Systematic Review with Meta-Analysis

Associations of dietary patterns with the risk of all-cause, CVD and stroke mortality: a meta-analysis of prospective cohort studies

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Abstract

Considerable controversy exists regarding the associations of dietary patterns with the risk of all-cause, CVD and stroke mortality. Therefore, a meta-analysis was conducted to elucidate the potential associations between dietary patterns and the risk of all-cause, CVD and stroke mortality. The PubMed database was searched for prospective cohort studies on the associations between dietary patterns and the risk of all-cause, CVD and stroke mortality published until February 2014. Random-effects models were used to calculate the summary relative risk estimates (SRRE) based on the highest v. the lowest category of dietary pattern scores. Stratified analyses were conducted based on sex, geographical region, follow-up duration, and adjustment/non-adjustment for energy intake. A total of thirteen prospective cohort studies involving 338,787 participants were included in the meta-analysis. There was evidence of inverse associations between the prudent/healthy dietary pattern and the risk of all-cause (SRRE = 0.76, 95% CI 0.68, 0.86) and CVD (SRRE = 0.81, 95% CI 0.75, 0.87) mortality and an absence of association between this dietary pattern and stroke mortality (SRRE = 0.89, 95% CI 0.77, 1.02). However, no significant associations were observed between the Western/unhealthy dietary pattern and the risk of all-cause (SRRE = 1.07, 95% CI 0.96, 1.20), CVD (SRRE = 0.99, 95% CI 0.91, 1.08) and stroke (SRRE = 0.94, 95% CI 0.81, 1.10) mortality. In conclusion, the findings provide evidence that greater adherence to a prudent/healthy dietary pattern is associated with a lower risk of all-cause and CVD mortality and not significantly associated with stroke mortality and that the Western/unhealthy dietary pattern is not associated with all-cause, CVD and stroke mortality. Further studies are required to confirm these findings.

Key words: Dietary patterns; Mortality; All-cause mortality; Meta-analysis

The proportion of elderly people as well as the incidence of chronic diseases, such as CVD, is increasing globally. CVD remains a major public health problem and represents the leading cause of mortality, affecting millions of people in both developed and developing countries. Furthermore, it is estimated that deaths due to CVD and cancer will account for more than 50% of total mortality cases in 2030(1). The incidence of CVD is rising at an alarming rate, especially among people aged ≥60 years, which will lead to a heavy social and economic toll worldwide(2). Therefore, strategies to promote health and prevent deaths due to major chronic diseases, such as CVD and stroke, are required to be implemented.

Dietary habits play an important role as determinants of health status. Nutrients and foods can never be eaten in isolation and have complex interactions, resulting in the masking of true associations(3). In recent decades, the dietary pattern analysis has emerged as an alternative and complementary approach to examine the effects of overall diet on all-cause, CVD and stroke mortality instead of the assessment

Abbreviations: FA, factor analysis; PCA, principal component analysis; SRRE, summary relative risk estimates.
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of a single or a few nutrients or foods. Several studies have demonstrated the associations between dietary patterns and major chronic diseases such as CVD, cancer and stroke(4,5). Furthermore, the associations of dietary patterns with the risk of all-cause, CVD and stroke mortality are gaining considerable attention. Recently, several prospective cohort studies have examined the associations between dietary patterns and the risk of all-cause, CVD and stroke mortality; however, their findings have led to considerable controversy(6–16). To date, a comprehensive assessment of the associations between dietary patterns and the risk of all-cause, CVD and stroke mortality has not been reported.

Therefore, we conducted a meta-analysis to elucidate the potential associations of dietary patterns with the risk of all-cause, CVD and stroke mortality on the basis of findings from all published prospective cohort studies.

Materials and methods

Literature search strategy

The present meta-analysis was carried out in accordance with the Meta-analysis Of Observational Studies in Epidemiology guidelines(17). An electronic literature search was conducted to identify prospective cohort studies on the associations between dietary patterns and the risk of all-cause, CVD and stroke mortality published until February 2014 in the PubMed database. The primary search included the following search items: ‘cardiovascular disease’ OR ‘CVD’ OR ‘heart’ OR ‘vascular’ OR ‘myocardial infarction (MI)’ OR ‘coronary’ OR ‘CHD’ OR ‘stroke’) AND (‘survival’ OR ‘mortality’ OR ‘death’ OR ‘fatal’ OR ‘lethal’) AND (‘dietary pattern’ OR ‘eating pattern’ OR ‘food pattern’ OR ‘dietary habit’ OR ‘diet’ OR ‘dietary’) AND (‘factor analysis’ OR ‘principal component analysis’ OR ‘Mediterranean diet’ OR ‘diet diversity’ OR ‘diet variety’ OR ‘quality’ OR ‘index’ OR ‘indices’ OR ‘scores’). The search focused on human studies, without restrictions on language. Furthermore, the reference lists of all the retrieved publications were assessed and searched again to identify relevant publications. Eligible articles were selected for a full-text review after an initial screen by titles and abstracts.

