Original Article

Effects of a liquid diet supplement containing structured medium- and long-chain triacylglycerols on bodyfat accumulation in healthy young subjects

Tatsuhiro Matsuo[1] PhD, Masako Matsuo[2] MSc, Michio Kasai[3] BSc and Hiroyuki Takeuchi[3] PhD

[1]*Faculty of Agriculture, Kagawa University, Kagawa, Japan*
[2]*Department of Health and Sport Sciences, Hiroshima University of Economics, Hiroshima, Japan*
[3]*Division of Food Science, Research Laboratory of The Nisshin Oil Mills, Yokosuka, Kanagawa, Japan*

The effects of a liquid-formula diet supplement containing structured medium- and long-chain triacylglycerols (SMLCT) composed of medium- (10%) and long-chain (90%) fatty acids were compared with those of long-chain triacylglycerols (LCT) on bodyfat accumulation in 13 healthy male volunteers aged 18–20 years. The subjects were randomly assigned the SMLCT or LCT group. The subjects in each group received a liquid-formula diet supplement of the SMLCT or LCT, which provided 1040 kJ plus daily energy intake for 12 weeks. Mean energy intake containing liquid diet throughout the 12-week period did not differ between the SMLCT and LCT groups. Bodyweight of subjects in both groups increased slightly from the baseline throughout the 12-week period, but the differences were not significant. Rates of variation of bodyfat percentage were significantly lower in the SMLCT group than in the LCT group throughout the 12-week period. Comparisons between the SMLCT and LCT groups at baseline and 12 weeks showed no significant differences in any of the biochemical blood parameters. These results suggest that replacing LCT with SMLCT over long periods of time could produce bodyfat loss in the absence of reduced energy intake.

Key words: body fat, healthy subjects, Hiroshima, Japan liquid-formula diet, medium-chain triacylglycerol, structured lipids.

Introduction

Obesity is characterized by an increase in lipid stores. It is generally associated with enhanced lipid consumption, which contributes to its development.[1,2] In westernized countries, obesity is an important health problem affecting a large proportion of individuals, who seek to prevent further weight gain or who decide to counteract the detrimental health consequences of obesity.[3] To attain these objectives, patients follow a wide variety of preventive or therapeutic methods, taken alone or in combination. Among these approaches, dietary restrictions involving lipids are considered most important. The bulk of fatty acids found in usual western diets consists of molecules comprising 12 or more carbon atoms. These long-chain fatty acids (LCFA), either saturated or unsaturated, originate from the long-chain triacylglycerols (LCT) provided by vegetable and/or animal oil and fat sources. They contribute to the supply of energy and fulfil essential fatty acid requirements.[4]

In contrast, medium-chain triacylglycerols (MCT) are edible oils composed of triacylglycerols with saturated medium-chain fatty acid (MCFA) moieties of six to 10 carbon atoms. These were introduced to clinical nutrition in the 1950s for dietary treatment of malabsorption syndromes because of their rapid absorption and solubility.[5] Medium-chain triacylglycerols are metabolized differently from LCT. They are transported to the liver directly via hepatic portal circulation and are oxidized to ketones, whereas LCT are absorbed via the intestinal lymphatic ducts and transported in chylomicrons through the thoracic duct to reach the systemic circulation.[6,7]

In animal studies, rats fed MCT do not gain as much weight as rats fed an isocaloric amount of LCT.[6–9] They have diminished fat deposition and increased resting metabolic rate.[7–10] In clinical assay, Seaton *et al.* reported that mean postprandial oxygen consumption after an MCT meal was higher than after the LCT meal.[5] These results suggest that MCT could be useful in the dietary treatment of obesity. However, it is difficult to substitute MCT for LCT in dietary fat for long-term dietary therapy, in part because utilization of MCT as cooking oil is limited by the lower smoke point.[11]

Recently, we developed a new type of cooking oil composed of structured medium- and long-chain triacylglycerols (SMLCT).[11] The SMLCT are structured lipids that contain MCFA and LCFA in the same triacylglycerol. They are made by transesterification of MCT and LCT. They are superior for cooking than physical mixtures of MCT and LCT because the smoke point of the former is higher than that of the latter.

