Effect of Medium-chain Triglycerides on the Postprandial Triglyceride Concentration in Healthy Men

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This study compared the serum lipid concentrations after a single dose of medium-chain triglycerides (MCT) or long-chain triglycerides (LCT) between individuals grouped according to the body mass index (BMI). Twenty-five males participated as volunteers, the test diet containing 10 g of MCT or LCT. Blood samples were collected up to 6 h after the intake of a test diet. The LCT diet resulted in significantly greater increases in areas under the curves (AUCs) for serum and chylomicron triglyceride in the BMI ≥ 23 kg/m2 group than those in the BMI < 23 kg/m2 group. The magnitude of response after intake of the MCT diet by the BMI ≥ 23 kg/m2 group was significantly lower than that after the LCT diet. These results suggest that, in subjects with BMI ≥ 23 kg/m2, the intake of MCT is preferable to that of LCT for maintaining postprandial triglyceride at a low concentration.

Key words: medium-chain triglycerides; long-chain triglycerides; body mass index; triglyceride; chylomicron

Obesity is a crucial health problem in developed and developing countries, and is generally associated with increased fat consumption.1,2 Therefore, diet therapy by restricting fat intake is considered to be the most efficient approach for the preventing obesity.

Ordinary dietary fats are mainly long-chain triglycerides (LCT) composed of long-chain fatty acids (LCFA) having carbon numbers ranging from 14 to 18. In contrast, medium-chain triglycerides (MCT) are composed of fatty acids having carbon numbers of 8 to 10, these being found in palm oil and coconut oil, minor components of a normal diet. MCT were introduced in clinical nutrition in the 1950s for the dietary treatment of malabsorption syndromes because of their solubility and absorbability.3–5 MCT and LCT are metabolized differently. MCT are readily and completely hydrolyzed to free fatty acids and glycerol via 2-monoyacylglycerol by pancreatic lipase and also by lingual or gastric lipase. Medium-chain fatty acids (MCFA) absorbed are transported to the liver directly via the hepatic portal circulation and readily oxidized to ketones. As a result, the diet-induced thermogenesis is accelerated.6 Due to this absorption behavior, MCT has been receiving attention as a dietary fat that may prevent body fat accumulation.7

On the other hand, many investigators have found other factors that influence the magnitude of postprandial lipemia in humans.8–13 Dietary fiber,12,13 glucose,14 soy protein15 and exercise16,17 have all been shown to reduce the serum lipid concentrations after eating. Several recent studies have also demonstrated the effects of dietary fatty acids on the postprandial serum lipid concentration.18–20 MCT does not raise the triglyceride and chylomicron concentrations in the blood.21,22

The postprandial lipids in chylomicrons and cholesterol-rich remnants have been implicated in arteriosclerosis.23–26 Similarly, an individual's body mass index (BMI) is proportionally related to the incidence of ischemic heart diseases and arteriosclerosis.27–29 Ko et al.30 have recently reported that the risk of cardiovascular disease, diabetes, and hypertension was higher in Hong Kong Chinese with BMI ≥ 23 kg/m2. In this context, the Japan Society for the Study of Obesity31 has classified BMI ≥ 23 kg/m2 as being overweight, and suggested that this can be used

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Abbreviations: MCT, medium-chain triglycerides; MCFA, medium-chain fatty acids; LCT, long-chain triglycerides; LCFA, long-chain fatty acids; BMI, body mass index; AUC, area under the curves; LDL, low-density lipoproteins; VLDL, very-low-density lipoproteins
as an objective value in the treatment of obesity in Japanese people. Therefore, the BMI value of 23 kg/m² seems to have an impact on the postprandial lipid metabolism.

To investigate the prevention of obesity in the preceding study, we conducted a long-term feeding trial on 78 healthy subjects in which ordinary cooking oil had been replaced by MCT at an equivalent caloric value. The results showed that a significant amount of body fat was reduced in those individuals with BMI ≥ 23 kg/m². We predicted from these results that the difference in increase of triglyceride in the blood after the intake of the MCT and LCT diets would be more marked in the BMI ≥ 23 kg/m² group.

This study investigates whether MCT in relation to LCT could in fact differently influence the serum lipid concentration in individuals with BMI ≥ 23 kg/m² and those with BMI < 23 kg/m².

