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Diet quality indices and their associations with all-cause mortality, CVD and type 2 diabetes mellitus: an umbrella review

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Abstract

Numerous observational studies have investigated associations between diet indices and health outcomes. Our aim was to systematically synthesise data that was previously summarised separately for each diet index in one umbrella review of all diet indices with sufficient evidence gained in systematic reviews and to assess the quality and strength of evidence for selected health outcomes. The MEDLINE, EMBASE and Scopus databases were systematically searched following the PRISMA guidelines through October 2021 for systematic reviews of observational studies investigating associations between adherence to diet indices and selected health outcomes (all-cause mortality, CVD incidence or mortality, type 2 diabetes mellitus incidence or mortality). Methodological quality and quality of evidence were assessed using the AMSTAR 2 and NutriGrade tools. The inclusion criteria were met by seven systematic reviews, entirely based on prospective cohort studies and reviewing five different diet indices – alternate healthy eating index (AHEI), dietary approaches to stop hypertension (DASH), dietary inflammatory index (DII), healthy eating index (HEI) and Mediterranean diet (MedDiet). All seven included systematic reviews showed that greater adherence to these diet indices reduces the risks of all-cause mortality, CVD incidence and mortality and type 2 diabetes mellitus incidence. Moderate meta-evidence was presented for AHEI and DASH for all outcomes, also for DII for all-cause mortality, CVD mortality and incidence, MedDiet for all-cause mortality and for HEI for CVD incidence and mortality. Our umbrella review provides further evidence for AHEI, DASH, DII and HEI diet indices to be used as predictors of selected health outcomes.

Key words: **Diet: Diet quality index: Umbrella review: Epidemiology**

Suboptimal diet is one of the leading and preventable causes of chronic non-communicable diseases incidence and mortality[1]. Initial studies first aimed to investigate the role of single nutrients or food groups in maintaining health or developing diseases. Although certain nutrients have clear health benefits, their effect is only limited when studied in isolation, and this approach cannot fully explain complex diet behaviours[2,3]. Building on this previous knowledge and epidemiological studies, several diet indices were designed to better assess dietary patterns and summarise various components of a diet[2–7].

Such indices are mainly based on dietary guidelines and designed to reduce the risk of non-communicable chronic diseases, trying to take into account the interdependent effects of individual nutrients and/or food items[3]. Even though different models of healthy diet have their own advantages and limitations, the main purpose of nutrition indices is to combine a large amount of nutrition information into a single indicator, useful for assessing the relationship between potential protective or risk factors and major diet-related diseases[8].

Two main methodological approaches, *a priori* and *a posteriori* analysis, have been proposed to evaluate the diet quality of the population[4,5,9]. *A posteriori* approach involves the use of statistical techniques (factor, cluster and principal component analysis). Therefore, these are specific to the population studied and did not necessarily define the healthiest dietary pattern[5,9]. However, in this umbrella review, the focus was on *a priori* diet indices that are based on current nutritional knowledge and identify nutritional components known to be important for health promotion and reflect risk gradients for major diet-related diseases[5].

There is already a large number of *a priori* diet indices and new improved ones are constantly being developed[2,4,7,9]. They have several similarities when defining healthy diet components, but also differ in construction criteria and in the capacity to determine associations between diet and chronic diseases[2,3,5,7]. Empirical validation in terms of associations with various health outcomes is widespread in the literature. However, this large amount of data can present a challenge in

Abbreviations: AHEI, alternate healthy eating index; AMSTAR, A Measurement Tool to Assess Systematic review; DASH, dietary approaches to stop hypertension; DII, dietary inflammatory index; HEI, healthy eating index.

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comparing and evaluating diet indices, especially as the number of studies and meta-analyses with varying quality of evidence is also constantly increasing. Consequently, it is important that all this published evidence on associations of diet indices and health outcomes is summarised, evaluated and presented in a systematic way to enhance its usefulness and practicality.

Although there are multiple systematic reviews and meta-analyses of observational studies analysing associations between adherence to diet indices and risks of health outcomes, to our knowledge, there is no umbrella review that simultaneously assesses the evidence for all diet indices and also conducts a methodological quality assessment and grading of the evidence. Therefore, the aim of our umbrella review was to summarise, aggregate and analyse data gathered in previous research and present clear evidence for associations between diet indices and some of the main diet-related outcomes (all-cause mortality, CVD incidence and mortality, type 2 diabetes mellitus incidence and mortality).