Inclusion and exclusion criteria

Studies that had an original prospective cohort study design and were carried out in human beings; studies that examined the associations between dietary patterns and the risk of all-cause, CVD and stroke mortality; studies that reported risk estimates (i.e. relative risk or OR) and their variability (i.e. 95 % CI); studies that provided sufficient information (e.g. raw data and P values) for estimation; and studies that examined food or dietary patterns using factor analysis (FA) and/or principal component analysis (PCA) were eligible for inclusion in the meta-analysis.

Only patterns sharing most foods with similar factor loadings were selected to minimise errors and combine the results. In this analysis, two common dietary patterns were identified: prudent/healthy dietary pattern, characterised by a high intake of foods such as vegetables, fruits, fish, poultry, whole grains and low-fat dairy products, and Western/unhealthy dietary pattern, characterised by a high intake of processed and/or red meat, refined grains, sweets, desserts, eggs and high-fat dairy products. Studies with dietary patterns having similar loadings of foods common to the prudent/healthy or Western/unhealthy dietary pattern were also included in spite of being named differently.

Data extraction

Information extracted from each eligible study included the following: first author’s name; year of publication; geographical region; number of cases; sample size; participant age range; study duration; follow-up duration; number of exposed cases; dietary intake assessment method; method used for identifying dietary patterns; naming of dietary patterns; endpoints; relative risk or OR and 95 % CI; number of food items in the FFQ; confounding factors that were adjusted for in the analysis. When a study presented different adjustment variables, results from the main multivariable model that included the maximum number of adjusted confounders were considered.

Quality assessment of each study was performed based on the following crucial components: clear definition of participant characteristics; clear examination of exposure and outcome; study duration; sufficient follow-up; person-years of follow-up; no selective loss during follow-up; control for potential confounding factors. If one of the above was not clearly reported by a study, it was assumed that the study underestimated the component rather than assuming that it had not been assessed. Literature search and data extraction were performed independently by two authors. Discrepancy in data extraction was resolved by repeating the study review and discussion.

Statistical analyses

Summary relative risk estimates (SRRE) were calculated for the highest v. the lowest category of dietary patterns in terms of tertiles, quartiles or quintiles of dietary factor scores in the included studies. Statistical heterogeneity across the studies was tested using the χ² test (significant with a P value < 0.10) and measured using the I² statistic(18). By assuming that the studies were carried out in populations with varying effect sizes, calculating the study weights from both in-study and between-study variances, and considering the extent of variation or heterogeneity, the random-effects models were used to study the associations and presented forest plots(19).
Some studies had more than one dietary pattern model (i.e. vegetables, fruits, sweets and meat) that met the inclusion criteria of the present meta-analysis for the prudent/healthy or Western/unhealthy dietary pattern. Separate risk estimates in individual studies were combined to obtain a unique study-specific estimate for this dietary pattern.

Publication bias was assessed using Begg’s rank correlation test and Egger’s linear regression test and funnel plots\(^{16,20}\). Because both tests have a low power to detect potential bias, \(P = 0.1\) was set as the statistical penalty for these tests in the present meta-analysis. In addition, subgroup analyses were conducted according to sex, geographical region, follow-up duration (\(\geq 10\) years or <10 years), and adjustment/non-adjustment for energy intake to explore the sources of heterogeneity. All statistical analyses were carried out using Stata statistical software, version 11.0 (StataCorp).

### Results

#### Study selection

The initial search yielded 1664 articles, of which 1419 were excluded after screening by titles and abstracts. Furthermore, 136 articles were excluded as they involved ecological studies, reviews or studies on single nutrients. The remaining 109 articles examining the associations between dietary patterns and the risk of all-cause, CVD and stroke mortality were assessed by full-text review. Of these 109 articles, twenty-two were excluded because their effect sizes and the corresponding 95% CI were not reported or could not be estimated due to insufficient information. The results of forty-five studies were not related to the purpose of the present meta-analysis. Moreover, twelve studies were excluded because dietary patterns were not examined using the FA or PCA. Another article was excluded due to an overlap of the study population with that of another study\(^{16,21}\). Therefore, the informative study was taken into account\(^{16}\). The studies carried out by Maruyama et al.\(^{(7)}\) and Osler et al.\(^{(16)}\) reported risk estimates for men and women separately and were therefore considered as two studies when the examined items were pooled. Finally, thirteen prospective cohort studies from eleven papers published between 2000 and 2014\(^{(6-10,16)}\) were included in the present meta-analysis. A flow chart of the study selection process is shown in Fig. 1.

