Dairy and industrial sources of \textit{trans} fat do not impair peripheral insulin sensitivity in overweight women\textsuperscript{1–3}

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\textbf{ABSTRACT}

\textbf{Background:} The 2 major dietary sources of \textit{trans} fatty acids (TFAs) are partially hydrogenated oils and ruminant-derived products. Epidemiologic data suggest that chronic consumption of industrial sources of TFAs could be damaging to insulin sensitivity, but intervention studies on this issue have remained inconclusive.

\textbf{Objective:} The trial was designed to compare the effects of dairy compared with industrial sources of TFAs on insulin sensitivity in overweight women.

\textbf{Design:} Sixty-three healthy women with abdominal obesity [waist circumference $\geq 88$ cm and a body mass index (in kg/m$^2$) $\geq 28$] were recruited. After a run-in period, the volunteers were randomly assigned to consume 1 of 3 four-week diets: 60 g low-TFA lipids/d (0.54 g/d; $n = 21$), ruminant TFA–rich lipids (4.86 g/d; $n = 21$), or industrial TFA–rich lipids (5.58 g/d; $n = 21$). Changes in peripheral insulin sensitivity were assessed by using hyperinsulinemic-euglycemic clamps.

\textbf{Results:} After the intervention period, fasting glycemia and insulinemia and insulin sensitivity were not significantly modified in either group ($P > 0.05$).

\textbf{Conclusions:} These data indicate that consumption of dairy- and industrial-source TFAs for 4 wk at nutritional levels do not impair peripheral insulin sensitivity in insulin-resistant women. Our study may not preassess the effects of TFAs in normal insulin-sensitive individuals. This trial was registered at clinicaltrials.gov as NCT00617435. \textit{Am J Clin Nutr} 2009;90:88–94.

\textbf{INTRODUCTION}

Of all the macronutrients, dietary fatty acids have received the greatest attention as potential inductors of insulin resistance. \textit{Trans} fatty acids (TFAs) are geometrical isomers of \textit{cis} monounsaturated fatty acid (MUFAs). More specifically, the hydrogen atoms in TFAs are on both sides of the fatty acid double bonds, which changes their configuration and chemical properties. The main food sources of TFAs are partially hydrogenated oils (industrial products) and ruminant-derived foods (milk, dairy products, and meat). Milk fat contains low amounts of TFAs (3–7\% by wt) (1) compared with partially hydrogenated oil (10–60\%wt), which makes it difficult to compare their respective effects. The major TFAs formed by partial hydrogenation of vegetable oils is generally elaidic acid (18:1\textit{trans}-9), whereas the main TFA resulting from rumen biohydrogenation is vaccenic acid (18:1\textit{trans}-11) (2). Epidemiologic data suggest that chronic consumption of industrial TFAs could increase the risk of developing type 2 diabetes, especially in obese women with low physical activity (3), but intervention studies on this issue have remained inconclusive. Short-term studies (4–5 wk) in young, lean, and healthy subjects have shown that dietary TFAs from both industrial (4–6) and ruminant sources (7) do not impair insulin and glucose metabolism. Moreover, we recently evidenced the lack of an adverse effect of dairy- or industrial-source TFAs on glucose tolerance in rats (8). In contrast, in obese and insulin-resistant subjects, a diet high in industrial TFAs has been reported to induce increased postprandial insulinemia, which suggests a decrease in glucose tolerance (9). Interventional studies performed on lean and obese volunteers have not been fully conclusive, either because of low numbers of volunteers (4, 5) or methodologic weaknesses in the evaluation of muscle insulin sensitivity (7, 9).

The endpoint of the study was to compare the effect of similar amounts of industrial- and dairy-source TFAs on insulin sensitivity in obese women. The first novel feature of the present clinical trial is that it focuses on the effects of ruminant TFAs on the development of insulin resistance—an aspect that has thus far been widely ignored (4). This is an important issue because ruminant-source TFAs are the major source of TFAs in Europe. The second novel feature of the study is that, contrary to previous trials (4, 5, 9), we assessed nutritional levels of TFAs recommended by food safety authorities.