Methods

The umbrella systematic review was performed following the PRISMA guidelines[10] and had been registered in the international registry of systematic reviews (PROSPERO registration number CRD42021276497).

Search strategy

Relevant studies published until the end of October 2021 were searched for in the following online databases: MEDLINE (through PubMed), EMBASE (through OVID) and Scopus. No restrictions in terms of language were used. Moreover, the reference lists of retrieved articles were checked to search for further relevant studies. The literature search was conducted by one author (AB). A complete search strategy based on selected keywords is presented in Supplementary Material (Supplementary Table 1)

Study selection

For the purpose of our research question, the following inclusion criteria were applied:

(1) systematic reviews with or without meta-analysis that include observational studies (prospective cohort studies, case–control studies, cross-sectional studies),

(2) studies that included general adult (> 18 years) population,

(3) used *a priori* dietary index as exposure,

(4) considered all-cause mortality, CVD incidence or mortality, type 2 diabetes mellitus incidence or mortality as outcomes.

Additionally, the following exclusion criteria were applied:

(1) umbrella systematic reviews,

(2) *posteriori* defined dietary patterns or healthy lifestyle indices that include dietary patterns,

(3) association of dietary indices with other health outcomes, physiological or biochemical parameters,

(4) systematic reviews that reviewed less than three primary studies for individual dietary index,

(5) other studies that were not systematic reviews.

If more than one systematic review was found for each outcome and diet index pair, we selected the one with the largest number of primary prospective cohort studies and/or the most recently updated one[11,12]. If two systematic reviews were too similar according to these criteria, we chose the one with fewer weaknesses in (non)critical items of A Measurement Tool to Assess Systematic reviews (AMSTAR 2)[13]. Retrieved articles were independently screened in duplicate (AB, MG) to identify studies that potentially met the inclusion criteria and achieved consensus on which studies to include.

Data extraction

From each systematic review of the included studies, data were extracted using a standardised form we developed, which includes information on author(s), year of publication, outcomes examined, name/type of diet quality index, design and number of studies included in the review, number of participants and events, risk or hazard ratio with 95 % CI and p-value, heterogeneity, method used for assessing the risk of bias in primary studies and publication bias. Additionally, we extracted the following data regarding primary studies: author(s), year of publication, study name, study location, follow-up duration, number of participants and events, sex and age of participants, diet assessment method and health of the study sample. As systematic reviews are sometimes missing data on primary studies, we then extracted missing data directly from the primary studies.

Data extraction was performed in duplicate (AB, MG), and any disagreements were resolved by consensus. If needed, we contacted the authors of the included systematic reviews for additional data.

Data analysis

We analysed extracted data quantitatively with the addition of basic descriptive analysis.

Methodological quality assessment and grading of evidence

The methodological quality of all included systematic reviews was assessed in duplicate (AB, MG) using the AMSTAR 2 quality assessment tool. We rated overall confidence in the results of the review in four groups (high, moderate, low, critically low) depending on the number of (non)critical weaknesses[13].

We used the NutriGrade scoring system to assess and grade included meta-evidence. NutriGrade is based on the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach[14] and is specifically designed for use in nutrition research to assess its specific requirements (data based on cohort studies, use of dietary assessment methods, funding bias) and need to summarise an increasing number of meta-analyses[15].

For systematic reviews of cohort studies, eight criteria are used for grading: risk of bias, study quality and limitations, precision, heterogeneity, directness, publication bias, funding bias, effect size and dose–response. We then classified them into four categories: very low (0–3·99 points), low (4–5·99 points), moderate (6–7·99 points) and high (≥ 8 points)[15].