#### Study characteristics

All the thirteen studies that were included in the meta-analysis were prospective cohort studies: three studies were conducted in Japan (one in men\(^{(7)}\), one in women\(^{(7)}\) and one in both men and women\(^{(12,13)}\); two in Denmark (one in men\(^{(16)}\), one in women\(^{(16)}\)); one each in Spain\(^{(6)}\), Bengal\(^{(8)}\), the UK\(^{(9)}\), the USA\(^{(10)}\), Australia\(^{(11)}\), China\(^{(12)}\), Italy\(^{(14)}\) and the Netherlands\(^{(15)}\). Most of the studies included in the meta-analysis used FFQ based on self-reports or interviewer-administered questionnaires to ascertain dietary intake information, despite variations in the length of item list in the questionnaire across the studies. The outcomes identified were all-cause mortality in nine studies (men\(^{(16)}\), women\(^{(16)}\), men and women\(^{(1,6,9,10,13-15)}\), CVD mortality in seven studies (men\(^{(7)}\), women\(^{(7)}\), men and women\(^{(8,10-13)}\)) and stroke mortality in five studies (men\(^{(7)}\), women\(^{(7)}\), men and women\(^{(8,12,13)}\)). In summary, thirteen studies with a sample size of 338,787 participants, comprising 9465 cases of all-cause death, 5543 cases of CVD death and 1918 cases of stroke death, were included in the meta-analysis. The characteristics of the included studies are given in Table 1.

#### Association of the prudent/healthy dietary pattern with the risk of all-cause, CVD and stroke mortality

A significant inverse association was observed between the highest v. the lowest category of prudent/healthy dietary pattern and the risk of all-cause mortality, with SRRE of 0.76 (95% CI 0.67, 0.86). Substantial heterogeneity was observed across the studies (\(P\) value for heterogeneity=0.039, \(I^2 = 52.6\%\); Table 2 and Fig. 2(a)). The Begg test (\(P = 0.133\)) and visual inspection of the funnel plot (not shown) did not indicate a publication bias, but the Egger test (\(P = 0.045\)) indicated a possible publication bias. Furthermore, greater adherence to a prudent/healthy dietary pattern was found to be associated with a lower risk of CVD mortality (SRRE = 0.81, 95% CI 0.75, 0.87), with no evidence of heterogeneity being found among the studies on CVD mortality (\(P\) value for heterogeneity=0.399, \(I^2 = 3.5\%\); Table 2 and Fig. 3(a)). However, no significant association was observed between this dietary pattern and the risk of stroke mortality (SRRE = 0.89, 95% CI 0.77, 1.02). There was no indication of heterogeneity among the studies on stroke mortality (\(P\) value for heterogeneity=0.102, \(I^2 = 48.2\%\); Table 2 and Table 3).