Correspondence address: Tatsuhiro Matsuo, Faculty of Agriculture, Kagawa University, Ikenobe, Mikicho, Kitagun, Kagawa 761-0795, Japan.
Tel: 81 87 891 3082; Fax: 81 87 8913021
Email: matsuo@ag.kagawa-u.ac.jp
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If SMLCT are similar biochemically and physiologically to MCT, SMLCT could be used in special cooking oils for dietary therapy.

The purpose of this study was to investigate the effects of 12-weeks of a liquid diet supplement containing either LCT or SMLCT on bodyfat accumulation in healthy young subjects.

Methods

Subjects

Thirteen male volunteers aged 18–20, who did not have a habit of daily exercise, were recruited from Hiroshima University of Economics (Hiroshima, Japan) to participate in this study. This study was conducted in accordance with the internationally agreed ethical principle for the conduct of medical research. After a detailed explanation of this study, each subject gave his informed written consent. The subjects were determined to be free of disease by a medical examination before the study. No subjects were using illegal drugs or taking medications that affect bodyweight.

The subjects were severally randomized and assigned to one of the following two groups: (1) subjects fed a liquid supplement containing SMLCT (SMLCT group) or (2) those fed a liquid supplement containing LCT (LCT group). The baseline characteristics of subjects belonging to the SMLCT group and the LCT group are shown in Table 1.

Test oils

The LCT (soybean oil), MCT and rapeseed oil were purchased commercially (Nisshin Oil Mills, Tokyo, Japan). The SMLCT were prepared by transesterification of MCT and rapeseed oil (Fig. 1). The composition of fatty acids and triacylglycerol of the test oils are shown in Tables 2 and 3. The SMLCT contains about 10% MCFA. The smoke points of MCT, rapeseed oil, physical mixtures of MCT and rapeseed oil, and SMLCT were 143, 230, 160 and 210°C, respectively.

Liquid diet supplements

The subjects in each group received a liquid-formula diet supplement based on a SMLCT or LCT (two packages per day, 200 g per package), which provided 1040 kJ plus daily energy intake. Both liquid diets contained the following ingredients, in g/kg: sucrose, 10; dextrin, 125; sodium caseinate, 66; fat (soybean oil or SMLCT), 50; coffee flavor, 15; emulsifier, 1; and water, 733. During the period of the study, each subject maintained a normal lifestyle and ate normal Japanese food (7000–9000 kJ) and liquid supplements ad libitum. Daily food intake was determined from questionnaires completed by the subjects. Food consumption was calculated by the Statistical Package for Macintosh (Kenpakusha, Tokyo, Japan).

Body composition

Body compositions of subjects were measured weekly. The subjects' height and weight, from which body mass index

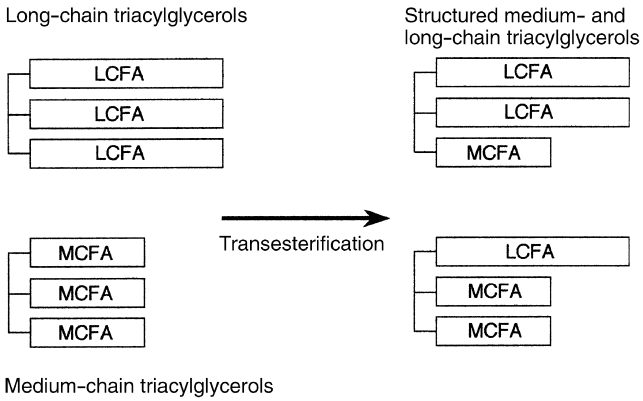

Figure 1. Preparation of structured medium- and long-chain triacylglycerols (SMLCT). After 900 g of rapeseed oil and 100 g of medium-chain triacylglycerols were mixed, SMLCT were prepared by transesterification using lipase derived from microorganisms. SMLCT were bleached by activated clay and deodorized by steam distillation. LCFA, long-chain fatty acids; MCFA, medium-chain fatty acids.

