Effects of one single bout of low-intensity exercise on postprandial lipaemia in type 2 diabetic men

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Type 2 diabetes is characterised by insulin resistance, and is associated with a breakdown of lipid homeostasis reflected by elevated levels of circulating NEFA and triacylglycerols in the fasting and postprandial period, low HDL-cholesterol and a preponderance of small, dense LDL. All these factors contribute to an increased risk of CVD in type 2 diabetes (Fraze et al. 1985; Chen et al. 1993; Isomaa et al. 2001; Taskinen, 2003). Exaggerated postprandial lipaemia has been linked to arteriosclerosis (Patsch et al. 1992; Ryu et al. 1992; Boquist et al. 1999; Karpe, 1999). The exaggerated triacylglycerol response in type 2 diabetes seems partly to derive from an increased substrate delivery of NEFA and glycerol from the adipose tissue to the liver and an increased hepatic secretion of VLDL particles due to extrahepatic and hepatic insulin resistance (Malmstrom et al. 1997). In addition to fasting triacylglycerol levels, diet, current smoking and alcohol consumption have been shown to influence postprandial lipid responses (Parks, 2001; Sharrett et al. 2001; Thomsen et al. 2003).

Alcohol in moderate amounts also seems to have a beneficial effect on the risk of developing both type 2 diabetes and CVD. The Health Professionals’ follow-up study showed that the regular intake of moderate alcohol amounts is associated with a reduced relative risk of developing type 2 diabetes by 50% (Conigrave et al. 2001). Also, drinking on at least 3 or 4 d/week is associated with a decrease in the relative risk of myocardial infarction by 37% (Mukamal et al. 1993). Type 2 diabetic women who engaged in moderate exercise for 4 h or more/week had a relative risk of a cardiovascular event of 0·55 compared with diabetic women who exercised for less than 1 h/week (Hu et al. 2001). Also, the relative risk of CVD in type 2 diabetic men with low fitness was found to be twice that of fit diabetic men (Wei et al. 2000). Some investigators have shown that one single bout of exercise less than 24 h before a meal can reduce postprandial lipaemia (Schierf et al. 1987; Tsetsonis & Hardman, 1996; Tsetsonis et al. 1997; Gill et al. 2002; Pettit et al. 2003). Few studies have compared how exercise influences postprandial lipaemia in response to alcohol intake (Hartung et al. 1993; Rasmussen et al. 1999; El Sayed & AL-Bayatti, 2001; Suter et al. 2001).

**Exercise:** Physical activity; Diabetes mellitus; Postprandial lipaemia; ethanol

Abbreviations: AUC, area under the curve; iAUC, incremental area under the curve.

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Fighting type 2 diabetes and its high risk of CVD, lifestyle intervention with diet and exercise is of uttermost importance. Epidemiological studies strongly suggest an inverse association between increased physical activity, moderate alcohol drinking and the incidence of both type 2 diabetes and CVD. However, alcohol is known to increase postprandial lipaemia, a risk marker of CVD, and exercise to reduce postprandial lipaemia in healthy individuals. The aim of the present study was to investigate how type 2 diabetic men respond, in the postprandial period, to a single exercise session feasible to perform on a daily basis for type 2 diabetic men. The twelve participants ingested a test meal containing 100 g butter, 50 g carbohydrate, together with 40 g alcohol, at each meal test, imitating a social meal situation. Two protocols included exercise sessions with 40 min at 40 % VO2max, one where they exercised 3·5 h after, and another the afternoon before the test meal. One protocol was without any exercise. No significant effect of low-intensity exercise on postprandial lipaemia following a fat-rich meal with alcohol was seen in the middle-aged type 2 diabetic men.

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Most of the literature concerning postprandial lipaemia and exercise includes healthy individuals engaged in moderate exercise for long periods (Petit & Cureton, 2003). Little is known about the influence of low-intensity exercise and alcohol on postprandial lipaemia in diabetic individuals, which is of relevance to describe in relation to future health recommendations regarding exercise and alcohol intake. The objective of the present study was to determine the acute effects of an exercise stimulus that would be realistic to perform on a daily basis on the postprandial responses in type 2 diabetic men when their metabolic system was challenged by alcohol and fat.

