High intakes of *trans* monounsaturated fatty acids taken for 2 weeks do not influence procoagulant and fibrinolytic risk markers for CHD in young healthy men

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Dietary *trans* fatty acids are associated with increased risk of CHD. We hypothesized that the changes in plasma lipids associated with a high intake of *trans* fatty acids would cause adverse effects on procoagulant and fibrinolytic activities. A randomized crossover controlled feeding study was conducted in twenty-nine men. A *trans*-rich diet supplying 10 % energy as *trans*-18:1 was compared with diets in which the *trans* fatty acids were replaced either with carbohydrate or oleate; each diet was taken for 2 weeks in random order. Fasting fibrinogen and D-dimer concentrations and factor VII coagulant, plasminogen activator inhibitor type 1 and tissue plasminogen activator did not differ between diets. Postprandially, tissue plasminogen activator activity increased and plasminogen activator inhibitor type 1 activity decreased on all diets. Factor VIIc increased postprandially by 15 and 17 % on the *trans* and oleate diets respectively, compared with an 11 % increase on the carbohydrate diet; the mean difference between oleate and carbohydrate diets was 6 (95 % CI 0·2, 11·9) %. The LDL-cholesterol: HDL-cholesterol and apolipoprotein B : apolipoprotein A-I ratios increased by 13 (95 % CI 5·7, 21·8) and 10 (95 % CI 3·1, 17·2) % respectively on the *trans* diet compared with the oleate diet and by 6 (95 % CI 0·1,12·7) and 7 (95 % CI 0, 13·5) % respectively compared with the carbohydrate diet. Plasma HDL-cholesterol concentration was 18 (95 % CI 0·7, 35·9) % lower on the *trans* diet compared with the oleate diet. The results confirm adverse effects of *trans* fatty acids on HDL-cholesterol concentrations, but suggest that *trans* fatty acids do not have any specific effects on known haemostatic risk markers for cardiovascular disease in healthy young men in the short-term.

Lipids: Fibrinolysis: Coagulation: *Trans* fatty acids

The industrial hardening of edible oils employed in the manufacture of margarine and cooking fats results in the formation of monounsaturated fatty acids with a *trans* configuration. The major *trans* isomers in human diets are *trans*-18:1 isomers (British Nutrition Foundation, 1995). Dietary *trans* fatty acids have been associated with an increased risk of CHD in the USA and Europe (Ascherio et al. 1996; Hu et al. 1997; Pietinen et al. 1997; Oomen et al. 2001), but this finding has not been confirmed by studies in Europe, where the dietary intake of *trans* fatty acids has been assessed by measuring the proportion of *trans* fatty acids in adipose tissue (Aro et al. 1995; Roberts et al. 1995; van de Vijver et al. 2000). The mechanism by which *trans* fatty acids may increase risk is uncertain. *Trans* isomers of 18:1 fatty acids increase the plasma LDL-cholesterol:HDL-cholesterol ratio compared with oleate (Mensink & Katan, 1990; Nestel et al. 1992; Judd et al. 1994; Almendingen et al. 1995; Aro et al. 1997; Lichtenstein et al. 1999), Some (Nestel et al. 1992; Almendingen et al. 1995; Aro et al. 1997) but not all studies (Clevidence et al. 1997) report that diets enriched with *trans* fatty acids increase lipoprotein(a) (Lp(a))

Abbreviations: FVIIc, factor VII coagulant activity; Lp(a), lipoprotein(a); PAI-1, plasminogen activator inhibitor type 1; TAG, triacylglycerol; t-PA, tissue plasminogen activator.

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concentrations. Elevated Lp(a) concentrations have been postulated to decrease fibrinolytic activity (Stein & Rosenson, 1997), which in turn may increase risk of CHD (Meade et al. 1993). Fibrinolytic activity is determined largely by the balance between tissue plasminogen activator (t-PA) and plasminogen activator inhibitor type 1 (PAI-1) activities (MacCallum et al. 1998). Elevated PAI-1 activity is associated with increased risk of CHD in young survivors of CHD (Hamsten et al. 1985), and is also associated with elevated plasma triacylglycerol (TAG) concentrations and low HDL-cholesterol concentrations.

