Nut Consumption and Blood Lipid Levels

A Pooled Analysis of 25 Intervention Trials

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Background: Epidemiological studies have consistently associated nut consumption with reduced risk for coronary heart disease. Subsequently, many dietary intervention trials investigated the effects of nut consumption on blood lipid levels. The objectives of this study were to estimate the effects of nut consumption on blood lipid levels and to examine whether different factors modify the effects.

Methods: We pooled individual primary data from 25 nut consumption trials conducted in 7 countries among 583 men and women with normolipidemia and hypercholesterolemia who were not taking lipid-lowering medications. In a pooled analysis, we used mixed linear models to assess the effects of nut consumption and the potential interactions.

Results: With a mean daily consumption of 67 g of nuts, the following estimated mean reductions were achieved: total cholesterol concentration (10.9 mg/dL [5.1% change]), low-density lipoprotein cholesterol concentration (LDL-C) (10.2 mg/dL [7.4% change]), ratio of LDL-C to high-density lipoprotein cholesterol concentration (HDL-C) (0.22 [8.3% change]), and ratio of total cholesterol concentration to HDL-C (0.24 [5.6% change]) (P < .001 for all) (to convert all cholesterol concentrations to millimoles per liter, multiply by 0.0259). Triglyceride levels were reduced by 20.6 mg/dL (10.2%) in subjects with blood triglyceride levels of at least 150 mg/dL (P < .05) but not in those with lower levels (to convert triglyceride level to millimoles per liter, multiply by 0.0113). The effects of nut consumption were dose related, and different types of nuts had similar effects on blood lipid levels. The effects of nut consumption were significantly modified by LDL-C, body mass index, and diet type: the lipid-lowering effects of nut consumption were greatest among subjects with high baseline LDL-C and with low body mass index and among those consuming Western diets.

Conclusion: Nut consumption improves blood lipid levels in a dose-related manner, particularly among subjects with higher LDL-C or with lower BMI.

Arch Intern Med. 2010;170(9):821-827
More than 25 human dietary intervention studies have been conducted investigating the effects of nut consumption on blood lipid levels. These studies differ in the type and amount of nuts consumed, study design, subject selection criteria, and duration. Because analyses have also varied, factors that may be responsible for inconsistencies among studies and for dose-response relationships have remained elusive.

We examined the effects of nut consumption on blood lipid levels and further examined whether these effects were consistent when stratified by different population groups and variables, including sex, age, type of nut, type of control diet, and body mass index (BMI [calculated as weight in kilograms divided by height in meters squared]) by pooling and analyzing raw data from 25 nut consumption trials conducted in 7 countries. Results have been published for 23 studies (1 study reported results from 2 different studies), and 2 studies remain unpublished (M. Most, PhD, unpublished data, 2004; and E.R., unpublished data, 2004).

STUDY METHODS

A comprehensive MEDLINE search was conducted for English-language human studies between January 1, 1992, and December 31, 2004, that assessed the effects of nut consumption on blood lipid levels. The cutoff (2004) was selected because of the changes in standards of care that occurred on release of the “Third Report of the National Cholesterol Education Program” Adult Treatment Panel guidelines and the potential problems with confounding in patients who may be taking statin drugs. Search terms included human, cholesterol, nuts, almond, cashew, peanut, pecan, pine nut, pistachio nut, macadamia nut, hazelnut, and walnut. Although peanuts are members of the legume family, we included them in the analysis given their comparable nutrient profile to nuts and their common identification as part of the nut food group. The literature search yielded 25 articles, one of which reported results from 2 different studies. We identified 2 unpublished studies, for a total of 28 studies, and contacted the authors of the published and unpublished research to obtain disaggregated data for inclusion in a pooled analysis.

Articles were selected for the pooled analysis based on the following a priori inclusion criteria: (1) the study involved human subjects; (2) a control group existed, or stable baseline lipid levels were consistent when stratified by different population groups and variables, including sex, age, type of nut, type of control diet, and body mass index (BMI [calculated as weight in kilograms divided by height in meters squared]); (3) the dietary intervention was exclusively nuts; (4) the nut consumption period was at least 3 weeks; (5) the subjects had no recent dietary intervention was exclusively nuts; (6) there were no lipid-lowering medications; and (7) there were no recent exposure to lipid-lowering medications; and (6) there were no body weight changes between diets at the end of the intervention period. Based on these inclusion criteria, 2 published studies were excluded because the intervention included other sources of monounsaturated fat in addition to nuts. Another published study was excluded because of dietary weight loss at the end of the intervention. In total, 25 studies (23 published and 2 unpublished) were selected for inclusion.