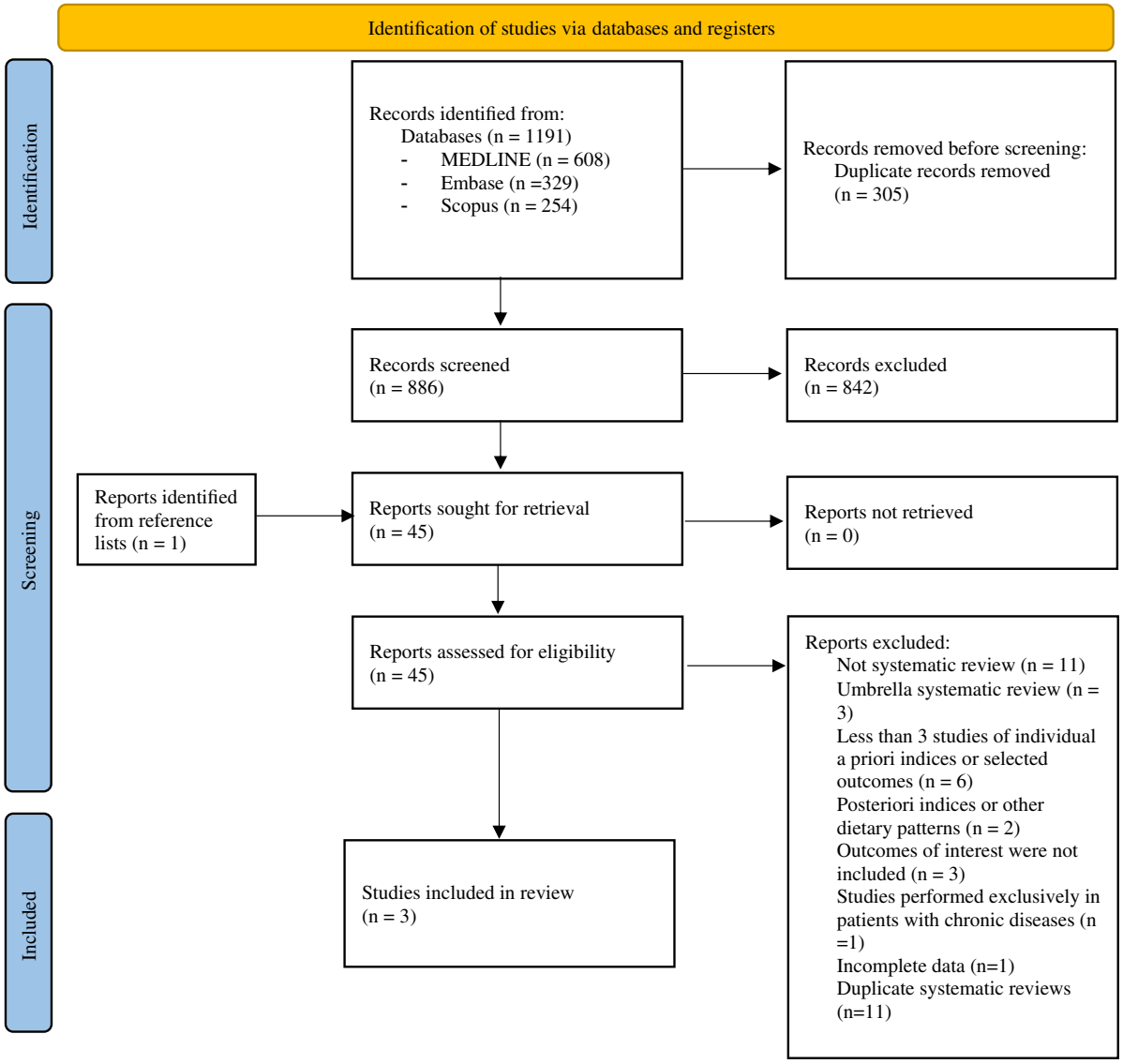

Fig. 1. Flow chart of the study selection process.

Results

Initially, 1191 records were identified (608 from MEDLINE, 329 from EMBASE and 254 from Scopus), of which 305 duplicate records were removed. Subsequently, 886 titles and abstracts were screened, leaving 44 suitable for full eligibility review. When checking the reference lists of the retrieved articles, one additional article was included to be reviewed for eligibility. After applying the inclusion criteria and reading their full text, twenty-six articles were excluded for the following reasons: not a systematic review (*n* 11)[2,4,9,16–23], umbrella systematic review (*n* 3)[7,24,25], fewer than three included studies of individual *a priori* index or selected outcomes (*n* 6)[26–31], posterior indices or other dietary patterns (*n* 2)[32,33], outcomes of interest were not included (*n* 3)[34–36], primary studies performed exclusively in patients with chronic diseases (*n* 1)[37], providing incomplete data (*n* 1)[38].We then excluded duplicate systematic reviews that reviewed the same associations (*n* 11)[39–49], resulting in seven eligible included studies[36,50–56]. PRISMA flow chart is shown in Fig. 1.