Table 1. Characteristics of subjects before the experiment

	SLMCT (n = 7)	LCT (n = 6)
Age (years)	19.1 ± 0.6	19.5 ± 0.7
Height (cm)	173 ± 2	173 ± 1
Weight (kg)	63.1 ± 4.4	61.7 ± 23
Body mass index (kg/m^2)	21.1 ± 1.4	20.9 ± 0.9
Bodyfat percentage	18.1 ± 2.4	14.8 ± 1.1
Fat free mass (kg)	51.1 ± 2.1	53.3 ± 1.7
Waist (cm)	75.6 ± 3.3	73.8 ± 2.2
Hip (cm)	96.1 ± 2.7	93.6 ± 2.1
Waist-to-hip ratio	0.79 ± 0.02	0.79 ± 0.02

Values are means ± SE for 6–7 subjects. SMLCT, structured medium- and long-chain triacylglycerol; LCT, long-chain triacylglycerol.

Table 2. Fatty acid composition of the test oils

Composition	Soybean oil (g/100 g)	SMLCT (g/100 g)
8:0	–	7.3
10:0	–	2.4
16:0	10.4	3.8
16:1	0.1	0.2
18:0	4.0	1.9
18:1	23.9	55.2
18:2	52.9	18.3
18:3	7.8	7.7
20:0	0.3	0.6
20:1	0.2	1.4
22:0	0.4	0.3
22:1	–	0.5
24:0	–	0.2
24:1	–	0.2
Total	100.0	100.0

SMLCT, structured medium- and long-chain triacylglycerols.

Table 3. Triacylglycerol composition of the test oils

	Soybean oil (g/100 g)	SMLCT (g/100 g)
L, L, L	100.0	63.3
L, L, M	–	28.9
L, M, M	–	6.4
M, M, M	–	1.4
Total	100.0	100.0

SMLCT, structured medium- and long-chain triacylglycerols; L, long-chain fatty acids; M, medium-chain fatty acids.

(BMI) was calculated, were measured by conventional methods. Percentage of bodyfat, fat mass and fat-free mass were determined by bioelectrical impedance analyser (Model TBF-102; Tanita, Tokyo, Japan). Waist and hip measurements were taken conventionally by tape measure; then the waist-to-hip ratio was calculated.

Blood biochemical test

Subjects underwent blood biochemical testing before starting the experiment and after 12 weeks while still on the experimental diet. Evaluations of blood cells and biochemical parameters of blood, plasma and serum from subjects were requested from Scripps Reference Laboratory (SRL, Tokyo, Japan).

Statistical analysis

Statistical analysis was conducted with a personal computer (Power Macintosh G3; Apple, Tokyo, Japan) running a statistical package program (Stat View, SAS Institute, NC, USA). Statistical differences in the parameters of blood biochemical test were analyzed by two-way analysis of variance (ANOVA). The data of body compositions were subjected to ANOVA with repeated measures. Post-hoc tests were performed by Scheffe's test.[12] Differences with $P < 0.05$ were considered significant.

Results

Energy intake

Mean energy intake including liquid supplement throughout the 12-week period did not differ between the SMLCT and LCT groups (9407 ± 825 and 9793 ± 310 kJ/day).

Bodyweight and body composition

Bodyweight of subjects in both groups increased slightly from baseline throughout the 12-week period, but the differences were not significant (Fig. 2). Mean weight gain at 12 weeks was 1.83 and 0.91 kg for the SMLCT and LCT groups, respectively. Body composition variables from the baseline to 12 weeks are shown in Figs 3 and 4. All groups showed significant increases in bodyfat percentage from the baseline throughout the 12-week period (Fig. 3). Rates of variation of bodyfat per cent were significantly lower in the SMLCT group than in the LCT group throughout the 12-week period. Increases in bodyfat percentage were 2.16 and 4.30% for the SMLCT and LCT groups, respectively. Fat weight gain over 12 weeks for the SMLCT and LCT groups were 2.01 and 2.79 kg, respectively. However, the change in fat free mass was negligible in the SMLCT and LCT groups for the 12-week experimental period (Fig. 4). Changes of fat free mass were – 0.1 and – 1.9 kg for the SMLCT and LCT groups, respectively.