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SUBJECTS AND METHODS

Study design

This was a 2-center study (led by the Auvergne and Rhône-Alpes Human Nutrition Research Centers) with a randomized, double-blind, controlled design. The experimental design was given approved by the relevant French authorities (Comité de Protection des Personnes, CPP Sud Est VI, AU 679). Information on the objective of the trial and dietary recommendations were provided to the volunteers. The subjects were then asked for written informed consent before participating in the trial. After a 1-wk run-in period, the volunteers were randomly assigned to 3 different diets: low-TFA lipids (Low-TFA diet), ruminant TFA–rich lipids (R-TFA diet), and industrial product–source TFA lipids (IP-TFA diet). Before and after the experimental period, peripheral insulin sensitivity was assessed by using the hyperinsulinenic-euglycemic clamp method. The run-in period was used to allow all subjects to adapt their dietary habits to the study requirements. During this period, all the volunteers received the Low-TFA diet. All the analyses were centralized.

Subjects

Healthy women aged 18–50 y with abdominal obesity [(waist circumference >88 cm and body mass index (BMI; in kg/m²) >28] were recruited. Recruitment was targeted to limit interindividual variability in insulin resistance, which can be cut down to 16% (B Morio personal data, 2003). Indeed, to obtain a test power of 0.8 with α and β risks of 0.05 and 0.20, respectively, 20 subjects per group were required to highlight a 10% variation in insulin sensitivity in one of the intervention groups. Three additional volunteers were recruited in case of possible dropout during the intervention period. Exclusion criteria were a normal medical check-up and preinclusion biological test [red and white blood cell counts, renal and liver function tests, and sodium, chloride, potassium, glucose, total cholesterol, HDL cholesterol, LDL cholesterol, triglyceride, albumin, C-reactive protein (CRP), and orosomucoid concentrations], unstable body weight within the past 3 mo, use of medical drugs interfering with the biological variables, metabolic disorders, menopause, pregnancy or likely to be pregnant, intense physical activity, and eating disorders explored by dietary survey.

Experimental diets

Experimental fat production and analysis

The fatty acid composition, including the trans 18:1 isomer distribution of each experimental fat, of the diets is given in Table 1. Low-TFA fat was obtained by mixing refined palm oil with hydrogenated sunflower oil and rapeseed oils (18% and 12% by wt, respectively) supplied by CEMA, Bondues, France. Its fatty acid composition was designed on the basis of our personal data and was not intended to modify the dietary lipid habits of the obese volunteers. The IP-TFA fat (enriched in elaidic acid) used was partially hydrogenated vegetable oil (V40; CEMA). The R-TFA blend (enriched in trans vaccenic acid) used was manufactured by mixing vaccenic acid–rich milk fat (VAMF) with refined palm and sunflower oils (95%, 2%, and 3% by wt, respectively). VAMF was produced at the “UMR Production de Lait” (INRA, Rennes, France). Briefly, 40 Holstein dairy cows were given a dietary regimen of ad libitum pasture (≈4–15 kg dry matter/d) supplemented with a mixed ration of 5.9% flaxseed oil (Huilerie Vandeputte, Mouscron, Belgium) and 8.8% corn silage. Milk was collected from day 7 of the intervention when the vaccenic acid content of the fat was high.

Experimental products: description and intake

Lactalis R&D prepared the 3 experimental fats in different food items: experimental butter (70% fat content), dessert cream (21.2% fat content), and biscuits (23.5% fat content). Microbiological tests were performed before starting the clinical study. In concert with the dietitians, it was considered that the average energy intake of overweight sedentary women was ≈9200 kJ/d, with lipids representing ≈40% of total energy intake (ie, 93 g lipids/d). Thus, the experimental foods were designed to provide 60 g lipids/d (ie, 64.5% of daily lipid intake), the remaining lipids being provided by trans-free foods, rapeseed oil, and ISO4 vegetable oil (Lesieur, Asnières, France). Every day, each
volunteer had to consume 25 g experimental butter, a 125 g pot of experimental dessert cream, and 68 g biscuits. The protocol required that food containing partially hydrogenated vegetable fat or fat of dairy origin (dairy products, cheeses, and fatty meats from ruminants) had to be avoided during the 5-wk experimental period because they are all sources of TFAs that could distort the results of our study. All volunteers were given dietary advices during the study, including a list of accepted TFA-free bakery, pastry, or snack foods.