Subjects and methods

Study group

Fourteen type 2 diabetic men were included in the present study; two participants left the study, because of their job situation. The mean duration of type 2 diabetes for the participants was 3.3 (SD 2.2) years. The mean age of the twelve participants was 59.3 (SD 10.4) years, BMI 27.9 (SD 2.8) kg/m², and waist circumference 104.0 (SD 5.9) cm. The screening level of HbA₁c was 7.2 (SD 1.3) %; the fasting triacylglycerol level was 2.8 (SD 2.0) mmol/l. The mean VO₂max was low (28 (SD 6) ml/kg per min). The workload during exercise ranged from 32.7 to 89.9 W. Mean workload was 59 (SD 21) W. We did not measure heart rate continuously during the exercise sessions.

Interventions

Nutritional supplement. The participants ingested a high-carbohydrate diet delivered by the dietitian, with an energy distribution of 50 % carbohydrate, 32 % fat and 18 % protein on the first day of each protocol. The food amount corresponded to individual energy requirements estimated by the Harris–Benedict equation with adjustment for activity (Pellett, 1990). After the meal test, a meal was served at the investigation site and a food pack for the rest of the day was delivered ensuring that total energy ingested on day 2 was similar to the energy ingested on day 1; however, the energy distribution was not similar due to the high content of fat in the test meal.

Test conditions. At each meal test the same meal with alcohol was served at T = 0 min. The meal consisted of an energy-free soup with 100 g butter (80 g fat) plus 40 g alcohol and 50 g carbohydrate as white bread. The meal contained mainly saturated fatty acids (72 % of total fat). The soup was chilled briefly and then butter was added. Sliced raw leek was added to give taste. The meal test ended at T = 480 min. The morning after each meal test, the participants arrived after an 11 h fast and delivered fasting blood samples (T = 0). No exercise was performed in protocol B. Exercise in 2 £ 20 min at 40 % VO₂max was performed 210 ± 21 min after T = 0 in protocol B, and in protocol C the same amount of exercise was performed during the afternoon about 16 h before T = 0.

The participants were instructed to standardise and minimise their physical activity 3 d before the protocols started.
No alcohol drinking or heavy physical work was allowed 24 h preceding each protocol. No smoking or intake of medication was allowed from day 1 in the protocols. On the second day, following an 11 h fast, the subjects arrived between 07.00 and 07.30 hours using a minimum of physical activity. Subsequently a catheter was placed in an antecubital vein and basal blood samples were drawn 15 min later (baseline period). The meal test started at T = 0 min and the meal was ingested during a 20 min period. The participants were allowed to walk freely in the ward during the meal test. Blood samples were drawn every 1 h the first 4 h and thereafter at T = 360 min and T = 480 min for analysis of glucose, insulin, fatty acids, triacylglycerol, total cholesterol and HDL-cholesterol. Plasma was immediately separated by centrifugation at 2000 g for 20 min at 4°C and kept frozen at −20°C until analysed.

**Bioanalysis**

Plasma glucose was measured by a glucose oxidase method (CV 3.8%) (MPR 3 166 391 glucose/GOD-PAP method; Boehringer Mannheim, Mannheim, Germany) (Trinder, 1969). Serum insulin concentrations were measured by an ELISA method (CV 1.7%) (Andersen et al. 1993). Serum triacylglycerols (CV 2.05%), serum cholesterol (CV 1.9%), serum HDL-cholesterol (CV 3.9%) (code no. 701912, 2016630, 543004, respectively; Roche Diagnostics GmbH, Mannheim, Germany), and serum fatty acids (CV 1.1%) were measured with standard enzymic colorimetric assays by using commercial kits (code no. 994-75409; Wako Chemicals GmbH, Neuss, Germany).

