Dietary Medium-Chain Triacylglycerols Suppress Accumulation of Body Fat in a Double-Blind, Controlled Trial in Healthy Men and Women

Hiroaki Tsuji,*[1] Michio Kasai,* Hiroyuki Takeuchi,* Masahiro Nakamura,* Mitsuko Okazaki† and Kazuo Kondo**

*Division of Healthcare Science Research Laboratory, Nisshin Oil Mills, Ltd., Kanagawa 239-0832, Japan; †Kagawa Nutrition University, Saitama 350-0288, Japan; and the **Institute of Environmental Science for Human Life, Ochanomizu University, Tokyo 112-8610, Japan.

ABSTRACT We investigated the effect of long-term ingestion of dietary medium-chain triacylglycerols (MCT) on body weight and fat in humans. Using a double-blind, controlled protocol, we assessed the potential health benefits of MCT compared with long-chain triacylglycerols (LCT) in 78 healthy men and women [body mass index (BMI) $\geq$ 23 kg/m^2: n = 26 (MCT), n = 30 (LCT); BMI $<$ 23 kg/m^2: n = 15 (MCT), n = 7 (LCT)]. Changes in anthropometric variables, body weight and body fat during the 12-wk MCT treatment period were compared with those in subjects consuming the LCT diet. The subjects were asked to consume 9218 kJ/d and 60 g/d of total fat. The energy, fat, protein and carbohydrate intakes did not differ significantly between the groups. Body weight and body fat in both groups had decreased by wk 4, 8 and 12 of the study. However, in the subjects with BMI $\geq$ 23 kg/m^2, the extent of the decrease in body weight was significantly greater in the MCT group than in the LCT group. In subjects with BMI $\geq$ 23 kg/m^2, the loss of body fat in the MCT group (-3.86 ± 0.3 kg) was significantly greater than that in the LCT group (-2.75 ± 0.2 kg) at 8 wk. In addition, in subjects with BMI $\geq$ 23 kg/m^2, the decrease in the area of subcutaneous fat in the MCT group was significantly greater than that in the LCT group at wk 4, 8 and 12. These results suggest that the MCT diet may reduce body weight and fat in individuals (BMI $\geq$ 23 kg/m^2) more than the LCT diet. J. Nutr. 131: 2853–2859, 2001.

KEY WORDS: • *fat intake* • *medium-chain triacylglycerols* • *body mass index* • *body fat* • *obesity* • *humans*

Medium-chain triacylglycerols (MCT),[2] composed of medium-chain fatty acids such as octanoic and decanoic acids, are readily hydrolyzed by lingual and gastric lipases. The medium-chain fatty acids formed are absorbed through the portal system without resynthesis of triacylglycerol in intestinal cells, are subjected predominantly to β-oxidation in the liver, and are not stored as fat. Consequently, MCT constitute a good energy source for patients with pancreatic insufficiency and fat malabsorption as well as preterm infants with pancreatic juice and bile acid insufficiency.

Because their intramitochondrial transport of medium-chain fatty acids does not require carnitine palmitoyltransferase (1), this does not represent a limiting step in their metabolism. Consequently, MCT are oxidized more than long-chain triacylglycerols (LCT) (2). For these reasons, MCT could be useful for the dietary treatment of obesity. In fact, it has been reported that the body weight gain of rats fed MCT is less than that of rats fed LCT (3–5), possibly because the oxygen consumption of the former rats is higher than that of the latter (6,7). However, such effects have not been reported in humans. In the present study, we assessed the potential health benefits of MCT compared with those of LCT, using 78 healthy men and women [BMI $\geq$ 23 kg/m^2: n = 26 (MCT), n = 30 (LCT); BMI $<$ 23 kg/m^2: n = 15 (MCT), n = 7 (LCT)], using a double-blind, controlled protocol. Data from subjects with BMI $\geq$ 23 kg/m^2 or $<$ 23 kg/m^2 were examined based on the Japan Society for the Study of Obesity report (8). Changes in anthropometric variables, body weight and body fat profiles during the 12 wk of MCT treatment were compared with those of subjects consuming the LCT diet.

MATERIALS AND METHODS

Subjects. The study subjects were 86 men and 15 women ranging in age from 20 to 58 y with a BMI of 24.7 $\pm$ 0.2 kg/m^2. All of the subjects were generally healthy and had no history of hypertension, diabetes or hyperlipidemia. Most of the subjects were classified as performing level 1 (mild) or level 2 (medium) daily activity according to the Fifth Recommended Dietary Allowance for Japanese (9). Subjects who discontinued the study or who did not maintain the regulated diet (n = 23) were excluded from the final study analysis.