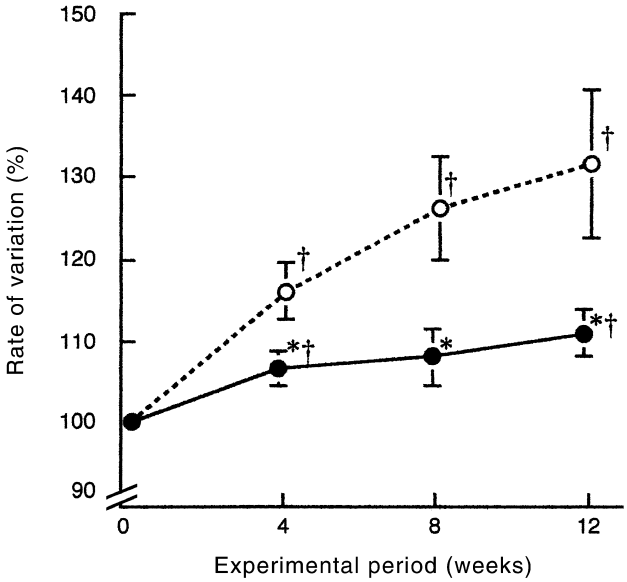

Figure 3. Changes in rate of variation of bodyfat percentage of subjects in the SMLCT (–●–) and LCT (--○--) groups. Values are means ± SE for 6–7 subjects. *Significantly statistical difference from the LCT groups. †Significantly statistical difference from pre-experiment value. Differences with $P < 0.05$ (2-factor repeated measures of ANOVA followed by Scheffe's test).

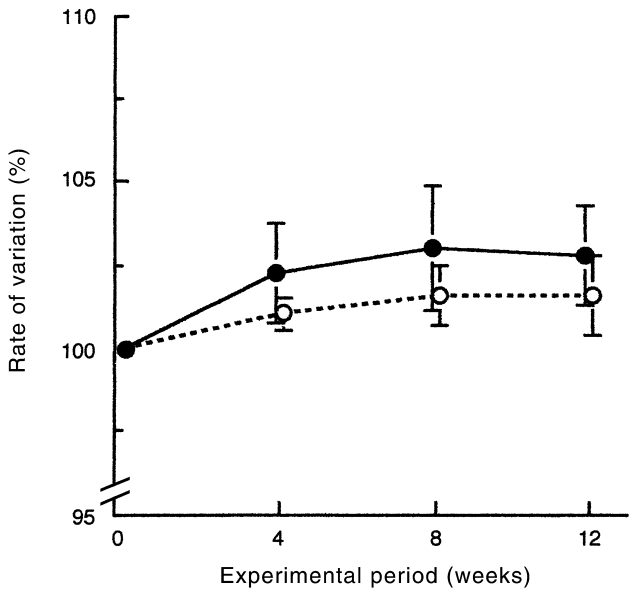

Figure 2. Changes in rate of variation of bodyweights of subjects in the SMLCT (–●–) and LCT (--○--) groups. Values are means ± SE for 6–7 subjects.

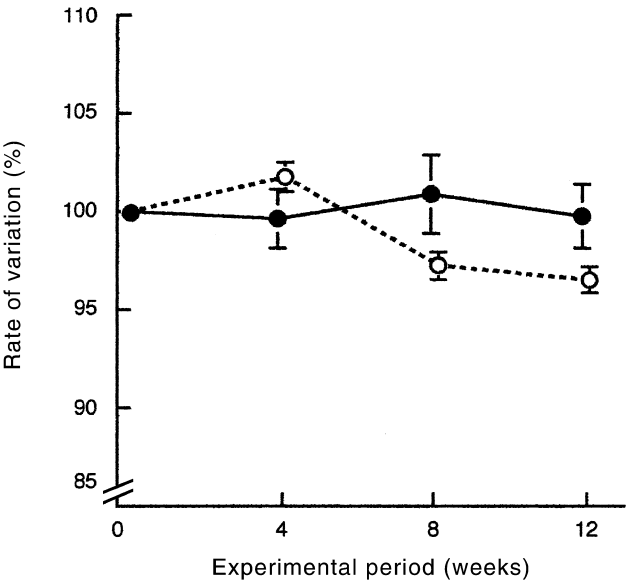

Figure 4. Changes in rate of variation of fat-free mass of subjects in the SMLCT (–●–) and LCT (--○--) groups. Values are means ± SE for 6–7 subjects.