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**Fig. 1.** Flow chart of the study selection process.
<table>
<thead>
<tr>
<th>First author and year</th>
<th>Study location</th>
<th>Cases</th>
<th>No. of participants</th>
<th>Follow-up duration (years)</th>
<th>Study period</th>
<th>FFQ list</th>
<th>Dietary pattern</th>
<th>Endpoints</th>
<th>RR</th>
<th>95% CI</th>
<th>P by trend</th>
<th>Adjustments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zazpe (2013)</td>
<td>Spain</td>
<td>148</td>
<td>16 008</td>
<td>10</td>
<td>1995-2009</td>
<td>136</td>
<td>Mediterranean</td>
<td>All-cause mortality</td>
<td>0.53</td>
<td>0.34-0.84</td>
<td>0.010</td>
<td>Age, sex, smoking status, BMI, total energy intake, alcohol consumption, television watching, PA (leisure time), depression, hypercholesterolaemia, hypertension, education level and special diets at baseline</td>
</tr>
<tr>
<td>Manuyama (2013) men</td>
<td>Japan</td>
<td>1240</td>
<td>26 598</td>
<td>12.6</td>
<td>1998-2003</td>
<td>40</td>
<td>Vegetables</td>
<td>CVD mortality</td>
<td>0.93</td>
<td>0.78-1.33</td>
<td>0.730</td>
<td>Age, smoking status, BMI, total energy intake, walking time, hours spent on sports, education level, perceived mental stress, sleep duration, and history of hypertension and diabetes</td>
</tr>
<tr>
<td>Manuyama (2013) women</td>
<td>Japan</td>
<td>1071</td>
<td>37 439</td>
<td>12.6</td>
<td>1998-2003</td>
<td>40</td>
<td>Vegetables</td>
<td>Stroke mortality</td>
<td>1.13</td>
<td>0.85-1.51</td>
<td>0.390</td>
<td>Age, smoking status, BMI, total energy intake, walking time, hours spent on sports, education level, perceived mental stress, sleep duration, and history of hypertension and diabetes</td>
</tr>
<tr>
<td>Chen (2013)</td>
<td>Bengal</td>
<td>185</td>
<td>11 116</td>
<td>6.6</td>
<td>2000-2009</td>
<td>39</td>
<td>Gourd and root vegetables</td>
<td>CVD mortality</td>
<td>1.04</td>
<td>0.69-1.59</td>
<td>0.840</td>
<td>Age, sex, smoking status, BMI and energy intake</td>
</tr>
<tr>
<td>Hamer (2010)</td>
<td>UK</td>
<td>683</td>
<td>1017</td>
<td>9.2</td>
<td>1994-2008</td>
<td>NR</td>
<td>Mediterranean</td>
<td>Stroke mortality</td>
<td>0.74</td>
<td>0.39-1.41</td>
<td>0.380</td>
<td>Age, sex, smoking status, BMI, total energy intake, education level, self-rated health status, medication, mutual adjustment for all diet patterns and supplements</td>
</tr>
<tr>
<td>Heidemann (2008)</td>
<td>USA</td>
<td>6011</td>
<td>72 113</td>
<td>18</td>
<td>1984-2002</td>
<td>116</td>
<td>Prudent</td>
<td>Total mortality</td>
<td>0.83</td>
<td>0.76-0.90</td>
<td>&lt;0.001</td>
<td>Age, smoking status, BMI, total energy intake, PA, follow-up period, hormone replacement therapy, missing FFQ data during follow-up, multivitamin supplement use and history of hypertension</td>
</tr>
<tr>
<td>Harriss (2007)</td>
<td>Australia</td>
<td>1104</td>
<td>40 653</td>
<td>10.4</td>
<td>1990-2003</td>
<td>121</td>
<td>Mediterranean</td>
<td>Stroke mortality</td>
<td>0.70</td>
<td>0.51-0.96</td>
<td>0.040</td>
<td>Age, sex, smoking status, BMI, total energy intake, walking time, education level and history of hypertension and diabetes</td>
</tr>
<tr>
<td>Shimazu (2007)</td>
<td>Japan</td>
<td>801</td>
<td>54 547</td>
<td>7</td>
<td>1994-2001</td>
<td>40</td>
<td>Japanese</td>
<td>CVD mortality</td>
<td>0.79</td>
<td>0.61-1.02</td>
<td>0.140</td>
<td>Age, smoking status, BMI, total energy intake, walking time, education level and history of hypertension and diabetes</td>
</tr>
<tr>
<td>Cai (2007)</td>
<td>China</td>
<td>1565</td>
<td>74 942</td>
<td>5.7</td>
<td>1996-2004</td>
<td>71</td>
<td>Vegetable rich</td>
<td>Overall mortality</td>
<td>0.97</td>
<td>0.85-1.12</td>
<td>0.922</td>
<td>Age, smoking status, BMI, education level, marital status, income per person, alcohol consumption, tea consumption, ginseng intake and PA energy expenditure</td>
</tr>
<tr>
<td>Masala (2007)</td>
<td>Italy</td>
<td>152</td>
<td>56 111</td>
<td>6.2</td>
<td>1993-2002</td>
<td>120</td>
<td>Prudent</td>
<td>Overall mortality</td>
<td>0.80</td>
<td>0.69-0.94</td>
<td>0.009</td>
<td>Age, sex, smoking status, BMI, energy intake, PA, country of birth, education level, waist:hip ratio, social isolation, dietary factors, CVD history, and family history of CVD, diabetes and hypertension</td>
</tr>
<tr>
<td>Waijers (2006)</td>
<td>Netherlands</td>
<td>277</td>
<td>54 257</td>
<td>8.3</td>
<td>1993-2002</td>
<td>178</td>
<td>Olive oil and salad</td>
<td>Overall mortality</td>
<td>0.85</td>
<td>0.74-1.35</td>
<td>0.660</td>
<td>Age, sex, smoking status, BMI, energy intake, PA, country of birth, education level, waist:hip ratio, social isolation, dietary factors, CVD history, and family history of CVD, diabetes and hypertension</td>
</tr>
<tr>
<td>Osler (2001) men</td>
<td>Denmark</td>
<td>398</td>
<td>36 98</td>
<td>15</td>
<td>1982-1998</td>
<td>28</td>
<td>Prudent</td>
<td>Overall mortality</td>
<td>0.70</td>
<td>0.48-0.87</td>
<td>0.125</td>
<td>Age, sex, smoking status, BMI, energy intake, PA, country of birth, education level, waist:hip ratio, social isolation, dietary factors, CVD history, and family history of CVD, diabetes and hypertension</td>
</tr>
<tr>
<td>Osler (2001) women</td>
<td>Denmark</td>
<td>231</td>
<td>36 18</td>
<td>15</td>
<td>1982-1998</td>
<td>28</td>
<td>Prudent</td>
<td>Overall mortality</td>
<td>0.70</td>
<td>0.49-1.00</td>
<td>0.400</td>
<td>Age, sex, smoking status, BMI, energy intake, PA, country of birth, education level, waist:hip ratio, social isolation, dietary factors, CVD history, and family history of CVD, diabetes and hypertension</td>
</tr>
</tbody>
</table>