STATISTICAL ANALYSIS

Each research team provided their original data sets electronically. On receipt, we conducted preliminary statistical analyses to confirm appropriate transfer of data. In all cases, we were able to reproduce the results presented in the original articles. Data were then combined into a single data set and were analyzed using statistical software (SAS version 9.1; SAS Institute, Cary, North Carolina). Each subject contributed 1 data point for each dietary treatment received. Therefore, subjects of crossover studies contributed 2 or more data points to the data set. The final data set contained 1284 observations contributed by 983 unique subjects. Analyses were conducted using mixed linear models that included a fixed-effects term for diet and random-effects terms for study, diet nested in study, and subject nested in study. To test for study heterogeneity, fixed-effects terms for study and diet × study interaction were included in the model.

We investigated whether sex, age, BMI, controlled vs uncontrolled study design, degree of investigator control over subjects’ diets, type of funding source, type of nut, and type of control diet modified the effects of nut consumption by adding appropriate fixed-effects terms for main effect × diet interaction to the model. For some analyses, subjects were stratified into the following 3 categories: Western (total fat), Mediterranean (monounsaturated fat), and Japanese (saturated and polyunsaturated fat). For some analyses, subjects were stratified into the following 3 categories: Western (total fat), Mediterranean (monounsaturated fat), and Japanese (saturated and polyunsaturated fat).

RESULTS

Of 25 studies in the pooled analysis, 16 used a crossover design, 7 used a consecutive design, and 2 used a parallel design. Sample size ranged from 10 to 49 subjects (median, 20 subjects), and age ranged from 19 to 86 years (mean age, 46 years). All but 4 studies included both sexes, and there were 307 men and 276 women. Subjects in 9 studies had hypercholesterolemia (mean range, 236-259 mg/dL for total cholesterol concentration [TC] and 154-178 mg/dL for LDL-C), and subjects in 16 studies had nor-
mocholesterolemia (125-222 mg/dL for TC and 67-142 mg/dL for LDL-C). Across studies, individual BMIs ranged from 17 to 49 (mean, 27). Daily nut consumption ranged from 23 to 132 g (mean, 67 g), which is approximately 0.8 to 4.8 oz/d (mean, 2.4 oz/d).

Compared with control diets, nut diets reduced TC, LDL-C, and triglyceride levels significantly (P < .001 for all). The effects of nut consumption on blood lipid levels were similar in men and women (P > .2 for all nut diet × sex interactions) and across all age groups (P > .2 for all nut diet × age interactions). They were independent of the specific type of nut consumed (P > .45 for all nut diet × nut type interactions).

The estimated cholesterol-lowering effects of nut consumption were greater for subjects with higher baseline LDL-C (Table 3 and Figure 1). Responses differed between subjects with baseline LDL-C of less than 130 mg/dL vs greater than 160 mg/dL (mean decrease, 12.5 mg/dL for TC and 14.9 mg/dL for LDL-C). There was also a differential cholesterol-lowering effect of nut consumption depending on baseline BMI, with greater response among subjects having lower BMI. A significant nut diet × BMI interaction was found for ratio of LDL-C to HDL-C and for ratio of TC to LDL-C (P = .02 for both).

Similar trends existed for TC, LDL-C, and triglyceride
The estimated effects of nut consumption on blood lipid levels were dose related (Figure 2). At 20% of dietary energy from nuts (equivalent to 71 g [2.5 oz] for a 2000-kcal diet), blood lipid levels were reduced by 9.9 mg/dL (4.5% change) for TC and by 9.5 mg/dL (6.5% change) for LDL-C. At 12.2% of dietary energy from nuts (equivalent to 43 g [1.5 oz]), the amount of nut consumption recommended by the US Food and Drug Administration, blood lipid levels were reduced by 7.1 mg/dL (3.2% change) for TC and by 7.2 mg/dL (4.9% change) for LDL-C. At 10% of dietary energy from nuts (equivalent to 35 g [1.2 oz]), blood lipid levels were reduced by 6.1 mg/dL (2.8% change) for TC and by 6.2 mg/dL (4.2% change) for LDL-C. Similar dose responses were estimated for ratio of LDL-C to HDL-C and for triglyceride level in subjects with baseline triglyceride levels of at least 150 mg/dL.