In vitro studies show that trans-18:1 leads to activation of factor VII in comparison with oleic acid (Mitropoulos et al. 1993). The Northwick Park Heart study (Meade et al. 1993) and the PROCAM study (Heinrich et al. 1994) found raised plasma fibrinogen and factor VII coagulant activity (FVIIc) to be associated with an increased risk of fatal CHD. Fasting FVIIc is positively associated with plasma cholesterol and TAG concentrations and increases following a meal high in fat. Fibrinogen is a more powerful risk factor for CHD, may act as marker for inflammation and is positively associated with obesity and smoking. Increased procoagulant activity is usually matched by increased fibrinolytic activity. The plasma concentration of D-dimer, which are products resulting from the degradation of fibrin by plasmin, is a sensitive indicator of the formation of fibrin and its digestion (Stoetzer et al. 1988) and has been used a global marker of fibrin turnover (Danesh et al. 2001).

Two previous studies (Almendingen et al. 1996; Mutanen & Aro, 1997) have reported the effects of longer-term intake of trans fatty acids on procoagulant and fibrinolytic CHD risk factors. However, both studies made comparison with diets rich in saturated fatty rather than carbohydrate or the corresponding cis-isomers. We hypothesized that an increased plasma concentration of trans-18:1 in lipoproteins would result in adverse changes in procoagulant and fibrinolytic activities in comparison with carbohydrate or oleate (cis-18:1n-9) in the diet. Because changes in plasma lipoprotein concentrations can be brought about in 2 weeks and the turnover of procoagulant and fibrinolytic factors is rapid (h rather than d), we decided to test this hypothesis by feeding male subjects for 2-week periods.

**Subjects, materials and methods**

**Subjects and setting**

Thirty-six healthy Caucasian men aged 18–35 years were recruited from among staff and students of King’s College, London, UK. The screening procedure involved the completion of a detailed questionnaire to establish general health, details of prescribed medicines, pattern of alcohol consumption and food preferences and aversions that may interfere with acceptability of the diets. Exclusion criteria included current use of anticoagulant medication, current smoker, diabetes mellitus, CHD, fasting cholesterol >6·5 mmol/l, fasting TAG concentration >2·3 mmol/l, HDL-cholesterol <0·9 mmol/l, BMI >28 kg/m², self-reported alcohol intake of more than twenty-one units per week, abnormal haematology or liver function tests, current use of vitamins or dietary supplements or following a vegetarian diet.

A small fasting venous blood sample (17 ml) was obtained for measurement of plasma total cholesterol, plasma HDL-cholesterol, plasma TAG, full blood count, FVIIc, fibrinogen, liver function tests and serum cotinine. Habitual dietary intake was assessed by a 3 d weighed dietary record; these were converted to nutrient intakes by computer from food tables based on data from McCance and Widdowson’s The Composition of Foods (Holland et al. 1991). Height and weight were measured using a beam balance and stadiometer in order to establish BMI.

Smoking was an exclusion criterion because of its effect on fibrinogen concentration (Meade et al. 1987). However, as it is well known that a significant proportion of subjects who report themselves as non-smokers are deceivers. In order to verify non-smoking status, measurement of plasma cotinine (Feyerabend & Russell, 1990) was conducted prior to entry into the study and at intervals throughout the study. Body weight and whole blood counts were further recorded at the end of each dietary period. Of the forty-two subjects who expressed interest in the study, thirty-six subjects met the inclusion criteria; of these, four subjects withdrew before completing the first dietary period and three further subjects withdrew after the first treatment period for personal reasons. A total of twenty-nine subjects completed the study and their details are shown in Table 1; four of the subjects who completed the study were found to have plasma cotinine concentrations that exceeded the cut-off points for non-smokers during the intervention period, and their results were excluded from the statistical analyses for fibrinogen. Subjects were given a detailed outline of the study requirements and all provided written informed consent, as did their general practitioners. No financial incentive was given, but all food during the study period was provided free of charge. The study protocol was reviewed and approved by the Research Ethics Committee of King’s College, London.