This study was carried out in accordance with the Helsinki Declaration of 1975, as revised in 1983, and was approved by the Ethics Committee of Ochanomizu University. The procedures were fully

[1] To whom correspondence should be addressed.
E-mail: hiroaki.tsuji@nisshin-seiyu.co.jp

[2] Abbreviations used: ALT, alanine aminotrasnferase; AST, aspartate aminotransferase; BMI, body mass index; CT, computed tomography; γ-GTP, γ-glutamyl transpeptidase; LCT, long-chain triacylglycerols; MCT, medium-chain triacylglycerols; PUFA, polyunsaturated fatty acid; WC, waist circumference; WHR, waist-to-hip ratio.

Manuscript received 30 April 2001. Initial review completed 18 June 2001. Revision accepted 22 August 2001.

explained to all the volunteers in advance, and all gave their signed informed consent before participating.

Test diets. MCT were purchased commercially (Nisshin Oil Mills, Tokyo, Japan). Common edible oil, blended rapeseed oil and soybean oil (Nisshin Oil Mills) were used as LCT. Fatty acid compositions were determined by a gas liquid chromatography system (6890 series; Agilent Technologies, Palo Alto, CA) with a capillary column (SP2340; Supelco, Bellefonte, PA) after esterification. The fatty acid compositions of MCT and LCT are given in **Table 1**. Bread containing LCT or MCT was prepared and was designated as the LCT or MCT test diet, respectively.

Protocol. The study was carried out in a double-blind, controlled manner. Body weight, height, energy intake, fat intake and daily activity were investigated before the beginning of the study. Subjects (n = 100) were randomly assigned to the LCT or the MCT diet group. The subjects were asked to consume 9218 kJ/d and 60 g/d of total fat, and to maintain their daily exercise at a fixed level during the 12-wk experimental period.

Before starting the study, all subjects were given thorough instructions in dietary regulation. The test diet was given only as breakfast, and the daily intake of the test oil was set at 10 g. The subjects were asked to consume the test diet every day throughout the study. For breakfast, lunch and dinner every day, the subjects consumed the same packaged meals for 12 wk under the guidance of the dietitian. The average energy contents of breakfast, lunch and dinner were ~1200, 3300 and 2600 kJ, respectively. The average total fat contents of breakfast, lunch and dinner were ~12, 25 and 20 g, respectively. The subjects were ask to consume 150 g/d of fruit and 150 g/d of vegetables (~630 kJ) and to consume side dishes or snacks containing 1467 ± 210 kJ and 3 ± 2 g of fat every day. If the subjects were unable to consume the packaged meal for any reason, they were asked to maintain the target intake of energy and total fat with food from a restaurant or fast food outlet. If the subjects were unable to consume this alternative food because of personal circumstances, individual directions were given on the basis of the menu obtained in advance. The daily intake of alcoholic beverages was restricted to 25 mL of ethanol equivalents.

The subjects were instructed to record the contents of daily meals, snacks and beverages in the diet diary for the entire test. The diary was collected weekly to confirm the meal intake, and, if necessary, the subject was immediately instructed to adhere to the dietary regimen. Daily intakes of energy, fat, protein, carbohydrate and fatty acids were calculated from the diary record by the dietitian on the basis of the Fourth Revision of the Standard Tables of Food Composition in Japan (10).

Anthropometric measurements. All measurements were performed by trained investigators. The participants wore light clothing without footwear. Body weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively. Waist circumference (WC) was measured at the umbilical level. Maximum hip circumference was obtained at the level of the greatest posterior protuberance. Both waist and hip circumferences were measured to the nearest 0.1 cm in a standing position. These measurements were performed at 0, 4, 8 and 12 wk.

Blood sampling and clinical analysis. At 0, 4, 8 and 12 wk, blood samples were collected from the subjects between 9:30 and 11:30 h after an overnight fast from 21:00 h on the previous day. Blood sampling and anthropometric measurements were performed on the same day. Analyses of serum triacylglycerol, cholesterol were carried out on a 7450 automated system (Hitachi, Tokyo, Japan) by enzymatic methods. Analyses of serum total ketone bodies were conducted using a JCA-BM12 automated system (JEOL, Tokyo, Japan) by enzymatic method. Serum aspartate aminotransferase (AST; UV method), alanine aminotransferase (ALT; UV method) and γ-glutamyl transpeptidase (γ-GTP; colorimetric analysis) were assayed on a 7170 automated system (Hitachi).