Table 2. Estimated Changes in Blood Lipid and Lipoprotein Levels Among Subjects Consuming Nut Diets vs Control Diets

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Change (95% Confidence Interval)</th>
<th>% Change</th>
<th>P Valuea</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>10.9 (-14.1 to -7.8)</td>
<td>-5.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>LDL-C</td>
<td>10.2 (-13.1 to -7.4)</td>
<td>-7.4</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>HDL-C</td>
<td>0.09 (-1.00 to 1.19)</td>
<td>0.2</td>
<td>.88</td>
</tr>
<tr>
<td>Ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDL-C/HDL-C</td>
<td>-0.2 (-0.3 to -0.1)</td>
<td>-8.3</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>TC/HDL-C</td>
<td>-0.2 (-0.3 to -0.1)</td>
<td>-5.6</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Triglyceride level, mg/dL</td>
<td>-3.1 (-7.2 to 1.2)</td>
<td>-2.8</td>
<td>.15</td>
</tr>
<tr>
<td>&lt;150</td>
<td>0.7 (-3.2 to 4.7)</td>
<td>0.7</td>
<td>.74</td>
</tr>
<tr>
<td>≥150</td>
<td>-20.6 (-30.7 to -9.9)</td>
<td>-10.2</td>
<td>&lt;.05</td>
</tr>
</tbody>
</table>

Abbreviations: HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol.

SI conversion factors: To convert cholesterol concentrations to millimoles per liter, multiply by 0.0259; to convert triglyceride level to millimoles per liter, multiply by 0.0113.

Table 3. Estimated Changes in Blood Lipid and Lipoprotein Levels by Baseline LDL-C Concentration and by Baseline BMI Among Subjects Consuming Nut Diets vs Control Diets

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Change (95% Confidence Interval)</th>
<th>% Change</th>
<th>P Valuea</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDL-C concentration, mg/dL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;130</td>
<td>-5.0 (-9.2 to -0.9)b</td>
<td>-3.5 (-7.5 to 0.5)</td>
<td>-0.11 (-0.19 to -0.02)b</td>
</tr>
<tr>
<td>130-160</td>
<td>-11.0 (-15.5 to -6.6)c</td>
<td>-9.9 (-14.2 to -5.6)c</td>
<td>-0.28 (-0.38 to -0.13)c</td>
</tr>
<tr>
<td>&gt;160</td>
<td>-17.5 (-22.0 to -13.0)c</td>
<td>-18.4 (-22.7 to -14.1)c</td>
<td>-0.38 (-0.52 to -0.24)c</td>
</tr>
<tr>
<td>BMI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;25</td>
<td>-12.0 (-15.9 to -8.1)c</td>
<td>-11.9 (-15.4 to -8.4)c</td>
<td>-0.24 (-0.32 to -0.16)c</td>
</tr>
<tr>
<td>25-30</td>
<td>-14.5 (-16.4 to -6.6)c</td>
<td>-9.5 (-12.9 to -5.7)c</td>
<td>-0.14 (-0.23 to -0.04)c</td>
</tr>
<tr>
<td>≥30</td>
<td>-13.5 (-15.7 to -4.1)c</td>
<td>-8.8 (-11.2 to -2.4)c</td>
<td>-0.15 (-0.21 to 0.02)</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol.

SI conversion factors: To convert cholesterol concentrations to millimoles per liter, multiply by 0.0259; to convert triglyceride level to millimoles per liter, multiply by 0.0113.

a Nut diet values minus control diet values.
b Difference between nut diet and control diet.

COMMENT

In this pooled analysis of 583 unique subjects in 25 clinical trials, incorporating nuts into the diet lowered TC, LDL-C, ratio of LDL-C to HDL-C, and ratio of TC to HDL-C.
Most important is the finding that the cholesterol-lowering effects of nut consumption are dose related and are more pronounced in subjects with higher baseline LDL-C or lower BMI. Nut consumption also lowered triglyceride levels in subjects with hypertriglyceridemia. Study design, type of funding source, and degree of dietary control did not significantly affect these outcomes. This study provides the best estimate of the effects of nut consumption on blood lipid levels. Specifically, a mean daily consumption of 67 g (2.4 oz) of nuts resulted in estimated mean reductions of 10.9 mg/dL (5.1% change) in TC, 10.2 mg/dL (7.4% change) in LDL-C, 0.22 (8.3% change) in ratio of LDL-C to HDL-C, and 0.24 (5.6% change) in ratio of TC to HDL-C. The estimated reductions in this pooled analysis are almost identical to those obtained in a recent meta-analysis of walnut consumption studies (−10.3 mg/dL for TC and −9.2 mg/dL for LDL-C). The similarity of the results obtained by different methodologic approaches confirms the validity of our findings.

