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# Dietary patterns and risk of cardiovascular diseases: a review of the evidence

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CVD are the main cause of death especially in high-income countries. Previously, research focused on single nutrients including saturated and MUFA, sodium and dietary fibre, or specific foods such as fish, fruit and vegetables, and olive oil, in the aetiology of CVD. In recent years, however, the effects of complete dietary patterns on the prevention of CVD have gained interest, to account for diet heterogeneity and food–nutrient interactions. Several dietary patterns have been investigated, such as the Paleolithic diet, the vegetarian and vegan diets, the Diet Approaches to Stop Hypertension (DASH), the Nordic and Mediterranean diets, with many contradictions remaining. The aim of this review is to give an overview of the effects of these dietary patterns on CVD risk, to discuss their overall nutrient adequacy and briefly discuss their environmental impact.

**Dietary patterns: Paleolithic diet: Vegetarian diet: Nordic diet: DASH diet: Mediterranean diet: CVD**

CVD is an umbrella term for a class of diseases, including mainly CHD, stroke and heart failure. It is widely accepted that CVD continues to be the leading cause of mortality in developed countries and one of the primary leading causes worldwide[1] with reports in 2008 from the WHO attributing about 30 % of global deaths to CVD[2]. The incidence of CVD increases with age, and the past years, higher rates are being observed in low- and middle-income countries, due to economic transition, reaching almost 80 % of CVD cases worldwide. CVD prevalence and incidence have been highly associated with behavioural risk factors, including unhealthy diet, physical inactivity, use of tobacco and excessive alcohol intake[3–5]; all these factors account for up to 80 % of CHD and cerebrovascular diseases.

Diet has been shown to have a fundamental role in the prevention of CVD[3,4,6–9], and although modifiable, it is difficult to achieve, making this factor of great interest. Meta-analyses have demonstrated a significant 22 % reduction for individuals achieving high diet quality scores[9], 19–28 % in women and 14–26 % in men[10]. One of the WHO global targets is a 25 % relative CVD reduction[2], the amount seen to be reduced by diet alone. Previously, research focused on single nutrients including saturated and MUFA, sodium, or specific dietary components such as fish, fruit and vegetables, and olive oil, in the aetiology of CVD. In recent years, however, the effects of complete dietary patterns have been investigated instead, in order to account for diet heterogeneity and food–nutrient interactions[11]. It has been proposed that dietary patterns may be a preferred approach, as diets are complex and cannot be deconstructed into individual nutrients. A debate remains on the preferred dietary pattern for CVD prevention since it is difficult to compare them, due to lack of consistency in methods used in dietary pattern research[10]. However, studies have shown preventive effects upon following various dietary patterns.

The aim of the current review is therefore to provide a summary of the evidence associating dietary patterns and

**Abbreviations:** DASH, Diet Approaches to Stop Hypertension; DBP, diastolic blood pressure; HNFI, Healthy Nordic Food Index; mMED, modified Mediterranean Diet Score; RCT, randomised controlled trial; RR, relative risk; SBP, systolic blood pressure.
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CVD outcome, and discuss their potential impact on the environment.

## Paleolithic diet

The Paleolithic diet characterises the nutritional patterns of human subjects of the Paleolithic era (2·6 million to 10 000 years ago). This specific pattern that differs considerably from current dietary habits of Westernised societies gained popularity worldwide because of its putative health benefits. Broadly speaking, Paleolithic diet includes lean meat, it is very low in grains, sugar and salt, it does not contain dairy and it includes fruit, nuts and vegetables.

Human subjects of the Paleolithic era gathered their food via hunting, with the majority being derived from animal food sources as shown by the ethnographic Atlas data[12]. A great majority (73 %) of the world's hunter-gatherers obtained over half of their subsistence from hunted and fished animal foods, whereas only 14 % obtained >50 % of their subsistence from gathered plant foods[13], with quantitative dietary studies carried out on a small percentage of the world's hunter-gatherer societies showing that the average score for animal food subsistence is 65 %, while that for plant food subsistence is 35 %[13].

