The effect of tree nut, peanut, and soy nut consumption on blood pressure: a systematic review and meta-analysis of randomized controlled clinical trials¹⁻³

Noushin Mohammadifard, Amin Salehi-Abargouei, Jordi Salas-Salvadó, Marta Guasch-Ferré, Karin Humphries, and Nizal Sarrafzadegan

ABSTRACT

Background: Although several studies have assessed the effects of nut consumption (tree nuts, peanuts, and soy nuts) on blood pressure (BP), the results are conflicting.

Objective: The aim was to conduct a systematic review and meta-analysis of published randomized controlled trials (RCTs) to estimate the effect of nut consumption on BP.

Design: The databases MEDLINE, SCOPUS, ISI Web of Science, and Google Scholar were searched for RCTs carried out between 1958 and October 2013 that reported the effect of consuming single or mixed nuts (including walnuts, almonds, pistachios, cashews, hazelnuts, macadamia nuts, pecans, peanuts, and soy nuts) on systolic BP (SBP) or diastolic BP (DBP) as primary or secondary outcomes in adult populations aged ≥18 y. Relevant articles were identified by screening the abstracts and titles and the full text. Studies that evaluated the effects for <2 wk or in which the control group ingested different healthy oils were excluded. Mean ± SD changes in SBP and DBP in each treatment group were recorded for meta-analysis.

Results: Twenty-one RCTs met the inclusion criteria. Our findings suggest that nut consumption leads to a significant reduction in SBP in participants without type 2 diabetes [mean difference (MD): −1.29; 95% CI: −2.35, −0.22; P = 0.02] but not in the total population. Subgroup analyses of different nut types suggest that pistachios, but not other nuts, significantly reduce SBP (MD: −1.82; 95% CI: −2.97, −0.67; P = 0.002). Our study suggests that pistachios (MD: −0.80; 95% CI: −1.43, −0.17; P = 0.01) and mixed nuts (MD: −1.19; 95% CI: −2.35, −0.03; P = 0.04) have a significant reducing effect on DBP. We found no significant changes in DBP after the consumption of other nuts.

Conclusions: Total nut consumption lowered SBP in participants without type 2 diabetes. Pistachios seemed to have the strongest effect on reducing SBP and DBP. Mixed nuts also reduced DBP. Am J Clin Nutr 2015;101:966–82.

Keywords: nut, almond, walnut, pistachio, cashew, blood pressure, randomized controlled trials

INTRODUCTION

Hypertension is one of the leading causes of cardiovascular events (1, 2) and the main contributor to >7 million deaths/y worldwide (3). Lifestyle modifications have been shown to be effective in regulating blood pressure (BP)⁴ (2). In particular, nutrition plays an important role in the prevention and control of hypertension (4).

Adherence to some dietary patterns, such as the DASH (Dietary Approaches to Stop Hypertension) and Mediterranean diets, seems to have a reducing effect on BP (5), which makes these patterns good choices for substantially reducing the risk of cardiovascular disease (CVD) (6). Nutrient-dense foods such as unprocessed nuts are one of the major components of these healthy diets. Nuts provide a wide variety of nutrients and phytochemicals but low amounts of sodium (4), which may affect BP (7). In this regard, the intake of nuts has been associated with lower BP measurements (8). For instance, some prospective longitudinal studies reported that individuals who consume nuts on a daily basis have a lower risk of hypertension and other cardiovascular disease risk factors than do individuals who do not consume nuts regularly (9, 10). Several studies have evaluated the effects of consumption of different types of nuts on BP measurements. However, randomized controlled trials (RCTs) provide conflicting results. These might be explained by the heterogeneity of the studies, which are of different designs, use different dosages, have different study durations, give the participants different types and amounts of nuts, target different populations, and have different eligibility criteria. For instance, after 3 mo of follow-up in the PREDIMED (Prevención con Dieta Mediterránea) trial, a Mediterranean diet supplemented with nuts was shown to reduce BP more than a low-fat diet (11).

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⁴Abbreviations used: BP, blood pressure; CAD, coronary artery disease; CVD, cardiovascular disease; DASH, Dietary Approaches to Stop Hypertension; DBP, diastolic blood pressure; MD, mean difference; RCT, randomized controlled trial; SBP, systolic blood pressure.

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However, most of the other RCTs reported that diets enriched with nuts have little effect on BP (12–14).

Furthermore, because the close association between BP and insulin resistance is a major problem for people with type 2 diabetes, and hypoglycemic approaches (including dietary modification and medications) can have an impact on blood pressure, the consumption of nuts could affect BP in patients with or without type 2 diabetes in different ways (15).

To the best of our knowledge, no systematic review has ever been published on the effect of nut consumption on blood pressure. Therefore, in the current study, we conducted a systematic review of RCTs in an attempt to summarize the evidence on primary and secondary effects of consuming nuts (pistachios, cashews, hazelnuts, almonds, walnuts, pecans, macadamia nuts, peanuts, and soy nuts) on systolic BP (SBP) and diastolic BP (DBP) in adults aged ≥18 y. When possible, we quantified the effect using meta-analysis while trying to find possible sources of heterogeneity among the RCT results. We also evaluated the effect of nut consumption in participants with and without type 2 diabetes.