Study characteristics

The main characteristics of the included systematic reviews are listed in Table 1. All included systematic reviews were published in the last 7 years, with four of them in the last 3 years[52,53,55,56] The median number of included primary studies for each pair of outcome and diet index was 12 (range: 6–31), the median number of participants 778 510 (range: 43 385–2 222 366) and the median number of cases 45 228 (range: 1330–221 603). Systematic reviews included only prospective cohort studies for selected outcomes (*n* 7). Two systematic reviews included more than one diet index, others focussed on one. The following five diet indices and their subversion were assessed in the included systematic reviews: Mediterranean diet (MedDiet)[50,51,56], healthy eating index (HEI)[53], alternate

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Table 1. Summary of diet indices and their associations with selected outcomes

	First author, year of publication	Study design and number of included studies	Comparison	Type of effect size metrics	Effect size	95 % CI	I^2 %	Risk of bias/ quality in primary studies	Number of cases	Number of participants	Publication bias -Egger test
AHEI											
All-cause mortality	Morze, 2020	13 cohort	High *v.* low	RR	0·79	0·76, 0·82	77	NOS	185 101	1 182 203	NR
CVD incidence/mortality	Morze, 2020	21 cohort	High *v.* low	RR	0·77	0·74, 0·80	45	NOS	77 235	1 615 807	NR
Type 2 diabetes	Morze, 2020	12 cohort	High *v.* low	RR	0·80	0·75, 0·86	77	NOS	71 077	677 361	NR
DASH											
All-cause mortality	Morze, 2020	15 cohort	High *v.* low	RR	0·82	0·79, 0·84	50	NOS	190 299	1 617 826	NR
CVD incidence/mortality	Morze, 2020	31 cohort	High *v.* low	RR	0·81	0·78, 0·85	60	NOS	78 662	2 222 366	NR
CVD mortality	Soltani, 2020	12 cohort	5-point increment	HR	0·97	0·95, 0·98	82·4	NOS	30 514	1 314 675	$P = 0·149$
Type 2 diabetes	Morze, 2020	9 cohort	High *v.* low	RR	0·78	0·72, 0·83	65	NOS	45 228	326 031	NR
DII											
All-cause mortality	Namazi, 2018	6 cohort	High *v.* low	RR	1·21	1·09, 1·35	72·6	NOS	32 677	107 306	$P = 0·08$
CVD incidence	Ji, 2020	6 cohort	High *v.* low	RR	1·41	1·12, 1·78	37·0	NOS	1310	43 385	$P = 0·21$
CVD mortality	Ji, 2020	10 cohort	High *v.* low	RR	1·31	1·19, 1·44	70·8	NOS	32 319	385 765	$P = 0·21$
HEI											
All-cause mortality	Morze, 2020	10 cohort	High *v.* low	RR	0·80	0·78, 0·82	52	NOS	214 410	1 587 638	NR
CVD incidence/mortality	Morze, 2020	13 cohort	High *v.* low	RR	0·81	0·77, 0·84	47	NOS	78 828	1 809 626	NR
Type 2 diabetes	Morze, 2020	6 cohort	High *v.* low	RR	0·88	0·82, 0·94	64	NOS	41 125	356 840	NR
MedDiet											
All-cause mortality	Soltani, 2019	29 cohort	2-point increment	HR	0·90	0·89, 0·91	81·1	ROBINS-I	221 603	1 676 901	$P = 0·008$
CVD incidence	Grosso, 2015	13 cohort	High *v.* low	RR	0·73	0·66, 0·80	36	NOS	13 434	275 162	NR
CVD mortality	Grosso, 2015	13 cohort	High *v.* low	RR	0·75	0·68, 0·83	75	NOS	9563	778 510	NR
Type 2 diabetes	Jannasch, 2016	8 cohort	High *v.* low	RR	0·87	0·82, 0·93	26	SIGN	17 561	183 392	$P < 0·0001$

AHEI, alternate healthy eating index; DASH, dietary approaches to stop hypertension; DII, dietary inflammatory index; NOS, Newcastle–Ottawa Scale; NR, not reported; RR, relative risk.

Table 2. Methodological quality of the included meta-analyses using AMSTAR 2

Author, year	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Overall confidence
Morze, 2020	Y	PY	Y	PY	Y	Y	N	PY	Y	Y	Y	Y	Y	Y	Y	Y	Low
Soltani, 2020	Y	PY	N	PY	Y	Y	PY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Moderate
Namazi, 2018	Y	N	N	N	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Critically low
Ji, 2020	Y	N	N	PY	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Critically low
Soltani, 2019	Y	Y	N	PY	Y	Y	PY	Y	Y	N	Y	Y	Y	Y	Y	Y	Moderate
Grosso, 2015	Y	N	Y	PY	Y	N	N	Y	Y	N	Y	N	N	Y	N	Y	Critically low
Jannasch, 2017	Y	N	N	N	Y	N	N	Y	Y	N	Y	Y	Y	N	Y	Y	Critically low