Materials and Methods

Subjects. Twenty-five healthy male volunteers of average age 33.5 ± 1.5 y with BMI 24.0 ± 0.6 kg/m², who had no history of hypertension, diabetes mellitus, or hyperlipidemia and were not receiving any medication, participated in this trial. The study was carried out in accordance with the Helsinki Declaration of 1964, as revised in 1989, and was approved by the Ethics Committee of Ochanomizu University. The procedures were explained in detail to all volunteers in advance, and all gave their signed informed consent before participating in the study. The characteristics of the study group are shown in Table 1.

Test diets. The source of MCT was a commercially available oil (Nisshin Oil Mills, Tokyo, Japan). Commercial edible oil, which was a blend of rapeseed oil and soybean oil (Nisshin Oil Mills), was used as LCT. The fatty acid compositions were measured by a gas-liquid chromatographic system (6890 series; Agilent Technologies, Palo Alto, CA, USA) with a capillary column (SP2340; Supelco, Bellefonte, PA, USA), after methylation with sodium methoxide. The fatty acid compositions of MCT and LCT are given in Table 2. Liquid formula test diets containing MCT or LCT were prepared by high-pressure homogenization with a particle diameter of 200–300 nm. The nutrient compositions of the test diets are shown in Table 3, each diet containing 10 g of the test oil.

Test protocol. This was a double-blind controlled study with a cross-over randomized design. Each phase of the study was performed in 2 days, and the phases were separated by a 1-wk interval. The subjects maintained a normal lifestyle during each experimental period. The subjects fasted from 21:00 h, and the investigation was started at 9:00 h on the following day. The subjects met in the examination room at 8:30 h. The 0-h blood collection was carried out from 9:00 h, and each subject received 200 g of a liquid formula test diet immediately after. Blood was collected every 2 h until 6 h after the intake of the test diet. The subjects were able to receive only enough water to moisten the throat during 6 h. The body weight and height of each subject were measured at the beginning of the procedure.

Blood sampling and analysis. Blood samples were

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**Table 1. Characteristics of the Study Groups**

<table>
<thead>
<tr>
<th>Index</th>
<th>BMI ≥ 23 group (n = 14)</th>
<th>BMI &lt; 23 group (n = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI (kg/m²)</td>
<td>25.9 ± 0.8*</td>
<td>21.6 ± 0.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.1 ± 1.8</td>
<td>172.9 ± 1.3</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>75.8 ± 2.3*</td>
<td>64.6 ± 1.7</td>
</tr>
<tr>
<td>Age (y)</td>
<td>35.4 ± 1.8</td>
<td>31.2 ± 2.4</td>
</tr>
</tbody>
</table>

* Mean ± SEM; n = 25.
* Significantly different from BMI < 23 group, P < 0.01 (Student's t test).

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**Table 2. Fatty Acid Composition of the Test Oils**

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Long-chain triglycerides</th>
<th>Medium-chain triglycerides</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/100 g of total fatty acids</td>
<td></td>
</tr>
<tr>
<td>8:0</td>
<td>ND*</td>
<td>74.4</td>
</tr>
<tr>
<td>10:0</td>
<td>ND</td>
<td>25.6</td>
</tr>
<tr>
<td>16:0</td>
<td>6.4</td>
<td>ND</td>
</tr>
<tr>
<td>16:1</td>
<td>0.2</td>
<td>ND</td>
</tr>
<tr>
<td>18:0</td>
<td>2.7</td>
<td>ND</td>
</tr>
<tr>
<td>18:1</td>
<td>48.6</td>
<td>ND</td>
</tr>
<tr>
<td>18:2</td>
<td>30.4</td>
<td>ND</td>
</tr>
<tr>
<td>18:3</td>
<td>10.7</td>
<td>ND</td>
</tr>
<tr>
<td>20:0</td>
<td>0.6</td>
<td>ND</td>
</tr>
<tr>
<td>22:0</td>
<td>0.4</td>
<td>ND</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* ND, not detected.
1 Blend of rapeseed oil and soybean oil (7:3, wt/wt).
2 Number of carbon atoms: number of double bonds.

