Received: 3 July 2023 | Revised: 14 November 2023 | Accepted: 25 November 2023

DOI: 10.1111/1747-0080.12860

Nutrition & Dietetics Journal of Dietitians Australia WILEY

REVIEW

Diet quality and cardiovascular outcomes: A systematic review and meta-analysis of cohort studies

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Funding information
National Health and Medical Research Council of Leadership Fellowship, Grant/Award Number: APP2009340

Open access publishing facilitated by The University of Newcastle, as part of the Wiley - The University of Newcastle agreement via the Council of Australian University Librarians.

Abstract

Aims: To evaluate relationships between diet quality and cardiovascular outcomes.

Methods: Six databases were searched for studies published between January 2007 and October 2021. Eligible studies included cohort studies that assessed the relationship between a priori diet quality and cardiovascular disease mortality and morbidity in adults. The Academy of Nutrition and Dietetics Checklist was used to assess the risk of bias. Study characteristics and outcomes were extracted from eligible studies using standardised processes. Data were summarised using risk ratios for cardiovascular disease incidence and mortality with difference compared for highest versus lowest diet quality synthesised in meta-analyses using a random effects model.

Results: Of the 4780 studies identified, 159 studies ($n = 6\,272\,676$ adults) were included. Meta-analyses identified a significantly lower cardiovascular disease incidence ($n = 42$ studies, relative risk 0.83, 95% CI 0.82–0.84, $p < 0.001$) and mortality risk ($n = 49$ studies, relative risk 0.83, 95% CI 0.82–0.84, $p < 0.001$) among those with highest versus lowest diet quality. In sensitivity analyses of a high number of pooled studies (≥13 studies) the Mediterranean style diet patterns and adherence to the heart healthy diet guidelines were significantly associated with a risk reduction of 15% and 14% for cardiovascular disease incidence and 17% and 20% for cardiovascular disease mortality respectively ($p < 0.05$).

Conclusions: Higher diet quality is associated with lower incidence and risk of mortality for cardiovascular disease however, significant study heterogeneity was identified for these relationships.

KEYWORDS
cardiovascular disease, diet quality, dietary patterns, meta-analysis, systematic review

1 | INTRODUCTION

Worldwide, cardiovascular diseases are the leading contributors to burden of disease, with total cardiovascular disease case numbers almost doubling (from 271 to 523 million) between 1990 and 2019.[1] Poor dietary patterns are the second leading cardiovascular disease risk factor, contributing to almost half of cardiovascular deaths annually.[1] Therefore, the development of cardiovascular disease is recognised as largely preventable by managing behavioural risk factors, especially poor dietary patterns.[1]

The favourable relationship between healthy dietary patterns and lower cardiovascular disease risk was first recognised by the 'Seven Countries Study' which was conducted in the 1950's. Cross-cultural analyses of 16 Seven Countries Study cohorts revealed that Mediterranean style dietary patterns and Japanese dietary patterns were positively correlated with lower 25-year coronary heart disease mortality.[2–4] Further research has extended on this body of evidence demonstrating the link between dietary patterns and health outcomes.[5,6] Consequently, nutritional epidemiology has shifted towards the analysis of whole dietary patterns, including the consumption of combinations of whole foods, rather than focussing on relationships with single nutrients or foods.[7] Evidence from diet quality scores or indexes used to assess dietary patterns are increasingly being translated into food-based recommendations for cardiovascular disease prevention. For example, the World Heart Federation: Diet and Nutrition,[8] the National Heart Foundation: Healthy eating to protect your heart[9] and Mayo Clinic's: A Clinician's Guide to Healthy Eating for Cardiovascular Disease Prevention[10] all encourage the consumption of plant-based foods, wholegrains, lean meats and foods rich in sources of unsaturated fatty acids, while limiting intakes of foods high in added sugar, salt and saturated and trans fatty acids. Therefore, synthesising the most recent evidence regarding the relationship of diet quality and cardiovascular health is essential to inform food-based recommendations and guidelines for cardiovascular disease prevention.

Authors of the current study previously systematically reviewed[11] observational studies published up to 2007 to evaluate the relationship between dietary patterns and all-cause and cardiovascular disease morbidity and mortality.[11] Although, four systematic reviews have meta-analysed studies up to March 2020, the literature searches were limited to only three databases.[12–15] Three of these reviews only focused on specific Diet Quality Indexes including Healthy Eating Index, Alternate Healthy Eating Index and Dietary Approaches to Stop Hypertension.[12–14]

Therefore, the aim of the current review was to synthesise the evidence from cohort studies on the relationship between diet quality and cardiovascular outcomes in adults (January 2007 to October 2021).[11] This review also compared cardiovascular incidence and mortality for Diet Quality Index categories based on three major approaches to the Diet Quality Index methodology: (i) based on food groups or specific foods; (ii) based on nutrient intakes; or (iii) derived from combinations of foods and nutrient intakes.

2 | METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses[16] checklist was used to guide the conduct and reporting of the current review. This review was registered with the Open Science Framework.[17]

The search strategy was informed by a previous review[11] and updated in consultation with a medical research librarian. An electronic search of human studies published in English was conducted. The first literature search included studies published between January 2007 and July 2018 while the second literature search (update) included studies between July 2018 and October 2021. The following databases were systematically searched for both literature searches: CINAHL (EBSCO), Cochrane Library (Wiley), MEDLINE (OVID), EMBASE (OVID), Public Health (ProQuest) and Scopus (Scopus). The search was conducted using the following Medical Subject Headings (MeSH) keyword search terms: diet, dietary, quality, variety, diversity, pattern, score, indicator, index, guideline, Healthy Eating Index, Alternative Healthy Eating Index, Recommended Food Score, chronic disease, cancer and cardiovascular disease with a combination of AND/OR between terms. Full details of the search strategy for each database are provided for the first literature search in Tables S1–S5 and second literature search in Tables S6–S10. The review screening was managed using the software program Covidence (Melbourne, VIC, Australia, Veritas Health Innovation 2015).