The paradox raised is the high consumption of animal-based food in the majority of hunter-gatherer societies and a lower CVD mortality rate compared to Western societies, as observed[14–16], since in 'Westernised' diets, higher animal food consumption is frequently associated with CVD. To add to this, studies on the dietary and blood lipid profiles of Greenland Eskimos who had low rates of CVD[17,18], compared to Danes, showed that despite their much greater animal food intake, Greenland Eskimos maintained healthier blood lipid levels (lower LDL, VLDL and total cholesterol levels, lower TAG and higher HDL).

Although the researchers largely attributed the relative absence of CVD in these people to the increased dietary intake of *n*-3 PUFA from fish, other dietary factors may have been involved including higher dietary monounsaturated and polyunsaturated fat, and lower saturated fat intakes. Reductions in plasma VLDL and TAG of the Greenland Eskimos certainly could have resulted from an increased *n*-3 polyunsaturated fat intake, but also may in part be due to a relatively lower intake of carbohydrates. Of course not all Paleolithic diets are rich in *n*-3 fatty acids from fish, but on the contrary, they could be rich in long chain SFA from other animal sources. Therefore, these findings could not be unanimously accepted as the effects of Paleolithic diets on CVD risk.

A recent meta-analysis with four randomised controlled trials (RCT) including 159 participants investigated the effects of Paleolithic diet on metabolic syndrome[19]. Metabolic syndrome increases the risk of CVD and is a term used in the presence of at least three of the following cardiovascular risk factors: (i) obesity, (ii) elevated blood pressure, (iii) hypertriglyceridaemia, (iv) low plasma HDL-cholesterol levels and/or (v) elevated plasma glucose levels. The four control diets were based on distinct national nutrition guidelines but they were broadly similar. The dietary patterns in the RCT were representative of the Paleolithic nutrition in current practice (i.e. comprising only unprocessed meat, fish, eggs, vegetables, fruit and nuts in variable proportions). Larger short-term improvements were found in multiple risk factors of CVD, specifically changes to waist circumference, TAG, systolic blood pressure (SBP), diastolic blood pressure (DBP), HDL-cholesterol and fasting blood glucose for individuals following the Paleolithic diet compared to controls. However, although it could be suggested that Paleolithic diets could improve metabolic syndrome, some issues have to be raised for this study. In particular, four of the six outcomes had non-significant CI, and all of the outcomes could not really be compatible with any major clinical effect. For example, the estimated average differences for most of the primary outcomes were small (SBP −3·6 mm Hg, DBP −2·5 mm Hg, HDL-cholesterol 0·12 mM, fasting blood glucose −0·16 mM). Moreover, the absence of an assessment of adverse events by the trial investigators in all of these studies appears to have been a significant limitation.

There are several concerns for individuals attempting to follow a Paleolithic diet pattern. Paleolithic diets are high in SFA, cholesterol and protein intakes. It has been suggested that individuals following the Paleolithic diet may not meet the daily recommended intakes for some micronutrients, such as calcium and possibly iodine, as well as fibre in some cases. Although, apart from the micronutrients already mentioned, all other targets of micronutrient intakes could be satisfied, in a recent review[20], some other risks have also been identified that affect various organs and/or physiological conditions. In particular, the effect of a high-protein intake on kidney function was raised, although some may argue that this could be debatable as long as it could be outweighed by the beneficial effects on abdominal obesity and other health-related variables[21,22]. Also, people with genetic hemochromatosis, a hereditary disease that results in enhanced iron absorption, were suggested that they have to limit their intake of meat and fish. Hypertensive patients on angiotensin-converting enzyme inhibitors, angiotensin II receptor blockers or diuretics should be gradually introduced to a salt-free Paleolithic diet in order to avoid a sharp drop in blood pressure[23]. Patients with type 2 diabetes who are on sulphonylurea preparations (glipizid, glibenklamid and glimepirid) are at risk of low blood glucose levels when making the radical switch to a Paleolithic diet, which is low in carbohydrates.