AMSTAR, A Measurement Tool to Assess Systematic reviews, Y, yes, N, no, PY, partially yes.
Q1: Did the research questions and inclusion criteria for the review include the components of population, intervention, comparison, outcome (PICO) framework?
Q2: Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?
Q3: Did the review authors explain their selection of the study designs for inclusion in the review?
Q4: Did the review authors use a comprehensive literature search strategy?
Q5: Did the review authors perform study selection in duplicate?
Q6: Did the review authors perform data extraction in duplicate?
Q7: Did the review authors provide a list of excluded studies and justify the exclusions?
Q8: Did the review authors describe the included studies in adequate detail?
Q9: Did the review authors use a satisfactory technique for assessing the risk of bias?
Q10: Did the review authors report on the sources of funding?
Q11: Did the review authors use appropriate methods for statistical combination of results?
Q12: Did the review authors assess the potential impact of RoB in individual studies on the results?
Q13: Did the review authors account for RoB in individual studies when interpreting/discussing the results of the review?
Q14: Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity?
Q15: Did the review authors carry out an adequate investigation of publication bias?
Q16: Did the review authors report any potential sources of conflict of interest?

healthy eating index (AHEI)[53], dietary approaches to stop hypertension (DASH)[53,55] and dietary inflammatory index (DII)[52,54].

Study results

The main study results are summarised in Table 1. All reviewed systematic reviews showed that high-quality diet, as assessed by diet indices, is inversely associated with the risk of all-cause mortality, CVD incidence and mortality and type 2 diabetes mellitus incidence. The only exception was the association of DII and type 2 diabetes mellitus incidence, for which we could not find any eligible systematic reviews. We also found no systematic reviews assessing the association between type 2 diabetes mellitus mortality and diet indices. Furthermore, for HEI, AHEI and DASH, we found no data for CVD incidence, so we included a combined RR for mortality and incidence, and additionally a separate RR for mortality associated with DASH. Additional data from systematic reviews and data from all primary studies reviewed in them are presented in Supplementary Material (online Supplementary Tables 2 and 3).

Methodological quality

The overall methodological quality (AMSTAR 2) of the included studies is presented in Table 2. Overall confidence in the results was rated moderate for two studies evaluating the association between MedDiet and all-cause mortality and DASH and CVD mortality[55,56], low for one that evaluated HEI, AHEI, DASH and all-cause mortality, CVD incidence/mortality and type 2 diabetes mellitus incidence[53] and critically low for the remaining four studies evaluating associations between remaining outcomes and diet indices[50–52,54]. The main reasons for the lower quality are that the authors rarely reported that protocols were written before conducting the review, did not perform a comprehensive literature search and did not explain the reasons for their selection of study designs for inclusion, provided insufficient details regarding excluded studies and rarely reported funding sources of the included primary studies.

Overall quality of evidence

When grading meta-evidence (NutriGrade), twelve pairs of diet indices and outcomes were graded as moderate and six of them were graded as low (Table 3). AHEI, DASH and DII were rated moderate for all outcomes. Similarly, DII was rated moderate for all outcomes. MedDiet was rated low for all outcomes (CVD incidence, CVD mortality, type 2 diabetes mellitus incidence) except for all-cause mortality. HEI was also rated low for all-cause mortality and type 2 diabetes mellitus incidence and moderate for CVD incidence and mortality.

Discussion

This umbrella systematic review presents a comprehensive review of associations between five diet indices (MedDiet, HEI, AHEI, DASH, DII) with sufficient evidence gained in systematic reviews to be included in our review and selected outcomes (all-cause mortality, CVD incidence and mortality and type 2 diabetes mellitus incidence). All seven included systematic reviews indicated that greater adherence to those diet indices may reduce the risks of all-cause mortality, CVD incidence and mortality and type 2 diabetes mellitus incidence, with the exception of an association between type 2 diabetes mellitus incidence and DII, for which we found no eligible systematic reviews. Moderate meta-evidence was presented for AHEI and DASH for all outcomes, also for DII for all-cause mortality, CVD mortality and incidence, for HEI for CVD incidence and mortality, and for MedDiet for all-cause mortality.