Titles and abstracts of the retrieved articles were compared against the inclusion and exclusion criteria by two

TABLE 1 Inclusion and exclusion criteria for selecting studies.

Criteria	Study design	Population	Predictor	Outcome
Inclusion	• Cohort studies • Human studies	• Adults (≥18 years) • Any gender or ethnicity	• Theoretically defined dietary patterns (diet indices/scores) • A priori diet quality measure based on current nutrition knowledge	• Measures of morbidity (not including cancer) and mortality • Incidence or risk of hypertension, metabolic syndrome, overweight/obesity, type 2 diabetes and cardiovascular disease biomarkers and clinical outcomes
Exclusion	• Case–control or cross-sectional studies • Intervention studies • Animal studies	• Children or pregnant women	• Dietary patterns derived a posteriori such as by cluster analysis or factor analysis	• No CVD outcome measures • Measures of morbidity including cancer or no other

independent reviewers (Table 1). Diet quality was defined as dietary patterns score using a metric based on constructs including adequacy, moderation, balance and variety, with the score used to quantify a relationship with cardiovascular disease outcomes. This scoring may be based on the intakes of food groups, specific foods and/or nutrients. Dietary patterns with conflicting evidence regarding relationships with cardiovascular health, such as a low carbohydrate dietary pattern which is associated with lower levels of dietary fibre intake,[18] have been included in order to represent all studies being conducted and to provide further insights into how differing dietary patterns, that met the inclusion criteria, are associated with cardiovascular disease risk. Intervention studies were excluded as this review explored the association between diet quality and cardiovascular disease incidence and mortality with a particular focus on how approaches to the diet quality methodology impacted on this relationship. Intervention studies such as randomised control trials, are higher level evidence but are generally short in duration compared with cohort studies. After the initial screening, full texts were retrieved and assessed for eligibility by two independent reviewers. Discrepancies between the reviewers regarding the eligibility of the articles were resolved by the decision of a third independent reviewer. This process was used for managing all discrepancies throughout the review.

The methodological quality of reporting for the eligible articles were assessed using the Academy of Nutrition and Dietetics Quality Criteria Checklist for Primary Research,[19] relevant for critically appraising nutrition studies. The methodological quality of eligible articles were assessed by two independent reviewers. The Quality Criteria Checklist[19] rates study design and execution based on the responses to 10 validity questions. Ratings assigned by the checklist include positive (highest quality rating assigned when responses were 'yes' to six or more validity questions, including all four priority questions), negative (lowest quality rating assigned when responses were 'no' to six or more validity questions), or neutral ('no' to one or more of four priority criteria questions).

Diet quality, cardiovascular disease incidence and indicators of morbidity and mortality data were independently extracted by one reviewer and checked by a second reviewer. Data extracted from the articles included study setting, study design, population characteristics, dietary assessment methods, outcome measures, results and conclusions. The country in which the study was conducted was classified into high (>United States [US] $12 235) upper middle (US$3956–$12 235), lower middle (US$1006–$3955) and low income (<US$1005) based on the World Bank estimates of 2016 gross national income per capita.[20]

Meta-analyses were performed for the risk ratio (i.e., hazard ratio, relative risk, odds ratio, or incidence rate ratio) of cardiovascular disease incidence and mortality among highest (i.e., most healthy) versus lowest (i.e., least healthy) diet quality using random effects models. Studies were grouped by the relevant outcomes including cardiovascular disease incidence and mortality. Cardiovascular disease incidence includes the combined fatal and non-fatal cases while cardiovascular disease mortality includes outcomes of fatality associated with cardiovascular disease. Where studies reported both unadjusted and adjusted results, the adjusted results were used as suggested by Metelli et al.[21] due to the fact that unadjusted results are more likely biased by not accounting for potential confounders. Subgroup analyses were performed for the most common dietary indexes including Healthy Eating Index and Mediterranean Diet Score, diet quality scores generated from adherence to national dietary guidelines (e.g., Healthy Diet Indicator, Dutch Healthy Diet-Index, Modified Australian Diet Quality Index) and heart healthy diet guidelines (e.g., Dietary Approaches to Stop Hypertension, American Heart Association diet scores), as well as scores generated from adherence to plant-based diets (e.g., Plant-Based Diet Score), anti-inflammatory diets (e.g., Dietary Inflammatory Index) and low carbohydrate diets (e.g., Carbohydrate-Restricted diet score). Diet quality measures that were not relevant to these major/ common diet indices categories were not included in the subgroup analysis. Sub-group analyses were also performed for diet indexes or diet quality measures based on if scoring was generated from food consumption patterns (e.g., Anti-inflammatory diet index, Food Quality Score), nutrient intake (e.g., Adherence to low-carbohydrate diet, Dietary Approaches to Stop Hypertension score) or both (e.g., Mediterranean Diet Score, Dietary Approaches to Stop Hypertension). Two reviewers with relevant knowledge and expertise initially categorised the diet indexes, and this was checked by a third reviewer. Some articles used multiple diet quality scores while other studies used the same cohort (e.g., Nurses' Health Study). Therefore, further sensitivity analyses were performed to assess if there was a clustering effect caused by the inclusion of multiple diet quality assessment measures and overlapping cohort samples reported by multiple studies. Comparison of effect sizes and 95% confidence intervals indicated that there were no significant effects on cardiovascular disease incidence and mortality by these factors. Heterogeneity between the studies was estimated and assessed by Higgins's I^2 test statistic. An I^2 value greater than 50% indicates substantial heterogeneity across the studies.[22] Publication bias was assessed by the symmetry of the funnel plots and data provided from rank correlation tests. Meta-analysis was conducted using Stata Statistical Software (version 14.2, StataCorp, LLC. Texas, USA).