<table>
<thead>
<tr>
<th>Table 1. Baseline characteristics of the twenty-nine male subjects who completed the study</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
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<td>5·9</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
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<td>2·2</td>
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<tr>
<td>Energy intake (MJ/d)</td>
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<td>2·9</td>
</tr>
<tr>
<td>Protein (% energy)</td>
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</tr>
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<td>8·1</td>
</tr>
<tr>
<td>Carbohydrate (% energy)</td>
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<td>7·0</td>
</tr>
<tr>
<td>Alcohol (% energy)</td>
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<td>5·0</td>
</tr>
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<td>10</td>
</tr>
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<td>Plasma cholesterol (mmol/l)</td>
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<td>0·69</td>
</tr>
<tr>
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<td>0·55</td>
</tr>
<tr>
<td>HDL-cholesterol (mmol/l)</td>
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<td>0·33</td>
</tr>
<tr>
<td>Plasma triacylglycerol (mmol/l)</td>
<td>1·23</td>
<td>0·61</td>
</tr>
<tr>
<td>Fibrinogen (mg/l)</td>
<td>2·66</td>
<td>0·57</td>
</tr>
<tr>
<td>Factor VII coagulant activity (% standard)</td>
<td>103</td>
<td>34</td>
</tr>
</tbody>
</table>
trans fatty acids diet and the high-fat diets. All the foodstuffs, e.g. lean meat and low-fat dairy products. The low-fat diet comprised the same meals as the two high-fat diets except that the 10% deficit in energy resulting from the use of the low-fat spread was supplied by additional carbohydrate in the form of bread and sucrose.

All food consumed by the subjects over the 6-week experimental period was specially prepared in a dietetic kitchen and provided in preweighed portions. The subjects were blind to the allocation of treatment with regard to trans- and oleate-rich diets. It was not possible to allocate the carbohydrate-rich diet blind. Coffee intake was restricted to not more than four cups per day. The subjects were not provided with alcoholic beverages, but were permitted to consume alcohol up to two standard units (20 ml ethanol) on each day during the study, except for the final 3 days of each dietary period when alcohol intake was forbidden. Black tea, white tea (with milk from the daily allowance) and low-energy soft drinks were permitted ad libitum.

Subjects were provided with a prepacked breakfast to consume at home and a prepacked lunchtime meal (sandwiches) each day. The subjects consumed their evening meal under supervision in a metabolic facility. At weekend subjects were provided with prepacked meals for consumption at home.

**Test meals**

On the last morning of each diet following the collection of a fasting blood sample, subjects consumed a test meal with a similar fatty acid composition to the background diet in the metabolic facility. The test meals, each supplying 6 MJ, consisted of food similar to that usually consumed in the main evening meal of the day; the fat content was calculated to be 90 g for the oleate- and trans-rich diets and 67 g for the carbohydrate-rich diet.

**Replicate meal analysis**

Replicates of the daily diet and test meals were analysed for total energy (bomb calorimetry), protein (Kjeldahl), total fat (Soxhlet) and fatty acids (GLC) using methods previously described (Sanders et al. 1997). The contribution of individual fatty acids to total energy intake was estimated assuming 37-7 kJ (9 kcal)/g fatty acid.

**Blood sampling**

Venous blood samples were obtained after an overnight fast on the last 2 days of each dietary period. Subjects were

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**Experimental design**

A randomized crossover design of three diets was employed. Each experimental diet was taken for 14 days and the diets were taken consecutively without any washout period. The subjects were allocated in random order to receive each of the diets in one of six sequences (ABC, ACB, BAC, BCA, CAB and CBA) according to an orthogonal Latin square design in order to balance out any possible treatment order effects. A treatment period of 14 days was selected, as this is sufficient to bring about changes in plasma lipid concentration (Mensink & Katan, 1992). A washout period was not employed as previous studies with trans fatty acids have shown that trans fatty acids do not have a persistent effect on blood lipids (Mensink & Katan, 1990), unlike long-chain n-3 fatty acids (Sanders et al. 1997). As haemostatic variables were the main targets of the present study and these have a rapid turnover, measurable in hours rather than days (Miller et al. 1991; de Maat, 2001), a study of 14 days was believed to be adequate to test whether a high intake of trans fatty acids had adverse effects on haemostatic function.

In order to check for carryover effects, measurements of the concentration of trans-18:1 in total plasma lipids and platelets were made. The outcome variables were changes in lipid and haemostatic variables; these were derived from blood samples that were obtained after an overnight fast on the last 2 days of each treatment period and following a standardized meal that had a similar fat composition to the treatment diet. For plasma lipids, fibrinogen and FVIIc measurements were made on both days to obtain a more accurate estimate.

