Published in final edited form as:
Atherosclerosis. 2009 November ; 207(1): 208–212. doi:10.1016/j.atherosclerosis.2009.03.039.

Substitution of vegetable oil for a partially-hydrogenated fat favorably alters cardiovascular disease risk factors in moderately hypercholesterolemic postmenopausal women[a,b]

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Abstract

Objective—Compared to vegetable oils in their unmodified state, partially-hydrogenated fat is associated with less favorable effects on cardiovascular disease (CVD) risk factors. Acceptable alternatives must be adjudicated. Our objective was to assess the effect of a recent commercial fat substitution, corn oil for partially-hydrogenated soybean oil.

Methods—Using a double-blind cross-over design, 30 postmenopausal women ≥50 y with LDL-cholesterol concentrations ≥120 mg/dL were randomly assigned to each of two 35-day phases; all food and beverage was provided to maintain body weight. Corn or partially-hydrogenated soybean oil was incorporated throughout the diet and contributed two-thirds of fat. Primary outcomes included fasting and non-fasting lipid, lipoprotein, apolipoprotein, and fasting high sensitivity C-reactive protein (hsCRP) concentrations; secondary outcomes included fasting small dense LDL (sdLDL)-cholesterol, remnant lipoprotein cholesterol (RemLC), glycated albumin, adiponectin and immunoreactive insulin concentrations, and endogenous cholesteryl ester transfer protein (CETP) and lecithin:cholesterol acyl transferase (LCAT) activities.

Results—Relative to the partially-hydrogenated soybean oil-enriched diet, the corn oil enriched diet resulted in lower fasting total cholesterol (7%; $P<0.0001$), LDL-cholesterol (10%; $P<0.0001$), VLDL-cholesterol (7%; $P=0.052$), apo B (9%; $P<0.0001$), Lp(a) (5%; $P=0.024$), sdLDL-cholesterol (17%; $P=0.001$), and RemLC (20%; $P=0.007$) concentrations, and no significant effect on the other outcomes. Changes in postprandial (4-h post-meal) lipid, lipoprotein and apolipoprotein concentrations were similar to the fasting state.

[a]This work was supported by NIH grant HL 54727 and the U.S. Department of Agriculture, under agreement No. 58-1950-4-401.

[b]Sonia Vega-López, Nirupa R. Matthan, Lynne M. Ausman, Masumi Ai, Seiko Otokozawa, Ernst J. Schaefer, Alice H. Lichtenstein, no conflicts of interest

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Conclusion—The replacement of partially-hydrogenated soybean oil with corn oil favorably affects a range of CVD risk factors and is an appropriate option to decrease cardiovascular disease risk factors in moderately hypercholesterolemic individuals.

Keywords

cardiovascular disease; *trans* fatty acids; polyunsaturated fatty acids; lipoproteins; partially-hydrogenated fat; vegetable oil; LDL-cholesterol; HDL-cholesterol; hsCRP; CETP; LCAT

Introduction

Epidemiologic studies suggest that partially-hydrogenated fat intake is associated with increased coronary heart disease (CHD) risk [1,2]. Dietary partially-hydrogenated fat, relative to unmodified vegetable oil, has been associated with elevated LDL-cholesterol, apo B, lipoprotein (a) [Lp(a)], cholesterol in small dense LDL (sdLDL), and high sensitivity C-reactive protein (hsCRP) concentrations. Under isoenergetic conditions, both saturated and *trans* fatty acids increase LDL cholesterol concentrations, however, under the same conditions saturated fatty acids increase HDL cholesterol concentrations whereas *trans* fatty acids do not [3]. Interventions using partially-hydrogenated fat, the major source of *trans* fatty acids in Western diets, have resulted in unfavorable effects on CVD risk factors [4–6]. Likewise, a one to one substitution of dietary *trans* for *cis* double bond containing fatty acids resulted in unfavorably effect one or more CVD risk factors [7–9].

Early public health recommendations called for the replacement of fats of animal origin, high in saturated fatty acids, with vegetable oils [10]. As a result, animal fats were replaced with partially-hydrogenated vegetable oils. As the adverse effects of partially-hydrogenated vegetable oils emerged, there is now a shift to replace partially-hydrogenated vegetable oils with unmodified vegetable oils. We took advantage of one such change by procuring both the pure sources of partially-hydrogenated vegetable oils previously used and the alternate oil.

The aim of this study was to estimate the effect of one approach to displace partially-hydrogenated fat in the food supply on common markers of CVD risk, and newer potential markers of CVD risk, in a group of moderately hypercholesterolemic women who would be candidates for dietary modification prior to the initiation of pharmacotherapy.