3 | RESULTS

A total of 4780 articles (excluding duplicates, $n = 777$) were identified from the search strategy and 786 full-text articles were assessed against the eligibility criteria. After completing the screening, numerous articles ($n = 422$) were assessed as eligible for inclusion in the review but deemed beyond the capacity of a single systematic review. Consequently, cross-sectional, and case–control studies ($n = 224$) were removed which was not originally specified in the exclusion criteria, therefore limiting the review to cohort studies ($n = 159$) included in the review (Figure 1). The review was limited to cohort studies, as this study design is a higher level of evidence in the research hierarchy compared with cross-sectional and case–control studies and therefore the likelihood of bias on the results is reduced. Comprehensive details of the 159 included articles are summarised in Table S11. Key study characteristics are reported in Table 2. A high proportion of studies ($n = 135$, 85%) were published from 2013 and conducted in high income countries ($n = 149$, 94%). The sample size of included studies ranged from 49[23] to 451 256[24] with a total number of 6 272 676 adults. More than half ($n = 110$, 69%) the participants were middle-aged (51–65 years) and older (>65 years) adults.

Dietary intake was commonly ($n = 134$, 81%) assessed by food frequency questionnaires across the studies. The number of question items within each food frequency questionnaire ranged from seven[25] to 280.[26] The number of time-points used to assess dietary intake ranged from one to 16 however, a high proportion (112, 70%) of the studies only assessed dietary intake at one time-point. There were 15 major types of Diet Quality Indexes used across the studies to assess diet quality. The most common indexes used were all variations of Mediterranean Diet Score ($n = 91$, 29%), Healthy Eating Index ($n = 61$, 20%) and Dietary Approaches to Stop Hypertension ($n = 47$, 15%). More than a third ($n = 69$, 42%) of studies used two or more Diet Quality Indexes.

A summary of the methodological quality assessment for each study is provided in Table S12. Assessment of the studies resulted in 80 studies awarded a positive rating, 78 studies with a neutral rating and one study received a negative rating. Based on the responses to 10 validity questions, a neutral rating was commonly attributed because of unclear inclusion and exclusion criteria and the use of less rigorous dietary assessment methods (e.g., a single 24-h food recall, food frequency questionnaire <120 food items).

Forty-two studies[25,27–67] reported cardiovascular disease incidence as a relative risk (95% CI) comparing the highest versus lowest diet quality and were included in a meta-analysis. The characteristics of these studies are described in Table S13. In the overall model including all diet indexes ($n = 97$), comparison of outcomes for those with the highest versus lowest diet quality found significantly lower cardiovascular disease incidence (relative risk 0.83, 95% CI 0.82–0.84, $p < 0.001$, $n = 42$ studies) (Figure 2). The I^2 test statistic indicated significant heterogeneity ($I^2 = 75.0\%$, $p < 0.001$). The funnel plot (Figure S1) and rank correlation test indicate evidence of publication bias, favouring studies with larger effect sizes (Kendall's tau = −0.12, $p < 0.001$).

In the first sensitivity analysis by type of diet index, comparing six index groups: Mediterranean Diet Score or variations, heart healthy guidelines, adherence to dietary

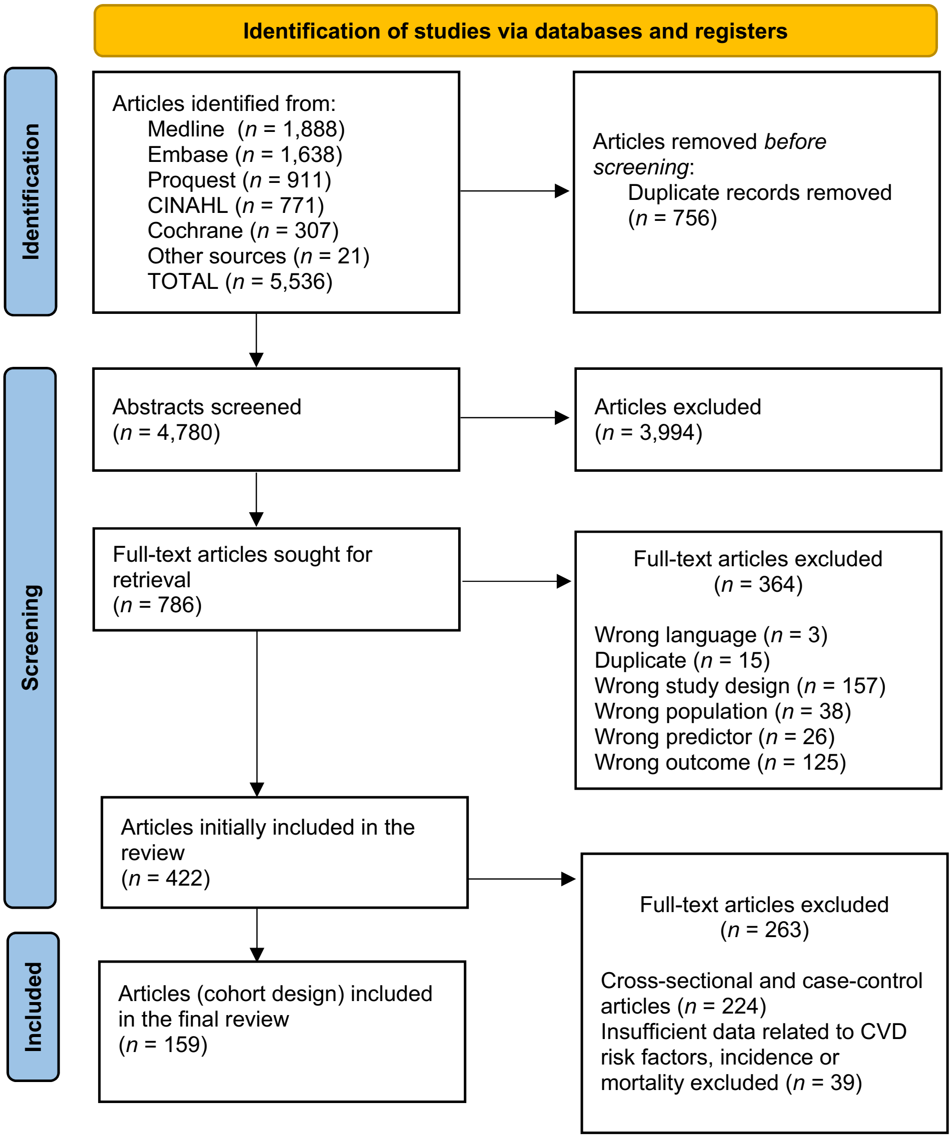

FIGURE 1 The PRISMA flow diagram for the systematic review detailing the database searches, the number of abstracts screened and the full texts retrieved.