Diets high in protein have been suggested to have calciuretic effects[24,25], hence they may have the potential to increase the risk of osteoporosis and bone demineralisation, in comparison to fruit and vegetable intake which yield a net alkaline renal load[26] and decreased urinary calcium excretion rates[27]. It can be hypothesised that in hunter-gatherer populations (following the Paleolithic diet) who consumed high-protein diets, derived from animal sources, but also high in fruit and vegetables, this calciuretic effect could be ameliorated.

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These results though need to be extrapolated with caution, since urine calcium is not a useful measure of bone health because it does not consider calcium absorption and retention[28].

### Vegetarian–vegan diets

The vegetarian diet has gained great popularity in recent years and is characterised by the complete abstention from meat and meat products, poultry, seafood and flesh from any other animal consumption[29]. This dietary pattern is very high in fibre, magnesium, $Fe^{3+}$ (non-haem iron from plant sources), folic acid, vitamins C and E, *n*-6 PUFA, phytochemicals and antioxidants and low in cholesterol, total fat and SFA, sodium, $Fe^{2+}$ (haem iron from animal sources), zinc, vitamins A, $B_{12}$, D and especially *n*-3 PUFA from fish.

Epidemiological studies of the effects of vegetarianism on health have derived data over the past 50 years. Although the health benefits of the vegetarian diet have been widely reported, these mostly come from cross-sectional and prospective studies, which are epidemiological in nature. Uncertainties therefore remain, due to the residual confounders potentially present, and the limited sample size in some of them. Furthermore, although some prospective studies were large, these included specific subject cohorts, e.g. some cohorts contained participants predominantly from specific ethnic backgrounds, questioning generalisability of results as well as the actual effect of this pattern on CVD outcome[30,31]. For example, vegetarians have been proposed to be more conscious for health aspects, slimmer and in better health when compared to omnivores[32], therefore direct comparison cannot be made.

In addition to the vegetarian diet, vegan diet, i.e. the total exclusion of any animal-derived substance, is a pattern that has been attracting an increasing interest among the public. Few studies have reported the health benefits of vegan diets and therefore no conclusive evidence can be proposed[33,34].

Regarding intermediary risk factors of CVD, a recent meta-analysis of seven clinical trials and thirty-two observational studies showed that consumption of vegetarian diets was associated with lower blood pressure[35], and in another meta-analysis of eleven RCT, vegetarian diets were found to have a significant lowering effect on blood total cholesterol, LDL-cholesterol, HDL-cholesterol and non-HDL-cholesterol, but a non-significant effect on TAG levels[36].

Regarding vegetarian diets and end points of CVD, a meta-analysis of seven prospective studies that included 124 706 participants reported 29 % lower mortality from IHD (relative risk (RR) 0·71, 95 % CI 0·56, 0·87), 16 % lower mortality from circulatory diseases (RR 0·84, 95 % CI 0·54, 1·14) and 12 % lower mortality from cerebrovascular disease (RR 0·88, 95 % CI 0·70, 1·06)[37]. Another, a more recent meta-analysis, including eighty-six cross-sectional and ten cohort prospective studies for a total population of over than 130 000 vegetarians and 15 000 vegans[38], showed significant reduced levels of BMI, total cholesterol, LDL-cholesterol and glucose levels in vegetarians and vegans compared to omnivores. Prospective study analysis resulted in a 25 % pooled significant risk reduction in incidence and/or mortality from IHD (RR 0·75, 95 % CI 0·68, 0·82) but no significant differences were found neither for total cardiovascular and cerebrovascular diseases nor for all-cause mortality.

Vegetarians may be at increased risk for a suboptimal supply of some nutrients including iron[39] which could lead to primary iron deficiency. Iron is the most common nutrient deficiency in the world affecting approximately 25 % of the world population[40,41]. This develops when the body's need for iron is not met by iron absorption from the diet. This is common among vegetarians and vegans, since their iron source is non-haem, which has low bioavailability, and its absorption is further affected due to the diet's high content in fibre and oxalates. In a systematic review and meta-analysis including twenty-seven cross-sectional studies and three interventional studies showed that adult vegetarians have significantly lower serum ferritin levels than their non-vegetarian controls[42]. Moreover, the inclusion of semi-vegetarian diets did not change the results considerably.