**Assessment of dietary compliance**

**Analysis of dietary records**

The volunteers had to record their daily food consumption over 5 d, including 2 weekend days. This food record process was scheduled for the run-in week and the end of the intervention period. The data collected were then analyzed by cross-referencing with French databases (GENI Micro6, Villers-lès-Nancy, France).

**Fatty acid profiling of plasma phospholipids**

Total plasma lipids were extracted as described by Folch et al (10). The phospholipid fraction was separated by thin-layer chromatography on a silica gel plate (Merck, Darmstadt, Germany) and 1-stage mobile phase development, which consisted of solvents of hexane, ethyl ether, and acetic acid in an 80:20:2 (vol: vol) ratio. The plates were dried and sprayed with dichlorofluorescein to visualize cholesterol esters, phospholipids, triacylglycerols, and free fatty acid bands under ultraviolet light. The phospholipid band was scraped off into separate test tubes, and the fatty acids were converted into methyl esters. Fatty acid methyl esters were prepared and analyzed as previously described (8).

**Body-composition measurements**

Body mass was measured to the nearest 0.1 kg on a SECA balance (SECA, Les Mureaux, France). Body composition was measured at the end of the run-in period by dual-energy X-ray absorptiometry with a Hologic QDR 4500 X-Ray bone densimeter (Hologic, Waltham, MA) in Clermont-Ferrand and with a Discovery A system (Hologic, Bedford, MA) in Lyon to determine total and regional body composition, as previously described (11).

**Assessment of insulin sensitivity by hyperinsulinemic-euglycemic clamp**

Insulin sensitivity was assessed before and after the experimental diet period by using the hyperinsulinemic-euglycemic clamp procedure according to De Fronzo (12). After an overnight fast, the subjects were admitted to each center and fitted with intravenous catheters placed in one arm for insulin and glucose infusion and in the other arm for blood sampling. A continuous infusion of insulin (Actrapid HMGe; Novo Nordisk Pharma-ceutique SA, Boulogne-Billancourt, France) diluted in a sterile salt solution was administered for 180 min at a rate of 1 mU · kg BW$^{-1} ·$ min$^{-1}$. The plasma glucose concentration was measured every 10 min by using a glucose reagent strip and a glucometer: a Glucotouch (Lifescan, Milpitas, CA) in Clermont-Ferrand and a Glucotrend (Roche, Burgess Hill, United Kingdom) in Lyon.

Glycemia was then maintained at a constant 0.9 g/L via interval adjustments of a 20% glucose infusion (Braun Medical AG, Emmenbrücke, Switzerland in Clermont-Ferrand and Aguettant, Lyon, France in Lyon) following the negative feedback principle. Glucose and insulin concentrations were measured 30 min before the clamp and then at 0, 150, 160, 170, and 180 min after the insulin perfusion began. Glucose concentrations were determined in plasma samples by using an automated system (Konelab, ThermoElectron Corporation, Waltham, MA). The chemicals used were purchased from the ThermoElectron Corporation. Insulin was measured by using an enzyme-linked immunosorbent assay kit purchased from Biosource (Camarillo, CA). The insulin sensitivity index was assessed by using the index from Katz (13):

$$\text{ISI} = \frac{M}{(G \times \Delta I)}$$

where $M$ is the steady state glucose infusion rate calculated at 10-min intervals, $G$ is the steady state blood glucose concentration, and $\Delta I$ is the difference between fasting and steady state insulin concentrations.