**Experimental diets**

The experimental diets supplied an energy intake of 13 MJ/day (consistent with energy balance in these subjects) and were designed so as to compare the effect of substituting 10% energy either as trans-18:1 or as carbohydrate or as oleate. The intake of saturated, polyunsaturated fatty acids, cholesterol and fibre were held constant. The intake of saturated, polyunsaturated fatty acids, cholesterol and fibre were held constant. The intake of saturated, polyunsaturated fatty acids, cholesterol and fibre were held constant. The intake of saturated, polyunsaturated fatty acids, cholesterol and fibre were held constant.
asked to avoid strenuous activity on the days preceding blood samples. Additional samples were collected at 3 and 7 h after each test meal. Blood was collected using the vacutainer technique and particular care was taken to avoid excessive venous stasis and cold-activation of factor VII; the detailed protocol for handling of the blood samples for the haemostatic assays has been described previously (Sanders et al. 2001); samples for haemostatic assays were rapidly frozen in liquid N\textsubscript{2} and stored in sealed polypropylene tubes at \(-70\degree\)C until assayed. A 2 ml EDTA sample for blood counts was maintained at room temperature until analysed on the same day at the Department of Haematology, St Thomas’s Hospital. Samples for lipid assays were collected into vacutainers (Becton Dickinson, Cowley, Oxford, UK) containing EDTA, chilled to 4\degree\Celsius\ and centrifuged within 3 h. Platelets were separated from the EDTA samples by low-speed centrifugation at 120 g for 20 min at 4\degree\Celsius\ to yield platelet-rich plasma. Platelet-poor plasma for lipid and lipoprotein analyses was prepared by centrifuging the platelet-rich plasma at 1500 g for 15 min at 4\degree\Celsius. The platelet pellet was washed three times with 5 ml ice-cold saline solution (8.9 g NaCl/l containing 40 mg EDTA/l); lipid extracts were prepared within 6 h of blood collection and stored in solvents containing 50 mg butylated hydroxytoluene/l at \(-20\degree\)C until analysed (Sanders & Roshanai, 1992). Plasma was kept at 4\degree\Celsius\ pending analysis of cholesterol, TAG and HDL subfractions within 5 d. Apolipoprotein concentrations were determined on samples of plasma stored at \(-70\degree\)C.

Laboratory measurements

Haemostatic assays were determined on frozen samples with all of the samples for one subject being assayed in the same batch in the coagulation laboratory of MRC Epidemiology and Medical Care Unit. The methods for determining plasma fibrinogen and FVIIc have previously been described (Sanders et al. 1997). Plasma d-dimer concentration was measured by ELISA (Chromogenix AB, Mølndal, Sweden); t-PA and PAI-1 activities were determined by chromogenic assay (Chromogenix AB). Full blood and platelet counts were determined on a Coulter counter (Coulter Instruments, Bedford, Beds., UK) in the Department of Haematology, St Thomas’s Hospital. Liver function tests were undertaken in the Department of Clinical Pathology, St Thomas’s Hospital and serum cotinine concentrations were determined by GC (Feyerabend & Russell, 1990) in the Medical Toxicology Unit (New Cross, London, UK).

Plasma cholesterol and TAG concentrations and apolipoprotein concentrations were determined by enzymatic and immunoturbidimetric assays, as previously described, at the Wynne Institute of Metabolic Medicine, London, UK (Sanders et al. 1997). Platelet glycerophospholipid fatty acid composition was determined by GLC using a 25 m BP75 capillary column (SGE Europe, Milton Keynes, UK). Chylomicrons were isolated from plasma from the 3 h postprandial sample by overlaying plasma with 0·195-M NaCl containing 1 g EDTA/l and centrifuging for 15 min at 19 000 rpm in a SW41 swing bucket rotor (Beckman Ltd, High Wycombe, UK). Lipids were extracted with chloroform–methanol (1:1, v/v) from the chylomicon fraction, given a ‘Folch wash’ and separated by TLC on plates coated with Silica Gel G (Merck UK, Poole, Dorset, UK) and then developed in hexane–diethyl ether–acetic acid (80:20:1, vol. vol.). The TAG fraction was methylated with HCl (5 g/l methanol)–toluene (4:1, v/v). Fatty acid methyl esters were analysed by GLC on a 50 m capillary column coated with CpSil88 (Chrompak, London, UK).

Statistical analysis

Twenty-nine subjects completed all dietary treatments. Each individual’s results for the two fasting samples were averaged in each period. Tests for differences between dietary periods were performed by ANOVA within subject. This approach assumes that the effects of treatment and the effects of period operate independently, and the model is invalid when significant interaction exists. Order effects and interaction were tested using the method of Pocock (1983). When significant differences were found between diets in the ANOVA, pairs of diets were compared using paired t tests. Adjustment for order effect was made when necessary using Bonferroni’s correction for multiple comparisons. The study had >80\% power to detect a 5\% difference in FVIIc and fibrinogen between pairs of diets \((P<0.05)\). For Lp(a), in which the distribution was highly skewed, period effects and interaction were sought on untransformed values using the Mann–Whitney test. In the comparison of three diets and non-paired comparisons, the non-parametric Friedman test and Sign test were employed on untransformed data respectively. Four subjects were found to be positive for plasma cotinine and their results were excluded from the statistical analysis for plasma fibrinogen.

