Comparison of Diet-Induced Thermogenesis of Foods Containing Medium- versus Long-Chain Triacylglycerols

Michio KASAI¹, Naohisa NOSAKA¹, Hideaki MAKI¹, Yoshie SUZUKI¹, Hiroyuki TAKEUCHI¹, Toshiaki AOYAMA¹, Atsushi OHRA², Youji HARADA², Mitsuko OKAZAKI³ and Kazuo KONDO⁴

¹ Research Laboratory and ² Center of Food Research and Development, Nisshin Oil Mills, Ltd., Shinmei-cho, Yokosuka, Kanagawa 239-0832, Japan

³ Kagawa Nutrition University, Chiyoda, Sakado, Saitama 350-0288, Japan

⁴ Institute of Environmental Science for Human Life, Ochanomizu University, Ohtsuka, Bunkyo-ku, Tokyo 112-8610, Japan

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Summary The purpose of this study was to investigate the effect of 5–10 g of medium-chain triacylglycerols (MCT) on diet-induced thermogenesis in healthy humans. The study compared diet-induced thermogenesis after ingestion of test foods containing MCT and long-chain triacylglycerols (LCT), using a double-blind, crossover design. Eight male and eight female subjects participated in study 1 and study 2, respectively. In both studies, the LCT was a blend of rapeseed oil and soybean oil. In study 1, the liquid meals contained 10 g MCT (10M), a mixture of 5 g MCT and 5 g LCT (5M5L), and 10 g LCT (10L). In study 2, the subjects were given a meal (sandwich and clear soup) with the mayonnaise or margarine containing 5 g of MCT or LCT. Postprandial energy expenditure was measured by indirect calorimetry before and during the 6 h after ingestion of the test meals. Diet-induced thermogenesis was significantly greater after 5M5L and 10M ingestion as compared to 10L ingestion. Ingestion of the mayonnaise or margarine containing 5 g MCT caused significantly larger diet-induced thermogenesis as compared to that of LCT. These results suggest that, in healthy humans, the intake of 5–10 g of MCT causes larger diet-induced thermogenesis than that of LCT, irrespective of the form of meal containing the MCT.

Key Words medium-chain triacylglycerols, healthy human, diet-induced thermogenesis, meal form

Medium-chain triacylglycerols (MCT) are found in edible oils that consist of C8 and C10 saturated fatty acids. The processes of digestion and absorption of MCT and long-chain triacylglycerols (LCT) are completely different (1). The rapid absorption of MCT makes it a valuable tool in the dietary treatment of malabsorption syndromes (2). Quite a few animal studies have provided evidence that MCT diets lead to less body fat deposition as compared to LCT diets (3–8). These results indicate that the substitution of MCT for LCT in dietary fat could reduce dietary obesity if energy intake remains constant (9).

Diet-induced thermogenesis plays an important role in the regulation of energy balance (10). It has been observed that diet-induced thermogenesis is increased after overfeeding, and is conversely decreased by starvation (11). Seaton et al. (9) and Hill et al. (12) reported that the ingestion of 400 kcal (48 g) MCT caused higher diet-induced thermogenesis than that of LCT in men. Flatt et al. (13) also observed greater diet-induced thermogenesis in healthy men after the ingestion of a mixed meal containing 40 g of MCT as compared to an isocaloric meal containing LCT. Scalfi et al. (14) found greater diet-induced thermogenesis in lean and obese

subjects after a mixed meal containing 30 g of MCT than that containing LCT.

Very recently, we demonstrated that the feeding of a MCT meal containing 10 g of MCT for 12 wk reduced body fat in healthy subjects to a greater extent than a LCT meal (15). However, the mechanism of greater body fat loss after ingestion of the MCT meal is not clear. The meal containing 10 g of MCT may cause higher diet-induced thermogenesis than that containing LCT. This study, therefore, was performed to investigate the effect of 5 and 10 g of MCT on diet-induced thermogenesis in healthy subjects as compared to LCT.

MATERIALS AND METHODS

Subject. Sixteen healthy volunteers, who had no history of hypertension, diabetes mellitus, or hyperlipemia and were not under any medication were recruited as test subjects. Eight males (mean $\pm$ SE: 26.8 $\pm$ 0.7 y; BMI, 22.7 $\pm$ 0.8 kg/m²) and eight females (28.1 $\pm$ 1.4 y; BMI, 18.8 $\pm$ 0.4 kg/m²) participated in study 1 and study 2, respectively. The studies were carried out in accordance with the Helsinki Declaration of 1964, as revised in 2000, and were approved by the Ethics Committee of Ochanomizu University. The study procedures were explained thoroughly to all subjects in advance, and all gave their signed informed consent be-

fore participating.