guidelines, Healthy Eating Index, anti-inflammatory diet, and plant-based diet, there was a significant difference in cardiovascular disease incidence by type of diet index ($p < 0.001$) (Figure S2). The relative risk of cardiovascular disease incidence comparing the highest versus lowest diet quality for each diet index was: Mediterranean Diet Score or variations of (relative risk 0.85, 95% CI 0.83–0.87, $p < 0.001$, $n = 17$ studies), heart healthy diet guidelines (relative risk 0.86, 95% CI 0.82–0.89, $p = 0.036$, $n = 13$), adherence to dietary guidelines (relative risk 0.85, 95% CI 0.82–0.88, $p = 0.059$, $n = 12$), Healthy Eating Index (relative risk 0.81, 95% CI 0.79–0.82, $p = 0.407$, $n = 10$), anti-inflammatory diet (relative risk 0.76, 95% CI 0.73–0.80, $p < 0.001$, $n = 2$), and plant-based diet (relative risk 0.87, 95% CI 0.84–0.89, $p = 0.408$, $n = 2$) (Figure S2).

In the second sensitivity analysis by type of diet index, comparing those based on foods only ($n = 15$ studies), nutrients only ($n = 3$) or food and nutrients ($n = 33$), there was no significant difference in cardiovascular disease incidence by type of diet index ($p = 0.063$) (Figure S3).

Forty-nine studies[24,26,29,34–36,39,40,54,58,68–106] reported cardiovascular disease mortality as a relative risk (95% CI) comparing the highest versus lowest diet quality and were included in a meta-analysis. The characteristics of these studies are described in Table S13. In the overall model including all diet indexes ($n = 111$), comparing the highest versus lowest diet quality, there was a significantly lower risk of cardiovascular disease mortality (relative risk 0.83, 95% CI 0.82–0.84, $p < 0.001$, $n = 49$) (Figure 3). The I^2 test statistic indicated substantial heterogeneity ($I^2 = 71.7\%$, $p < 0.001$). The funnel plot (Figure S4) and rank correlation test indicate no evidence of publication bias (Kendall's tau $= -0.15$, $p = 0.55$).

TABLE 2 Summary of study characteristics ($n = 159$).

Characteristics		Total n (%)
Publication year	≤2006	0 (0.0)
	2007–2009	10 (6.3)
	2010–2012	14 (8.8)
	2013–2015	39 (24.5)
	2016–2018	48 (30.2)
	>2018	48 (30.2)
Country of publication	High income	149 (93.7)
	Upper-middle income	10 (6.3)
	Lower-middle & low income	0 (0.0)
Number of participants included in the analysis	Total (*n*)	6 272 676
	Range	49–451 256
Mean age of study sample	18–35 years	4 (2.5)
	36–50 years	45 (28.3)
	51–65 years	86 (54.0)
	>65 years	24 (15.0)
Ethnicity/race	≥80% white	26 (16.4)
	≤80% white	27 (17.0)
	Not reported	106 (66.7)
Dietary assessment method	Food frequency questionnaire	134 (80.7)
	24-h food recall/s	12 (7.2)
	Food/diet questionnaire	7 (4.2)
	Diet history	5 (3.0)
	7-day food records (estimated portions)	4 (2.4)
	4-day food records (estimated portions)	2 (1.2)
	3-day food records (estimated portions)	1 (0.6)
	3-day weighed food records	1 (0.6)
Number of dietary assessment methods	1	155 (97.5)
	2	2 (1.3)
	3	2 (1.3)
Number of timepoints for dietary assessment	Not reported	2 (1.3)
	1	112 (70.4)
	2	20 (12.6)
	3	8 (5.0)
	>3	17 10.7)
	Mean(SD)	1.0 (0.3)
Diet Quality Index	Mediterranean Diet Indexes (all versions)	91 (29.1)

(Continues)

TABLE 2 (Continued)

Characteristics		Total n (%)
	HEI (all versions)	61 (19.5)
	DASH (all versions)	47 (15.0)
	Plant-based Diet Indexes	21 (6.7)
	DII	11 (3.5)
	HDI (all versions)	8 (2.6)
	Diet Diversity Indexes	8 (2.6)
	DQI (all versions)	6 (1.9)
	Nordic Diet Index (all versions)	1 (1.2)
	Adherence to Low Carbohydrate Indexes	3 (1.0)
	Antioxidant Content Indexes	3 (1.0)
	AHA Recommended Dietary Patterns	2 (0.6)
	Anti-inflammatory Diet Index	2 (0.6)
	Programme National Nutrition Santé guidelines score (all versions)	2 (0.6)
	FSA-NPS DI	2 (0.6)
	Miscellaneous	42 (13.4)
Number of Diet Quality Indexes used within the cohort	1	92 (57.9)
	2	20 (12.6)
	3	20 (12.6)
	>3	27 (17.0)
	Mean(SD)	2.0 (1.7)
Length of follow-up from baseline (years)	0–5.99	19 (11.9)
	6–10.99	53 (33.3)
	11–15.99	33 (20.8)
	16–0.99	31 (19.5)
	>21	23 (14.5)
	Mean(SD)	13.5 (7.9)

Abbreviations: AHA Recommended Dietary Patterns, American Heart Association Recommended Dietary Patterns; DASH, Dietary Approaches to Stop Hypertension; DII, Dietary Inflammatory Index, DQI, Diet Quality Index, FSA-NPS DI, Food Standards Agency Nutrient Profiling System Dietary Index; HDI, Healthy Diet Indicator; HEI, Healthy Eating Index.