Table 3. Overall quality of evidence (NutriGrade)

	Risk of bias, study quality, and study limitations*	Precision†	Heterogeneity‡	Directness§	Publication bias‖	Funding bias¶	Effect size**	Dose–response††	NutriGrade score
AHEI									
All-cause mortality	2	1	0·6	1	0·5	1	0	0	6·1 (moderate)
CVD incidence/ mortality	2	1	0·6	1	1	1	1	0	7·6 (moderate)
Type 2 diabetes	2	1	0·6	1	1	1	0	0	6·6 (moderate)
DASH									
All-cause mortality	2	1	0·6	1	0·5	1	0	0	6·1 (moderate)
CVD incidence/ mortality	2	1	0·6	1	1	1	0	0	6·6 (moderate)
CVD mortality	2	1	0·8	1	1	1	0	1	7·8 (moderate)
Diabetes type 2	2	1	0·3	1	1	1	1	0	7·3 (moderate)
DII									
All-cause mortality	2	1	0·4	1	0	1	1	0	6·4 (moderate)
CVD incidence	2	1	0·4	1	0	1	1	0	6·4 (moderate)
CVD mortality	2	1	0·8	1	0·5	1	1	0	7·3 (moderate)
HEI									
All-cause mortality	2	1	0·6	0	0·5	1	0	0	5·1 (low)
CVD incidence/ mortality	2	1	0·6	1	0·5	1	1	0	7·1 (moderate)
Type 2 diabetes	2	1	0·3	0	1	1	0	0	5·3 (low)
MedDiet									
All-cause mortality	0·75	1	0·8	1	0·5	1	0	1	6·05 (moderate)
CVD incidence	1	1	0·8	1	0	1	1	0	5·8 (low)
CVD mortality	1	1	0·8	1	0	1	1	0	5·8 (low)
Type 2 diabetes	1·75	1	0·4	1	0	1	0	0	5·15 (low)

AHEI, alternate healthy eating index; DASH, dietary approaches to stop hypertension; DII, dietary inflammatory index, HEI, healthy eating index.
* Risk of bias, study quality and study limitations (0 to 2 points) - 2 points if mean Newcastle–Ottawa Score for a comparison ≥ 7 or if other criteria are fulfilled.
† Precision (0 to 1 point) - 1 point if ≥ 500 events and 95 % CI excluded null value or if ≥ 500 events and 95 % CI overlaps null value but excludes important benefit or harm (relative risk [RR] < 0·8 or > 1·2).
‡ Heterogeneity (0 to 1 point) - 1 point if ≥ 10 studies, heterogeneity measures adequately reported, no important heterogeneity found or otherwise subgroup/sensitivity analyses conducted.
§ Directness (0 to 1 point) - 1 point if no important differences in the population or intervention; hard clinical outcome.
‖ Publication bias (0 to 1 point) - 1 point if no evidence for publication bias with test or plot (10 or more studies).
¶ Funding bias (0 to 1 point) - 1 point if funded from academic or research institution.
** Effect size (0 to 2 points) - 2 points if RR < 0·5 or > 2·0 and corresponding test statistically significant (highest *v.* lowest category).
†† Dose–response (0 to 1 point) - 1 point if significant linear/nonlinear dose–response relation in prospective cohort studies.

Effect sizes were consistently the highest for DII[52,54] through all outcomes and in the range of moderate effect sizes based on the NutriGrade scoring system. However, as the index is relatively new in comparison with others, systematic reviews are based on a lower number of studies with fewer participants. Consequently, effect sizes may decrease when larger studies will be conducted. We found no suitable systematic reviews assessing the association between type 2 diabetes mellitus and DII, which indicates the need for more prospective cohort studies for this outcome. Even though MedDiet is one of the most researched indices, the overall quality of evidence was rated low for all outcomes except one, which indicates that further high-quality cohort studies and meta-analyses are needed to improve confidence in effect estimates. In contrast, systematic reviews of AHEI, DASH and DII provided a higher quality of evidence, with moderate confidence in effect estimates.

Heterogeneity was generally high, with most pairs of outcomes and diet indices (14/17) showing I^2 value ≥ 40 %, with four of them showing very high heterogeneity with I^2 > 75 %. However, almost all of the included studies used random effects models and further explored reasons for high heterogeneity with subgroup analysis or meta-regression and sensitivity analyses. As acknowledged by all included systematic reviews, high heterogeneity could be partly explained by differences in diet scoring methods (different food groups included, scoring criteria or categorical cut-off points) among the same indices, because researchers frequently apply modifications to original indices as they try to improve quality or simplify their use in studies (e.g., due to different nutritional data available). Another reason for high heterogeneity may be based on the geographical location of the primary studies[50,54,56,57]. This is particularly emphasised in studies of MedDiet indices, as stronger inverse associations are detected in Mediterranean populations. Possible reasons could be different patterns of adherence in Mediterranean regions[50,56] and the use of median intakes as cut-offs for included components – individuals classified with high adherence in non-Mediterranean population might be classified as poorly adherent in Mediterranean populations[56]. As DASH scoring also uses quantile distribution of intake specific for observed populations and consequently different cut-off points, it encounters a similar problem[53].