Test oil. MCT was purchased commercially (Nisshin Oil Mills Ltd., Tokyo, Japan). Common edible oil, a blend of rapeseed oil and soybean oil (Nisshin Oil Mills), was used as the source of LCT. The fatty acid compositions were determined by a gas-liquid chromatography system (6890 series; Agilent Technologies, Palo Alto, CA, USA) with a capillary column (SP2340; Supelco, Bellefonte, PA, USA) after methylation with sodium methoxide (15). The fatty acid compositions of MCT and LCT are shown in Table 1.

Protocol. The studies were carried out in a double-blind controlled manner with a crossover design. Throughout each study, the subjects were asked to keep their usual lifestyle, including diet and physical activity expect for the day before the diet-induced thermogenesis experiment. On that day, the subjects had dinner by 2100 h, and fasted overnight.

Study 1: The subjects were randomly assigned to one of three experimental sessions and administered one of three liquid meals containing 10 g MCT (10M), a mixture of 5 g MCT and 5 g LCT (5M5L), or 10 g LCT (10L). The energy content of each liquid meal was 242, 246, and 250 kcal/200 g, respectively, with proportions of protein : fat : carbohydrate (P : F : C) 21 : 36 : 43%. The liquid meal consisted of casein, sucrose, and dextrin. The subjects ingested test meals at 1100 h, and then rested for 6 h. The oxygen consumption, carbon dioxide production and respiratory quotient (RQ) were measured by an Aeromonitor AE-300S (Minato Medical Science, Osaka, Japan) before and after ingestion of the test meal for 6 h at 1 h intervals. The resting energy expenditure was calculated from oxygen consumption and carbon dioxide production using the equations of Weir (16). The Aeromonitor AE-300S consists of a microcomputer, a hot-wire flow meter, and gas analyzers containing an infrared carbon dioxide analyzer and a permanent-magnetic oxygen analyzer. Diet-induced thermogenesis was evaluated by a method reported previously (17).

Study 2: The experimental sessions were divided into two, one in which subjects were served meals with mayonnaise containing test oils, and one in which they were served meals with margarine containing test oils. The margarine and mayonnaise each contained 5 g of either MCT or LCT. With the exception of the test oils, the mayonnaise contained vegetables oils, vinegar, starch, mustard, and sucrose, but not eggs. The margarine contained hydrogenated oils, powdered skimmed milk, and salts. The meal was served in the form of a sandwich and clear soup. The sandwich was comprised of bread, lettuce, and tomato. The energy content of the meals containing 5 g LCT and MCT were 253 and 249 kcal/test meals, respectively, for the mayonnaise, and 244 and 240 kcal/test meals, respectively, for the margarine (P : F : C = 10 : 40 : 50% for both meal forms). One experimental session was arranged for 2 d in a week at 1 or 2 d intervals to synchronize with either a low-temperature term or a high-temperature term of the menstrual cycle (18, 19). The same experimental

Table 1. Fatty acid composition of test oils.

Fatty acid	Long-chain triacylglycerols ¹	Medium-chain triacylglycerols
g/100 g total fatty acids		
8:0 ²	ND	74.4
10:0	ND	25.6
16:0	6.4	ND
16:1	0.2	ND
18:0	2.7	ND
18:1	48.6	ND
18:2	30.4	ND
18:3	10.7	ND
20:0	0.6	ND
22:0	0.4	ND
Total	100.0	100.0

¹ Blended mixture of rapeseed and soybean oils (7 : 3).

² Number of carbon atoms:number of double bonds. ND, not detected.

time schedule as used in study 1 was used for study 2. Diet-induced thermogenesis measurements were carried out under fixed conditions at a room temperature of 25–26°C and a room humidity of around 50–55%.

Statistics. Data are presented as means ± SE. In study 1, results were analyzed by ANOVA, and significant differences among the liquid meals were determined by Scheffe's multiple comparison. The statistical significance of differences between the meals was tested by Student's paired *t*-test in study 2. All analyses were performed using SPSS for Windows (Version 10.0J; SPSS Japan, Tokyo, Japan). Differences with *p* < 0.05 were considered statistically significant.