METHODS

Data sources and search strategy

The present systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement and was registered in an international prospective register of systematic reviews [PROSPERO (Prospective Register of Systematic Reviews); registration code CRD 42013005829] (16). The search results recorded studies conducted from 1958 to October 2013. To find relevant articles, searches were made in MEDLINE via PubMed (www.pubmed.com; National Library of Medicine), Scopus (www.scopus.com), ISI Web of Science (www.thomsonreuters.com), and Google Scholar (www.scholar.google.com). Searches were not restricted by language or anything else. Three groups of medical subject headings (MeSH) and non-MeSH keywords were selected to search the databases, as follows—keyword group 1: “nut”, “almond”, “pistachio”, “hazelnut”, “walnut”, “cashew”, “macadamia”, “pecan”, “peanut”, or “soy nut”; keyword group 2: “blood pressure”, “serum lipids”, “lipoproteins, HDL”, “triglyceride”, “glucose tolerance test”, “insulin”, “blood glucose”, “insulin resistance”, “low density lipoprotein”, “high density lipoprotein”, “TG”, “TC”, “GTT”, “FBS”, “FBG”, “FGT”, “fasting insulin”, “fasting blood sugar”, “fasting blood glucose”, “fasting plasma glucose”, “insulin sensitivity”, “blood sugar”, “lipid profile”, “serum lipid”, “blood pressure”, “hypertension”, “cardiovascular disease”, “coronary disease”, “coronary artery disease”, “CVD”, coronary artery disease (“CAD”), “obesity”, and “weight”; and keyword group 3: “randomized”, “intervention”, “controlled trial”, “random”, and “placebo”. We searched keyword group 1 in combination with both keyword groups 2 and 3. We used keywords related to blood lipids, glucose, and CVDs because BP might be measured as a secondary outcome in some studies.

Inclusion criteria

The following inclusion criteria were used for the present systematic review and meta-analysis: 1) RCTs; 2) studies focusing on the effect on SBP or DBP as primary or secondary outcomes of consuming single or mixed nuts, including walnuts, almonds, pistachios, cashews, hazelnuts, macadamia nuts, pecans, peanuts, and soy nuts; and 3) studies conducted in populations aged ≥18 y. Two investigators (NM and AS-A) screened the abstracts and titles and full texts of the articles that seemed to meet the inclusion criteria to identify relevant articles, which were then retrieved for further screening. A reference list of related articles was also checked for any missing related articles. In the case of multiple publications from the same trial we selected only the most recent or informative.

Exclusion criteria

Exclusion criteria were as follows: 1) studies evaluating only postprandial and acute effects for <2 wk (17); 2) trials not assessing BP as a primary or secondary outcome; 3) studies in which the control group ingested different healthy oils such as olive, flaxseed, or soy protein oil (11, 12, 14, 17–20); 4) RCTs that did not report mean (SD) changes in SBP and DBP in each treatment group and did not calculate changes from the data available; and 5) articles that reported the results of the same studies (21, 22).

Data extraction

We recorded the following information about each of the studies: the last name of the first author, the year of publication, the country in which the study was implemented, the design of the study (crossover or parallel), the mean/range age of participants, the use of run-in or washout periods (which was mentioned only for descriptive purposes), the total number of participants by gender, the details of the intervention including the exact amount of nuts consumed (grams per day, percentage of energy from nuts), the kind of diet or any other intervention carried out in the control group, the treatment period, and the number of participants who completed the follow-up period. We also noted the specific inclusion and exclusion criteria of each study. Mean (SD) changes in SBP and DBP in each treatment group were used for meta-analysis. This was accomplished by calculating the correlation coefficient (r = 0.70) and using it to calculate changes in DBP and SBP for studies in which SDs for change were not reported (11, 12, 19, 26–40). Studies with multiple control groups (23) or multiple dosages of nuts (31, 32, 39) were included separately in the meta-analysis. For a study by Foster et al. (28), which reported the effect for 6 and 18 mo of follow-up, we considered the effect size over the longer follow-up period when its results were included in the meta-analysis. To obtain the data that were not presented in the articles, we e-mailed the authors at least 3 times, 2 wk apart.

Risk of bias in individual studies

The risk of bias of each study was assessed by 2 reviewers (NM and AS-A) with the Cochrane Collaboration Risk of Bias tool (25). The factors regarded as contributing to study quality were the generation of the allocation sequence, allocation concealment, blinding, blinding outcome data, incomplete outcome data, and selective reporting. We classified these factors as low risk of bias, high risk of bias, or unclear. Because blinding is not possible in clinical trials with dietary interventions, we judged the quality of the studies on the basis of the other 5 items (generation of the allocation sequence, allocation concealment, blinding outcome data,
incomplete outcome data, and selective reporting). Studies with a low risk of bias for at least 3 items were regarded as good quality; studies with a low risk of bias for 2 items were regarded as fair; and studies with a low risk for no items or only 1 item were regarded as poor (25).

**Statistical analysis**

The mean difference (MD) between the intervention (nut intake period or group) and control groups in change in SBP and DBP and its SD was used as the effect size for the meta-analysis. Summary weighted means and their corresponding SDs were estimated following DerSimonian and Laird (41) and by using the random-effects model, which takes the variability among studies into account. Subgroups were analyzed to check for a specific source of heterogeneity. Statistical heterogeneity among studies was evaluated with Cochran’s Q test and the $I^2$ statistic ($I^2$) (42). In fact, heterogeneity was assessed in all analyses. We assessed the heterogeneity of all of the studies once and also verified the heterogeneity for each nut category subgroup. Then, we examined the same effects (including the summary effect and heterogeneity) for the studies that recruited participants without type 2 diabetes and analyzed the nut-type subgroups. Subsequently, we reported the summary effect and its heterogeneity for each subgroup. Diet interventions might affect participants with type 2 diabetes differently, so to reduce heterogeneity, we removed the studies that recruited participants with type 2 diabetes. To explore the extent to which inferences might depend on one study or one group of studies, sensitivity analysis was performed by excluding the studies one by one or by excluding studies conducted in a group of subjects with the same disease. Publication bias was assessed by visual inspection of funnel plots (43), and the funnel plot asymmetry was statistically assessed by using Egger’s regression asymmetry test and adjusted rank correlation test (44). Statistical analyses were conducted by using STATA, version 11.2 (Stata Corp.). $P$ values $<0.05$ were considered to be significant.