Methods

Participants

Thirty-seven postmenopausal women ≥50 y with LDL-cholesterol ≥120 mg/dL but otherwise apparently healthy were recruited from the greater Boston area. Participants were excluded if they had abnormal kidney, liver, thyroid or cardiac function, elevated fasting glucose concentration, diabetes, active cancer or other known chronic disease; took medications known to affect blood lipid concentrations or dietary supplements; consumed more than 2 daily alcoholic drinks; smoked cigarettes; or had a body mass index (BMI) ≥35 kg/m^2. Postmenopausal status was defined as self-reported cessation of menstruation for at least 12 consecutive months. All study participants gave written consent. The study protocol was approved by the Human Investigation Review Committee of Tufts University and Tufts Medical Center, and was registered in the ClinicalTrials.gov registry (Identifier #NCT00175071). Seven participants initially recruited did not complete the study, four of whom dropped out during phase 1 and three during phase 2. Their data were not included in the statistical analysis. The target enrollment of 30 participants was achieved. Baseline characteristics of these participants are summarized in Table 1.

Experimental Design

This was a randomized cross-over design study consisting of two 35-day diet phases with a 14-day intervening period. The participants, investigators and laboratory personnel were blinded to the diet phases. Participants visited our Metabolic Research Unit 3-times per week for blood pressure and weight monitoring, review of changes in exclusion criteria or medical condition, consumption of one meal, and food pick-up. All food and drink not consumed on site were provided to the participants in containers appropriate for either microwave or conventional ovens to obviate the need to transfer food so as to minimize potential losses. Participants were required to consume all that was provided and not supplement with any additional food or beverage with the exception of water and non-caloric beverages.

Diets

The experimental diets were designed to have a similar content of total fat, carbohydrate, protein, fiber and cholesterol. This was confirmed by chemical analysis (Covance Laboratories, Madison, WI, USA) (Table 2). The same foods were included in each of the two diet phases. The only difference was the type of fat added to the foods given to the study participants (corn or partially-hydrogenated soybean oil). The experimental fats were provided, on investigator's request, from Frito-Lay, (Plano, TX), and represented two-thirds of the total fat content of the diet (Table 2). Body weight was monitored 3-times per week and caloric intake was adjusted, when necessary, to maintain a stable body weight (±1.0 kg from initial weight).

During the last week of each diet phase blood samples were collected after a 12-h fast on three separate days for measurement of serum lipids or EDTA-containing tubes for the other measures. Mean values were used for statistical analysis. A non-fasting blood sample was collected during one of the 3 test days 4-h after the mid-day experimental meal. Serum and plasma were separated by centrifugation at 1100 × g at 4°C and stored at −80°C for subsequent analysis.

Biochemical measurements

Serum total cholesterol, LDL-cholesterol, HDL-cholesterol and triglyceride concentrations were measured using an Olympus AU400 with enzymatic reagents (Olympus America Inc., Melville, NY). VLDL-cholesterol concentrations were calculated as the difference between total cholesterol and LDL-cholesterol plus HDL-cholesterol. Plasma apoprotein (apo) A–I and apo B (KAMIYA Biomedical Company, Seattle, WA), and Lp(a) concentrations (Wako Chemicals USA, Inc., Richmond, VA) were measured using an Olympus AU400 immunoturbidimetrically. Plasma hsCRP was measured using a Roche Cobas Fara centrifugal clinical chemistry analyzer (Roche Diagnostics, Indianapolis, IN) immunoturbidimetrically (DiaSorin, Inc., Stillwater, MN). Proficiency testing for these procedures was done through the College of American Pathologists (CAP) Interlaboratory Comparison and Survey Proficiency Program (Northfield, IL). Linearity studies for all procedures were done through the Verichem Laboratories Linear Testing Program (Providence, RI).

Measurement of plasma RemLC was performed using a homogenous assay allowing for measurement of cholesterol in chylomicron remnants, VLDL remnants and intermediate density lipoproteins [11]. Plasma sdLDL-cholesterol was measured using a heparin-magnesium precipitation method [12]. Plasma glycated albumin was measured enzymatically [13]. Plasma adiponectin was measured using a latex particle-enhanced turbidimetric immunoassay [14]. Plasma immunoreactive insulin was measured with a latex immunoassay [15]. Endogenous cholesteryl ester transfer protein (CETP) and lecithin:cholesterol acyl transferase (LCAT) activities were measured as previously reported [16].