### Dietary Approaches to Stop Hypertension diet

The Dietary Approaches to Stop Hypertension (DASH) eating pattern was initially developed to improve blood pressure in hypertensive patients[43], and is characterised by its lower salt, cholesterol and saturated fat content compared to the usual Western-type diet. DASH recommends fruit and vegetables, low-fat dairy products, grains, poultry, fish, and nuts and limits red meat, all types of other products rich in saturated fat, sweets and sugar-sweetened beverages.

It is therefore high in potassium, calcium, magnesium, fibre and lean protein. A network meta-analysis of sixty-seven trials (17 230 participants in total), investigating the effects of thirteen different dietary RCT, including DASH, on blood pressure was carried out in hypertensive and pre-hypertensive patients[44]. Other dietary patterns included in the meta-analysis were low-fat, moderate carbohydrate, high-protein, low-carbohydrate, Mediterranean, Paleolithic, vegetarian, low-glycaemic index/glycaemic load, low-sodium, Nordic, Tibetan and control. In total, the DASH, the Mediterranean, the low-carbohydrate, the Paleolithic, the high protein, the low-glycaemic index, the low-sodium and the low-fat dietary patterns were significantly more effective in reducing SBP (−8·73 to −2·32 mmHg) and DBP (−4·85 to −1·27 mmHg) compared to a control diet, with DASH being ranked as the most effective dietary approach in reducing SBP and DBP. Although the credibility of evidence was rated low, the Paleolithic, and the low-carbohydrate ranked third for SBP reduction and the Mediterranean diets ranked third for DBP. Overall results should be extrapolated with caution, since multiple dietary patterns have been analysed with

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low-to-moderate credibility of evidence in total with the exception for the DASH *v.* the low-fat dietary approach.

Following evidence of the anti-hypertensive effects of the DASH diet, and due to CVD's high association with hypertension, several prospective studies have investigated the potential reduction of various types of CVD[45,46]. Inconsistent findings resulted from studies reporting DASH effects on CHD[45–47], stroke CHD[45–48] and heart failure[49,50] risk.

A recent meta-analysis however, of six cohort studies, which investigated the association of DASH-style diet in relation to CVD, CHD, stroke and heart failure[3], reported that imitating a DASH-like diet could significantly reduce total CVD, CHD and stroke rate by approximately 20 %, and heart failure by 29 %. A linear and negative association was obtained between DASH-style diet concordance and all CVD, as well.

Other than the effects of the DASH diet on decreasing hypertension, and CVD incidence rates, studies have also investigated the effects of this dietary pattern on CVD prevention, through various mechanisms, including fasting glucose control, decrease in insulin resistance as well as the amelioration of blood lipids[51,52]. The effective results of the DASH pattern on glycaemic control were shown from a meta-analysis of intervention trials[53], where a significant lower fasting insulin level was found in total and upon conducting a study period subgroup analysis. In the latter case, the meta-analysis showed that the DASH diet could significantly reduce fasting insulin levels when prescribed for more than 16 weeks. No significant reduction however resulted on fasting blood glucose levels and on insulin resistance (measured via HOMA-IR). More studies are therefore required to address the effect of the DASH diet on glycaemic control.

## Nordic diet

The healthy Nordic dietary pattern was defined based on the intake of whole grains including oats, rye and barley, and specific fruit and vegetables; apples/pears, berries, root vegetables, cabbages and fish[54,55]. Several of these components have individually been associated with a lower risk of CVD, including fish, whole grains and phytochemicals in fruit and vegetables. The basis of the Nordic diet was to combine these individual effects and examining them in a dietary pattern, which can result in an even greater effect on CVD risk reduction. Intervention trials conducted have shown various beneficial effects of the Nordic dietary pattern on short-term CVD biomarkers with results varying with the population and/or with the marker(s) investigated. More specifically with those with mild hypercholesterolaemia on the Nordic diet had a significant decrease in cholesterol levels and body weight[56], individuals with metabolic syndrome features had a decrease in DBP and arterial pressure[57] and obese subjects had a perceived weight loss and blood pressure reduction[58].