Measurement of body fat. At 0, 4, 8 and 12 wk, body fat was measured by the air-replacement method (11), using a MAB-1000 body densitometer (Nihon Kohden, Tokyo, Japan).

Measurement of fat by computed tomography (CT). The subjects underwent CT scanning within 3 d before or after anthropometric measurements at Yokohama Red Cross Hospital (Yokohama, Japan) using Pro Seed (GE Yokogawa Medical System, Tokyo, Japan). Subcutaneous and visceral fat areas were determined from the CT images at the umbilical level by the method of Tokunaga et al. (12).

Statistical analyses. Values were expressed as means ± SEM. Data from the subjects with BMI over 23 kg/m^2 or under 23 kg/m^2 are presented individually expect for nutritional intake. The differences in raw data were examined by two-way (dietary fat groups × period) ANOVA. In addition, the significance of differences between the groups for the same period was examined by unpaired Student's t test (two-tailed). Differences with $P < 0.05$ were considered significant. These statistical calculations were performed with SPSS for Windows, Version 10.0J (SPSS Japan, Tokyo, Japan).

TABLE 1

Fatty acid composition of test oils

Fatty acid	LCT[1]	MCT
	g/100 g total fatty acids	
8:0[2]	ND[3]	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

[1] Blended oil of rapeseed oil and soybean oil (7:3).
[2] Number of carbon atoms: number of double bounds.
[3] ND = not detected.

RESULTS

Energy consumption. There were no differences between the MCT group and the LCT group in energy intake, nutrient intake and fat composition of the test foods during the test period, except for (n-3) polyunsaturated fatty acids (PUFA; **Table 2**). There were no differences in energy and fat intakes before the test period between the BMI < 23 kg/m^2 and BMI ≥ 23 kg/m^2 groups. During the 12-wk test period, the energy, fat, protein and carbohydrate intakes did not differ significantly between the groups (Table 2). However, the medium-chain fatty acid intake of the MCT group was higher ($P < 0.05$) than that of the LCT group. Intake of saturated fatty acids by the LCT group, except for medium-chain fatty acids, was higher than by the MCT group. Intakes of monounsaturated fatty acids, (n-6) PUFA and (n-3) PUFA by the LCT group were higher than by the MCT group.

Anthropometrics variables. Body weight in both groups decreased during the study. However, in the subjects with BMI ≥ 23 kg/m^2, the extent of the decrease in body weight was significantly greater in the MCT group than in the LCT group at the same time-points (**Table 3**). In the subjects with BMI < 23 kg/m^2, body weight in both groups decreased but the groups did not differ. In the subjects with BMI ≥ 23 kg/m^2, WC had decreased significantly more in the MCT group than in the LCT group after 4 and 12 wk (Table 3), and the waist-to-hip ratio (WHR) in the MCT group had decreased significantly more after 12 wk than in the LCT group. In subjects with BMI < 23 kg/m^2, changes in WC and W/H did not differ between the groups.

Body fat analysis. The amount of body fat was significantly decreased at 4, 8 and 12 wk of the study in both groups

TABLE 2

Intakes of energy, fat, protein, carbohydrate and fatty acids of men and women consuming either long-chain triacylglycerol (LCT) or medium-chain triacylglycerol (MCT) diets for 12 wk[1]

	wk	LCT diet group	MCT diet group
		kJ/d	
Energy	Before	8845 ± 264	8996 ± 239
	1–12	9113 ± 17	9080 ± 13
		g/d	
Fat	Before	70.8 ± 3.0	69.8 ± 2.6
	1–12	59.0 ± 0.1	58.9 ± 0.1
Protein	Before	82.1 ± 2.7	82.2 ± 2.7
	1–12	68.7 ± 0.8	68.4 ± 0.7
Carbohydrate	Before	275 ± 9	277 ± 9
	1–12	332 ± 2	332 ± 1
Saturated fatty acids[2]	Before	20.1 ± 0.9	19.4 ± 0.9
	1–12	13.0 ± 0.0	10.8 ± 0.0*
Monounsaturated fatty acids	Before	25.9 ± 1.2	24.9 ± 0.9
	1–12	25.3 ± 0.0	20.5 ± 0.0*
(n−6) polyunsaturated fatty acids	Before	14.1 ± 0.7	14.4 ± 0.6
	1–12	12.2 ± 0.0	9.4 ± 0.0*
(n−3) polyunsaturated fatty acids	Before	2.86 ± 0.18	2.97 ± 0.14*
	1–12	2.60 ± 0.01	1.90 ± 0.01*
Medium-chain fatty acids	Before	0.36 ± 0.04	0.28 ± 0.03
	1–12	0.02 ± 0.00	9.24 ± 0.00*

[1] Values are means ± SEM, $n = 41$ (MCT) or 37 (LCT). Significantly different from LCT diet group: * $P < 0.05$.
[2] Medium-chain fatty acids excluded.