**Table 3. Composition of the Liquid Formula Test Diets**

<table>
<thead>
<tr>
<th></th>
<th>Long-chain triglyceride diet</th>
<th>Medium-chain triglyceride diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kJ)</td>
<td>1045</td>
<td>1012</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>36</td>
<td>34</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>43</td>
<td>44</td>
</tr>
<tr>
<td>Water (g)</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Total (g)</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

1 The liquid formula test diets consisted of the test oil, casein, dextrin and sucrose.
collected from the subjects at 0, 2, 4 and 6 h after intake of the test diets. Analyses of serum total cholesterol, triglyceride and phospholipids were carried out with a 7450 automated system (Hitachi, Tokyo, Japan) by an enzymatic method. The analysis of serum free fatty acids was carried out with a 7170 automated system (Hitachi) by an enzymatic method. Analyses of the serum lipoprotein cholesterol and triglyceride fractions were carried out with a rapid electrophoresis scanning (REP) automated system (Helena Laboratories, Saitama, Japan) by an agarose-gel electrophoretic method. The analysis of serum insulin was conducted with an ARC590 automated system (Jeol, Tokyo, Japan) by an enzymatic method. Analyses of plasma glucose and serum total ketone bodies were carried out with a JCA-BM12 automated system (Jeol, Tokyo, Japan) by an enzymatic method.

Statistical analysis. Each data value is presented as the mean ± SEM. The areas under the time-concentration curves (areas under the curves, AUCs) were calculated by the trapezoidal method. Blood profiles of both BMI groups consuming either the MCT or LCT liquid formula diet were compared by a three-way repeated-measures analysis of variance (ANOVA). Interactions of BMI×diet×sampling period were included in the model as fixed effects. When significant differences were observed, a comparison of means was carried out by Student’s paired t test (two-tailed) to examine the difference in postprandial effect of the dietary fat. Comparisons between the BMI≥23 kg/m² and BMI<23 kg/m² groups within the same fat loading were performed by repeated-measures ANOVA (BMI×sampling period). If a significant difference was detected, Student’s unpaired t test (two-tailed) was performed for evaluate the differences within the same diet group. Comparisons between the MCT and LCT diets within the same BMI group were also performed by repeated-measures ANOVA (diet×sampling period). If a significant difference was detected, Student’s paired t test (two-tailed) was utilized to assess differences within the same BMI group. Statistical significance was set at P<0.05. All analyses were performed by SPSS for WINDOWS (version 10.0J; SPSS Japan, Tokyo, Japan).

Results

Blood chemistry

The results of three-way repeated-measures ANOVA (BMI×diet×sampling period) between the BMI≥23 kg/m² and BMI<23 kg/m² groups, and between the MCT and LCT diets indicated no significant differences among any parameters derived from the blood analyses after intake of the liquid formula diet (Table 4). However, the serum triglyceride concentration showed a decreasing trend by three-way repeated-measures ANOVA (P=0.058).

Two-way repeated-measures ANOVA (BMI×sampling period) between the BMI≥23 kg/m² and BMI<23 kg/m² groups showed that the concentrations of serum triglyceride and phospholipids were significantly different. With both diets, the serum triglyceride concentration of the BMI≥23 kg/m² group throughout the test period was significantly higher than that of the BMI<23 kg/m² group. Moreover, for the LCT diet, the serum phospholipids concentrations in the BMI≥23 group at 2, 4 and 6 h were significantly greater than those in the BMI<23 kg/m² group.

Two-way repeated-measures ANOVA (diet×sampling period) between the MCT and LCT diets showed significant differences in serum low-density lipoprotein (LDL) cholesterol, triglyceride, insulin and total ketone bodies. In the BMI≥23 kg/m² group, the decrease in triglyceride concentration with the MCT diet at 2 and 4 h was significantly greater than that with the LCT diet. In both BMI groups, the MCT diet showed significantly increased total ketone bodies at 2 h when compared with the LCT diet.

Analyses of AUCs for serum cholesterol and triglyceride

Three-way ANOVA (BMI×diet×sampling period) showed AUCs of total cholesterol and of chylomicron-, very-low-density lipoprotein (VLDL)-, LDL-, and high-density lipoprotein (HDL)-cholesterol for both diets with no difference between the BMI≥23 kg/m² and BMI<23 kg/m² groups (Table 5). In respect of triglyceride with the LCT diet, increases in the AUCs of serum and chylomicron triglycerides in the BMI≥23 kg/m² group were significantly greater than those in the BMI<23 kg/m² group in the 0–2, −4 and −6-h periods (Table 6). However, there was no significant difference in other AUC values in the 0–2, −4 and −6-h periods between the two BMI groups on either diet. In the BMI≥23 kg/m² group, decreases in the AUCs of serum and chylomicron triglycerides were significantly greater with the MCT diet than with the LCT diet throughout the test period. Moreover, in the BMI≥23 kg/m² group, the decrease in AUC of LDL triglycerides was slightly greater with the MCT diet than with the LCT diet in the 0–4 and −6-h periods. However, in the BMI≥23 kg/m² group, there was no significant difference in AUC of VLDL triglyceride in the 0–4 and −6-h periods between the diets.