Results

Table 1 shows the details of the twenty-nine subjects who completed the study; there were five subjects in each treatment sequence except for the sequence ACB where there were four. Body weights remained stable throughout the study. Four subjects had plasma cotinine values >14 μg/l and were, therefore, regarded as smokers and their results were excluded from the statistical analysis for plasma fibrinogen. Plasma cotinine levels were low in the other twenty-five subjects throughout the study: the median value was 0·7 (range 0·1–5·3) μg/l.

Dietary characteristics and fatty acid composition

Table 2 shows the analysed composition of the experimental diets. The intakes as a proportion of the dietary energy were close to those planned. The intake of cis-polysaturated fatty acids and saturated fatty acids was similar for all three diets. The proportion of energy derived from oleic acid (18:1\(\text{ cis}\)) was similar on the carbohydrate and trans diets but was twice as high in the oleate diet. Trans fatty acids accounted for 0·1\% energy intake on both the carbohydrate and oleate diets compared with 9·6\% on the trans diet. The oleate and trans test meals were designed to provide 6 MJ, 90 g fat, 41 g protein and 116 g carbohydrate.
On analysis, the oleate and trans meals supplied 87 g fat compared with the target value of 90 g. The carbohydrate meal was designed to provide 6 MJ, 67 g fat, 48 g protein and 167 g carbohydrate. On analysis the carbohydrate test meal supplied 65 g fat compared with the target value of 67 g. The fatty acid composition of the test meals was found to be similar to that of the parent diets (results not shown).

Biochemical indices of compliance to the diet

The trans diet led to a marked rise in trans-18 : 1 in plasma, but there was no evidence of any carryover effect between treatment periods (Fig. 1). The proportion of trans-18 : 1 in platelet lipids (P<0.001) increased to 4·2 (SEM 0·28) compared with 0·2 (SEM 0·06) and 0·3 (SEM 0·8) g/100 g total fatty acids on the carbohydrate and oleate diets respectively. The increase in the proportion of trans-18 : 1 was paralleled by a significant reduction (P<0.01) in the proportion of stearic acid (18:0) to 15·4 (SEM 0·26) compared with 18·3 (SEM 0·29) and 17·3 (SEM 0·35) g/100 g total fatty acids on the carbohydrate and oleate diets respectively. This change was short-lived and there was no evidence of any carryover effect into the next treatment period.

Plasma lipids and lipoproteins

Table 3 shows the results for the fasting plasma lipids and lipoproteins concentrations. Statistically significant differences between diets in HDL- and HDL2-cholesterol concentrations (P=0·009 and P=0·042) were noted between diets. Plasma HDL- and HDL2-cholesterol concentrations were lower on the trans diet compared with the oleate diet (P=0·018 and P=0·05 respectively). Repeated-measures ANOVA revealed a significant effect of diet on the LDL-cholesterol:HDL-cholesterol and apolipoprotein B:apolipoprotein A-I ratios (P=0·0004 and P=0·0027). The LDL-cholesterol:HDL-cholesterol and apolipoprotein B:apolipoprotein A-I ratios were significantly higher on the trans diet compared with the oleate (both P<0·01) and carbohydrate diets (both P<0·05).

Table 4 shows the postprandial changes in plasma cholesterol and TAG concentrations. Plasma cholesterol fell compared with the fasting value on all diets (P<0·001) following the test meals. There was a significant difference between diets in the postprandial changes in plasma cholesterol (P=0·05); the normalized area under the curve for the postprandial change in plasma cholesterol following the oleate diet was 18·5 (95 % CI 6·9, 30·0) % lower (P<0·01) compared with the high-carbohydrate diet. As expected, the increase in plasma TAG concentration from fasting was greater on the oleate diet and the trans diet than on the carbohydrate diet.