An improved lipid profile and a beneficial effect of low-grade inflammation[59] have also been reported among individuals following the Nordic diet. The pooled estimate of five RCT (*n* 513) in a recent meta-analysis reported that the Nordic dietary pattern significantly reduced total and LDL-cholesterol levels compared with the controls but there was no significant effect seen on HDL-cholesterol and TAG levels[60]. At the same study, four eligible RCT revealed that the Nordic diet significantly reduces SBP and DBP.

The Swedish Women's Lifestyle and Health cohort, a 20-year follow-up of 43 310 women, however, failed to show an association between the Nordic dietary pattern and overall CVD risk or any of the subgroups investigated[61]. Although many questions can be raised for potential reporting and other types of bias that accompany epidemiological studies, one needs to account that these studies are performed in real-life situations and specific CVD end points were evaluated in comparison to the RCT mentioned earlier, which evaluated intermediate biomarkers.

## Mediterranean diet

The concept of the Mediterranean diet was developed to reflect food patterns typical of Crete, much of the rest of Greece, and Southern Italy in the early 1960s[62]. Although the Mediterranean diet varies from one country to another, its key traditional features include high consumption of grains and cereals (traditionally mainly whole grains), legumes, fruit, nuts, vegetables and fish; daily use of olive oil as the main fat, with the consequent high monounsaturated/saturated fat ratio; moderate consumption of milk and dairy products; low-to-moderate wine consumption (mainly at meals); and low consumption of meat and meat products.

The Mediterranean diet has been associated with several health benefits including reduced total mortality[63,64], reduced metabolic syndrome risk and with several components linked to the metabolic syndrome (obesity, hypertension, hyperglycaemia and hyperlipidaemia)[65]. The Mediterranean diet has also been shown to reduce the risk of type 2 diabetes mellitus[66]. More specifically, results upon assessing the efficacy of nine different dietary approaches on glycaemic control in type 2 diabetic patients (*n* 4937 participants) showed that for reducing fasting glucose, the Mediterranean diet was ranked as the best approach, followed by Paleolithic diet and Vegetarian diet and for reducing HbA1c, the low-carbohydrate diet was found the best approach, followed by the Mediterranean and the Paleolithic diets. Moreover, the network analysis showed that all dietary approaches significantly reduce HbA1c (−0·82 to −0·47 % reduction) and fasting glucose (−1·61 to −1·00 mM reduction) compared to a control diet.

Apart from the studies investigating the association of the Mediterranean Diet with all-cause mortality and risk factors of CVD, there are also studies, which have investigated the association of the Mediterranean diet with specific CVD end points, such as myocardial infarction and stroke.



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In a meta-analysis analysing such prospective studies, the pooled RR estimate for unspecified CVD, of eleven studies, comparing the highest *v.* the lowest category of the Mediterranean Diet Score was 0·81 (95 % CI 0·74, 0·88), and the corresponding pooled RR for coronary-IHD/acute myocardial infarction risk was 0·70 (95 % CI 0·62, 0·80) [67]. It is noteworthy that this inverse relationship observed was consistent across strata of study design, end point (incidence and mortality), sex, geographic area and the Mediterranean Diet Score used. In the same meta-analysis, six studies investigated unspecified stroke and an overall RR for these was 0·73 (95 % CI 0·59, 0·91) again for the highest *v.* the lowest category of the Mediterranean Diet Score, while the corresponding values for ischaemic (five studies) were 0·82 (95 % CI 0·73, 0·92) and for haemorrhagic stroke (four studies) 1·01 (95 % CI 0·74, 1·37). Results of this meta-analysis suggest that the Mediterranean diet could decrease the risk of both myocardial infarction and stroke.