RESULTS

Study 1

The resting energy expenditure before ingestion of the liquid meals was similar in the three experimental sessions: 1,690 ± 70 kcal/d (RQ, 0.82 ± 0.02) for 10M, 1,608 ± 65 kcal/d (RQ, 0.82 ± 0.03) for 5M5L, and 1,642 ± 51 kcal/d (RQ, 0.81 ± 0.02) for 10L. Increases in oxygen consumption were greater after the ingestion of 5M5L and 10M than after ingestion of 10L during the 6 h measurement period (Fig. 1). The increases in oxygen consumption were significantly greater 30 min after ingestion for the 5M5L and 10M groups as compared to the 10L group. Increases in oxygen consumption were also significantly higher at 120 and 180 min after ingestion for the 10M group as compared to the 10L group. Values of change in RQ were significantly smaller after the ingestion of 5M5L and 10M as compared to 10L (Fig. 2). Value of change in RQ was also significantly smaller at 30 min after ingestions for the 10M group as compared to the 10L group.

Diet-induced thermogenesis was significantly greater after the ingestion of 5M5L or 10M as compared with the ingestion of 10L; however, there was no significant difference between the 5M5L and 10M groups (Table 2). Rates of diet-induced thermogenesis/energy of food

Fig. 1. Change in oxygen consumption before and after the ingestion of a liquid meal (study 1) containing 10 g of long-chain triacylglycerols (10L, i.e. OM), a mixture of 5 g medium-chain triacylglycerols and 5 g of long-chain triacylglycerols (5M5L) or 10 g of medium-chain triacylglycerols (10M). * Significant different between the OM and 10M meals, $p<0.05$; ** $p<0.01$. ## Significantly different between the OM and 5M5L diets, $p<0.01$.

Fig. 2. Change in respiratory quotients before and after the ingestion of a liquid meal (study 1) containing 10 g of long-chain triacylglycerols (10L, i.e. OM), a mixture of 5 g medium-chain triacylglycerols and 5 g of long-chain triacylglycerols (5M5L) or 10 g of medium-chain triacylglycerols (10M). * Significantly different between the OM and 10M meals, $p<0.05$. ## Significantly different between the OM and 5M5L diets, $p<0.01$.

Table 2. Diet-induced thermogenesis during 6 h after ingestion of liquid meal containing 0, 5 or 10 g of medium-chain triacylglycerols (study 1).¹

	Test meal		
	10L ²	5M5L ²	10M ²
Diet-induced thermogenesis (cal/kg)	172.6±36.0	387.1±102.0**	412.5±112.6**
Rate of diet-induced thermogenesis (%) ³	4.81±1.05	10.30±2.38**	11.53±3.15**

¹ Mean±SE; n=8.
² Liquid diet containing 10 g long-chain triacylglycerols (10L), mixture of 5 g medium-chain triacylglycerols and 5 g long-chain triacylglycerols (5M5L) or 10 g medium-chain triacylglycerols (10M).
³ Rate of diet-induced thermogenesis was calculated as diet-induced thermogenesis/energy of food consumption.
** Significantly different from the 10L diet, $p<0.01$.

Table 3. Diet-induced thermogenesis during 6 h after ingestion of meal (sandwich and clear soup) with mayonnaise and margarine containing 5 g of long-chain triacylglycerols or medium-chain triacylglycerols (study 2).¹

Test oil	Mayonnaise (n=7) ²		Margarine (n=8)	
	5 g LCT	5 g MCT	5 g LCT	5 g MCT
Diet-induced thermogenesis (cal/kg)	220.7±71.3	399.0±65.4*	273.8±81.9	574.1±156.7*
Rate of diet-induced thermogenesis (%) ³	4.62±1.49	8.05±1.33*	5.75±1.82	12.12±3.54*

¹ Mean±SE.
² One female subject could not participate in a experiment with mayonnaise owing to personal matters.
³ Rate of diet-induced thermogenesis was calculated as diet-induced thermogenesis/energy of food consumption.
* Significantly different from the meal containing 5 g LCT, $p<0.05$.

consumption were also significantly greater after the ingestion of 5M5L or 10M ingestion as compared to 10L.