![Fig. 1. Plasma concentrations of trans-18 : 1 in total plasma lipids according to treatment sequence. T, trans; C, carbohydrate; O, oleate. For details of subjects, diets and procedures, see Tables 1 and 2 and p. 768. Values are means with 95% CI for five subjects, except for sequence C–T–O when n=4.](https://www.cambridge.org/core/terms).
Table 3.  Body weight and fasting plasma lipid and lipoprotein concentrations in subjects following diets containing 10% energy from trans-18:1 compared with diets where the energy from trans-18:1 had been replaced with oleate or carbohydrate‡.

<table>
<thead>
<tr>
<th>Diet</th>
<th>Mean</th>
<th>SD</th>
<th>Statistical significance of effect (F, P)</th>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>F</td>
</tr>
<tr>
<td>Trans</td>
<td>78·2</td>
<td>8·3</td>
<td>NS</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>4·28</td>
<td>0·44</td>
<td>NS</td>
</tr>
<tr>
<td>LDL-cholesterol</td>
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<td>0·44</td>
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<tr>
<td>HDL cholesterol</td>
<td>1·18††</td>
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<tr>
<td>HDL3-cholesterol</td>
<td>1·01</td>
<td>0·19</td>
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<td>LDL-cholesterol:HDL-cholesterol</td>
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<tr>
<td>Lp(a)</td>
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<td>NS</td>
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<tr>
<td>Apolipoprotein A-I</td>
<td>1·12</td>
<td>0·20</td>
<td>NS</td>
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<tr>
<td>Apolipoprotein A-II</td>
<td>0·38</td>
<td>0·06</td>
<td>NS</td>
</tr>
</tbody>
</table>

‡ For details of subjects, diets and procedures, see Tables 1 and 2 on p. 768.

§ Geometric mean values with approximate SD.

{Median values with interquartile range.}

The intake of trans fatty acids in the UK diet is estimated to be approximately 2% energy intake, equivalent to 5 g/d (British Nutrition Foundation, 1995). The present study used an intake of trans fatty acids some five-fold greater than this when expressed in terms of % energy. The absolute intake of trans fatty acids was even greater, about 38 g/d, as the energy intake of the subjects was relatively high. Margarine was chosen as the source of trans fatty acids as studies have reported an association between trans fatty acids provided by margarine, as opposed to those provided by ruminant animal fats, and risk of CHD (Willett et al. 1993). A high intake was employed in order to provoke potentially adverse effects on haemostatic function.

The trans diet supplied a mixture of isomers of trans-18:1, typical of that found in industrially hydrogenated fat (Wolff et al. 1998). Platelet glycerophospholipid fatty acid composition was measured as a biomarker of trans fatty acid intake (Mensisk & Hornstra, 1995). Trans-18:1 was incorporated into the platelets mainly at the expense of
This finding that the trans-18:1 compared with diets where the energy from trans-18:1 had been replaced with oleate or carbohydrate† (Mean values and standard deviations)

<table>
<thead>
<tr>
<th>Diet...</th>
<th>n</th>
<th>Time</th>
<th>Carbohydrate</th>
<th>Oleate</th>
<th>Trans</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Cholesterol (mmol/l)</td>
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<td>3 h</td>
<td>4·27</td>
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<td></td>
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<td>7 h</td>
<td>4·24</td>
<td>0·68</td>
<td>4·08</td>
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<td>Triacylglycerol (mmol/l)</td>
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<td>3 h</td>
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<tr>
<td></td>
<td></td>
<td>7 h</td>
<td>1·64</td>
<td>0·70</td>
<td>2·23†‡ 1·50</td>
</tr>
<tr>
<td>PAI-1 (units × 10^3/l)</td>
<td>27</td>
<td>3 h</td>
<td>13·92</td>
<td>5·47</td>
<td>12·84</td>
</tr>
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<td></td>
<td></td>
<td>7 h</td>
<td>9·03†‡</td>
<td>3·34</td>
<td>8·88†‡ 4·39</td>
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<tr>
<td>t-PA (units × 10^3/l)§</td>
<td>28</td>
<td>3 h</td>
<td>1·68</td>
<td>1·14</td>
<td>1·86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 h</td>
<td>2·19††</td>
<td>0·89</td>
<td>2·65†† 1·03</td>
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<tr>
<td>D-dimer (µg/l)</td>
<td></td>
<td>29</td>
<td>3 h</td>
<td>37</td>
<td>29–83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 h</td>
<td>42</td>
<td>26–92</td>
<td>39</td>
</tr>
<tr>
<td>Fibrinogen (g/l)¶</td>
<td>25</td>
<td>3 h</td>
<td>2·43</td>
<td>0·44</td>
<td>2·37</td>
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<tr>
<td></td>
<td></td>
<td>7 h</td>
<td>2·42</td>
<td>0·51</td>
<td>2·35</td>
</tr>
<tr>
<td>FVIIc (%)</td>
<td>29</td>
<td>3 h</td>
<td>101</td>
<td>27</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 h</td>
<td>112†‡</td>
<td>31</td>
<td>118*‡‡ 30</td>
</tr>
</tbody>
</table>