**Analysis of fasting blood samples**

Blood samples were obtained before and after the intervention period after the subjects had fasted overnight. The samples were immediately frozen at −80°C. Fasting plasma lipids (ie, triglycerides, glycero1, free fatty acids, total cholesterol, HDL cholesterol, and LDL cholesterol), inflammatory markers (ie, CRP and orosomucoids), and markers of liver function (ie, aspartate aminotransferase, alanine aminotransferase, and γ-glutamyltransferase) were measured in plasma samples by using an automated system (Konelab 20; ThermoElectron Corporation). Chemicals were obtained from Randox (Crumlin, United Kingdom) for the glucolcerol and free fatty acid tests and from ThermoElectron Corporation for the all other variables measured.

**Statistical analysis**

The statistical analyses were performed by using Statview version 5.0 (SAS Institute Inc, Cary, NC). Results are expressed as means ± SDs. One-factor analysis of variance with repeated measures was used to examine the effect of diets on body composition, insulin sensitivity, and plasma concentrations. A Bonferroni test was used for post hoc analyses. Correlations were determined with bivariate regression analysis (z test). The level of significance was set at 5%.

We decided to make a per protocol and not an intention-to-treat analysis because good compliance with the protocol was a primary outcome in the analysis. In fact, as we enriched the diets in TFAs, the endpoint of the study was to explain their effects and not to give an estimate of the benefit of a change in diet policy in practice. In addition, the insulin sensitivity of the volunteers was variable because of their obesity. Thus, by using per protocol analysis, we reduced the uncertainty due to missing values because it was observed in the intention-to-treat analysis. Finally, because the dropouts reported were independent of the treatment arm, we determined that the per protocol analysis was suitable.
RESULTS

Subject characteristics

Five subjects dropped out during the experimental period: 1 for personal reasons, 1 for incompatible medication during the protocol, and 2 because of acute hepatolithiasis during the trial. The medical history of these 2 volunteers showed a posteriori previous alerts that had not been mentioned during the inclusion interviews. The patient flow diagram of the clinical trial is presented in Figure 1. The subjects’ characteristics before and after the intervention are presented in Table 2. Weight loss and decreased BMI were observed during the experimental period, but without significant effect on insulin sensitivity ($r^2 = 0.001$, $P = 0.80$). Despite our advice, the volunteers changed their dietary habits during the protocol by increasing carbohydrate intakes and decreasing lipid ingestion (time effect, $P < 0.05$) without significant change in total energy intake. During the experimental diet period, trans fat represented on average 2.04 ± 0.27% of the daily energy intake (DEI) in the R-TFA group and 2.59 ± 0.48% of the DEI in the IP-TFA group.

Dietary compliance

As previously described (14, 15), the fatty acid profile of plasma phospholipids showed good incorporation of TFAs. Thus, after the experimental diet period, the plasma phospholipid content in vaccenic acid (18:1trans-11) increased from 0.12 ± 0.08 at baseline to 0.67 ± 0.29 after the intervention period (+458%) in the R-TFA group, whereas it remained unchanged in the other groups ($P < 0.0001$ for time, diet, and the interaction of both). Similarly, the plasma phospholipid content in elaidic acid (18:1trans-9) increased from 0.05 ± 0.03 at baseline to 0.27 ± 0.14 at the end of the experimental period in the IP-TFA group (+440%), whereas it remained unchanged in the other groups ($P < 0.0001$ for time, diet, and the interaction of both). These results indicated excellent dietary compliance from all subjects. All groups showed an increase in the plasma phospholipid content in total n-3 polyunsaturated fatty acids (+6.9%; time effect, $P < 0.05$) and a decrease in the plasma phospholipid content in total saturated fatty acids (−1.1%; time effect $P < 0.01$), and n-6 polyunsaturated fatty acids (−2.2%; time effect, $P < 0.01$). cis-Monounsaturated fatty acids remained unchanged.

Analysis of the hyperinsulinemic-euglycemic clamps

The experimental diets had no effect on fasting glycemia and insulinemia in any of the groups (NS). The steady state glucose infusion rate and insulin sensitivity index were not significantly affected in either group after the experimental period (Table 3). In the R-TFA group, fasting and steady state insulinemia were

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**FIGURE 1.** Patient flow diagram of the Trans-Insulin clinical trial. After a run-in period of 1 wk, the volunteers were randomly assigned into 3 diet groups: low trans fatty acids (Low-TFA), ruminant TDA–rich (R-TFA), and industrial product-source TFA–rich (IP-TFA) diets.
TABLE 2
Subject characteristics according to body composition, fat mass, and dietary habits before and after 4 wk of experimental low trans fatty acid (Low-TFA), ruminant TFA–rich (R-TFA), and industrial product-source TFA–rich (IP-TFA) diets.