As we mentioned, differences between diet scoring methods and different (sub)versions of diet indices contribute to heterogeneity, which the authors further explored with subgroup analyses. For example, original version of HEI was only associated with CVD incidence/mortality, but not with all-cause

mortality and type 2 diabetes mellitus. As suggested by the authors, this may be explained as the original HEI does not distinguish between refined and unrefined grains[53,58]. When analysing MedDiet, the authors of the primary studies used different definitions of MedDiet and included various diet indices[50,56]. Consequently, only one systematic review identified a specific index (Panagiotakos MedDiet score) that showed a stronger association with all-cause mortality. However, only two primary studies used this index, which along with the reasons stated above, makes these comparisons less reliable[56]. On the other hand, systematic reviews found no differences when comparing versions of AHEI and DASH[53,55].

FFQ are the main method for diet assessment in primary studies, as they enable researchers to assess long-term dietary intakes and are generally more appropriate than 24-hour recalls[36,54,56]. However, they are still susceptible to measurement error due to misclassification. To improve diet assessment, some authors propose combining FFQ 24-hour dietary recalls (multiple source method) and/or validated biomarkers of intake[53,55]. However, combining dietary assessment types does not resolve their underlying systematic biases or errors. For more comparable data, a comprehensive food classification and description system should be used, such as FoodEx, developed by European Food Safety Authority (EFSA), to provide more comparable data on food consumption at EU level. Another improvement would be the use of longitudinal dietary intake data, as most primary studies use dietary assessment only at the beginning, even though diet habits may change over time and influence results[53–55].

Associations in primary studies were controlled for different potential confounders, with variability between studies. One of the important, but not always included confounders, is energy intake, which may result in bias if not assessed. However, similar to other elements of dietary assessment, it is also beneficial to assess energy intake repeatedly throughout the study[36,54].

All systematic reviews included primary studies that collectively represented both sexes sufficiently. Different age ranges were represented in samples, and even though most participants were middle-aged, some studies specifically focussed on people older than 70 years, showing similar results in the elderly. North America was the most represented region in samples, especially for HEI and AHEI. The second most prevalent region was Europe, where MedDiet stood out. Asian and African countries were seldom represented, and none of the primary studies were performed in South America. Because the studies mainly concentrated on western countries, results may not be generable for all populations. Since these results may depend on multiple factors, additional studies in societies with different dietary habits, cultures, genetic predispositions and environmental determinants are needed[16]. Included systematic reviews neither did systematically report ethnicity or education of participants nor did they analyse possible differences among these groups in subgroup analysis, which may be additionally addressed in further systematic reviews.

We found six similar umbrella reviews, two of them reviewing MedDiet[25,59], three DII[11,12,60] and one several different diet indices[7] and their associations with multiple health outcomes. All of them supported our results which indicate that adhering to MedDiet, DII, HEI, AHEI and DASH lowers risks for all-cause mortality, CVD mortality and incidence. Associations between these diet indices and type 2 diabetes are also supported, except for DII, where this was not assessed or no studies were found. Although risk estimates point in the same direction and effect sizes are similar, umbrella reviews differ in their approach to grading the evidence and assessing the certainty of the evidence, making comparison difficult. One umbrella review did not attempt to grade the evidence[25], three of them relied on arbitrary cut-offs mainly based on statistical significance[12,59,60], one only assessed consistency and validity against outcomes with their own criteria[7] and only one of them used additional criteria included in the GRADE approach to achieve a more complex evaluation of the results[11].