The first sensitivity analysis by type of diet index compared seven dietary index groups: Mediterranean Diet Score or variations, heart healthy guidelines, adherence to dietary guidelines, Healthy Eating Index, anti-

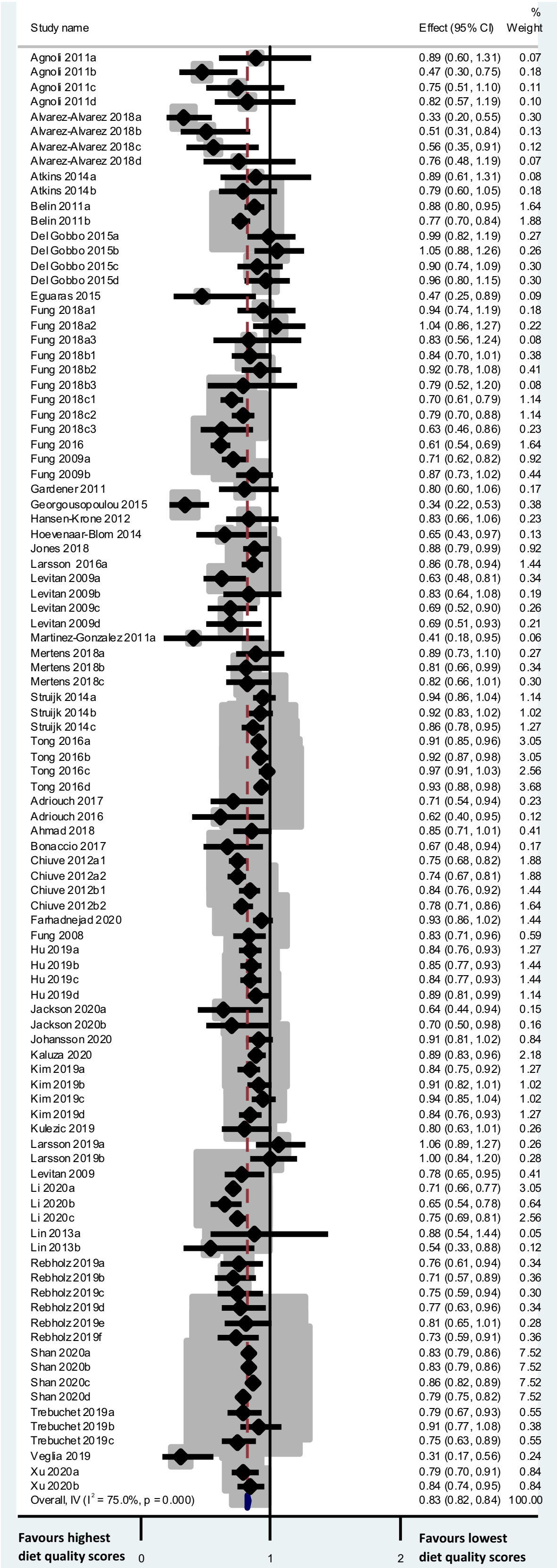

FIGURE 2 Forest plot of results for the risk of CVD incidence comparing the highest versus lowest diet quality across 42 studies ($n = 97$ diet indexes).