TABLE 3

The change in anthropometric measurements of men and women consuming either long-chain triacylglycerol (LCT) or medium-chain triacylglycerol (MCT) diets for 12 wk[1]

			LCT		MCT	
	BMI, kg/m[2]	wk		Δ[2]		Δ
Body weight, kg	≥23	0	72.8 ± 1.1		75.7 ± 1.9	
		4	70.8 ± 1.1#	−2.02 ± 0.2	72.9 ± 1.7#	−2.82 ± 0.3*
		8	69.4 ± 1.0#	−3.36 ± 0.3	71.3 ± 1.7#	−4.50 ± 0.4*
		12	68.0 ± 2.2#	−4.78 ± 0.4	69.6 ± 1.6#	−6.12 ± 0.5*
	<23	0	62.7 ± 2.5		63.7 ± 1.4	
		4	61.7 ± 2.4#	−1.04 ± 0.3	62.4 ± 1.2#	−1.24 ± 0.3
		8	60.6 ± 2.2#	−2.13 ± 0.6	61.5 ± 1.2#	−2.21 ± 0.4
		12	59.6 ± 2.2#	−3.08 ± 0.7	60.4 ± 1.1#	−3.30 ± 0.6
Waist circumference, cm	≥23	0	87.9 ± 1.0		89.6 ± 1.2	
		4	87.0 ± 1.1#	−0.90 ± 0.4	87.7 ± 1.1#	−1.91 ± 0.3*
		8	85.6 ± 1.1#	−2.26 ± 0.5	86.5 ± 1.1#	−3.05 ± 0.4
		12	84.2 ± 1.1#	−3.74 ± 0.5	83.9 ± 1.1#	−5.67 ± 0.5*
	<23	0	77.9 ± 0.6		80.3 ± 1.0	
		4	78.0 ± 0.7	0.04 ± 0.6	79.3 ± 1.0#	−0.98 ± 0.4
		8	76.7 ± 0.5	−1.19 ± 0.6	78.5 ± 1.0#	−1.80 ± 0.5
		12	75.5 ± 0.6#	−2.40 ± 0.6	76.5 ± 1.0#	−3.71 ± 0.7
WHR[3]	≥23	0	0.899 ± 0.009		0.902 ± 0.010	
		4	0.901 ± 0.011	0.002 ± 0.004	0.895 ± 0.009#	−0.007 ± 0.003
		8	0.895 ± 0.011	−0.004 ± 0.005	0.895 ± 0.009	−0.007 ± 0.005
		12	0.889 ± 0.010	−0.010 ± 0.005	0.877 ± 0.010#	−0.025 ± 0.005*
	<23	0	0.833 ± 0.009		0.858 ± 0.009	
		4	0.842 ± 0.016	0.009 ± 0.009	0.855 ± 0.008	−0.003 ± 0.004
		8	0.841 ± 0.012	−0.007 ± 0.005	0.854 ± 0.009	−0.004 ± 0.004
		12	0.826 ± 0.013	−0.007 ± 0.007	0.838 ± 0.009#	−0.020 ± 0.006

[1] Values are means ± SEM, $n = 26$ (MCT, BMI ≥ 23), 30 (LCT, BMI ≥ 23), 15 (MCT, BMI < 23), 7 (LCT, BMI < 23). Significantly different from the initial value: # $P < 0.05$. Significantly different from LCT diet group: * $P < 0.05$.
[2] Four-, 8-, and 12-wk values minus 0-wk value.
[3] Waist-to-hip circumference ratio.