This umbrella review has numerous strengths. To our knowledge, we were the first to grade both meta-evidence (NutriGrade) and methodological quality of the included systematic reviews (AMSTAR 2) for all diet indices for which sufficient evidence was gathered and systematic reviews were made. Using specific scoring systems provides a better estimation of the certainty of the evidence than relying solely on statistical methods or on self-made criteria that are not a part of well-established tools to grade meta-evidence[14,15,61]. As these two tools assess different concepts, their overall scores may be different. NutriGrade assessment depends more on the quality of evidence provided in primary studies and does not assess the methodological quality of systematic reviews[15]. On the contrary, AMSTAR 2 assesses the methodologic quality of systematic review itself[13]. Both scores need to be interpreted in order to sufficiently present both aspects. We summed up the gathered evidence into a single umbrella review to identify evidence-based diet indices and enable comparisons between them. Our conclusions are based entirely on prospective cohort studies, so recall and selection bias are avoided. Moreover, by including only systematic reviews, we were able to provide a more accurate and reliable conclusion and minimise publication bias. Finally, in addition to reporting the main characteristic of the systematic reviews, we also reported the characteristics of each primary study included in them, in Supplementary Material (Supplementary Table 3).

Nevertheless, there are some limitations that need to be considered when interpreting the findings. First, heterogeneity among studies was generally high in the included systematic reviews. Even though all meta-analyses used statistical methods to explore heterogeneity (subgroup analyses, meta-regression, sensitivity analyses) and possible reasons were identified, heterogeneity was still generally high and partially unexplained. Second, although estimation of dietary intakes by direct methods can be very accurate, estimates can be incomparable due to different collection techniques, limited with target exposure nutrients or food pattern indices. Because a FFQ consists of a pre-specified list of foods, a single FFQ may not reflect the eating patterns of a given population. Thus, the performance of a particular FFQ in a particular population may not reflect its performance in a different population. An additional limitation arises if a FFQ, that was designed specifically for a certain diet index or target exposure, is used to evaluate other exposures. Third, we

decided not to include randomised control studies, which may provide additional evidence and allow us to infer causality. However, the use of randomised control studies in studying diet–disease relationship is limited by lack of double blinding, poor compliance and difficulty in providing adequate adherence in long-term follow-up, crossover bias and high-dropout rates[15,53]. Furthermore, most of randomised control studies are focussed only on surrogate outcomes (blood pressure, blood lipids or glucose), yet we wanted to focus only on hard clinical endpoints (morbidity, mortality). Consequently, prospective cohort studies are an essential source of evidence in nutritional epidemiology. Especially, when using tools such as NutriGrade to evaluate credibility, large and high-quality prospective cohort studies may provide better estimates of long-term lifestyle behaviours on outcomes. In addition, systematic reviews of a sufficient number of observational studies are much more prevalent and their number is adequate to summarise gathered data in umbrella review. Fourth, although most of the included systematic reviews evaluated risk of bias and/or quality of primary studies, only two of them graded the overall meta-evidence, one using the NutriGrade scoring system and the other using the GRADE approach. Authors of systematic reviews should embrace this approach to allow better interpretation of the gathered evidence. In addition, as AMSTAR 2 consists of comprehensive and strict criteria, the assessed methodological quality of the included studies was generally low, even when the authors followed the PRISMA guidelines for reporting. To provide the highest quality of evidence, it seems important to incorporate these criteria in all stages of conducting systematic reviews. Authors should follow guidelines for conducting systematic reviews and be especially careful when planning and reporting. AMSTAR 2 authors also strongly advise against combining individual items to create an overall score (e.g. from 0 to 32), which was frequently applied when using the first version of AMSTAR[13,25,59]. This approach was also used in some previous umbrella reviews that used AMSTAR 2, resulting in higher overall confidence, even when individual item scores were more or less the same as ours[12]. Even though the assessed methodological quality of some included systematic reviews was rated low, these were the most recent, comprehensive and the highest quality of all currently published and available systematic reviews for these diet indices. Fifth, our umbrella review was focussed only on some of the main diet-related outcomes, while excluding others that may be equally important for our research question. In recent years, several new dietary indices have been developed (PURE, Japanese Diet, Nordic Food Index, Empirical Dietary Inflammatory Pattern Score, Danish Dietary Guidelines Index)[2,4,7,9]. However, only the indices for which systematic reviews and meta-analyses were made are included in our review. This does not mean that others are not relevant in preventing chronic diseases, only that more research is needed before they are widely implemented.

Conclusion

The present umbrella review of systematic reviews indicates that diet quality assessed by MedDiet, HEI, AHEI, DASH and DII diet indices is significantly inversely associated with all-cause and CVD risk and mortality, as well as with MedDiet, HEI, AHEI, and DASH and type 2 diabetes risk. This provides further evidence for these diet indices to be used as a valid tool for the assessment of diet quality in the adult population and/or as predictors of the reviewed health outcomes. On the contrary, identified key research gaps should be addressed in further prospective cohort studies and systematic reviews to provide stronger evidence.

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There are no conflicts of interest.

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114522003701

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