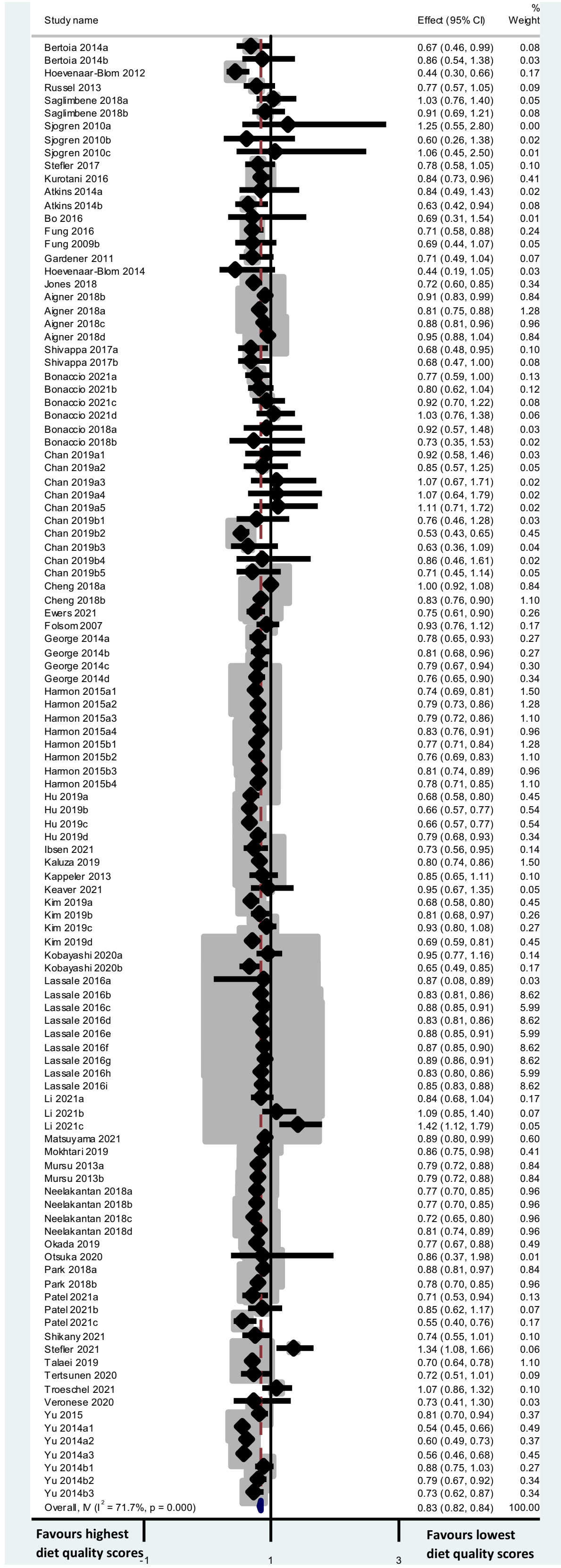

FIGURE 3 Forest plot of results for the risk of CVD mortality comparing the highest versus lowest diet quality across 49 studies ($n = 111$ diet indexes).

inflammatory diet, plant-based diet and low carbohydrate diet. There was a significant difference in the risk of cardiovascular disease mortality by type of diet index ($p < 0.001$) (Figure S5). Cardiovascular disease incidence comparing the highest versus lowest diet quality for each diet index was: Mediterranean Diet Score or variations (relative risk 0.83, 95% CI 0.81–0.85, $p < 0.001$, $n = 21$ studies), heart healthy guidelines (relative risk 0.80, 95% CI 0.78–0.82, $p < 0.001$, $n = 16$), adherence to dietary guidelines (relative risk 0.85, 95% CI 0.84–0.87, $p < 0.001$, $n = 14$), Healthy Eating Index (relative risk 0.81, 95% CI 0.79–0.83, $p < 0.001$, $n = 12$), anti-inflammatory diet (relative risk 0.81, 95% CI 0.77–0.84, $p = 0.390$, $n = 5$), plant-based diet (relative risk 0.80, 95% CI 0.82–0.84, $p < 0.001$, $n = 3$) and low carbohydrate diet (relative risk 0.93, 95% CI 0.68–1.18, $p = 0.795$, $n = 2$) (Figure S5).

In the second sensitivity analysis by type of diet index, comparing those based on foods only to those based on food and nutrients, there was a significant difference in the risk of cardiovascular disease mortality by type of diet index ($p = 0.002$) (Figure S6). The risk of cardiovascular disease mortality comparing the highest versus lowest diet quality for diet indexes based on foods only was (relative risk 0.85, 95% CI 0.83–0.86, $p < 0.001$, $n = 15$ studies), and for those based on food and nutrients was (relative risk 0.82, 95% CI 0.81–0.83, $p < 0.001$, $n = 33$).

Seven studies reported the relationship between diet quality and incidence of or risk of having Metabolic Syndrome, as a cardiovascular disease risk factor[107–113] (Table S14). Most studies found a significant inverse relationship between diet quality and Metabolic Syndrome incidence ($n = 3$),[108,109,113] risk of Metabolic Syndrome ($n = 2$)[107,112] or odds of Metabolic Syndrome reversion ($n = 1$).[111] Intakes in the highest quintile for Mediterranean-Style Dietary Pattern Score were associated with a lower incidence of Metabolic Syndrome compared with those in the lowest quintile (38.5% compared with 30.1%; $p = 0.01$).[108] Steffen et al.[109] reported that higher adherence to the Mediterranean diet was associated with a reduced 25-year cumulative incidence of Metabolic Syndrome components such as abdominal obesity and low HDL cholesterol concentrations (p-trend $= 0.02$). Pimenta et al.[113] found that only two of 13 diet indexes (Pro-Vegetarian Diet and Dietary Approaches to Stop Hypertension) were associated with a reduced incidence of Metabolic Syndrome (Incidence rate ratio: 0.63 (0.43–0.93) and relative risk: 0.41 (0.20–0.85). Higher Mediterranean Diet Score (odds ratio: 0.47 (0.32–0.69); p-trend $= 0.001$) scores were associated with a significant lower 6-year incidence of Metabolic Syndrome.[112] While higher unhealthy plant-based diet index scores were significantly associated with a 50% increased risk of Metabolic Syndrome (hazard ratio: 1.50, 95% CI 1.31–1.71; p-trend <0.001).[107] Akbaraly et al.[111] reported higher Diet Quality Indexes to be associated with increased odds of Metabolic Syndrome reversion over a 5-year follow-up (odds ratio: 3.74, 95% CI: 1.37–10.2).[111] Mirmiran et al.[110] did not find a significant association between diet quality (measured using the Mediterranean Diet Score and Sofi- Mediterranean Diet Score) and Metabolic Syndrome.

Eight studies reported the association between diet quality and incidence and/or risk of hypertension as a risk factor for cardiovascular disease[55,82,114–119] (Table S14). Five studies[55,82,114,116,119] found a significant inverse relationship between diet quality and hypertension. Folsom et al.[82] found that higher adherence to the Dietary Approaches to Stop Hypertension diet was inversely associated with the incidence of hypertension (hazard ratio: 0.87 (p-trend $= 0.02$)).Two studies reported participants in the highest quartile (best diet quality) versus lowest quartile (worst diet quality) categories for four dietary indexes had a lower risk of developing hypertension (range hazard ratios = 0.70–0.90).[114,116] One study reported participants with a pro-inflammatory diet score versus an anti-inflammatory diet score had higher odds of developing hypertension (odds ratio = 1.24, 95% CI: 1.06–1.45).[119] Higher diet quality scores measured using the Australian Recommended Food Score and Mediterranean Diet Score were associated with a 46% and 27% lower odds of developing hypertension respectively.[55] No significant relationship between higher Diet Quality Index scores and hypertension were found in three studies.[115,117,118]