Discussion

Many investigators have studied the triglyceride response after an intake of MCT and/or LCT by humans. However, there are no reports of the
postprandial triglyceride response to MCT and LCT diets as a function of BMI for the Japanese population. This study investigated the effect on postprandial triglyceride response of a liquid formula diet containing 10 g of MCT or LCT in subjects with BMI ≥ 23 kg/m² and BMI < 23 kg/m².

In the postprandial state, a triglyceride in blood originates from intestinal absorption of digested LCT and hepatic synthesis. 35) In studies on lipid metabolism with obese and lean subjects, 36, 37) Diraison et al. 20) have reported that hepatic lipogenesis in obese subjects was higher than that in lean subjects. Furthermore, Binnert et al. 39) have reported that lipid oxidation in the liver of obese subjects was lower than that in lean subjects. These reports suggest that, in obese subjects, the triglyceride concentration in blood after the intake of LCT was at a high level. In fact, we found that the triglyceride response in those subjects with BMI ≥ 23 kg/m² after ingesting the LCT diet was higher than that in subjects with BMI < 23 kg/m² (Table 6; 0-6 h, P < 0.05). Furthermore, we found a tendency for a lower level of total ketone bodies in those subjects with BMI ≥ 23 kg/m² at 4 and 6 hours after ingesting the LCT diet in comparison with that of the subjects with BMI < 23 kg/m² (Table 4; 4 and 6 h, P = 0.054). Therefore, the mechanisms for hepatic lipogenesis 38) and lipid oxidation 39) are likely to have led to an increase in the postprandial serum and chylomicron triglyceride response in the BMI ≥ 23 kg/m² group.

In support of our results, Couillard et al. 36) and Mekki et al. 37) have reported that the postprandial

Table 4. Responses of Liquids Containing Either Long- or Medium-chain Triglycerides in the Serum, Fasting Glucose, Insulin and Total Ketone Bodies in the Postprandial Period1

<table>
<thead>
<tr>
<th>BMI ≥ 23 group (n = 14)</th>
<th>Long-chain triglyceride diet</th>
<th>Medium-chain triglyceride diet</th>
<th>Long-chain triglyceride diet</th>
<th>Medium-chain triglyceride diet</th>
<th>Diet × Period</th>
<th>BMI × Period</th>
<th>BMI × Diet × Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cholesterol (mmol/l)</td>
<td>0.54 ± 0.26</td>
<td>5.52 ± 0.23</td>
<td>4.93 ± 0.19</td>
<td>4.90 ± 0.22</td>
<td>0.491 ± 0.376</td>
<td>0.698</td>
<td></td>
</tr>
<tr>
<td>LDL cholesterol (mmol/l)</td>
<td>0.50 ± 0.25</td>
<td>5.41 ± 0.21</td>
<td>4.89 ± 0.17</td>
<td>4.85 ± 0.24</td>
<td>0.007 ± 0.321</td>
<td>0.801</td>
<td></td>
</tr>
<tr>
<td>HDL cholesterol (mmol/l)</td>
<td>0.17 ± 0.05</td>
<td>1.23 ± 0.07</td>
<td>1.45 ± 0.07</td>
<td>1.59 ± 0.09</td>
<td>0.699 ± 0.588</td>
<td>0.305</td>
<td></td>
</tr>
<tr>
<td>Triglyceride (mmol/l)</td>
<td>2.00 ± 0.35**</td>
<td>1.74 ± 0.30*</td>
<td>0.93 ± 0.12</td>
<td>0.89 ± 0.08</td>
<td>&lt;0.0001 ± 0.006</td>
<td>0.058</td>
<td></td>
</tr>
<tr>
<td>Phospholipids (mmol/l)</td>
<td>2.41 ± 0.41**</td>
<td>1.98 ± 0.31**</td>
<td>2.03 ± 0.40**</td>
<td>1.97 ± 0.29**</td>
<td>0.138 ± 0.431</td>
<td>0.615</td>
<td></td>
</tr>
<tr>
<td>Free fatty acids (mmol/l)</td>
<td>5.30 ± 0.06</td>
<td>0.52 ± 0.05</td>
<td>0.53 ± 0.06</td>
<td>0.52 ± 0.05</td>
<td>0.0001 ± 0.006</td>
<td>0.058</td>
<td></td>
</tr>
<tr>
<td>Fasting glucose (mmol/l)</td>
<td>0.20 ± 0.10**</td>
<td>0.21 ± 0.05</td>
<td>0.20 ± 0.10**</td>
<td>0.21 ± 0.05</td>
<td>0.690 ± 0.173</td>
<td>0.701</td>
<td></td>
</tr>
<tr>
<td>Insulin (pmol/l)</td>
<td>0.26 ± 0.07</td>
<td>0.58 ± 0.04</td>
<td>0.32 ± 0.07</td>
<td>0.37 ± 0.04</td>
<td>0.019 ± 0.066</td>
<td>0.779</td>
<td></td>
</tr>
<tr>
<td>Total ketone bodies (µmol/l)</td>
<td>34.1 ± 5.1</td>
<td>33.1 ± 3.2</td>
<td>28.1 ± 2.8</td>
<td>28.0 ± 3.0</td>
<td>0.014 ± 0.054</td>
<td>0.220</td>
<td></td>
</tr>
</tbody>
</table>