**RESULTS**

The literature search retrieved 1572 articles. After screening, 239 articles were identified for full-text revision. Of these, we excluded 218 studies after applying the inclusion and exclusion

![Flowchart of the study selection process.](https://academic.oup.com/ajcn/article-abstract/101/5/966/4577579)
### TABLE 1
RCTs eligible for inclusion in the systematic review and meta-analysis

<table>
<thead>
<tr>
<th>First author, year (ref)</th>
<th>Sex: no. of participants</th>
<th>Country</th>
<th>Study design</th>
<th>Age, y</th>
<th>Diet type</th>
<th>Duration, wk</th>
<th>Notes on follow-up</th>
<th>No. randomized/no. analyzed and results</th>
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</thead>
<tbody>
<tr>
<td>Bakhtiary, 2012 (13)</td>
<td>F: 50</td>
<td>Iran</td>
<td>RCT, parallel</td>
<td>60–70 (64.2 ± 2.9)</td>
<td>Control + 35 g soy nuts (not reported whether salted or unsalted); baseline: SBP, 127.3 ± 4.4; DBP, 79.4 ± 6.5</td>
<td>12</td>
<td>Adherence to intervention assessed by 3-d DR; no biomarker; no reported baseline diet; no run-in period</td>
<td>75/75</td>
</tr>
<tr>
<td>Foster, 2012 (28)</td>
<td>M/F: 123</td>
<td>USA</td>
<td>RCT, parallel</td>
<td>18–75</td>
<td>Low-calorie diet + 56 g almonds (raw and roasted); baseline: SBP, 123.8 ± 15.0; DBP, 72.2 ± 9.9</td>
<td>72</td>
<td>1-wk run-in period; no reported baseline; method of adherence to intervention not detectable</td>
<td>123/— (ITT)</td>
</tr>
<tr>
<td>West, 2012 (39)</td>
<td>M/F: 28</td>
<td>USA</td>
<td>RCT, crossover</td>
<td>35–61 (48 ± 1.5)</td>
<td>Low-fat diet + 30 g pistachios (50% raw and 50% roasted and salted); baseline: SBP, 121.5 ± 13.2; DBP, 74.4 ± 6.3</td>
<td>4</td>
<td>Meal provided; 2-wk run-in period</td>
<td>28/28</td>
</tr>
<tr>
<td>Casas-Agustench, 2011 (26)</td>
<td>M/F: 50</td>
<td>Spain</td>
<td>RCT, parallel, single-blind</td>
<td>18–65 (51.7 ± 8.4)</td>
<td>Healthy diet + 30 g mixed nuts (raw); baseline: SBP, 145 ± 15; DBP, 86 ± 8</td>
<td>12</td>
<td>Adherence to intervention assessed by 3-d DR every 4 wk; plasma α-Linolenic acid as biomarker of walnut intake; no reported baseline diet</td>
<td>52/50</td>
</tr>
<tr>
<td>Jenkins, 2011 (31)</td>
<td>M/F: 117</td>
<td>Canada</td>
<td>RCT, parallel</td>
<td>62 ± 9</td>
<td>1. Therapeutic lifestyle diet + half dose of muffins + 37 g mixed nuts; baseline: SBP, 123 ± 12.6; DBP, 71 ± 6.3 2. Therapeutic lifestyle diet + 73 g mixed nuts (unsalted and mostly raw); baseline: SBP, 121 ± 9.7; DBP, 70 ± 9.7</td>
<td>12</td>
<td>Adherence to intervention assessed by 3-d DR every 2 wk; no biomarker; no reported baseline diet</td>
<td>117/— (ITT)</td>
</tr>
<tr>
<td>Li, 2011 (33)</td>
<td>M/F: 20</td>
<td>China</td>
<td>RCT, crossover</td>
<td>58 ± 2</td>
<td>Step II + 56 g almonds (20% of daily calories; unsalted); baseline: SBP, 131.8 ± 16.5; DBP, 73.1 ± 11.5</td>
<td>4</td>
<td>Meal provided; 2-wk run-in period; 2-wk washout; adherence to intervention assessed by 3-d DR; no biomarker; no reported baseline diet</td>
<td>22/20</td>
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<tr>
<th>First author, year</th>
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<tbody>
<tr>
<td>Ghadimi Nouran, 2010 (29)</td>
<td>M: 54</td>
<td>Iran</td>
<td>RCT, crossover</td>
<td>25–65 (54 ± 6)</td>
<td>Regular diet + 75 g peanuts (20% of energy; roasted and lightly salted); baseline: SBP 120.1 ± 18.3; DBP 80.6 ± 10.8</td>
<td>4</td>
<td>Adherence to intervention assessed by three 24-h dietary recalls in each period; 2-wk run-in period; 2-wk washout; MUFAs as biomarker of peanut intake; no reported baseline diet</td>
<td>60/54</td>
</tr>
<tr>
<td>Ma, 2010 (34)</td>
<td>M/F: 24</td>
<td>USA</td>
<td>RCT, crossover</td>
<td>30–75 (58 ± 6)</td>
<td>Ad libitum diet + 56 g walnuts (unsalted); baseline: SBP 133.2 ± 14; DBP 77.7 ± 7.3</td>
<td>8</td>
<td>Adherence to intervention assessed by 3-d DR in each diet period; 4-wk run-in period; 8-wk washout; no biomarker; no reported baseline diet</td>
<td>24/21 (but analyses based on ITT)</td>
</tr>
<tr>
<td>Sari, 2010 (36)</td>
<td>M: 32</td>
<td>Turkey</td>
<td>RCT, crossover</td>
<td>21–24 (22 ± 6)</td>
<td>Mediterranean diet + 60–100 g pistachios (20% of daily energy; roasted and unsalted); baseline: SBP 117 ± 8; DBP 73 ± 8</td>
<td>4</td>
<td>Meal provided and supervised by dietitian to ensure complete intake; no biomarker; no reported baseline diet</td>
<td>33/32</td>
</tr>
<tr>
<td>Wien, 2010 (24)</td>
<td>M/F: 54</td>
<td>USA</td>
<td>RCT, parallel</td>
<td>(53.5 ± 10)</td>
<td>American Diabetic Association diet + 56 g almonds (raw or dry roasted); baseline: SBP 117 ± 8; DBP 73 ± 8</td>
<td>16</td>
<td>Adherence to intervention assessed by 3-d DR before intervention, at the beginning and every 4 wk; Plasma α-tocopherol as biomarker of almond intake; no differences between MUFA and PUFA intake at baseline</td>
<td>65/53</td>
</tr>
<tr>
<td>Wu, 2010 (19)</td>
<td>M/F: 283</td>
<td>China</td>
<td>RCT, parallel</td>
<td>25–65 (48.4 ± 8.2)</td>
<td>Low-fat diet + 30 g walnuts; baseline: SBP 135 ± 16.2; DBP 86.5 ± 9.9</td>