PA, physical activity; NR, not reported; DFA, a high-dairy, high-fruit-and-vegetable, low-alcohol dietary pattern.
Fig. 4(a)). No statistical evidence of publication bias was indicated by the Begg or Egger tests among the studies on CVD mortality (Begg: $P = 0.37$ and Egger: $P = 0.22$) and stroke mortality (Begg: $P = 1.00$ and Egger: $P = 0.94$).

### Table 2. Summary of the results of the meta-analysis of the associations of dietary patterns (high intake v. low intake*) with the risk of all-cause, CVD and stroke mortality

<table>
<thead>
<tr>
<th>Analysis specifications</th>
<th>Studies</th>
<th>SRRE</th>
<th>95% CI</th>
<th>$P$†</th>
<th>$I^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prudent/healthy dietary pattern</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-cause mortality</td>
<td>8</td>
<td>0.76</td>
<td>0.67, 0.86</td>
<td>0.039</td>
<td>52.6</td>
</tr>
<tr>
<td>Non-Europe</td>
<td>2</td>
<td>0.84</td>
<td>0.78, 0.91</td>
<td>0.583</td>
<td>0.0</td>
</tr>
<tr>
<td>Europe</td>
<td>6</td>
<td>0.67</td>
<td>0.55, 0.82</td>
<td>0.029</td>
<td>59.8</td>
</tr>
<tr>
<td>Women</td>
<td>4</td>
<td>0.76</td>
<td>0.64, 0.91</td>
<td>0.04</td>
<td>64.0</td>
</tr>
<tr>
<td>Men</td>
<td>2</td>
<td>0.64</td>
<td>0.48, 0.85</td>
<td>0.39</td>
<td>0.0</td>
</tr>
<tr>
<td>Follow-up duration (&lt;10 years)</td>
<td>4</td>
<td>0.84</td>
<td>0.76, 0.92</td>
<td>0.298</td>
<td>18.5</td>
</tr>
<tr>
<td>Follow-up duration (≥10 years)</td>
<td>4</td>
<td>0.65</td>
<td>0.48, 0.87</td>
<td>0.014</td>
<td>71.6</td>
</tr>
<tr>
<td>Adjustment for energy intake</td>
<td>4</td>
<td>0.80</td>
<td>0.74, 0.87</td>
<td>0.117</td>
<td>49.0</td>
</tr>
<tr>
<td>Non-adjustment for energy intake</td>
<td>4</td>
<td>0.76</td>
<td>0.62, 0.94</td>
<td>0.034</td>
<td>65.4</td>
</tr>
<tr>
<td>CVD mortality</td>
<td>7</td>
<td>0.81</td>
<td>0.75, 0.87</td>
<td>0.399</td>
<td>3.5</td>
</tr>
<tr>
<td>Non-Asia</td>
<td>2</td>
<td>0.74</td>
<td>0.65, 0.83</td>
<td>0.744</td>
<td>0.0</td>
</tr>
<tr>
<td>Asia</td>
<td>5</td>
<td>0.86</td>
<td>0.78, 0.95</td>
<td>0.640</td>
<td>0.0</td>
</tr>
<tr>
<td>Follow-up duration (&lt;10 years)</td>
<td>3</td>
<td>0.84</td>
<td>0.72, 0.97</td>
<td>0.480</td>
<td>0.0</td>
</tr>
<tr>
<td>Follow-up duration (≥10 years)</td>
<td>4</td>
<td>0.80</td>
<td>0.73, 0.87</td>
<td>0.217</td>
<td>32.6</td>
</tr>
<tr>
<td>Stroke mortality</td>
<td>5</td>
<td>0.89</td>
<td>0.77, 1.02</td>
<td>0.102</td>
<td>48.2</td>
</tr>
<tr>
<td><strong>Western/unhealthy dietary pattern</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-cause mortality</td>
<td>7</td>
<td>1.07</td>
<td>0.96, 1.20</td>
<td>0.073</td>
<td>48.0</td>
</tr>
<tr>
<td>Non-Europe</td>
<td>2</td>
<td>1.14</td>
<td>0.99, 1.32</td>
<td>0.095</td>
<td>64.1</td>
</tr>
<tr>
<td>Europe</td>
<td>5</td>
<td>1.02</td>
<td>0.91, 1.15</td>
<td>0.300</td>
<td>18.0</td>
</tr>
<tr>
<td>Men</td>
<td>3</td>
<td>1.07</td>
<td>0.89, 1.30</td>
<td>0.120</td>
<td>52.8</td>
</tr>
<tr>
<td>Women</td>
<td>4</td>
<td>1.16</td>
<td>1.08, 1.24</td>
<td>0.138</td>
<td>45.6</td>
</tr>
<tr>
<td>Follow-up duration (&lt;10 years)</td>
<td>3</td>
<td>1.06</td>
<td>0.96, 1.18</td>
<td>0.306</td>
<td>15.7</td>
</tr>
<tr>
<td>Follow-up duration (≥10 years)</td>
<td>4</td>
<td>1.00</td>
<td>0.80, 1.26</td>
<td>0.061</td>
<td>59.3</td>
</tr>
<tr>
<td>Adjustment for energy intake</td>
<td>3</td>
<td>1.10</td>
<td>0.95, 1.30</td>
<td>0.10</td>
<td>57.9</td>
</tr>
<tr>
<td>Non-adjustment for energy intake</td>
<td>4</td>
<td>1.01</td>
<td>0.92, 1.12</td>
<td>0.744</td>
<td>0.0</td>
</tr>
<tr>
<td>CVD mortality</td>
<td>7</td>
<td>0.99</td>
<td>0.91, 1.08</td>
<td>0.135</td>
<td>38.6</td>
</tr>
<tr>
<td>Non-Asia</td>
<td>2</td>
<td>1.07</td>
<td>0.80, 1.42</td>
<td>0.076</td>
<td>68.3</td>
</tr>
<tr>
<td>Asia</td>
<td>5</td>
<td>0.95</td>
<td>0.85, 1.05</td>
<td>0.400</td>
<td>1.2</td>
</tr>
<tr>
<td>Follow-up duration (&lt;10 years)</td>
<td>3</td>
<td>1.06</td>
<td>0.90, 1.25</td>
<td>0.855</td>
<td>0.0</td>
</tr>
<tr>
<td>Follow-up duration (≥10 years)</td>
<td>4</td>
<td>0.96</td>
<td>0.81, 1.15</td>
<td>0.034</td>
<td>6.4</td>
</tr>
<tr>
<td>Stroke mortality</td>
<td>5</td>
<td>0.94</td>
<td>0.81, 1.10</td>
<td>0.611</td>
<td>0.0</td>
</tr>
</tbody>
</table>