PAI-1, plasminogen activator inhibitor type 1; t-PA, tissue plasminogen activator; FVIIc, Factor VII coagulant activity.
Mean values were significantly different from those of the carbohydrate diet: *P<0·05, **P<0·01.
Mean values were significantly different from fasting values: †P<0·05, ††P<0·01.
† For details of subjects, diets and procedures, see Tables 1 and 2 and p. 768.
§ Geometric mean values and standard deviations.
¶ Median values and interquartile ranges.
† Values for non-smoking subjects only.

Stearic acid (18 : 0) and demonstrated good compliance to the dietary regimen. The absorption of trans fatty acids appeared to be high as the proportion of trans fatty acids in chylomicron TAG was similar to that in the dietary fat. The plasma concentrations of trans-18:1 in plasma total lipids increased markedly following the consumption of the trans diet but importantly returned to normal values following the high-carbohydrate and high-oleate diets. This demonstrates that the effects of trans fatty acids on plasma lipids are short-lived and the study was not confounded by carryover effects. Furthermore, statistical testing for carryover effects did not reveal any significant effect of treatment order on the outcome variables.

The main effect of the trans diet was to lower HDL- and HDL2-cholesterol concentrations, which is in agreement with another report (Judd et al. 1994). In agreement with previous reports (Sanders et al. 1997), plasma cholesterol concentrations were found to fall significantly following a meal. Plasma cholesterol concentrations fell to a greater extent postprandially following the oleate diet compared with carbohydrate diet. The reason for this requires further study. Patsch et al. (1992) have argued that elevated TAG concentrations 6–8 h following a meal indicate impaired clearance of TAG-rich lipoproteins and are associated with risk of CHD. Both the 3 h plasma TAG concentrations and normalized areas under the curves were greater on the oleate and trans diets compared with the carbohydrate diet. This finding that the trans isomers of 18 : 1 does not differ from oleic acid is in agreement with the results of a test meal study (Sanders et al. 2000). As neither fasting nor postprandial TAG concentrations were greater on the trans diet, the lower HDL-cholesterol concentrations cannot be attributed to increased VLDL synthesis. The lower HDL2-cholesterol could result from increased hepatic lipase activity or cholesteryl ester transfer protein activity (Abbey & Nestel, 1994), which would cause a higher rate of catabolism of HDL. In the present study the trans-18:1 diet did not differ with regard to its effects on Lp(a) from oleate, in agreement with Clevidence et al. (1997), or from carbohydrate. We have previously argued (Sanders et al. 1997) that Lp(a) concentrations are influenced by dietary fatty acid chain-length rather than cis–trans configuration.

The main purpose of the present study was to investigate the effects of trans fatty acids on haemostatic risk factors for CHD in both the fasted and fed state. In the present study, we were careful to ensure that venepunctures wereatraumatic and we have previously demonstrated that under the conditions used plasma concentrations of fibrinopeptide A are low (Sanders et al. 2000, 2001). FVIIc and fibrinogen were also measured on two occasions at the end of each treatment period to decrease error. Fasting plasma FVIIc has been reported to be similar on diets containing trans fatty acids compared with diets rich in saturated fatty acids (Almendingen et al. 1996; Mutanen & Aro, 1997). In the present study, fasting plasma FVIIc did not differ between oleate or trans-18:1 rich diets. However, plasma FVIIc activity increased postprandially
to a greater extent on the oleate diet than on the carbohydrate diet. Furthermore, FVIIc remained elevated 7 h following the test meal on both the oleate and trans-18:1 diets, but had returned to the fasting value on the carbohydrate diet. Our present observations do not support the contention by Larsen et al. (1999) that a diet rich in oleic acid results in a fall in FVIIc and are consistent with our previous study (Sanders et al. 1997).