Statistical analyses

Prior to the analysis, descriptive statistics and graphs (PROC UNIVARIATE and PROC MEANS) (SAS v 9.1 for Windows, Cary, N.C.) were used to summarize the overall effects of diets and distributions of the outcome measures. When violations of the basic testing assumptions were noted, log10- transformations of the data were used to achieve normality prior to analysis (as indicated in the tables). Data were analyzed using a paired t-test. When no transformation was appropriate, a nonparametric signed-rank test was used to compare means. Untransformed data are presented in text and tables as mean ± SD.

Results

The energy intake (mean ± SD) of the study participants was 2300 ± 302 kcal and 2312 ± 329 kcal during the corn oil and partially-hydrogenated soybean oil phases (P=0.742), respectively. There were no significant differences in mean body weight, BMI, waist and hip circumferences, systolic or diastolic blood pressures and immunoreactive insulin at the end of the diet phases (Table 3).

Displacement of partially-hydrogenated soybean oil with corn oil improved fasting plasma total cholesterol, LDL-cholesterol and VLDL-cholesterol concentrations by 7% (P<0.0001), 10% (P<0.0001) and 7.4% (P=0.052), respectively (Table 4). Plasma apo B concentrations mirrored those of LDL-cholesterol concentrations (9% lower; P<0.0001). Consistent with these results the total cholesterol:HDL-cholesterol ratio was more favorable after participants consumed the corn oil relative to the partially-hydrogenated soybean oil enriched diet (9% lower; P<0.0001). Albeit modest, Lp(a) concentrations were significantly lower after participants consumed the corn oil than partially-hydrogenated soybean oil enriched diet (5%; P=0.024).

The effects of displacing partially-hydrogenated soybean oil with corn oil on potential CVD risk factors were inconsistent (Table 4). Relative to partially-hydrogenated soybean oil, corn oil resulted in lower concentrations of sdLDL and RemLC concentrations (17%; P=0.001 and 20%; P=0.007, respectively) and marginally lower adiponectin concentrations (2%; P=0.048). HDL-cholesterol, apo AI, triglyceride, hsCRP, and glycated albumin concentrations, and endogenous CETP or LCAT activities were not significantly different at the end of the two diet phases.

Plasma lipid, lipoprotein, apolipoprotein and hsCRP concentrations were assessed 4-hours after the mid-day meal to approximate the habitual postprandial state (supplementary table). With the exception of VLDL-cholesterol, which is strongly affected by triglyceride concentrations, the results in the non-fasting state were similar to those observed in the fasting state. Postprandial total cholesterol concentrations were 6% lower after the corn oil enriched diet relative to the partially-hydrogenated soybean oil diet (5.46 mmol/L vs. 5.82 mmol/L, respectively; P<0.001). Substituting partially-hydrogenated soybean oil with corn oil resulted in postprandial LDL-cholesterol concentrations which were 10% lower (3.58 mmol/L vs. 3.21 mmol/L, respectively; P<0.001). No significant differences were observed in postprandial HDL-cholesterol, VLDL-cholesterol or triglyceride concentrations after consumption of the two diets (data not shown). Similar to differences observed in postprandial LDL-cholesterol concentrations, postprandial plasma apo B concentrations were 10% lower after the corn oil enriched diet relative to the partially-hydrogenated soybean oil diet (1.00 g/L vs. 1.11 g/L, respectively; P<0.001). Lp(a) concentrations were significantly lower after participants consumed the corn oil than partially-hydrogenated soybean oil enriched diet (0.89 μmol/L vs. 0.95 μmol/L, respectively; P=0.032). Apo AI and hsCRP concentrations were not significantly different at the end of the two diet phases (data not shown).

Discussion

Recommendations for CVD prevention and treatment encourage the displacement of partially-hydrogenated fat, the major source of *trans* fatty acids, with unmodified vegetable oils [17, 18]. We took advantage of one substitution to evaluate its potential effect on standard and potential CVD risk markers in a group of individuals who according to current guidelines would be candidates for dietary modification. Incorporated into the study design was the assumption that these individuals represented a group who would habitually consume traditional sources of partially-hydrogenated fat, equivalent to approximately 4% of energy as *trans* fatty acids [19], hence would experience a shift in the type of fat consumed were there to be a secular shift in the food supply. This study differs from prior work that focused on a one-to-one molar substitution of *cis* for *trans* fatty acids, used specially formulated fats, or incorporated extremely high levels of *trans* fatty acids into the diet, and expanded the scope of variables monitored.