* The intake contrast (i.e. exposure v. referent group) for each study is reported in Table 1.
† $P$ value for heterogeneity.

#### Association of the Western/unhealthy dietary pattern with the risk of all-cause, CVD and stroke mortality

No significant association was observed between the Western/unhealthy dietary pattern and the risk of all-cause mortality (SRRE = 1.07, 95% CI 0.96, 1.20), although variability was detected ($P$ value for heterogeneity = 0.073, $I^2 = 48.0\%$; Table 2 and Fig. 2(b)). The Begg ($P = 0.368$) and Egger ($P = 0.137$) tests, as well as visual inspection of the funnel plot (not shown), did not indicate a publication bias. Furthermore, there was no evidence of any association between the Western/unhealthy dietary pattern and the risk of CVD mortality (SRRE = 0.99, 95% CI 0.91, 1.08; Table 2 and Fig. 2(b)) and stroke mortality (SRRE = 0.94, 95% CI 0.81, 1.10; Table 2 and Fig. 4(b)). There was less evidence of heterogeneity among the studies on CVD mortality ($P$ value for heterogeneity = 0.135, $I^2 = 38.6\%$) and stroke mortality ($P$ value for heterogeneity = 0.611, $I^2 = 0\%$). There was also no statistical evidence of publication bias among the studies on CVD mortality (Begg: $P = 0.55$ and Egger: $P = 0.70$) and stroke mortality (Begg: $P = 0.31$ and Egger: $P = 0.14$).

### Subgroup analyses

When studies were stratified by sex, geographical region, follow-up duration, and adjustment/non-adjustment for energy intake in models, the results of the subgroup analyses were found to be consistent with the primary findings. The Begg and Egger tests provided no evidence of a substantial publication bias in any subgroup (not shown).