<table>
<thead>
<tr>
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<th>Low-TFA</th>
<th>R-TFA</th>
<th>IP-TFA</th>
<th>ANOVA</th>
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<tr>
<td><strong>Body composition</strong></td>
<td></td>
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<tr>
<td>Body weight (kg)</td>
<td>87.8 ± 8.7</td>
<td>87.2 ± 8.5</td>
<td>87.0 ± 9.8</td>
<td>86.7 ± 10.9</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>32.7 ± 2.8</td>
<td>32.5 ± 2.7</td>
<td>32.7 ± 3.4</td>
<td>32.5 ± 3.5</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>96.1 ± 7.1</td>
<td>96.1 ± 7.4</td>
<td>96.9 ± 9.8</td>
<td>97.2 ± 9.9</td>
</tr>
<tr>
<td>Fat mass (%)</td>
<td>40.5 ± 3.0</td>
<td>NA</td>
<td>39.1 ± 3.9</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Dietary records</strong></td>
<td></td>
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<tr>
<td>Energy intake (× 10³ kJ)</td>
<td>8.74 ± 1.49</td>
<td>9.23 ± 1.49</td>
<td>9.41 ± 1.54</td>
<td>9.14 ± 1.42</td>
</tr>
<tr>
<td>Carbohydrates (% of DEI)</td>
<td>39.8 ± 4.7</td>
<td>43.2 ± 6.0</td>
<td>44.0 ± 4.2</td>
<td>45.4 ± 4.4</td>
</tr>
<tr>
<td>Proteins (% of DEI)</td>
<td>14.3 ± 2.4</td>
<td>13.9 ± 3.6</td>
<td>13.2 ± 1.8</td>
<td>12.7 ± 2.2</td>
</tr>
<tr>
<td>Lipids (% of DEI)</td>
<td>45.4 ± 4.7</td>
<td>41.7 ± 5.7</td>
<td>42.5 ± 4.5</td>
<td>41.6 ± 4.0</td>
</tr>
<tr>
<td>Including TFAs (% of DEI)</td>
<td>0.24 ± 0.04</td>
<td>0.23 ± 0.04</td>
<td>0.22 ± 0.04</td>
<td>2.04 ± 0.27</td>
</tr>
</tbody>
</table>

1 All values are means ± SDs. All data were measured in 19, 20, and 19 volunteers in the Low-TFA, R-TFA, and IP-TFA groups, respectively. Comparisons are based on repeated-measures ANOVA with post hoc Bonferroni multiple comparison tests. NS = P > 0.05.

2 Significantly different from baseline of the same diet, P < 0.0001.

3 Significantly different from the Low-TFA group at the same diet duration, P < 0.0001.

TABLE 3
Insulin clamp values before and after 4 wk of the experimental low trans fatty acid (Low-TFA), ruminant TFA–rich (R-TFA), and industrial product-source TFA–rich (IP-TFA) diets.