Study 2

Due to personal circumstances, one of the female

subjects was unable to participate in the experiment that included the consumption of mayonnaise. The resting energy expenditure before ingestion of the meals containing 0 or 5 g of MCT were the same in the four experimental sessions: $1,211\pm35$ kcal/d (RQ,

0.84±0.04) and 1,182±53 kcal/d (RQ, 0.83±0.03), respectively, for the mayonnaise, and 1,201±76 kcal/d (RQ, 0.81±0.05) and 1,137±71 kcal/d (RQ, 0.82±0.03), respectively, for the margarine. Both of the meals with the mayonnaise and margarine containing 5 g of MCT resulted in significantly greater diet-induced thermogenesis compared with that of LCT (Table 3). In both meals of mayonnaise and margarine, the rates for diet-induced thermogenesis/energy of food consumption were significantly higher after the ingestion of 5 g MCT as compared to LCT ingestion. The rates of diet-induced thermogenesis energy of food consumption were similar after ingestion of the two types of meals.

DISCUSSION

A greater thermogenic effect of MCT than LCT has been demonstrated in humans after the ingestion of a considerable amount (30 g or more) (8, 12–14). However, the effect of 5–10 g MCT, which could be easily replaced with cooking oil on diet-induced thermogenesis is not known well in healthy humans. In study 1, diet-induced thermogenesis after the ingestion of a liquid meal containing 0, 5 or 10 g of MCT was measured in healthy men. Diet-induced thermogenesis was significantly greater after the ingestion of 5M5L or 10M as compared to 10L. Ingestion of 5M5L or 10M resulted in approximately twice as much in diet-induced thermogenesis as the ingestion of 10L. These results suggest that an intake of MCT at a volume of 5–10 g causes larger diet-induced thermogenesis than the intake of LCT in healthy humans. Dulloo et al. (20) observed greater 24 h energy expenditure in subjects that ingested a typical Western breakfast, lunch and dinner containing 5 g of MCT, respectively, as compared to an isocaloric meal containing LCT. Our results in this study are compatible to the findings reported by Dulloo et al.

Form and palatability of meal influence diet-induced thermogenesis. Diet-induced thermogenesis was greater after the ingestion of a normal meal as compared to the ingestion of a finely ground meal (21). Therefore, in study 2, we compared diet-induced thermogenesis after the ingestion of a meal (sandwich and clear soup) containing 5 g of MCT or LCT. In both meals, with mayonnaise and margarine, diet-induced thermogenesis was significantly greater after the ingestion of MCT as compared to LCT ingestion. Ingestion of the meals with mayonnaise and margarine containing MCT resulted in approximately double the diet-induced thermogenesis as compared to the ingestion of the meals containing only LCT. The results of this study strongly suggest that an intake of 5 g MCT causes larger diet-induced thermogenesis as compared to the intake of LCT in healthy humans. White et al. (22) reported that diet-induced thermogenesis was greater after the ingestion of a MCT-enriched diet (7.1±0.1 g/d) for 14 d as compared to the ingestion of a LCT diet, but not significantly. In their study, butter and coconut oil, which contain mainly lauric and myristic acids rather than caprylic and capric acids, were the fats used to increase the proportion of MCT in the diet. The MCT used in our experi-

ment, however, contained only caprylic and capric acids (Table 1).

Long-chain fatty acids absorbed at the small intestine flow into the venous system via lymphatic vessels and are transported to peripheral tissues such as adipose tissue and muscle. Most medium-chain fatty acids, however, transfer to the liver via the portal vein (2). Medium-chain fatty acids can be transported through the mitochondrial membrane without binding to carnitine and easily move into the mitochondria, where β -oxidation occurs (1). Because liver contributes about 30% to the basal metabolic rate (23), direct transportation of MCT from the small intestine to the liver may be related to the larger diet-induced thermogenesis (9, 24). On the other hand, Dulloo et al. (20) observed that 24 h urinary noradrenaline, an index of sympathetic activity, was increased after the ingestion of MCT, and proposed that the higher energy expenditure resulting from the ingestion of MCT is mediated through activation of the sympathetic nervous system. A detailed study is required to clarify the mechanism.

In conclusion, our results suggest that the intake of 5–10 g of MCT by healthy humans gives larger diet-induced thermogenesis than that of LCT, irrespective of the form of meal containing the MCT. These data suggest the possibility that the substitution of MCT for cooking oil is useful to control body weight and fat in healthy subjects.

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