As would be predicted [5,9,20–24] displacement of partially-hydrogenated soybean oil with corn oil had favorable effects on fasting and non-fasting serum total cholesterol, LDL-cholesterol and apo B concentrations. These effects are consistent with a decreased intake of *trans* fatty acid and increased *cis* polyunsaturated fatty acid intake [25,26]. HDL-cholesterol or apo AI concentrations were not significantly different between the two diet phases. The detrimental effect of *trans* fatty acids on HDL cholesterol and apo AI concentrations occurs when the comparison is made between *trans* fatty acids and saturated fatty acids, and when either replaces *cis* unsaturated fatty acids. In this study the major difference between the dietary fats was not in thesaturated fatty acid component, but rather the relative proportion of *cis* and *trans* fatty acid double bond containing polyunsaturated fatty acids.

No significant effect of dietary fat on hsCRP concentrations was observed, either in the fasted or non-fasted state. Data on the effect of *cis* relative to *trans* fatty acids on hsCRP concentrations have been highly variable, as for other biomarkers of inflammation [1,7,27–29]. Displacement of partially-hydrogenated soybean oil with corn oil resulted in lower concentrations of cholesterol in sdLDL and RemLC. We have previously reported that diets containing traditional margarine (high in *trans* fatty acids), compared to vegetable oil, resulted in a smaller mean LDL particle size [30]. In contrast, we have not previously observed a significant difference in RemLC concentrations [4]. Differences in methodology used to measure remnant particles cannot be ruled out as a plausible explanation for this discrepancy. In both cases the differences between the two dietary fats on sdLDL and RemLC would be consistent with increased CVD risk, as is reported for *trans* fatty acids [1,2].

Consistent with the HDL-cholesterol and apo AI data there were no significant differences in endogenous LCAT and CETP activities at the end of the two diet periods. Among previous studies, differences reported for CETP and/or LCAT activities in response to partially-hydrogenated fat/*trans* fatty acids were relative to saturated fatty acids [31,32] or unsaturated fatty acids [32,33], and were reflected in HDL-cholesterol concentrations. Studies in which no significant effect was reported for HDL cholesterol concentrations likewise did not observe a significant effect on the activity of the enzymes associated with HDL metabolism [23,34].

The intent of this study was to use two dietary fats conveniently available, one that was being phased out and the replacement fat in an attempt to assess the potential effect of this trend and identify potential adverse effects, were there to be any. A limitation of the study is that this level of substitution for a single fat was extreme. It was designed that way to allow for the evaluation of an approach whereby the majority of partially-hydrogenated fat in food products is displaced by *cis* unsaturated fat. Another limitation of the study is that non-fasting outcomes were monitored 4-hours after consumption of a mid-day meal consistent with each diet phase.

This approach was taken, rather than the conventional fat load approach, to mimic habitual non-fasting fluctuations. The study population was limited to moderately hypercholesterolemic postmenopausal women; hence extrapolation to other populations deserves caution. A strength of the current study was the use of a randomized crossover design, with which we were able to account for the potential confounding by differences in study participant characteristics, such as variation in baseline body mass index, fasting glucose and triglyceride concentrations, and inclusion of participants with mildly elevated values for these variables. Predictive equations have been generated to estimate changes in lipid, lipoprotein and apolipoprotein concentrations in response to a change in fatty acid intake [3]. However, these equations only predict change relative to carbohydrate substitution and cannot be applied to the current study in which polyunsaturated fatty acids replaced *trans* fatty acids.

In conclusion, substituting partially-hydrogenated soybean oil with an unmodified vegetable oil (corn oil) favorably affects cardiovascular risk factors in moderately hypercholesterolemic postmenopausal women in both the fasting and non-fasting state. Because of the beneficial effects on cardiovascular risk, the practice of displacing partially-hydrogenated fats from the food supply should be encouraged.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

The authors want to acknowledge Susan M. Jalbert, Blanche Ip and Dr. Alice Dillard for their helpful contributions, and the study participants for their cooperation.

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Table 1

Baseline characteristics of participants[1]

Variable	*N*=30	Range
Age (y)	64.2 ± 7.5	52 – 80
Body mass index (kg/m^2)	25.6 ± 3.6	18.4 – 31.3
Weight (kg)	67.0 ± 10.8	44.9 – 86.5
Height (m)	1.62 ± 0.07	1.45 – 1.82
Systolic BP (mm Hg)	127 ± 15	93 – 161
Diastolic BP (mm Hg)	74 ± 8	59 – 96
Glucose (mmol/L)	5.11 ± 0.40	4.16 – 6.05
Serum lipids and lipoproteins		
Total cholesterol (mmol/L)	5.94 ± 0.67	4.91 – 7.77
LDL-cholesterol (mmol/L)	3.84 ± 0.49	3.20 – 5.24
VLDL-cholesterol (mmol/L)	0.60 ± 0.28	0.21 – 1.23
HDL-cholesterol (mmol/L)	1.50 ± 0.33	1.00 – 2.27
Triglyceride (mmol/L)	1.33 ± 0.61	0.48 – 2.72
Total cholesterol:HDL-cholesterol	4.10 ± 0.81	2.61 – 5.64

[1] Values are mean±SD. BP: blood pressure; LDL: low density lipoprotein; VLDL: very low density lipoprotein; HDL: high density lipoprotein.