In a recent longitudinal study (REGARDS (Reasons for Geographic and Racial Differences in Stroke)) two dietary pattern scores were compared, the Paleolithic and the Mediterranean, regarding all-cause and cause-specific mortality[68]. Participants completed questionnaires, including a block FFQ, at baseline and were contacted every 6 months to determine their health status. Of the analytic cohort (*n* 21 423), a total of 2513 participants died during a median follow-up of 6·25 years. The results showed that for those in the highest relative to the lowest quintiles of the Paleolithic and Mediterranean diet scores, the multivariable adjusted hazard ratios for all-cause mortality were, respectively, 0·77 (95 % CI 0·67, 0·89) and 0·63 (95 % CI 0·54, 0·73), and for all-CVD mortality, they were 0·78 (95 % CI 0·61, 1·00) and 0·68 (95 % CI 0·53, 0·88). Consequently, both diets were beneficial to reduce all-cause mortality and CVD mortality but it could also be suggested that the Mediterranean diet could be more effective than the Paleolithic diet.

In another study, two commonly promoted healthy diet scores (the modified Mediterranean Diet Score (mMED) and the Healthy Nordic Food Index (HNFI)) and the combined effect of the two scores in association with all-cause and cause-specific mortality (cancer, CVD and IHD) were assessed[69]. The study included 38 428 women (median age of 61 years) from the Swedish Mammography Cohort. The mMED and HNFI were generated and each was categorised into low-, medium- and high-adherence groups. The combination of mMED and HNFI was then used to jointly classify study participants into further three categories. During follow-up (median: 17 years), 10 478 women died. In the high-adherence compared with the low-adherence categories, the hazard ratio for all-cause mortality was 0·76 (95 % CI 0·70, 0·81) for mMED and 0·89 (95 % CI 0·83, 0·96) for HNFI. Higher adherence to mMED was associated with lower mortality in each stratum of HNFI in the combined analysis. In general, mMED, compared with HNFI, was more strongly associated with a lower cause-specific mortality. Also, both mMED and HNFI were inversely associated with all-cause and cardiovascular mortality but the combined analysis indicated an advantage to be adherent to the mMED.

It is noteworthy that all constituents do not attribute equally to the decrease of the risk. In a study by Grosso *et al.*[70], pooled analyses of individual components of the diet revealed that the protective effects of the diet appear to be most attributable to olive oil, fruit, vegetables and legumes. An average reduced risk of 40 % for CVD mortality as well as for incidence of myocardial infarction and stroke has been retrieved when pooling the results of RCT. In another meta-analysis of prospective cohort studies and after pooling fatal and non-fatal CVD events together, a decreased risk of 10 % for a two-point increase in Mediterranean diet adherence score was reported, but there were no analyses for specific outcomes, such as the risk of CHD, myocardial infarction and stroke[63].

The PREDIMED study is one of the most widely known RCT with specific CVD end points. This study investigated the effects of Mediterranean diet enriched with extra virgin olive oil or with nuts[71]. Although due to some problems of the randomisation procedure, the initial paper, originally published in 2013, was retracted, the revised one showed a protective effect of a Mediterranean diet. More specifically following an intention-to-treat analysis including all the participants and upon adjusting for baseline characteristics and propensity scores, the hazard ratio was 0·69 (95 % CI 0·53, 0·91) for a Mediterranean diet with extra virgin olive oil and 0·72 (95 % CI 0·54, 0·95) for a Mediterranean diet with nuts, as compared with the control diet. Results were similar after the omission of 1588 participants whose study-group assignments were known or suspected to have departed from the protocol. This study therefore suggested that a Mediterranean diet pattern enriched with either extra virgin olive oil or nuts could decrease CVD end points (myocardial infarction, stroke or death from cardiovascular causes) by approximately 30 %, compared to a diet low in fat.

## Environmental impact

Apart from the effect on health status, dietary habits have a great impact on the environment, although there is a lack of information concerning the whole diet. The environmental impact of omnivores, ovo-lacto-vegetarians and vegans in Italy (*n* 153; fifty-one individuals per group), and the inter-individual variability within dietary groups were assessed in a real-life context, using a 7 d dietary record[72]. Nutritional values and environmental impacts, including carbon, water and ecological footprints, were calculated for each pattern. The results of this study showed that the omnivorous choice generated worse carbon, water and ecological footprints compared to the ovo-lacto-vegetarians and the vegans but no differences were found for the environmental impacts between the ovo-lacto-vegetarians and the vegans. Based on nutrition value, ovo-lacto- and vegans also had diets more adherent to the Mediterranean pattern.