**Statistical analysis**

Results are expressed as mean values and standard deviations of individually analysed data for the twelve participants. For paired comparisons between fasting values, area under the curve (AUC), incremental AUC (iAUC) and one-way repeated measures of ANOVA were used. Whenever data were not normally distributed, the Friedman repeated measures ANOVA on ranks was used. In case of statistical differences between these groups, a Student–Newman–Keuls post hoc test was used. Significance was assessed by two-tailed tests (SigmaStat version 2.03; BMDP Statistical Software, Berkeley, CA, USA). P<0.05 was considered statistically significant. The trapezoidal rule was used to calculate the AUC and iAUC for glucose, insulin, NEFA, total and HDL-cholesterol and triacylglycerol. The iAUC is calculated from the summation of the mean concentration for each time period after subtraction of the mean basal value, multiplied by the number of minutes in the time period. Values below baseline were calculated as negative. The iAUC derived expresses both the duration and the magnitude of the responses, while correcting for baseline values. Insulin sensitivity was calculated, for each of the three protocols, by the homeostasis model assessment model for the fasting values at T = 0 min and T = 1440 min (Matthews et al. 1985; Haffner et al. 1996). Insulin resistance was calculated as follows:

\[
\text{Insulin resistance} = \frac{(\text{fasting insulin} \times \text{fasting glucose})}{22.5}
\]

**Results**

**Basal values, areas under the curve and incremental areas under the curve**

Twelve type 2 diabetic men completed the present study. Weight decreased slightly during the study period from 91.6 (SD 12.2) to 90.8 (SD 12.3) kg at the end of the study (P = 0.045).

No differences between fasting values at T = 0 for each of the three protocols (Table 1) were seen except for the
lower values of HDL-cholesterol for protocol B compared with protocol A (Table 1).

**Triacylglycerols.** No significant differences between the three protocols were detected (Tables 1, 2 and 3). Triacylglycerol levels after 8 h were increased by about 75 % compared with the fasting values (Fig. 2).

**Non-esterified fatty acids.** No differences between protocols were observed for NEFA (Tables 1, 2 and 3).

**Cholesterol responses.** Fasting HDL-cholesterol was higher at $T = 0$ in protocol A compared with protocol B (Table 1). No significant differences in AUC or iAUC for total cholesterol or HDL-cholesterol between the three protocols were detected (Tables 2 and 3).

**Glucose, insulin and insulin sensitivity.** No significant differences in iAUC of glucose and insulin between the three protocols were detected (Table 2). The AUC for insulin on meal test C was significantly higher than the two other days (Table 3). No significant differences in insulin sensitivity, measured by the homeostasis model assessment model, were found (Table 4).

**Discussion**

In the present study, we did not detect any immediate impact on postprandial lipaemia by an amount of exercise that we estimated realistic in daily living for semi-sedentary

### Table 1. Basal fasting glucose, insulin and lipids in twelve type 2 diabetic men for each of the protocols* (Mean values and standard deviations)

<table>
<thead>
<tr>
<th></th>
<th>Protocol A</th>
<th>Protocol B</th>
<th>Protocol C</th>
<th>P value (comparisons between protocols)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma glucose (mmol/l)</td>
<td>9.3 ± 2.7</td>
<td>8.9 ± 2.0</td>
<td>9.2 ± 2.4</td>
<td>0.92</td>
</tr>
<tr>
<td>Serum insulin (pmol/l)</td>
<td>43.1 ± 35.5</td>
<td>45.2 ± 37.5</td>
<td>49.4 ± 49.9</td>
<td>0.53</td>
</tr>
<tr>
<td>Serum triacylglycerol (mmol/l)</td>
<td>2.6 ± 1.6</td>
<td>2.4 ± 1.6</td>
<td>2.7 ± 2.5</td>
<td>0.21</td>
</tr>
<tr>
<td>Serum NEFA (mmol/l)</td>
<td>0.7 ± 0.2</td>
<td>0.7 ± 0.2</td>
<td>0.7 ± 0.2</td>
<td>0.57</td>
</tr>
<tr>
<td>Serum cholesterol (mmol/l)</td>
<td>6.0 ± 1.0</td>
<td>5.7 ± 0.7</td>
<td>5.9 ± 0.9</td>
<td>0.25</td>
</tr>
<tr>
<td>Serum HDL-cholesterol (mmol/l)</td>
<td>1.07± 0.29</td>
<td>0.88± 0.36</td>
<td>0.97± 0.26</td>
<td>0.02</td>
</tr>
</tbody>
</table>

* ab Mean values within a row with unlike superscript letters were significantly different ($P = 0.02$)

* In protocol A, participants did not exercise; in protocol B, participants rested the day before the meal test and exercised for 40 min at 40% $V_{O2\max}$ on the day of the meal test; in protocol C, participants exercised for 40 min at 40% $V_{O2\max}$ the day before the meal test.

