a higher number of positively scored components than negatively scored components. For example, DASH includes 5 healthy and 3 unhealthy components and MDS includes 7 healthy and 2 unhealthy. Therefore, we need to consider uncontrolled confounding by "healthy" foods and if there should be more emphasis on avoiding "unhealthy" foods.

The positive or negative classification is also differentially weighted between scores. For example, in the traditional MDS algorithm, dairy is classified as a component to limit, based on the traditional MD, whereas evidence from the DASH trial has shown that low-fat dairy is beneficial in relation to BP management (120). The alternative MDS published in 2005 omitted dairy from the scoring algorithm based on the benefit of low-fat dairy on cardiometabolic health (119). Another important example is the inclusion of alcohol in the traditional MDS but not in DASH. Red wine

was traditionally consumed in the Southern Mediterranean (121). However, in the MDS, alcohol (ethanol grams/day) is included in the score but the source (e.g., wine) is not specified. Alcohol is a nonessential nutrient contributing significantly to energy intake. Evidence on the benefits of moderate alcohol intake on cardiometabolic health is contradictory. As part of the MDS, moderate alcohol intake may prove beneficial (75). However, excessive alcohol intake is associated with CVD intermediaries including hypertension and atrial fibrillation (122). The moderate alcohol consumption levels suggested by the MDS (up to 3 units per d) contradict UK Public Health England guidance of a safe limit for alcohol consumption (123).

It is important to consider how much of a population's typical diet is represented by any score. The food standard agency NPS includes all items consumed in a population's diet, whereas the DASH score covers only part of the diet (39, 55). The impact of partial diet representation in these scores depends on whether the dietary components included in the score drive health outcomes or the dietary components not included are highly correlated with those driving benefit.

A final consideration is that even when the same score system was used across studies, various modifications were found (17, 22, 29, 71). Lack of consensus in defining different scores leads to variations that may cause misclassification of score categories. As presented in this review, there is a large amount of heterogeneity across families of diet quality scores in terms of food groups included and cutoffs applied in calculations (Supplemental Table 3). Assessing the relations between the different diet quality scores and individual CVD outcomes is outside the scope of this review. Although we have constructed a narrative summary to illustrate the general direction of associations with combined CVD outcomes, researchers should be cautious in the pooling of studies for analytical assessment based on the heterogeneity in the calculation and application of seemingly similar diet quality scores.

Challenges in universal application

In review of diet quality indices, it is important to account for cultural differences when applying a score, such as in the availability of various foods (e.g., olive oil), or in food preparation and consumption. Cooking methods vary across cultures; chicken can be boiled, deep fried, or roasted, each producing a different dietary quality. Reflecting cultural differences, the MDS was found to have stronger inverse associations with CVD mortality in Spain than in the Netherlands (60). Applying Western developed scores like the DASH score in China is challenging because dairy intake, especially low-fat dairy, is generally low in Chinese populations (124). Other factors like age, gender, race, physical activity level, and presence of comorbidities are also important considerations when applying diet quality indices.

Methods of dietary data collection are important in the use of diet quality indices. Use of 24-h dietary recalls and FFQs may fail to capture seasonal variations in intake, and use of single measures of FFQ, as seen in many of the studies

reviewed here, is particularly subject to measurement error and may not accurately assess intake of certain nutrients like sodium, a major component of the DASH score.

Moreover, there is a lack of objective validated measures of diet quality scores. Although the field of metabolomics is progressing in the use of objective measures of specific foods and nutrients (125), only 2 studies investigating the use of metabolomic profiles distinguished high and low adherence to a priori dietary patterns (126). Advances in molecular epidemiology also have the potential to elucidate mechanisms linking dietary patterns to cardiometabolic outcomes (125).

Finally, identifying diet quality based on the indices discussed here is a challenge. Because scores can assess only one aspect of food intake, implementation at a population level will be the future challenge for public health nutrition practitioners considering several factors like social status, education, accessibility to healthy food stores, compliance, and other lifestyle and behavioral aspects that can affect adherence to a healthy dietary pattern (127).

Conclusions

The present review identifies a pressing need for population-specific dietary indices that can accurately monitor CVD risk and related risk factors based on cultural patterns and lifestyles. **Box 1** lists recommendations for the future application and interpretation of dietary indices in nutritional epidemiologic studies investigating diet quality and cardiovascular health.

Box 1:
Recommendations for the future application and interpretation of dietary indices in nutritional epidemiologic studies investigating diet quality and cardiovascular health.

- Clearly define foods/beverages, nutrients, or other food components included in scores for replication of calculations on other population cohorts.
- If modifying a previously reported score, state the modification and the rationale.
- Use clearly defined cutoff values, or scoring systems based on specified amounts (e.g., per 1000 kcal).
- Report systematic statistical identification of key components within each score that drive association with outcomes [e.g., testing independent associations between individual dietary components in a score and cardiovascular disease (CVD) outcomes].
- Consider food as well as nutrients when interpreting a score. For example, scores that rely only on foods may overlook the importance of the intercorrelation of nutrients such as calcium and magnesium with CVD outcomes.

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