1 Mean ± SEM; n = 25.
2 Including 3-hydroxybutyric acid and acetocetatic acid.

Significantly different from the BMI < 23 group with the same diet, *P < 0.05; **P < 0.01 (ANOVA [BMI × period) and t test). Significantly different from the long-chain triglyceride diet in the same experimental period, *P < 0.05; **P < 0.01 [ANOVA [diet × period) and paired t test].
triglyceride response was associated with the amount of abdominal fat, and that the postprandial triglyceride response was positively correlated with BMI. In our study, a significant positive correlation was found between BMI and the postprandial triglyceride response in subjects given the LCT diet ($r = 0.708$, $P < 0.001$; data not shown).

Many researchers have reported the metabolism of MCT. This is a readily hydrolyzed, and absorbed MCT is directly transported to the liver via the hepatic portal circulation and readily oxidized to ketones. Accordingly, in the BMI $\geq 23$ kg/m$^2$ group, the concentration of total ketone bodies 2 h after ingesting the MCT diet was higher than that from the LCT diet. This result suggests that MCT was oxidized and consumed in the liver. Therefore, the postprandial serum and chylomicron triglyceride response was associated with the amount of abdominal fat, and that the postprandial triglyceride response was positively correlated with BMI.
response after ingesting the MCT diet hardly increased.

On the other hand, in the BMI <23 kg/m² group, the postprandial triglyceride concentration did not differ between the MCT and LCT diets. This result is likely to be explained by mechanism for hepatic lipogenesis and lipid oxidation according to Diraison et al.39 Briefly, in a lean subject, lipogenesis in the liver is not only low, but lipid oxidation in the liver is also high in comparison with obese subjects. We therefore consider that the postprandial triglyceride response between the MCT and LCT diets was hardly any different.

However, Seaton et al.5 have reported that, in 7 subjects with a mean BMI of 21.6 kg/m², the plasma triglyceride concentration increased by 68% after ingesting 400 kcal of LCT, but did not change after ingesting 400 kcal of MCT. These results are different from those in the present study, but are considered attributable to the fat content. Cohen et al.5 have reported that the quantity of fat in a meal is dependent on the postprandial triglyceride concentration in the blood. A 44-g amount of fat was provided to the subjects in the study by Seaton et al.,5 but we gave the subjects only 10 g of fat in present study. It is therefore conceivable that the triglyceride concentration was low in the BMI <23 kg/m² group after ingesting 10 g of the LCT diet.

The criterion for obesity in Japan is generally indicated by a BMI value of 25 or more.33 When we analyzed the present findings between the subjects with BMI≥25 (n=8) and those with BMI<25 (n=17), the result was similar to that between subjects with BMI≥23 and BMI<23 kg/m².

In conclusion, we found that the postprandial triglyceride response to 10 g of the LCT diet was greater in those individuals with BMI≥23 kg/m² than in those with BMI<23 kg/m². Furthermore, in the BMI≥23 kg/m² group, the triglyceride response to 10 g of MCT was lower than that to 10 g of LCT. However, in the BMI<23 kg/m² group, there was no difference between the postprandial triglyceride responses to 10 g of MCT and LCT. These results suggest that MCT may be useful for treating disorders of triglyceride metabolism, at least in subjects with a high BMI value.

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Effect of MCT on Postprandial Triglyceride