<table>
<thead>
<tr>
<th></th>
<th>Low-TFA</th>
<th>R-TFA</th>
<th>IP-TFA</th>
<th>ANOVA</th>
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<tr>
<td><strong>Baseline</strong></td>
<td></td>
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<tr>
<td>Fasting glucose (g/L)</td>
<td>0.93 ± 0.10</td>
<td>0.95 ± 0.09</td>
<td>0.96 ± 0.11</td>
<td>0.95 ± 0.08</td>
</tr>
<tr>
<td>Fasting insulin (µU/mL)</td>
<td>9.6 ± 5.1</td>
<td>10.0 ± 5.1</td>
<td>13.0 ± 9.9</td>
<td>11.9 ± 9.2</td>
</tr>
<tr>
<td>HOMA²</td>
<td>2.25 ± 1.35</td>
<td>2.36 ± 1.31</td>
<td>3.26 ± 3.08</td>
<td>2.79 ± 2.20</td>
</tr>
<tr>
<td>Steady state glucose (g/L)</td>
<td>0.86 ± 0.11</td>
<td>0.88 ± 0.08</td>
<td>0.95 ± 0.10</td>
<td>0.95 ± 0.12</td>
</tr>
<tr>
<td>Steady state insulin (µU/mL)</td>
<td>110.4 ± 35.2</td>
<td>120.4 ± 35.3</td>
<td>135.6 ± 33.7</td>
<td>133.2 ± 27.6</td>
</tr>
<tr>
<td>M (ng · kg body wt⁻¹ · min⁻¹)³</td>
<td>5.64 ± 2.49</td>
<td>5.64 ± 2.01</td>
<td>5.57 ± 1.37</td>
<td>5.71 ± 1.65</td>
</tr>
<tr>
<td>ISI⁴</td>
<td>7.69 ± 5.45</td>
<td>6.41 ± 3.25</td>
<td>5.18 ± 1.83</td>
<td>5.39 ± 2.31</td>
</tr>
</tbody>
</table>

¹ All values are means ± SDs. All data were measured in 19, 20, and 19 volunteers in the Low-TFA, R-TFA, and IP-TFA groups, respectively. In the R-TFA group, one volunteer was excluded from the measurements of fasting and steady state insulinemia and homeostasis model assessment (HOMA). Comparisons are based on repeated-measures ANOVA with post hoc Bonferroni multiple comparison tests. NS = P > 0.05.

² HOMA of insulin resistance = [fasting glyceremia (mmol/L) × fasting insulinemia (µU/mL)]/22.5.

³ M is the steady state glucose infusion rate calculated at 10-min intervals.

⁴ The insulin sensitivity index was assessed by using the index of Katz et al (13), ie, ISI = M(G × ΔI), where G is the steady state blood glucose concentration and ΔI is the difference between fasting and steady state insulin concentrations.
used in the food industry. Therefore, food safety authorities need clear, scientifically proven information to further legislate on the subject.

Many interventional studies have focused on the effect of TFAs on the global risk of developing type 2 diabetes measured by meal- or glucose-tolerance tests or fasting glyceremia and insulinemia. Indeed, in a population with a broad range of glucose tolerance, Lovejoy et al (16) failed to show any association between either self-reported IP-TFA intake or serum lipid TFA concentrations and the insulin response to an oral-glucose-tolerance test. In contrast, in obese and insulin-resistant subjects, a diet high in industrial TFAs (20% of total DEI) for 6 wk has been reported to induce increased postprandial insulinemia after a meal-tolerance test, which suggests a decrease in glucose tolerance (9). More recently, new data were obtained on the effects of TFAs of dairy origin because it is now possible to produce experimental dairy vaccenic acid–enriched fat. A nutritional intervention study performed in healthy young men found no effects of vaccenic acid–rich dairy fat on fasting insulin and glucose (7). Experimentally, in Wistar rats, we observed no changes in the insulin and glucose responses to an intraperitoneal injection of glucose after 8 wk of experimental diets enriched in TFAs of either dairy or industrial origin at 4.1% of total DEI (8). These data were reinforced by recent findings by Wang et al (17), ie, consumption of a diet enriched in vaccenic acid for 4 wk had no effect on insulin and glucose metabolism in obese rats in response to a meal-tolerance test. Thus, given the results of these studies, TFAs of dairy origin may not impair glucose tolerance at a physiologic dose or during a short-term period.

However, the previous studies failed to distinguish the effects of TFAs on either insulin resistance or insulin secretion. In fact, peripheral resistance to insulin action is an important feature in step forward type 2 diabetes because it preceded by 10–20 y its development. Louheranta et al (4, 18) showed no adverse effect of industrial TFAs of either dairy or industrial origin at 5.1% of total DEI on insulin secretion by the pancreas is an important feature in the increased risk of developing type 2 diabetes. Louheranta et al (4, 18) failed to show an effect of industrial TFAs (5.1% of total DEI) on insulin secretion in healthy lean women. Presently, there are no available data on the effect of TFAs of dairy origin on insulin secretion. Thus, to fully understand the effects of dairy-source TFAs on type 2 diabetes, further in vivo investigations are needed to assess their effect on β cell metabolism.