Almendingen et al. (1996) compared the effects of partially hydrogenated fish oil, partially hydrogenated soya-bean oil and butterfat on fibrinolytic and coagulation variables in thirty-one young men using a crossover design with each diet being taken for 3 weeks. A criticism of that study is that the intakes of saturated fatty acids were not controlled and consequently the observed effects cannot be attributed to the trans fatty acid content of the diet. Mutanen & Aro (1997) used a parallel design to study the effects of changing from a butter-rich diet either to one containing 8·7% energy as trans-18:1 from partially hydrogenated vegetable oil or to a diet high in stearic acid for 5 weeks in predominantly young female subjects. However, in that study the comparison was between diets high in saturated fatty acids, which may have adverse effects on coagulation and fibrinolysis, and menstrual cycle variations are known to lead to substantial variations in haemostatic variables. Furthermore, neither of the previous studies adequately controlled for smoking habit, which can affect plasma fibrinogen.

The PAI-1 and t-PA activities reported in the present study are similar to the values reported (Sanders et al. 1997) in male subjects consuming diets supplying 30% energy from fat, which were either high (butter) or low (olive oil) in saturated fat. Almendingen et al. (1996) found that the consumption of partially hydrogenated soya-bean oil resulted in higher PAI-1 antigen concentrations and PAI-1 activity compared with a butter-rich diet or a diet containing partially hydrogenated fish oil. However, Mutanen & Aro (1997) found no change on a diet high in trans-18:1 compared with a stearate-rich or a butter-fat diet. Muller et al. (2001) compared the effects of three diets with three different margarines, one based on palm oil, one based on partially hydrogenated soya-bean oil and one with a high content of polyunsaturated fatty acids, on diurnal postprandial haemostatic variables in nine subjects. These authors found no effect on PAI-1 activity, but reported lower t-PA activity on the partially hydrogenated soya-bean oil diet. The results of the present study, which suggest that trans-18:1 (where the trans fatty acids were derived from isomerized high-oleic acid sunflower) had no effect on PAI-1 or t-PA activity. It is possible that partially hydrogenated soya-bean oil contains other isomeric fatty acids not found in the isomerized high-oleic acid sunflower oil used in the present study and that these exert differing effects, especially as isomers are formed from linolenic acid (18:3n-3), which is present in significant concentrations in soya-bean oil. Increased PAI-1 activity is strongly associated with plasma TAG concentration and, therefore, might be expected to increase following the consumption of a high-fat meal. However, in the present study, PAI-1 activity was found to decline, in agreement with previous studies from our group (Oakley et al. 1998; Sanders et al. 2001). It is notable that PAI-1 activity was not increased on the carbohydrate diet compared with the oleate diet; this is in contrast with a study by Lopez-Segura et al. (1996), who reported a significant decline in PAI-1 activity in twenty-one young male subjects following a high-oleate diet compared with a reduced-fat diet (National Cholesterol Education Program Step I diet; Yu-Poth et al. 1999).

Plasma fibrinogen is an acute-phase protein and can reflect inflammation. Almendingen et al. (1996) reported that plasma fibrinogen decreased on a diet containing partially hydrogenated fish oil compared with a butter-rich diet. However, Mutanen & Aro (1997) reported a significant increase in plasma fibrinogen on a stearic acid-rich diet but not on the trans-18:1-rich diet compared with a butter-rich diet. In the present study care was taken to exclude any influence of cigarette smoking, which is known to elevate plasma fibrinogen, and non-smoking status was confirmed by measurement of plasma cotinine. Furthermore, replicate measurements of fibrinogen were made to decrease error. The variation in plasma fibrinogen was lower and the geometric mean values differed by <2%. Our present results suggest that plasma fibrinogen is not influenced by the oleic or trans-18:1 content of the diet in healthy men. There was no evidence of any change in D-dimer concentrations: D-dimer is a global marker of fibrin degradation and this would be consistent with a lack of effect on procoagulant and fibrinolytic activity.

The trans-18:1 diet increased the LDL-cholesterol:HDL-cholesterol ratio by 13% compared with a high-oleate diet and by 6% compared with a carbohydrate-rich diet similar to the National Cholesterol Education Programme Step I diet (Yu-Poth et al. 1999). The changes were even less favourable when compared with the high-oleate diet: the trans-18:1 diet decreased the concentrations of HDL- and HDL-2 cholesterol by 6 and 18% respectively. In conclusion, trans-18:1 has an unfavourable effect on some lipid indices of CHD risk, but does not appear to differ from oleate with regard to its effects on known procoagulant and fibrinolytic risk markers in healthy young non-obese men, at least in the short-term. Other mechanisms are required to explain the apparent adverse effects of trans fatty acids on risk of CHD.

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References


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