While the blood lipid level and lipoprotein results corroborate those of previous clinical trials, the observed effect of a nut diet × BMI interaction on blood lipid level responses is a novel finding. In agreement with this observation, Mukuddem-Peterson et al recently reported that high consumption of either walnuts nor cashews was associated with blood lipid level changes in subjects with obesity and metabolic syndrome. It is well established that obese subjects have an attenuated cholesterol-lowering response to dietary reduction of saturated fatty acids compared with lean individuals, probably because obesity is characterized by elevated endogenous production of cholesterol in relation to insulin resistance. However, in most of the nut consumption trials in our pooled analysis, nut diets and

![Figure 1. Estimated effects of nut consumption on blood lipid and lipoprotein levels by baseline LDL-C concentration (A) and by baseline BMI (B). *P < .001 and †P < .05 for difference between nut diet and control diet. To convert cholesterol concentrations to millimoles per liter, multiply by 0.0259. BMI indicates body mass index (calculated as weight in kilograms divided by height in meters squared); HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; and TG, triglycerides.](image1)

![Figure 2. Estimated effects of nut consumption on blood lipid and lipoprotein levels by type of control diet. *P < .001 and †P < .05 for difference between type of control diet. HDL-C indicates high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; and TG, triglycerides.](image2)

![Figure 3. Estimated effects of nut consumption on blood lipid and lipoprotein levels by percentage of dietary energy from nuts. *Estimated using values from participants with triglyceride levels of at least 150 mg/dL (to convert triglyceride level to millimoles per liter, multiply by 0.0113). Dietary intakes from nuts of 10%, 12.2%, and 20% are equivalent to 35, 43, and 71 g, respectively, based on a 2000-kcal diet. †Recommended by the US Food and Drug Administration; 12.2% is equivalent to 43 g/d (1.5 oz/d). HDL-C indicates high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; and TG, triglycerides.](image3)
control diets were matched for saturated fat content. Obesity and metabolic syndrome are each associated with reduced intestinal cholesterol absorption.\(^4\) Nuts are rich in plant steryl, natural compounds that might contribute to cholesterol lowering by interfering with cholesterol absorption.\(^44\) and this effect would be blunted when cholesterol absorption rates are low. More research is needed to answer the important question of why nuts are less effective in lowering blood cholesterol concentration among subjects with obesity.

When the effects of diets incorporating increasing amounts of nuts are compared with those of nut-free control diets, a dose-response effect is manifested. These findings are consistent with results from 2 clinical trials specifically designed to assess dose response between nut consumption and blood lipid levels. Sabate et al\(^4\) found proportionally greater reductions in LDL-C with a 20% energy (68 g [2.4 oz]) replacement of almonds into the usual diet (9.0% reduction) than a 10% energy (34 g [1.2 oz]) replacement (3.3% reduction). Jenkins et al\(^27\) found graded decreases in LDL-C with a “full dose” (73 g [2.6 oz]) of almonds (9.4% decrease) compared with a “half dose” (37 g [1.3 oz]) (4.4% decrease). To achieve a clinically relevant reduction in blood lipid levels, patients with hyperlipidemia may benefit from higher amounts of nut consumption than that recommended by the US Food and Drug Administration\(^4\) for the general public.

Incorporating nuts into the diet of patients with hyperlipidemia provides cardiovascular benefits beyond lowering blood cholesterol concentration. The 7.4% estimated mean reduction of LDL-C observed in this pooled analysis is modest compared with the effect of statin drugs.\(^45\) However, the value of regular nut consumption for CHD prevention is unlikely due to the blood cholesterol–lowering effect alone, as the 37% summary estimate risk reduction from frequent nut consumption in epidemiological investigations\(^2\) is more than double that attributable to lowering LDL-C by 7.4%.\(^4\) Nut consumption exerts beneficial effects by improving endothelial function,\(^35\) lowering oxidative stress,\(^20,27,37\) and reducing lipoprotein(a) level.\(^24,27\) In addition, nut consumption is associated with lower risk of developing type 2 diabetes mellitus,\(^36\) and research has shown that frequent nut consumption does not lead to weight gain.\(^47\)\(^-\)\(^49\)