<td>12</td>
<td>Adherence to intervention assessed by asking to bring unused bread; erythrocyte α-linolenic acid as biomarker of walnut intake; no reported baseline diet</td>
<td>283/277 (but analyses based on ITT)</td>
</tr>
<tr>
<td>Claesson, 2009 (27)</td>
<td>M/F: 25</td>
<td>Sweden</td>
<td>RCT, parallel</td>
<td>18–30 (23.4 ± 2.7)</td>
<td>Regular diet + 75 g peanuts (20% of daily energy; salted); baseline: SBP 117 ± 8.5; DBP 69.2 ± 8.1</td>
<td>2</td>
<td>Adherence to intervention assessed by 3-d DR; MUFAs and PUFAs at baseline diet did not differ; no biomarker</td>
<td>26/25</td>
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<tr>
<th>First author, year (ref)</th>
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<th>Study design</th>
<th>Age, y</th>
<th>Diet type$^3$</th>
<th>Duration, wk</th>
<th>Notes on follow-up</th>
<th>No. randomized/no. analyzed and results</th>
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<tbody>
<tr>
<td>Spaccarotella, 2008 (38)</td>
<td>M: 21 USA</td>
<td>RCT, crossover</td>
<td>47–75</td>
<td>Average American diet + 75 g walnuts; baseline BP: not reported</td>
<td>8</td>
<td>Adherence to intervention assessed by 3-d DR at baseline and every 4 wk of each diet; 2-wk washout period; plasma a-tocopherol measurement as biomarker of walnut intake; no reported baseline diet</td>
<td>22/21</td>
<td></td>
</tr>
<tr>
<td>Azadbakht, 2007 (12)</td>
<td>F: 42 Iran</td>
<td>RCT, crossover</td>
<td>—</td>
<td>DASH diet +30 g soy nuts (unsalted); baseline: SBP, 116 ± 4.5; DBP, 87 ± 1.3</td>
<td>4</td>
<td>Adherence to intervention assessed by 3-d DR at baseline and after 1 mo; 4-wk washout period; no biomarker; no reported baseline diet</td>
<td>42/42</td>
<td></td>
</tr>
<tr>
<td>Mukudden-Petersen, 2007 (23)</td>
<td>M/F: 64 South Africa</td>
<td>RCT, parallel</td>
<td>21–65 (45 ± 10$^4$)</td>
<td>Control diet + 63–108 g walnuts (20% of daily energy); baseline: SBP, 128 ± 5.8; DBP, 78.7 ± 5.5</td>
<td>8</td>
<td>Adherence to intervention assessed by control feeding protocol (lunch in the metabolic ward), and breakfast and dinner were provided (food was weighed, and complete intake ensured by dietitian) and complete dairy questionnaire; 2-wk run-in period; no biomarker; no reported baseline diet</td>
<td>68/64</td>
<td></td>
</tr>
<tr>
<td>Sheridan, 2007 (37)</td>
<td>M/F: 15 USA</td>
<td>RCT, crossover</td>
<td>36–75 (60 ± 11.6$^4$)</td>
<td>Regular diet + 30–90 g pistachios (15% of daily energy; not reported whether salted or unsalted); baseline: SBP, 129 ± 14.3; DBP, 84 ± 10.4</td>
<td>4</td>
<td>Adherence to intervention assessed by 1-d food diary questionnaire every 1 wk; no biomarker; MUFAs did not differ and increased in intervention group compared with baseline diet</td>
<td>20/15</td>
<td></td>
</tr>
<tr>
<td>Estruch, 2006 (11)</td>
<td>M/F: 515 Spain</td>
<td>RCT, parallel</td>
<td>55–80 (69 ± 6$^4$)</td>
<td>Mediterranean diet + 30 g mixed nuts; baseline BP: not reported</td>
<td>12</td>
<td>Biomarker: linolenic acid plasma content by gas chromatography as a measure of adherence to mixed nut intake</td>
<td>772/769 (but analyses based on ITT) Significant reduction in SBP and DBP</td>
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<tr>
<th>First author, year (ref)</th>
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<tbody>
<tr>
<td>Ros, 2004 (35) M/F: 21</td>
<td>Spain RCT, crossover</td>
<td>25–75</td>
<td>Mediterranean diet + 40–65 g walnuts (32% of daily energy); baseline: SBP, 131 ± 17; DBP, 80 ± 9</td>
<td>4</td>
<td>Adherence to intervention was assessed by measuring plasma $\alpha$-tocopherol, as biomarker of walnut intake and 7-d dietary recall; 4-wk run-in period; baseline diet was reported</td>
<td>21/20</td>
<td>Significant increase in DBP</td>
<td></td>
</tr>
<tr>
<td>Wien, 2003 (40) M/F: 65</td>
<td>USA RCT, parallel</td>
<td>27–79 (55 ± 2)</td>
<td>Low-calorie diet + 84 g almonds (salted and unblanched); baseline: SBP, 143 ± 17; DBP, 77 ± 11.3</td>
<td>24</td>
<td>Adherence to intervention was assessed by completing detailed daily food questionnaire; 2 groups had different concentrations of MUFAs and PUFAs at baseline but were equally balanced on total calories, protein, cholesterol, and SFAs; no biomarker</td>
<td>65/52</td>
<td>Significant reduction in SBP</td>
<td></td>
</tr>
<tr>
<td>Iwamoto, 2002 (30) M: 10</td>
<td>Japan RCT, single-blind</td>
<td>20–36 (23.8 ± 0.7)</td>
<td>Average Japanese diet + 58 g walnuts (12.5% of daily energy); baseline: SBP, 117 ± 13; DBP, 73 ± 11</td>
<td>4</td>
<td>Adherence to intervention assessed by control feeding protocol (lunch in the metabolic ward), breakfast and dinner were provided, tray checks after meals eaten on site and by self-report on standardized forms for packed meals; 5-d run-in period; no biomarker; MUFAs reduced and PUFAs increased in intervention diet compared with baseline diet</td>
<td>10/10</td>
<td>Significant reduction in SBP and increase in DBP</td>
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TABLE 1 (Continued)