#### Discussion

The method used for the analysis of dietary patterns may yield a more comprehensive understanding of how dietary patterns affect diseases compared with analysing a single nutrient and food using traditional nutritional epidemiological analyses. To the best of our knowledge, this is the fist meta-analysis on the associations of dietary patterns with the risk of all-cause, CVD and stroke mortality. A total of thirteen prospective cohort studies involving 338 787 participants were included in the meta-analysis. The results indicated that a prudent/healthy dietary pattern may decrease the risk of all-cause mortality (Begg: $P = 0.55$ and Egger: $P = 0.70$) and stroke mortality (Begg: $P = 0.31$ and Egger: $P = 0.14$).
Study ID
(a) Prudent/healthy dietary pattern
Zazpe et al. (6) 0.53 0.34, 0.84 4.37
Hamer et al. (9) 0.87 0.76, 1.00 8.98
Heidemann et al. (10) 0.83 0.76, 0.90 9.62
Cai et al. (13) 0.64 0.43, 0.95 5.03
Masala et al. (14) 0.70 0.52, 0.95 6.37
Waijers et al. (15) 0.88 0.73, 1.07 8.16
Oser et al. (16a) (men) 0.70 0.49, 1.00 5.55
Oser et al. (16b) (women) 0.46 0.30, 0.72 4.53
Total (I²=52.6%, P=0.039) 0.76 0.67, 0.86 52.61
(b) Western/unhealthy dietary pattern
Zazpe et al. (6) 0.51 0.78, 1.13 3.35
Hamer et al. (9) 1.04 0.90, 1.21 8.83
Heidemann et al. (10) 1.21 1.12, 1.32 9.65
Cai et al. (13) 1.42 0.97, 2.08 5.22
Masala et al. (14) 1.04 0.89, 1.22 8.69
Oser et al. (16a) (men) 0.92 0.69, 1.23 6.56
Oser et al. (16b) (women) 0.87 0.59, 1.29 5.09
Total (I²=48.0%, P=0.073) 1.07 0.96, 1.20 47.39

Fig. 2. Meta-analysis of studies that examined the associations of all-cause mortality with the (a) prudent/healthy dietary pattern and (b) Western/unhealthy dietary pattern. ES, effect size. A colour version of this figure can be found online at http://www.journals.cambridge.org/bjn.

Study ID
(a) Prudent/healthy dietary pattern
Maruyama et al. (7a) (men) 0.93 0.78, 1.13 9.65
Maruyama et al. (7b) (women) 0.82 0.67, 1.00 8.27
Chen et al. (8) 1.04 0.69, 1.59 1.90
Heidemann et al. (10) 0.87 0.69, 0.95 6.09
Harriss et al. (11) 0.75 0.64, 0.88 13.07
Shimazu et al. (12) 0.80 0.68, 0.94 12.64
Cai et al. (13) 0.92 0.55, 1.53 1.27
Total (I²=3.5%, P=0.399) 0.81 0.75, 0.87 56.40
(b) Western/unhealthy dietary pattern
Maruyama et al. (7a) (men) 0.82 0.67, 1.00 8.27
Maruyama et al. (7b) (women) 0.93 0.78, 1.13 9.65
Chen et al. (8) 1.20 0.75, 1.91 1.52
Heidemann et al. (10) 1.22 1.01, 1.48 9.08
Harriss et al. (11) 0.91 0.70, 1.18 4.86
Shimazu et al. (12) 1.04 1.00, 1.54 7.11
Cai et al. (13) 1.04 0.75, 1.44 3.12
Total (I²=38.6%, P=0.135) 0.99 0.91, 1.08 43.60

Fig. 3. Meta-analysis of studies that examined the associations of CVD mortality with the (a) prudent/healthy dietary pattern and (b) Western/unhealthy dietary pattern. ES, effect size. A colour version of this figure can be found online at http://www.journals.cambridge.org/bjn.
and CVD mortality, but may not be associated with stroke mortality. Furthermore, no significant overall associations were observed between the Western/unhealthy dietary pattern and the risk of all-cause, CVD and stroke mortality.

A greater heterogeneity was detected among the studies on all-cause mortality probably due to various causes of death and differences in study populations, model selection, analytical methodology and exposure assessment. A significant proportion of the observed heterogeneity may be explained through the subgroup analyses based on sex, geographical region, follow-up duration, and adjustment/non-adjustment for energy intake. Furthermore, little variability was observed among the studies on CVD or stroke mortality and their subgroup analyses. In addition, there was no significant publication bias in these analyses with either the Begg or Egger test, except that the Egger test carried out on studies examining the association of the prudent/healthy dietary pattern with the risk of all-cause mortality indicated a possible publication bias.