### Table 2. Incremental areas under the curve (iAUC) of glucose, insulin and lipids following a test meal in twelve type 2 diabetic men for each of the protocols* (Mean values and standard deviations)

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>iAUC glucose (mmol/l × 480 min)</td>
<td>202 ± 535</td>
<td>73 ± 555</td>
<td>74 ± 609</td>
<td>0.42</td>
</tr>
<tr>
<td>iAUC triacylglycerol (mmol/l × 480 min)</td>
<td>31.56 ± 17.0 97</td>
<td>28.64 ± 19.4 17</td>
<td>34.51 ± 21.6 26</td>
<td>0.56</td>
</tr>
<tr>
<td>iAUC fatty acids (mmol/l × 480 min)</td>
<td>–75 ± 94</td>
<td>–69 ± 92</td>
<td>–67 ± 96</td>
<td>0.85</td>
</tr>
<tr>
<td>iAUC cholesterol (mmol/l × 480 min)</td>
<td>–77 ± 72</td>
<td>–20 ± 89</td>
<td>–24 ± 115</td>
<td>0.07</td>
</tr>
<tr>
<td>iAUC HDL-cholesterol (mmol/l × 480 min)</td>
<td>–83 ± 84</td>
<td>9 ± 134</td>
<td>–32 ± 89</td>
<td>0.08</td>
</tr>
</tbody>
</table>

* Test meal consisted of soup plus carbohydrate (50 g) plus alcohol (40 g) plus butter (100 g). In protocol A, participants did not exercise; in protocol B, participants rested the day before the meal test and exercised for 40 min at 40% $V_{O2\max}$ on the day of the meal test; in protocol C, participants exercised for 40 min at 40% $V_{O2\max}$ the day before the meal test.

### Table 3. Areas under the curve (AUC) of glucose, insulin and lipids following a test meal in twelve type 2 diabetic men for each of the protocols* (Mean values and standard deviations)

<table>
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<th>Protocol A</th>
<th>Protocol B</th>
<th>Protocol C</th>
<th>P value (comparisons between protocols)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUC glucose (mmol/l × 480 min)</td>
<td>4658 ± 1432</td>
<td>4347 ± 1170</td>
<td>4493 ± 1183</td>
<td>0.2</td>
</tr>
<tr>
<td>AUC insulin (pmol/l × 480 min)</td>
<td>51.518± 31.204</td>
<td>50.320± 35.736</td>
<td>58.233± 42.865</td>
<td>0.03</td>
</tr>
<tr>
<td>AUC triacylglycerol (mmol/l × 480 min)</td>
<td>1803 ± 1023</td>
<td>1741 ± 1261</td>
<td>1932 ± 1595</td>
<td>0.72</td>
</tr>
<tr>
<td>AUC fatty acids (mmol/l × 480 min)</td>
<td>267 ± 76</td>
<td>252 ± 66</td>
<td>257 ± 88</td>
<td>0.52</td>
</tr>
<tr>
<td>AUC cholesterol (mmol/l × 480 min)</td>
<td>2783 ± 480</td>
<td>2726 ± 340</td>
<td>2830 ± 480</td>
<td>0.72</td>
</tr>
<tr>
<td>AUC HDL-cholesterol (mmol/l × 480 min)</td>
<td>432 ± 117</td>
<td>433 ± 103</td>
<td>435 ± 102</td>
<td>0.37</td>
</tr>
</tbody>
</table>

* ab Mean values within a row with unlike superscript letters were significantly different ($P = 0.03$).