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<thead>
<tr>
<th>First author, year (ref)</th>
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<th>Study design</th>
<th>Age, y</th>
<th>Diet type</th>
<th>Duration, wk</th>
<th>Notes on follow-up</th>
<th>No. randomized/no. analyzed and results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iwamoto, 2002 (30)</td>
<td>F: 10</td>
<td>Japan</td>
<td>RCT, single blind crossover</td>
<td>20–36 (23.8 ± 0.7&lt;sup&gt;1&lt;/sup&gt;)</td>
<td>Average Japanese diet + 58 g walnuts (12.5% of daily energy); baseline: SBP, 109 ± 12; DBP, 66 ± 7</td>
<td>4</td>
<td>Adherence to intervention assessed by control feeding protocol (lunch in the metabolic ward), breakfast and dinner were provided, tray checks after meals eaten on site and by self-report on standardized forms for packed meals; 5-d run-in period; no biomarker; MUFAs reduced and PUFAs increased in intervention diet compared with baseline diet</td>
<td>10/10</td>
</tr>
<tr>
<td>Jenkins, 2002 (32)</td>
<td>M/F: 27</td>
<td>Canada</td>
<td>RCT, crossover</td>
<td>48–86 (64 ± 9&lt;sup&gt;1&lt;/sup&gt;)</td>
<td>Step II diet + half dose of whole-wheat muffin + 37 g almonds; baseline: SBP, 121 ± 15.6; DBP, 75 ± 10.4 Step II diet + half dose of whole-wheat muffin + 73 g almonds (raw and unblanched); baseline: SBP, 120 ± 10.4; DBP, 75 ± 10.4</td>
<td>4</td>
<td>Adherence to intervention assessed by 1-d DR and completing checklist on which subjects recorded supplements consumed and return of uneaten supplements, which were weighed and recorded; 2-wk washout period; no biomarker; no baseline reported</td>
<td>43/27</td>
</tr>
</tbody>
</table>

<sup>1</sup>BP, blood pressure; DASH, Dietary Approaches to Stop Hypertension; DBP, diastolic blood pressure; DR, dietary report; ITT, intention-to treat analysis; RCT, randomized controlled trial; ref, reference; SBP, systolic blood pressure.

<sup>2</sup>Values are ranges and/or means ± SDs or means ± SEs, as indicated.

<sup>3</sup>Values are means ± SDs. DBP and SBP values are given in mm Hg.

<sup>4</sup>Mean ± SD.