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In a relatively simplified manner (Double Pyramid Model), the environmental impacts from three different menus were compared[73]. All menus were equally balanced and comparable in terms of nutrition, but they differed in relation to the presence or absence of animal flesh and animal products. The first dietary pattern (omnivorous) included both animal flesh and products, the second (lacto-ovo-vegetarian) included animal products (eggs and dairy) but no flesh and the third (vegan) was solely plant-based. The results showed that a diet based on the principles of the Mediterranean diet can generate a lower environmental impact compared to diets that were heavily based on daily meat consumption.

Springman *et al.*[74] also assessed three sets of diet scenarios. The authors analysed nutrient levels, diet-related and weight-related chronic disease mortality, and environmental impacts were performed. The first set, based on environmental objectives, replaced 25–100 % of animal-source foods with plant-based foods. The second set, based on food security objectives, reduced the levels of underweight, overweight and obesity by 25–100 %. The third set, based on public health objectives, consisted of four energy-balanced dietary patterns: flexitarian, pescatarian, vegetarian and vegan. In the nutrient analysis, nutrient intake and changes in adequacy based on international recommendations and a global dataset of nutrient content and supply were calculated. In the health analysis, changes in mortality using a comparative risk assessment with nine diet- and weight-related risk factors were estimated. In the environmental analysis, country-specific and food group-specific footprints for greenhouse gas emissions, cropland use, freshwater use, nitrogen application and phosphorus application were combined to analyse the relationship between health and environmental impacts of dietary change. The results showed that following environmental objectives by replacing animal-source foods with plant-based ones was particularly effective in high-income countries for improving nutrient levels, lowering premature mortality (reduction of up to 12 % with complete replacement) and reducing mainly greenhouse gas emissions (reductions of up to 84 %), although it also increased freshwater use up to 16 %. However, this replacement of animal- with plant-based sources had little effectiveness in countries with low or moderate consumption of animal-source foods.

Following food-security objectives, reducing underweight and overweight by improving energy balance resulted in a similar decrease in premature mortality (up to 10 % decrease), and moderately improved nutrient levels. However, improvement of energy balance resulted in small reductions in environmental impacts at the global level (all impacts changed by <15 %), with a moderate decrease found in high-income and middle-income countries (8–18 %), where levels of overweight and obesity required energy intake reduction. In comparison, in low-income countries, where levels of underweight required an increase in energy intake, impacts for greenhouse gas emissions, cropland use and freshwater use were increased by 3–8 %. Following public health objectives by adopting energy-balanced, low-meat dietary patterns that are in line with available evidence on healthy eating led to an adequate nutrient supply for most nutrients and large reductions in premature mortality (reduction of 19 % for the flexitarian diet to 22 % for the vegan diet). Achieving public health objectives by adopting energy-balanced, low-meat dietary patterns also markedly reduced the environmental impacts globally (reducing greenhouse gas emissions by 54–87 %, nitrogen application by 23–25 %, phosphorus application by 18–21 %, cropland use by 8–11 % and freshwater use by 2–11 %) and in most regions, except for some environmental domains (cropland use, freshwater use and phosphorus application) in low-income countries.

## Conclusion

Epidemiological studies have demonstrated protective effects of various dietary patterns on CVD prevalence and incidence. Although limitations of temporal effect and recall bias in cross-sectional and case–control studies, and potential residual confounding in prospective cohort studies, findings from RCT strengthen the evidence of diet's role in CVD reduction. Dietary patterns based on plant food and including some animal food, such as the DASH diet, the Mediterranean diet and the Nordic diet have protective effects on CVD risk, based mainly on results from prospective studies and a limited number of well-designed RCT with end points of the disease. Dietary patterns such as the Paleolithic diet on the one hand and the vegan diet on the other could possibly have some benefits, especially the vegan diet, but they lack certain nutrients and therefore could not be considered as balanced. Finally the more plant-based the dietary pattern is, the more it is environment-friendly.

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## Conflict of Interest

None.

## Authorship

The authors were jointly responsible for all aspects of preparation of this paper.

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