Blood biochemical test

Biochemical parameters of blood, plasma and serum in SMLCT and LCT groups before and after 12-week experimental periods were normal in accordance with the standard values, as shown in Table 4. Comparisons between the SMLCT and LCT groups at baseline and 12 weeks showed no significant differences in any of the biochemical parameters in Table 4.

Discussion

The results show that bodyfat accumulation was lower in subjects that received 20 g SMLCT than in those who received 20 g LCT for 12 weeks. As both groups of subjects were offered diets delivering the same energy throughout the 12-week experimental period, the difference in bodyfat accumulation between the two groups is ascribed to the different fats in the liquid diet supplements.

Few human studies have examined the effects of MCT versus LCT in diet on body composition. Rath *et al.* studied 24 obese women who experienced severe fasting during 5 consecutive days before undergoing two different hypocaloric diets for 3 weeks.[13] Twelve subjects were on a 2300 kJ regimen providing 50 g protein and 30 g MCT, and the others received a 2100 kJ regimen with 60 g protein and 10 g MCT as whipped cream. At the end of the experiment, bodyweight losses were identical in both groups. Another clinical survey by Yost and Eckel enrolled 16 obese women in two different hypocaloric regimens (3350 kJ and 30% energy as fat supply) for 4 or 12 weeks.[14] The first regimen used only LCT, whereas the second used 6% LCT and 24% MCT. The bodyweight losses were comparable with both lipids. Hill *et al.* investigated non-obese male volunteers who were given a regimen providing 150% of the recommended dietary allowances for 6 days. Lipids were ingested as 40% LCT or 40% MCT in a randomized cross-over design.[15,16] No significant change in bodyweight was recorded at the end of either diet protocol. These previous studies did not examine the changes in body fat mass or bodyfat percentage, so they can not be directly compared with our results. However, our findings demonstrated that bodyweight gain did not differ between SMLCT and LCT groups during the 12-week experimental period. Dietary SMLCT and MCT, but not dietary LCT, might influence bodyfat mass more than fat-free mass and/or bodyweight. Rath *et al.* suggested that nitrogen retention was higher in the group than in the LCT group during the 13-day experimental period.[13]

Medium-chain triacylglycerols are currently used in clinical nutrition as energy-yielding substrates. Many studies have been performed on the thermic effects of MCT. According to some reports, MCT have a greater thermogenic effect than LCT.[5,11,15,17,18] Other studies have found that MCT and LCT produce similar thermic effects.[19,20] Scalfi *et al.* examined the diet-induced thermogenesis (DIT) response to consumption of a 5477 kJ test meal containing 30 g of MCT or LCT in lean subjects.[17] Total energy expenditure increased and the respiratory quotient decreased after the MCT test meal, resulting in a significantly elevated thermogenic response. Hill *et al.* reported that the thermic response to ingestion of a 4190 kJ test meal containing 40% MCT was significantly higher compared to LCT.[15] Dulloo *et al.* saw a 5% increase in 24 h energy expenditure when humans were fed a diet containing 15–30 g MCT.[18] Our own previous findings suggested that DIT and postingestive total energy expenditure were significantly higher after 1680 kJ of SMLCT ingestion than after LCT ingestion.[11] Conversely, Flatt *et al.* compared the effect of ingesting an 3595 kJ test meal containing 40 g MCT versus 40 g LCT over 9 h.[19] Energy expenditure due to the consumption of the test meals was similar and equivalent to 11.2% and 12.5% of the energy contained in the LCT and MCT meals, respectively. The discrepancies among these findings may be partly as a result of differences in the composition of the test meals.

Medium-chain triacylglycerols has a different metabolic fate than LCT, which may account for the difference in