The prudent/healthy dietary pattern was found to be associated with a lower risk of all-cause and CVD mortality. This dietary pattern, mainly characterised by a higher intake of vegetables, fruits, fish, poultry, whole grains and low-fat dairy products, has beneficial effects on health because of the higher content of vitamins, minerals, antioxidants, fibre, MUFA and n-3 fatty acids in the diet. In particular, it has been demonstrated that greater adherence to this dietary pattern could be favourably correlated with the reduction of the incidence of lipid abnormalities, hypertension, arrhythmias, diabetes and obesity and some psychological disorders through the amelioration of insulin sensitivity and their anti-inflammatory and antioxidant actions, which would be a possible explanation for the primary preventive effects of the prudent dietary pattern on all-cause and CVD mortality observed in the present meta-analysis. Furthermore, oxidised LDL concentrations play a vital role in the early development of atherosclerotic lesions. The prudent dietary pattern is also associated with increased total antioxidant capacity and decreased oxidised LDL concentrations, which may explain the inverse association between this dietary pattern and the risk of CVD mortality. However, the quantitative analysis indicated that the summary association between this dietary pattern and the risk of stroke mortality was not statistically significant.

The Western/unhealthy dietary pattern identified in the present meta-analysis was characterised by frequent consumption of processed and/or red meat, refined grains, sweets, desserts, eggs and high-fat dairy products. Although some studies have reported that this dietary pattern, which is rich in saturated fat, has positive associations with the risk of weight gain and plasma concentrations of systemic inflammatory and endothelial markers, no overall associations were observed between this dietary pattern and the risk of all-cause, CVD and stroke mortality in the analyses carried out, which is consistent with the results of most of the included studies. Several explanations are possible for the unexpected lack of associations. One explanation is that the cardioprotective effects of overall diet mediated primarily through plant products may have been attenuated because of greater intakes of meat products instead of more beneficial diets.
plant foods from the diet \cite{20}. It is also possible that unmeasured or unknown residual confounders that were not considered in the analyses may have contributed to this lack of associations. Another explanation is that the participants exhibiting greater adherence to the Western/unhealthy dietary pattern may have also consumed more amounts of some potentially beneficial foods, such as olive oil, fish and poultry \cite{20}.

The present meta-analysis has several important strengths. This is the first systematic epidemiological assessment of the associations between dietary patterns and the risk of all-cause, CVD and stroke mortality. This meta-analysis included only prospective cohort studies involving a large sample size and a long follow-up period, which significantly enhanced the statistical power to detect more stable associations and provide more reliable estimation. Furthermore, dietary patterns in the studies included in the meta-analysis were identified by the FA/PCA, which has long-term reproducibility and stability and could minimise the risk of bias \cite{24}. Another strength is the robustness of the findings from the multiple subgroup analyses. The overall findings were consistent with the results of the subgroup analyses independent of sex, geographical region, follow-up duration, and adjustment/ non-adjustment for energy intake.

There are several potential limitations that should be considered when interpreting the results of the present meta-analysis. First, the FA/PCA used to derive dietary patterns has reasonable reproducibility and validity compared with other approaches, but it involves subjective aspects with opportunities for variation throughout the analytical process and could result in different results based on different choices \cite{22,20}, which may lead to the masking of the true diet–disease associations \cite{9}. Second, although studies included in the meta-analysis had adjusted for a wide range of dietary and lifestyle variables and established risk factors, i.e. age, sex, smoking status, BMI, family history and total energy intake, the possibility that other unmeasured or unknown confounding factors might play roles in the summary associations cannot be excluded. Third, a low level of heterogeneity was detected in some pooled risk estimates, which may have been caused by differences in the follow-up duration, various characteristics of the participants, such as age, sex, and education level, and other factors. However, the major sources of heterogeneity were explored through subgroup analyses. An additional limitation is that the geographical regions covered in this meta-analysis included Asia (China, Bengal and Japan)\cite{7,8,13}, Europe (Spain, the UK, Demark, the Netherlands and Italy)\cite{9,14,16}, the USA\cite{10} and Australia\cite{11}; therefore, the results of the meta-analysis have limited generalisation to other regions (e.g. Latin America and Africa).

Conclusions

In summary, the findings from the present meta-analysis provide evidence that greater adherence to a prudent/healthy dietary pattern is associated with a lower risk of all-cause and CVD mortality, but is not significantly associated with stroke mortality. Furthermore, these findings suggest that there are no significant associations between the Western/unhealthy dietary pattern and the risk of all-cause, CVD and stroke mortality. Further studies are required to confirm these findings and elucidate the pathogenic mechanisms.

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None of the authors has any conflicts of interest to declare.

References