Twelve studies reported the relationship between diet quality and waist circumference, body weight and/or the risk of overweight and obesity as a risk factor for cardiovascular disease[108–110,117,120–127] (Table S14). Of the 12 studies reporting overweight/obesity, seven reported a significant inverse relationship between higher Diet Quality Index scores and body weight or the risk of overweight/obesity.[108,109,117,120,121,125,126] Higher diet quality scores, assessed by three indexes, were inversely associated with body mass index ($p < 0.05$).[117,125] Kang et al.[126] reported that a substantial improvement in diet quality scores (≥1 SD increase), assessed by four indexes, was associated with lesser weight gain (by 0·55–1·17 kg in men and 0·62–1·31 kg in women) over 10 years. Four studies reported that participants in the highest quintiles (best diet quality) had lower risks of overweight/obesity, measured using waist circumference ($n = 2$) ($p < 0.001$)[108,109] and BMI ($n = 2$) (range hazard ratio 0.68–0.76).[120,121] Two studies reported that diet quality scores were negatively associated with waist circumference.[123,124] Three studies did not find a significant relationship between diet quality scores and changes in waist circumference or risk of overweight/obesity.[110,122,127]

Twelve studies evaluated the relationship between diet quality and biomarkers and clinical outcomes[23,44,117,123,125,128–134] (Table S14). Higher diet quality scores were favourably associated with the following biomarkers: triglycerides ($n = 2$),[125,131] LDL cholesterol ($n = 2$),[123,131] HDL cholesterol ($n = 1$),[129] blood glucose ($n = 1$),[133] insulin levels ($n = 2$),[117,133] C-reactive protein ($n = 2$)[44,117] and high-sensitivity cardiac troponin T levels ($n = 1$).[128] Ceramide ratio (C24:0/C16:0) were not significantly associated with diet quality scores measured by Dietary Guidelines Adherence Index and Mediterranean Diet Score.[134] Long-term adherence to the French Nutrition and Health Program guidelines was associated with a significantly lower heart rate (60.2 ± 8.0 vs. 64.3 ± 8.4 beats/min, $p = 0.042$), a lower heart rate × systolic blood pressure product (7166 ± 1323 vs. 7788 ± 1680 beats ×mmHg/min; $p = 0.009$), and a shorter tension–time index (2145 ± 489 vs. 2307 ± 428 ms mmHg; $p = 0.018$) compared with those that did not continuously adhere to the guidelines.[23] Gao et al.[130] investigated the balance construct of diet quality and calculated a scoring metric based on the percentage of energy intake from carbohydrates and protein and fat derived from plant and animal-based food sources. This study found that dietary patterns with a higher energy contribution from protein and fat derived from animal-based sources (score 16–27 points) were linked with a higher risk of coronary artery calcium progression (hazard ratio: 1.456, 95% CI, 1.015–2.089; $p = 0.041$) while no significant association was found with a higher energy contribution from protein and fat derived from plant-based sources (score 14–27 points, $p = 0.884$).[130]

Nouri et al.[132] found that poor diet quality, measured by the Diet Quality Index was associated with higher scores for latent profile, indicating greater impairment of cardiovascular disease risk factors.

Seventeen studies reported the relationship between diet quality on the incidence of type 2 diabetes as a cardiovascular disease risk factor (Table S14).[106,127,129,133,135–147] Fifteen out of 17 studies identified an inverse relationship between diet quality scores, measured by eight types of dietary indexes with risk of developing type 2 diabetes (hazard ratio range: 0.69–0.96). Yu et al.[106] reported that higher Chinese Food Pagoda and Alternate Healthy Eating Index-2010 scores in men and higher Modified Dietary Approaches to Stop Hypertension scores in women were associated with a significantly reduced risk of diabetes mortality ($p < 0.05$). One study by Zamora et al. did not identify a significant relationship between diet quality and type 2 diabetes incidence.[129]

4 | DISCUSSION

The current review examined the relationship between diet quality measured by a range of dietary quality indexes and cardiovascular disease incidence, mortality and cardiovascular disease risk factors. This is the most comprehensive review and meta-analysis that has been conducted to date and included 159 cohort studies with 6.2 million participants. Numerous sensitivity analyses were conducted to compare cardiovascular disease incidence and mortality by type of dietary index used. This review identified that a prolific number of diet quality studies have been published in the past 5 years, although most have been conducted in high-income countries only. Findings from the meta-analyses indicated that among those with the highest diet quality scores, measured across all dietary indexes, there was a 17% risk reduction in cardiovascular disease incidence and mortality. While significant heterogeneity between the studies meant that a meta-analysis could not be undertaken for all cardiovascular disease outcomes, findings across the cohort studies support that a high diet quality is inversely associated with incidence or risk of developing Metabolic Syndrome (6 of 7 studies), hypertension (5 of 8), overweight/obesity (7 of 12), adverse cardiovascular disease biomarkers and clinical outcomes (12 of 12) and type 2 diabetes (15 of 17).

Findings from the current review indicated that a high-quality diet is protective against cardiovascular disease incidence and mortality. Although, significant study heterogeneity was identified in the analysis of these relationships, likely due to the wide range of dietary assessment methods (e.g., 24-h food recall, food frequency questionnaire) and type of diet index/es used, as well as the modifications made to the diet index/es to evaluate diet quality, which impacts on the ability to compare studies.