* Test meal consisted of soup plus carbohydrate (50 g) plus alcohol (40 g) plus butter (100 g). In protocol A, participants did not exercise; in protocol B, participants rested the day before the meal test and exercised for 40 min at 40% $V_{O2\max}$ on the day of the meal test; in protocol C, participants exercised for 40 min at 40% $V_{O2\max}$ the day before the meal test.
type 2 diabetic men. This contrasts with previous studies on exercise and postprandial lipaemia in healthy subjects (Tsetsonis & Hardman, 1996; Gill et al. 2001). In the latter studies, however, a much higher exercise intensity and duration was chosen than in the present study. We decided to examine a less intensive exercise since large-scale epidemiological studies have shown that light and moderate daily exercise have a striking effect on the risk of CVD (Hu et al. 2001), and of type 2 diabetes (Hu et al. 2003). According to the present acute study, with all its limitations, the cardioprotective effect of light exercise seems not to be mediated through a reduction in postprandial lipaemia. To be able to separate the effects of alcohol and exercise, studies using a similar amount of exercise on a meal test without alcohol should have been carried out. Although Danes do not habitually consume 40 g alcohol in the morning, it is quite common on festive occasions. In the Insulin Resistance Atherosclerosis Study, physical activity was found to be positively associated with increased insulin sensitivity (Mayer-Davis et al. 1998) and one single bout of glycogen-depleting exercise in type 2 diabetic patients increased the non-oxidative glucose

Fig. 2. Serum postprandial cholesterol (a), NEFA (b), triacylglycerols (c), plasma glucose (d), HDL-cholesterol (e) and insulin (f) in twelve type 2 diabetic men following a meal of soup with 100 g butter plus 40 g alcohol plus 50 g carbohydrate. Protocol A (●) participants did not exercise. Protocol B (○) participants rested the day before the meal test and exercised for 40 min at 40% VO2max on the day of the meal test. Protocol C (▲) participants exercised for 40 min at 40% VO2max the day before the meal test and rested during the meal test. Values are means, with standard errors of the mean represented by vertical bars.
VO₂max 30 min after a test meal with alcohol compared with two diabetic patients were reduced by 30 min exercise at 40 % et al. Rasmussen and weight-matched controls.

Impairment of both the insulin suppression of NEFA and exercise. Some studies have shown that moderate exercise that was similar for meal tests with and without the ingested triacylglycerol was absorbed. It could be that exercising 45 min rather than 3·5 h after a meal more effectively reduces the postprandial glucose responses. There were two reasons for exercising our participants after exercise for 45 min at 53 % VO₂max carried out 45 min after a mixed meal significantly reduced the 4 h postprandial AUC for glucose and insulin in type 2 diabetic patients (Larsen et al. 1997). The explanation might be that their patients consumed a carbohydrate-rich meal and exercised 45 min after breakfast, when glucose and insulin levels were increasing, whereas our participants consumed a high-fat meal and exercised 3·5 h after the meal, when glucose and insulin levels were decreasing, and most of the ingested triacylglycerol was absorbed. It could be that exercising 45 min rather than 3·5 h after a meal more effectively reduces the postprandial glucose responses. After a moderate intake of alcohol and exercise have beneficial effects on postprandial lipaemia in type 2 diabetic individuals needs further investigation.

Acknowledgements
We thank Kirsten Eriksen and Tove Skrumsager for excellent technical assistance, and Eva Pedersen for dietetic assistance. The present study was supported by grants from the Danish Diabetes Association, Eli Lilly Diabetes Research Foundation, The Danish Medical Research Council, The Institute of Clinical Experimental Research, Aarhus University, and Novo Nordisk Foundation.

References
Boquist S, Ruotolo G, Tang R, Bjorkegren J, Bond MG, de Faire

Table 4. Insulin resistance using the homeostasis model assessment (HOMA) following a test meal in twelve type 2 diabetic men for each of the protocols* (Mean values and standard deviations)

<table>
<thead>
<tr>
<th>Protocol A</th>
<th>Protocol B</th>
<th>Protocol C</th>
<th>P value (difference between protocols)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOMA, T=0 min</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>2·9</td>
<td>2·3</td>
<td>3</td>
<td>2·4</td>
</tr>
<tr>
<td>HOMA, T = 1440 min</td>
<td>2·8</td>
<td>2·6</td>
<td>3</td>
</tr>
</tbody>
</table>

*Test meal consisted of soup plus carbohydrate (50 g) plus alcohol (40 g) plus butter (100 g). In protocol A, participants did not exercise; in protocol B, participants rested the day before the meal test and exercised for 40 min at 40 % VO₂max on the day of the meal test; in protocol C, participants exercised for 40 min at 40 % VO₂max the day before the meal test. HOMA was calculated as mean (fasting insulin (μU/ml) × fasting glucose (mmol/l))/22·5.
Effects of exercise on lipaemia in diabetics