Our study may not be able to pre-assess the effects of higher doses of TFAs, but it does confirm the food safety authority recommendations that their intake should be limited to 2% of the total DEI. In fact, the content of total fatty acids and TFAs in the diet is an important determinant in the metabolic response. Indeed, the large total lipid intake (~41–44% of the total DEI) during our trial could have interfered with our results. This phenomenon was previously observed in the KANWU (Kuopio,

### Table 4

<table>
<thead>
<tr>
<th></th>
<th>Low-TFA</th>
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<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Follow-up</td>
<td>Baseline</td>
<td>Follow-up</td>
</tr>
<tr>
<td>Triglycerides (g/L)</td>
<td>0.80 ± 0.35</td>
<td>0.95 ± 0.59</td>
<td>0.13 ± 0.10</td>
<td>0.98 ± 0.39</td>
</tr>
<tr>
<td>Total-C (g/L)</td>
<td>1.85 ± 0.27</td>
<td>1.77 ± 0.27</td>
<td>1.88 ± 0.38</td>
<td>1.94 ± 0.33</td>
</tr>
<tr>
<td>HDL-C (g/L)</td>
<td>0.55 ± 0.14</td>
<td>0.52 ± 0.13</td>
<td>0.53 ± 0.15</td>
<td>0.51 ± 0.13</td>
</tr>
<tr>
<td>LDL-C (g/L)</td>
<td>1.16 ± 0.27</td>
<td>1.09 ± 0.25</td>
<td>1.15 ± 0.35</td>
<td>1.24 ± 0.30</td>
</tr>
</tbody>
</table>

1 All values are means ± SDs. All data were measured in 19, 20, and 19 volunteers in the Low-TFA, R-TFA, and IP-TFA groups, respectively. HDL-C, HDL cholesterol; LDL-C, LDL cholesterol; Total-C, total cholesterol. Comparisons are based on repeated-measures ANOVA with post hoc Bonferroni multiple comparison tests. NS = P > 0.05.

2 Significantly different from baseline of the same diet, P < 0.05.
Aarhus, Naples, Wollong, and Upsala) study, which showed that the beneficial effect of cis monounsaturated fatty acids on insulin sensitivity was lost when the total fatty acid intake was 37% of the DEI (21). Therefore, in the same manner, it may be possible that the decrease in lipid intake in all groups could have masked the TFA-induced development of muscular insulin resistance; however, in this case we would have found an increase in insulin sensitivity in the Low-TFA group. Thus, the discrepancy between our results and those of Christiansen et al (9) in obese volunteers is probably due to the amount of industrial TFAs consumed (2.6% compared with 20% of the total DEI).

Finally, it is important to note that our results may not preclude the effect of TFAs on the other components of the metabolic syndrome. More specifically, in the present study, HDL cholesterol decreased in response to the intervention in all groups (P < 0.001). This result is surprising because our results indicated a significant decrease in the volunteers’ body weight and lipid intake. However, for the Low-TFA group, the explanation could be that we used a palm oil–based blend to obtain a control diet similar to the baseline dietary habits for intake of saturated and cis monounsaturated fatty acids. Palm oil has been reported to decrease HDL cholesterol similarly to partially hydrogenated fat (22). In addition, previous studies reported a decrease in HDL cholesterol of 7.5% in the industrial-source TFA experimental diet and of 2.3% in the dairy-source TFA experimental diet in healthy young women (19).

Dairy- and industrial-source TFAs ingested at nutritionally normal levels do not impair muscle insulin sensitivity in overweight and obese women. However, the principle of precaution requires that our conclusion, which focused on skeletal muscle weight and obese women. However, the principle of precaution requires that our conclusion, which focused on skeletal muscle

REFERENCES