Table 2

Composition of experimental diets[1]

Constituent	Corn Oil	Partially-Hydrogenated Soybean Oil
	Percent of energy	
Protein	16.7	17.6
Carbohydrate	57.1	57.2
Fat	26.6	25.4
Saturated fatty acids	5.7	6.3
Monounsaturated fatty acids	7.2	7.8
Polyunsaturated fatty acids	12.1	5.9
Trans fatty acids	0.3	4.3
	g/1000 kcal	
Cholesterol	0.084	0.084
Fiber	11	11

[1] Macronutrients, fiber, cholesterol and fatty acid profiles were determined by chemical analysis of a composite diet.

Table 3

Anthropometric characteristics, blood pressure and immunoreactive insulin at end of two experimental diet phases

	Corn Oil	Partially-Hydrogenated Soybean Oil	*P* value
Body weight (kg) [1]	67.3 ± 10.8[2]	67.1 ± 10.8	0.280
Body mass index (kg/m^2)	25.6 ± 3.6	25.6 ± 3.5	0.205
Waist circumference (cm)	84.9 ± 10.0	84.1 ± 9.3	0.810
Hip circumference (cm)	102.2 ± 9.5	101.9 ± 9.8	0.434
Systolic blood pressure (mm Hg)	115 ± 10	112 ± 8	0.073
Diastolic blood pressure (mm Hg)	70 ± 7	69 ± 6	0.249
Immunoreactive insulin (pmol/L)	31.8 ± 22.8	26.7 ± 14.7	0.094[#]

[1] N=30 participants.

[2] Values are mean±SD. A paired t-test was used to compare the data at the end of each diet phase.

[#] A nonparametric signed-rank test was used for this comparison.

Table 4

Fasting lipoprotein related parameters, hsCRP, glycated albumin and adiponectin concentrations, and LCAT and CETP activities at the end of two experimental diet phases

	Corn Oil	Partially-Hydrogenated Soybean Oil	*P* value
Total cholesterol (mmol/L) [1]	5.52 ± 0.59[2]	5.91 ± 0.64	0.0001
LDL-cholesterol (mmol/L)	3.51 ± 0.48	3.89 ± 0.52	0.0001
VLDL-cholesterol (mmol/L)	0.50 ± 0.27	0.54 ± 0.29	0.052
HDL-cholesterol (mmol/L)	1.50 ± 0.37	1.47 ± 0.36	0.074
Triglyceride (mmol/L)	1.37 ± 0.59	1.42 ± 0.63	0.267
Total cholesterol:HDL-cholesterol	3.85 ± 0.86	4.21 ± 0.94	0.0001
Lipoprotein (a) (μmol/L)	0.91 ± 0.91	0.96 ± 0.93	0.024*
Apoprotein B (g/L)	1.01 ± 0.14	1.11 ± 0.17	0.0001
Apoprotein AI (g/L)	1.56 ± 0.21	1.55 ± 0.20	0.450
hsCRP (mg/L; n=27)	1.96 ± 1.80	1.84 ± 1.68	0.941*
sdLDL-cholesterol (mmol/L)	1.01 ± 0.29	1.22 ± 0.38	0.001*
RemLC (mmol/L)	0.16 ± 0.08	0.20 ± 0.12	0.007
Glycated Albumin (%)	14.5 ± 1.03	14.5 ± 1.08	0.733
Adiponectin (mg/L)	12.4 ± 6.2	12.7 ± 6.1	0.048*
LCAT (μmol chol • L^{-1} • h^{-1})	49.0 ± 10.3	48.0 ± 11.8	0.743
CETP (μmol chol • L^{-1} • h^{-1})	33.1 ± 20.5	37.1 ± 16.7	0.394

[1] N=30 participants with the exception of hsCRP as noted.

[2] Values are mean±SD. A paired t-test was used to compare the data at the end of each diet phase. LDL=low density lipoprotein; VLDL=very low density lipoprotein; HDL=high density lipoprotein; hsCRP=high sensitivity C-reactive protein; sdLDL=small, dense LDL; RemLC=remnant lipoprotein cholesterol; LCAT=lecithin:cholesterol acyl transferase; CETP=cholesterylester transfer protein.

* A log10 transformation was needed to achieve normality.