<sup>5</sup>Mean ± SE.
<table>
<thead>
<tr>
<th>First author, year (ref)</th>
<th>Inclusion criteria</th>
<th>Exclusion criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakhtiary, 2012 (13)</td>
<td>MetS based on ATP-III</td>
<td>Currently or previously using estrogen therapy; taking soy products or supplements; treatment with aspirin; taking antibiotics; history of CVD; hyper- and hypothyroidism; kidney, liver, breast, or any cancer; vegetarian diet; smoking; and allergic reaction to soy consumption</td>
</tr>
<tr>
<td>Foster, 2012 (28)</td>
<td>Obese [BMI (kg/m²): 27–40]</td>
<td>Uncontrolled hypertension (defined as a BP &gt;180/100 mm Hg), established CVD or an inflammatory condition (e.g., lupus), type 2 diabetes or use of antihyperglycemic medications, dyslipidemia requiring prescription drug therapy as defined by the ATP-III, or any known allergy or sensitivity to nuts</td>
</tr>
<tr>
<td>West, 2012 (39)</td>
<td>Healthy, nonsmoker, high LDL, normal or mild hypertension</td>
<td>BP- or TC-lowering medication; use of nut supplement; pregnancy; weight loss &gt;10% of body weight in the previous 6 mo; vegetarian or weight-loss diets; liver, kidney, autoimmune, or vascular disease</td>
</tr>
<tr>
<td>Casas-Agustench, 2011 (26)</td>
<td>MetS based on ATP-III</td>
<td>Nut allergy; history of alcohol abuse/withdrawal; type 2 diabetes; endocrine disorders; BMI &gt;35; acute/chronic infection; chronic inflammatory disease; history of cancer; treatment with anti-inflammatory, corticosteroid, hormonal, or antibiotic agents; a restrictive diet or weight change &gt;5 kg during the 3 mo before the study, as assessed by medical history, a complete physical examination, and laboratory tests</td>
</tr>
<tr>
<td>Jenkins, 2011 (31)</td>
<td>Type 2 diabetes and postmenopausal women</td>
<td>CVD or renal or liver disease (alanine aminotransferase &gt; 3 times the upper normal limit) or a history of cancer; after surgery or myocardial infarction &lt; 6 mo</td>
</tr>
<tr>
<td>Li, 2011 (33)</td>
<td>Type 2 diabetes, hyperlipidemia</td>
<td>Insulin therapy; medications or supplements known to alter lipid metabolism; stable blood lipid and sugar concentrations within 3 mo before the study; CVD; hepatic, gastrointestinal, or renal disease; alcoholism; smoking</td>
</tr>
<tr>
<td>Ghadimi Nouran, 2010 (29)</td>
<td>Hypercholesterolemic men</td>
<td>Type 2 diabetes, kidney, liver, and thyroid diseases; cancer; the presence of inflammatory or infectious disease; vitamin supplements; hormone therapy or medications that might have influenced the study variables (e.g., antihypertensive and antilipidemic agents administered in the 4 mo before the study); recent history of weight gain or loss (≥9 kg) in past 6 mo; very atypical diet; rigorous exercise; allergy or aversion to nuts; habitual consumption of nuts &gt;70 g/wk; cigarette smokers; first-degree family history of CAD</td>
</tr>
<tr>
<td>Ma, 2010 (34)</td>
<td>Type 2 diabetes, nonsmokers</td>
<td>Vasoactive medications or supplement, current eating disorder, known atherosclerosis, sleep apnea, pregnancy, restricted diet, nut allergy, use of lipid-lowering or antihypertensive medications &lt;3 mo</td>
</tr>
<tr>
<td>Sari, 2010 (36)</td>
<td>Acute and chronic medical disorders</td>
<td>Smoking; frequent nut consumption (&gt;1/wk), nut or food allergy; regular use of any drugs or vitamin supplement; history of any known disease, inflammatory diseases (infections, recent surgical procedures), dyslipidemia</td>
</tr>
<tr>
<td>Wien, 2010 (24)</td>
<td>Prediabetic</td>
<td>Self-reported allergy to almonds, history of irritable bowel disease or diverticulitis, use of corticosteroids or immunosuppressant medications, or presence of liver disease, renal disease, and/or severe dyslipidemia (TGs &gt;400 or TC &gt;300 mg/dL)</td>
</tr>
<tr>
<td>Wu, 2010 (19)</td>
<td>MetS based on ATP-III</td>
<td>History of allergy or high consumption of nuts, flaxseed, or sesame seeds (120 g/wk); clinically diagnosed renal, liver, heart, pituitary, thyroid, or mental diseases or alimentary tract ulceration or diseases affecting absorption; history of CVD, cancer, or mental disorders; current or previous (in the preceding 6 mo) use of antidepressants, estrogen, or steroid therapy; pregnancy or lactation</td>
</tr>
<tr>
<td>Claesson, 2009 (27)</td>
<td>Healthy subjects</td>
<td>Nonobese (BMI: 27) and free from current diseases, including eating disorders</td>
</tr>
</tbody>
</table>

(Continued)
EFFECT OF NUT CONSUMPTION ON BLOOD PRESSURE

### TABLE 2 (Continued)

<table>
<thead>
<tr>
<th>First author, year (ref)</th>
<th>Inclusion criteria</th>
<th>Exclusion criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spaccarotella, 2008 (38)</td>
<td>Healthy, nonsmoking men</td>
<td>Allergies to nuts; use of prescription and nonprescription preparations known to alter PSA, hormone concentrations, BP or blood lipids; men taking vitamin E supplement were eligible if they discontinued use 2 mo before entering the study</td>
</tr>
<tr>
<td>Azadbakht, 2007 (12)</td>
<td>MetS based on ATP-III; postmenopausal women</td>
<td>Any secondary cause of hyperglycemia, current or previous (in the preceding 6 mo) use of estrogen therapy, treatment with insulin or oral hypoglycemic agents, untreated hypothyroidism, smoking, kidney or liver diseases, breast malignancy or breast cancer</td>
</tr>
<tr>
<td>Mukudden-Petersen, 2007 (23)</td>
<td>MetS based on ATP-III</td>
<td>Pregnancy or lactation, thiazide (&gt;25 mg/d) and β-blocker (nonspecific, β1 and β2) use, nut allergies, type 2 diabetes</td>
</tr>
<tr>
<td>Sheridan, 2007 (37)</td>
<td>Moderate hypercholesterolemia</td>
<td>Treated for hyperlipidemia, hypertension, type 2 diabetes, kidney or liver disease, food allergies, smokers, consuming &gt;3 alcoholic drinks/wk, women receiving hormone therapy</td>
</tr>
<tr>
<td>Estruch, 2006 (11)</td>
<td>Type 2 diabetes or 3 CVD risk factors</td>
<td>CVD or any severe chronic illness, drug or alcohol addiction, history of allergy or intolerance to olive oil or nuts, or low predicted likelihood of changing dietary habits according to the stages-of-change model</td>
</tr>
<tr>
<td>Ros, 2004 (35)</td>
<td>Nonsmokers, moderate hypercholesterolemia</td>
<td>Chronic illnesses or secondary hypercholesterolemia, allergy to nuts, vitamin supplements, hormone replacement therapy, medications known to affect lipid metabolism</td>
</tr>
<tr>
<td>Wien, 2003 (40)</td>
<td>Obese (BMI: 24–55)</td>
<td>Patients taking lipid-lowering medications and women receiving hormone replacement therapy</td>
</tr>
<tr>
<td>Iwamoto, 2002 (30)</td>
<td>Healthy subjects</td>
<td>Frequent nut consumption, food allergies, cigarette smoking, history of hypertension or atherosclerotic or metabolic disease, regular medication, or considered unable to comply with the study protocol</td>
</tr>
<tr>
<td>Jenkins, 2002 (32)</td>
<td>Healthy hyperlipidemic and postmenopausal women</td>
<td>Food allergies, abdominal discomfort, type 2 diabetes, liver or renal disease, hyperlipidemic or BP medications, hormone replacement therapy</td>
</tr>
</tbody>
</table>

1ATP-III, Adult Treatment Panel III; BP, blood pressure; CAD, coronary artery disease; CVD, cardiovascular disease; MetS, metabolic syndrome; ref, reference; TC, total cholesterol; TG, triglyceride.