As expected, nut consumption led to more pronounced reduction of TC and LDL-C compared with a Western diet vs Mediterranean or low-fat diet. Greater cholesterol-lowering effect is found when nuts replace saturated fat than when olive oil or carbohydrates are replaced. This finding has important clinical and public health applications. For patients with dyslipidemia and for the general population consuming a Western diet, the incorporation of nuts into their daily diet will result in greater improvement of blood lipid levels than for individuals already following a healthy Mediterranean or low-fat diet.

Although duration of the dietary intervention trials pooled herein ranged from 3 to 8 weeks, other investigators have found that favorable lipid levels resulting from nut consumption are sustainable. One-year findings from the Prevención con Dieta Mediterránea trial\(^50\) evaluating the effects of nut consumption in the context of a Mediterranean diet on metabolic syndrome status showed that mixed nut consumption of 30 g/d significantly reduced the prevalence of high waist circumference, hypertriglyceridemia, and hypertension compared with a control group receiving a nut-free low-fat diet. Tapsell et al\(^41\) found significantly decreased LDL-C and significantly increased HDL-C and ratio of TC to HDL-C in patients with type 2 diabetes mellitus consuming 30 g/d of walnuts for 6 months as part of a modified low-fat diet compared with those receiving nut-free, low-fat, or modified low-fat diets.

Our findings confirm the results of epidemiological studies showing that nut consumption lowers CHD risk and support the inclusion of nuts in therapeutic dietary interventions for improving blood lipid levels and lipoproteins and for lowering CHD risk. Nuts are a whole food that have been consumed by humans throughout history. Increasing the consumption of nuts as part of an otherwise prudent diet can be expected to favorably affect blood lipid levels (at least in the short term) and have the potential to lower CHD risk.

Accepted for Publication: October 19, 2009.

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Author Contributions: Mr Oda had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Sabaté. Acquisition of data: Sabaté and Ros. Analysis and interpretation of data: Sabaté, Oda, and Ros. Drafting of the manuscript: Sabaté. Critical revision of the manuscript for important intellectual content: Sabaté, Oda, and Ros. Statistical analysis: Oda. Obtained funding: Sabaté. Study supervision: Sabaté.

Financial Disclosure: Drs Sabaté and Ros have received research funding from the California Walnut Commission, the Almond Board of California, the National Peanut Board, and the International Tree Nut Council; they are also unpaid members of the Scientific Advisory Council of the California Walnut Commission. Dr Sabaté has received an honorarium as a member of the Pistachio Scientific Advisory Board.

Funding/Support: This research was partially funded by a grant from the McLean Research Fund of the Department of Nutrition, Loma Linda University, and by the International Tree Nut Council Nutrition Research and Education Foundation.

Role of the Sponsors: The funding sources had no role in the design or conduct of the study; collection, management, analysis, or interpretation of the data; or preparation, review, or approval of the manuscript.

Additional Contributions: Jay S. Tanzman, MPH, assisted with data analysis, and Michelle Wien, DrPH, RD, CDE, edited the manuscript. We thank the trial investigators who shared their original data with us, which made this study possible.

REFERENCES

7. Kushi LH, Folsom AR, Prineas RJ, Mink PJ, Wu Y, Bostick RM. Dietary antioxi-
9. Albert CM, Gaziano JM, Willett WC, Manson JE. Nut consumption and de-
10. US Food and Drug Administration. Qualified Health Claims: Letter of Enforce-
14. Abbey M, Noakes M, Belling GB, Nestel PJ. Partial replacement of saturated fatty acids with almonds or walnuts lowers total plasma cholesterol and low-density- 
19. O’Byrne DJ, Knauta DA, Shireman RB. Low fat–monounsaturated rich diets con-
20. Bland DK, Hu FB. Effect of walnut consumption on blood lipids and other car-
28. Bes-Rastrollo M, Sabaté J, Gómez-Grajera E, Alonso A, Martínez JA, Martínez- 
31. Salas-Salvadó J, Fernández-Ballart J, Ros E, et al; PREDIMED Study Investiga-
tors. Effect of a Mediterranean diet supplemented with nuts on metabolic syn-