Table 4. Pre- and post-experiment blood biochemical test results in subjects

	SMLCT		LCT	
	Before	After	Before	After
Glucose (mg/100 mL)	89.7 ± 2.7	92.4 ± 5.4	87.5 ± 1.5	853 ± 2.9
Insulin (μU/mL)	7.7 ± 0.7	11.9 ± 6.2	7.7 ± 0.8	5.7 ± 0.7
Triacylglycerol (mg/100 mL)	75.1 ± 9.1	88.7 ± 17.5	61.7 ± 6.4	71.5 ± 16.8
Free fatty acids (mmol/L)	0.51 ± 0.12	0.38 ± 0.04	0.41 ± 0.09	0.45 ± 0.11
Total cholesterol (mg/100 mL)	166 ± 7	172 ± 5	197 ± 31	200 ± 33
HDL-cholesterol (mg/100 mL)	56.1 ± 4.1	56.9 ± 4.7	58.2 ± 3.4	58.8 ± 5.3
Acetoacetic acid (μmol/L)	183 ± 6.7	17.6 ± 1.7	11.0 ± 2.0	16.7 ± 6.1
3-Hydroxybutylate (μmol/L)	71.0 ± 29.3	35.9 ± 6.0	43.2 ± 14.9	38.7 ± 16.8
GOT (U/L)	19.0 ± 2.7	17.0 ± 2.8	17.7 ± 0.9	18.0 ± 1.0
GPT (U/L)	18.6 ± 4.7	20.7 ± 5.9	12.5 ± 1.3	14.2 ± 2.1
Red blood cells ($\times 10^4$/μL)	517 ± 11	517 ± 8	529 ± 8	526 ± 9
Hemoglobin (g/100 mL)	15.6 ± 0.3	15.8 ± 0.1	15.9 ± 0.3	16.1 ± 0.3
Hematocrit (%)	47.8 ± 1.0	49.3 ± 0.7	43.6 ± 5.7	493 ± 1.1
MCV (fl)	92.4 ± 0.8	95.5 ± 1.1	91.7 ± 1.1	93.6 ± 1.2
MCH (pg)	30.1 ± 0.3	30.7 ± 0.4	30.0 ± 0.3	30.4 ± 0.3
MCHC (%)	32.5 ± 0.2	31.9 ± 0.2	32.8 ± 0.3	32.7 ± 0.3
White blood cells (/μL)	5771 ± 429	6443 ± 1044	6550 ± 597	5767 ± 572
Platelets ($\times 10^4$/μL)	21.0 ± 1.4	233 ± 1.6	203 ± 2.0	20.8 ± 2.2

Values are mean ± SE for 6–7 subjects. SMLCT, structured medium- and long-chain triacylglycerol; LCT, long-chain triacylglycerol; MCV, mean red cell volume; MCH, mean red cell hemoglobin; MCHC, mean red cell hemoglobin concentration; GOT, glutamate oxaloacetate transaminase; GPT, glutamate-pyruvate transaminase; HDL, high-density lipoprotein.

postprandial thermogenesis. The MCT are rapidly absorbed in the small intestine and is transported to the liver as free fatty acids via hepatic portal circulation.[21–23] Medium-chain fatty acids enter the mitochondria of liver cells independent of fatty acyl-CoA-carnitine transferase, which is necessary for transport of LCFA into mitochondria.[7,24] Acetyl-CoA formed by β-oxidation can be further oxidized via Krebs cycle to carbon dioxide and water or can be used in the synthesis of LCFA and cholesterol. Two molecules of acetyl-CoA condense to form ketones. Utilization of ketones by peripheral tissues is concentration dependent and oxidation could cause a significant increase in oxygen consumption if oxidation of other substrates were not reduced appropriately.[25] The thermic effect of MCT would be related to production and oxidation of ketone bodies.[4] Synthesis of LCFA from acetyl-CoA in the liver requires large amounts of energy.[16,24] However, the concentration of ketone bodies and triacylglycerol did not differ between the SMLCT and LCT groups after the 12-week experimental period. In this study, we used the blood samples collected under fasting condition, so serum ketones and lipids may be not influenced directly by dietary SMLCT and LCT.

The values of the blood biochemical test for all subjects were normal compared with standard values before and after the 12-week experimental period.[26] These results confirmed that the subjects were in good health before the liquid diet supplement and this study was performed safely.

In this study, we used a liquid-formula diet based on 20 g oils. This level would be expected in normal daily cooking in Japan. The SMLCT are better for cooking than MCT or the physical mixture of MCT and LCT because of the higher smoke point, which allows the use of larger amounts of cooking oil, for example, for deep-frying. This study raises the possibility that replacing LCT with SMLCT over long periods of time could produce bodyfat loss in the absence of reduced energy intake. Further clinical studies are needed to clarify details concerning the effects of SMLCT on bodyfat loss during dietary therapy.

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