The cardiovascular benefits arising from dietary patterns that score highly across Diet Quality Indexes may be attributed to the emphasis on the frequent consumption of a diversity of nutrient-rich foods such as fruit, vegetables, wholegrains/cereals, lean meats, fish and seafood, in the most commonly used dietary indexes (e.g., Mediterranean Diet Score, Dietary Approaches to Stop Hypertension, Healthy Eating Index). A meta-analysis ($n = 16$ prospective studies) found that intakes of 800 g/day of fruits and 600 g/day of vegetables are associated with a 28% reduction in relative risk of cardiovascular disease for both food groups.[148] Fruit and vegetables are a rich source of dietary fibres as well as antioxidants that may neutralise reactive oxygen species and reduce DNA damage and inflammation.[149] Higher intakes (>90 grams) of wholegrains have also been associated with improvements in cardiovascular disease risk factor levels, including blood pressure[150,151] and plasma lipids.[152] A meta-analysis of 10 prospective cohort studies found that a three serve per day (90 grams) increase in wholegrain intake was associated with a 22% reduction in the relative risk of cardiovascular disease.[153] A systematic review of 14 intervention trials indicated that oily fish consumption (ranging from 20 to 150 g per day) over 9 weeks led to improvements in cardiovascular disease biomarkers, including plasma triglycerides (−0.11 mmol/L; 95% CI: −0.18 to −0.04; $p = 0.002$) and HDL-cholesterol (0.06 mmol/L, 95% CI 0.02–0.11; $p = 0.008$).[154] The interactive effects of the nutrients acquired from consuming a combination of these foods is likely to be more important and potent for cardiovascular disease health promotion, rather than isolated nutrients or food groups. Interestingly, in the current review higher diet quality scores for food and nutrient indexes were significantly associated with a 3% higher risk reduction for cardiovascular disease mortality compared with food only indexes. Food and nutrient indexes included in the meta-analysis were predominantly (58%) Mediterranean diet scores, Healthy Eating Index and Dietary Approaches to Stop Hypertension whereas there was a wide range of food-based indexes used ($n = 17$). The scoring components of these three indexes are based on a large body of evidence of known dietary factors associated with the development of cardiovascular disease.[53,155,156] A higher proportion (39%) of food and nutrient indexes considered alcohol consumption compared with recommendations or alcohol as a macronutrient in the scoring component compared with food-based indexes which may have also contributed to the differences observed. However, the Mediterranean Diet Score (19% of food and nutrient indexes) assigns one point for alcohol consumption with a range of intake (10–50/g day for men, 5–25 g/d for women) while alcohol consumption outside this range is assigned zero points. Therefore, diet quality scores may not clearly distinguish between alcohol abstainers compared with those that consume alcohol excessively which may impact on the accuracy of estimates for diet and disease associations. Based on the high number of pooled studies in the sensitivity analyses comparing food and nutrient indexes with food only indexes (≥13 studies), the Mediterranean style diet patterns and adherence to the heart healthy diet guidelines (e.g., Dietary Approaches to Stop Hypertension, American Heart Association diet scores) were significantly associated with a risk reduction of 15% and 14% for cardiovascular disease incidence and 17% and 20% for cardiovascular disease mortality respectively. Although, almost half of the studies (8 of 17)[25,27,28,32,37,43,50,66] included in the meta-analysis of the relationship between diet quality and cardiovascular disease incidence were conducted in populations from the Mediterranean region, they were more likely to have a larger effect sizes compared to those studies conducted outside this region and therefore these findings may not be generalisable to non-Mediterranean population.[35,36,39,46] Similarly, a previous meta-analysis also reported a lower risk ratio for coronary heart disease and acute myocardial infarction in adults with the highest adherence to Mediterranean Diet Score, showing stronger associations among studies conducted in those residing in the Mediterranean region [relative risk: 0.61(0.46–0.79)] compared to participants from outside the region [relative risk: 0.79(0.70–0.89)].[157]

Limitations of the evidence presented in the current review include that significant heterogeneity observed in the meta-analysis, which may be explained by the variation in population samples, age and sample sizes between studies. Significant publication bias was also detected for some outcomes. While these factors cannot always be controlled for, other comparable reviews have reported similar issues.[12,14] Most studies assessed dietary intake using food frequency questionnaires that provided self-reported data and therefore the risk of recall bias cannot be excluded. Furthermore, more than 50% of the included studies only assessed dietary intake at a single timepoint and used a single dietary index to evaluate diet quality.

The limitations of the methods used for this systematic review include that the literature search was limited to cohort studies published between January 2007 and October 2021. A variation was made to the original protocol to exclude cross-sectional and case control studies as it was beyond the capacity of the research team to manage more than 400 eligible articles. In the second literature search for studies published between July 2018 to October 2021, a further 74 articles were eligible and included in the current review. It is likely that many cohort studies have since been published since October 2021 which are not included in the current review. The current systematic review of cohort studies with meta-analysis demonstrates that higher diet quality, as measured by a range of Diet Quality Indexes, was associated with a significant reduction in cardiovascular disease incidence and risk reduction for cardiovascular disease mortality. There is a stronger body of evidence to support greater alignment with Mediterranean style dietary patterns and heart healthy dietary guidelines and lower cardiovascular disease incidence and mortality. The current findings also highlight the importance of higher quality dietary patterns overall in optimising cardiovascular disease health, including consumption of a variety of healthful foods for the prevention of cardiovascular disease.

AUTHOR CONTRIBUTIONS

RLH, TLB and CEC contributed to the design/methodology of the review. RMT and JB contributed to the screening. RMT, JH, MW, LT, JDV, MSJ, AK, PN, NN and EC contributed to data extraction and/or quality

checking. RMT, JH, MW and CEC were involved in the categorisation of the Diet Quality Indexes. MW and TLB completed the meta-analysis. RMT, JH and EC collated the results and drafted the manuscript. All authors read and approved the final manuscript. We thank Debbie Booth, senior librarian from the University of Newcastle, for developing the search strategy, Katherine Brain and Rachael Jaenke for screening articles and Kee June Ooi for checking the data extraction and assisting with the preparation of the supplementary information.

FUNDING INFORMATION

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. CEC is supported by a National Health and Medical Research Council of Leadership Fellowship (APP2009340).

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Taylor RM, Haslam RL, Herbert J, et al. Diet quality and cardiovascular outcomes: A systematic review and meta-analysis of cohort studies. *Nutrition & Dietetics*. 2024;81(1): 35-50. doi:10.1111/1747-0080.12860