criteria. Finally, 21 RCTs, which studied a total of 1652 adults aged 18–86 y, were selected for the present systematic review and meta-analysis. Figure 1 shows the study selection process. Table 1 presents the characteristics and the main outcomes of the 21 RCTs included in the systematic review (11–13, 19, 23, 24, 26–40). In brief, the intervention period in these RCTs ranged between 2 and 16 wk. Some studies used a randomized crossover design (12, 26, 29, 30, 32–39), 2 of which were also single blind (26, 30). Six studies reported having a washout period (12, 29, 32–34, 38), and 8 studies reported a run-in period (23, 28–30, 33–35, 39). The others had no run-in or washout periods or did not report this. Table 1 shows the studies that had run-in and washout periods, although these variables were not used in the analysis. Seven studies were conducted in the United States (24, 28, 34, 37–40), 3 in Spain (11, 26, 35), 1 in South Africa (23), 3 in Iran (12, 13, 29), 2 in Canada (31, 32), 2 in China (19, 33), and 1 each in Japan (30), Sweden (27), and Turkey (36). The effect of walnuts was examined in 6 studies (19, 23, 30, 34, 35, 38), almonds in 5 studies (24, 28, 32, 33, 40), pistachios in 3 studies (36, 37, 39), peanuts in 2 studies (27, 29), soy nuts in 2 studies (12, 13), and mixed nuts in 3 studies (11, 26, 31). The effect of 2 dosages of nut consumption on BP was evaluated in 3 studies (31, 32, 39), and the effect of 2 different types of nuts was examined in 1 study (23). Iwamoto et al. (30) also reported the effect of nut consumption among men and women separately; 2 effect sizes were therefore extracted from these studies and were included as separate studies in the meta-analysis. In 5 studies, the analyses were based on the intention-to-treat principle (11, 19, 28, 31, 34) and the others were based on per protocol analysis (12, 13, 23, 24, 26, 27, 29, 30, 32, 33, 35–40). Table 2 shows the inclusion and exclusion criteria, including health and disease status and medication.

### Risk of bias

Table 3 shows the methodologic quality of the studies. Briefly, none of the studies was suitable for all of the 6 items considered for the methodologic quality assessment because none of them were blind. Approximately 42% of studies were rated as appropriate (11, 13, 19, 23, 24, 28, 31, 38, 40), whereas the method used to generate the allocation sequence was unclear in the others (12, 21, 26, 27, 29, 30, 32–37, 39). Allocation concealment and blinding of outcome were appropriate in only 9% (11, 24) and 5% (31) of studies, respectively. In contrast, 86% and 81% of studies had a low risk of bias for incomplete outcome data (12, 13, 23, 24, 26–38, 40) and selective reporting (11–13, 23, 24, 26, 28, 29, 31–37, 39, 40), respectively. Thus, these categories provide the lowest risk of bias. The overall quality was assessed and rated as “good” (low risk of bias) for 6 studies (13, 19, 23, 28, 31, 40), “fair” for 12 studies (11, 12, 26, 29, 32–39), and “poor” for 3 studies (19, 27, 30).

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1ATP-III, Adult Treatment Panel III; BP, blood pressure; CAD, coronary artery disease; CVD, cardiovascular disease; MetS, metabolic syndrome; ref, reference; TC, total cholesterol; TG, triglyceride.
Effect of nut consumption on SBP

Our preliminary analysis in a total of 1652 adults from 21 RCTs indicated that all-type nut intake had no significant reducing effect on SBP (MD: \(-0.91; 95\% \text{ CI}: -2.18, 0.36; P = 0.16\)). However, there was significant heterogeneity among studies (Cochran’s Q test = 95.31, \(P < 0.001\), \(I^2 = 73.8\%\)) (Figure 2). Subgroup analyses stratified by specific types of nut suggested that pistachios had a significant reducing effect on SBP (MD: \(-1.82; 95\% \text{ CI}: -2.97, -0.67; P = 0.002\)). On the contrary, analyses suggested that almonds, walnuts, cashews, mixed nuts, peanuts, and soy nuts do not have a significant reducing effect on SBP (Figure 2). No significant heterogeneity was observed among studies examining the effect of pistachios, peanuts, and soy nuts. On the other hand, heterogeneity was found among studies on almonds (Cochran’s Q test = 15.97, \(P = 0.007\), \(I^2 = 68.7\%\)) and mixed nuts (Cochran’s Q test = 39.34, \(P < 0.001\), \(I^2 = 84.7\%\)) and mixed nuts (Cochran’s Q test = 14.21, \(P = 0.003\), \(I^2 = 78.9\%\)) (Figure 2).

When only the studies that recruited participants without type 2 diabetes were considered, a significant overall reducing effect on SBP was observed (MD: \(-1.29; 95\% \text{ CI}: -2.35, -0.22; P = 0.018\)) and the heterogeneity among studies was significant (Cochran’s Q test = 44.93, \(P = 0.002\), \(I^2 = 53.3\%\)). The subgroup analysis showed that the effect of different types of nut intake on lowering SBP did not change after participants with type 2 diabetes were removed from the analysis (Figure 3). However, heterogeneity disappeared in each category except for almonds (Cochran’s Q test = 15.97, \(P = 0.007\), \(I^2 = 68.7\%\)).

Effect of nuts on DBP

According to our analysis in 1652 adults, overall nut consumption had no significant effect on DBP (MD: \(0.21; 95\% \text{ CI}: -0.54, 0.97; P = 0.58\)). There was significant heterogeneity among the studies (Cochran’s Q test = 82.31, \(P < 0.001\), \(I^2 = 69.6\%\)) (Figure 4). The subgroup analysis based on the type of nut revealed that pistachios (MD: \(-0.80; 95\% \text{ CI}: -1.43, -0.17; P = 0.01\)) and mixed nuts (MD: \(-1.19; 95\% \text{ CI}: -2.35, -0.03; P = 0.04\)) lowered DBP significantly, whereas other types did not (Figure 4). Heterogeneity was significant among studies that assessed the effect of walnuts on DBP (Cochran’s Q test = 28.89, \(P < 0.001\), \(I^2 = 79.2\%\)) but not for other types of nut (Figure 4). Our analysis of subjects without type 2 diabetes showed that only pistachios decrease DBP (MD: \(-0.80; 95\% \text{ CI}: -1.43, -0.17; P = 0.01\)) and that there was no heterogeneity among the studies (Cochran’s Q test = 2.68, \(P = 0.44\), \(I^2 = 0.0\%\)) (Figure 5).

Sensitivity analysis and publication bias

Sensitivity analysis showed that the removal of any of the studies from the whole sample or subgroups did not considerably change the effect of nut consumption on SBP and DBP. Exclusion of the trials with soy nuts from the overall analysis did not significantly change our previous findings on the effect of nuts on SBP and DBP in all studies or in those studies that focused only on participants without type 2 diabetes (data not shown). Although a slight asymmetry was seen in funnel plots, there was no evidence of publication bias for studies examining the effect of nut consumption on SBP (Begg’s test, \(P = 0.29\); Egger’s test, \(P = 0.99\)) and DBP (Begg’s test, \(P = 0.23\); Egger’s test, \(P = 0.77\)).

DISCUSSION

In the present systematic review and meta-analysis of 21 studies involving 1652 participants, we found that overall nut consumption had no significant effect on SBP. Subgroup analyses based on the type of nut suggest that pistachios significantly
reduce both SBP and DBP, whereas mixed nuts reduce only DBP. Sensitivity analysis for participants without type 2 diabetes showed an overall reduction only in SBP. Furthermore, by removing participants with type 2 diabetes from the analysis, only pistachios significantly reduced both SBP and DBP. To the best of our knowledge, the present study is the first systematic review and meta-analysis to analyze the effect of nut consumption on BP.

Two prospective cohort studies investigated the association between nut consumption and incident hypertension as the primary outcome (9, 10). They both included healthy subjects and showed controversial results. The first, conducted in 15,966 subjects from the cohort of the Physicians’ Health Study I, showed that men who consumed nuts ≥7 times/wk had an 18% lower risk of developing hypertension than did those who did not consume nuts. However, this association was mainly observed...
in lean, not obese, individuals (10). The second was the SUN (Seguimiento Universidad de Navarra) study, which included 9919 Spanish university graduates followed up for a median of 4.3 y. After adjustment for potential confounders, no association was found between nut consumption and the incidence of hypertension (9).

The RCTs in this systematic review that investigated the effect of mixed nuts, almonds, pistachios, walnuts, and cashews also reported conflicting findings on SBP and DBP (11, 19, 23, 24, 26, 28, 30–40). These nuts are of very similar nutritional composition and, as reported, most of them tended to reduce BP. However, RCTs on soy nuts and peanuts, which, botanically, are considered to be legumes, found no significant effect on BP (12, 13, 27, 29). It should be pointed out that the nutritional composition of soy nuts is quite different to that of the other nuts. Soy nuts are rich in carbohydrate and protein and less rich in vegetable unsaturated fatty acid, and this may explain their lack of effect on BP. However, we found no difference in overall effect of nuts on BP when we excluded the soy nut studies (12, 13).

**FIGURE 3** Forest plot showing the overall effect of nut consumption on systolic blood pressure and analysis of nut-type subgroups by using sensitivity analysis in participants without type 2 diabetes. Note: weights are from random-effects analysis.
Our results are in agreement with various recent systematic reviews and meta-analyses that showed that nut consumption is inversely associated with the incidence of several diseases related to BP, such as hypertension (45, 46) and ischemic heart disease (46–48), and with all-cause mortality (47). A pooled analysis of clinical trials by Salas-Salvadó et al. (49) also reported that nuts had a protective effect on metabolic syndrome, of which hypertension is one of the main components.

CVD-protective dietary patterns, including the DASH and Mediterranean diets, recommend frequent nut consumption, because nuts contain little SFA and 40–60% unsaturated fatty acids, mostly PUFAs in walnuts and MUFAs in almonds, hazelnuts, macadamia nuts, pecans, pistachios, and peanuts. However, the antihypertensive effect of nuts probably depends on non–fatty acid compounds such as dietary fiber, plant proteins, antioxidants, and bioactive substances such as flavonoids.

FIGURE 4  Forest plot showing the overall effect of nut consumption on diastolic blood pressure and analysis of nut-type subgroups. Note: weights are from random-effects analysis.
or phytosterols, vitamins, and minerals (mainly potassium and magnesium) (50).

In the present study, our data suggest that pistachio consumption significantly reduces SBP and DBP. Pistachios contain MUFAs and high amounts of phytosterols, which may have beneficial effects on lowering BP. Because of their specific composition and richness in lutein, β-carotene and γ-tocopherol, pistachios are prone to affect the inflammatory and oxidative state, C-reactive protein, and circulating IL-6, leading to a reduction in oxidized LDL cholesterol and improved the total antioxidant status, all recognized factors mediating the endothelial function. Nuts are also very rich in arginine (51), a precursor of endogenous nitric oxide, which is a potent vasodilator acting via second intracellular cyclic guanosine-5′-monophosphate (52). These might be the main reasons for the significant lowering effect of these types of nuts on BP in our meta-analysis (21, 37).

The current meta-analysis has some limitations, which must be taken into account when the results are interpreted. Six trials

![FIGURE 5 Forest plot showing the overall effect of nut consumption on diastolic blood pressure and analysis of nut-type subgroups by using sensitivity analysis in participants without type 2 diabetes. Note: weights are from random-effects analysis.](https://academic.oup.com/ajcn/article-abstract/101/5/966/4577579)
and approved the final manuscript. None of the authors declared a conflict of interest.

REFERENCES