(**Table 4**). In subjects with BMI ≥ 23 kg/m^2, the decrease in body fat of the MCT group (−3.86 ± 0.3 kg) was significantly greater than that of the LCT group (−2.75 ± 0.2kg) at 8 wk. In the subjects with BMI < 23 kg/m^2, the change in body fat did not differ between diet groups. In the subjects with BMI ≥ 23 kg/m^2, the decrease in the area of subcutaneous fat was significantly greater in the MCT group than in the LCT group at 4, 8 and 12 wk (Table 4). However, in subjects with BMI < 23 kg/m^2, changes in subcutaneous fat area in both groups did not differ. In the subjects with BMI ≥ 23 kg/m^2, the change in area of visceral fat did not differ significantly between the groups. However, in the subjects with BMI < 23 kg/m^2, the decrease in area of visceral fat area of the MCT group was greater than that of the LCT group at 12 wk.

Blood chemistry. In the subjects with BMI ≥ 23 kg/m^2, triacylglycerols were significantly decreased during the study. Total cholesterol in both groups was significantly decreased after intake of the test diets (**Table 5**). However, there was no significant difference in blood lipid composition between the groups. In contrast, in the subjects with BMI ≥ 23 kg/m^2, total ketone bodies in the MCT group were higher than in the LCT group at 8 and 12 wk. However, these values were within the normal range. In the subjects with BMI < 23 kg/m^2, total ketone body levels did not differ between groups. AST, ALT and γ-GTP activities were within normal ranges in all groups.

DISCUSSION

In this long-term study, we investigated the effect of MCT on body weight and fat in healthy subjects. Obesity is an important predictor of cardiovascular death (13,14), partly due to its close associations with increased prevalence of hypertension, diabetes mellitus and dyslipidaemia (15,16). In contrast, BMI, WC and WHR are all useful anthropometric indices and provide important information on cardiovascular risk. However, the relative predictive values of these indices for obesity and cardiovascular risk remain controversial. In Americans and Canadians, obesity is often defined as a BMI ≥ 27–30 kg/m^2 in both men and women (17,18). In 1998 the World Health Organization defined BMI values exceeding 25 and 30 kg/m^2 as indicative of being overweight and obese, respectively (19). However, these definitions cannot be readily applied to Asians, who often have smaller body frames than do Americans and Canadians. It is important from a public health perspective to determine what values of simple anthropometric measurements are associated with the presence of adverse cardiovascular risk factors such as diabetes, hypertension or dyslipidemia to provide an indication for additional detailed investigations. Ko et al. (20) reported that risk factors for cardiovascular disease, diabetes and hypertension were increased in Hong Kong Chinese with BMI ≥ 23 kg/m^2. The cardiovascular disease risk factors in Asian populations may be lower risk than those in Western populations (21). Recently, the Japan Society for the Study of Obesity (8) reported that a BMI ≥ 23 kg/m^2 indicates being overweight and can be used as an objective value in the treatment of obesity in Japan. Therefore, in this study, all data from the subjects with BMI over or under 23 kg/m^2 were presented individually, expect for nutritional intake. In subjects with BMI ≥ 23 kg/m^2, body weight and body fat in the MCT group were significantly lower than those in the LCT group for both measurement and Δ value at 0, 4, 8 and 12 wk.

Many investigators using animal models have found that

TABLE 4

The change in the body fat composition of men and women consuming either long-chain triacylglycerol (LCT) or medium-chain triacylglycerol (MCT) diets for 12 wk[1]

			LCT diet group		MCT diet group	
	BMI, kg/m2	wk		Δ[2]		Δ
Body fat weight, kg	≥23	0	18.9 ± 0.8		20.1 ± 1.1	
		4	17.3 ± 0.8#	−1.60 ± 0.2	18.4 ± 1.0#	−1.74 ± 0.2
		8	16.2 ± 0.9#	−2.75 ± 0.2	16.4 ± 1.0#	−3.86 ± 0.3*
		12	15.3 ± 0.9#	−3.61 ± 0.4	15.5 ± 1.0#	−4.57 ± 0.5
	<23	0	12.4 ± 0.6		12.9 ± 0.5	
		4	11.7 ± 0.8#	−0.73 ± 0.2	12.0 ± 0.6#	−0.96 ± 0.3
		8	10.4 ± 0.5#	−2.02 ± 0.4	11.2 ± 0.7#	−1.72 ± 0.4
		12	10.0 ± 0.6#	−2.49 ± 0.5	10.6 ± 0.8#	−2.36 ± 0.5
Subcutaneous fat area, cm2	≥23	0	164.7 ± 9.9		179.5 ± 12.0	
		4	154.3 ± 9.9#	−10.4 ± 2.2	161.3 ± 11.4#	−18.1 ± 2.8*
		8	145.7 ± 10.2#	−18.9 ± 2.5	147.9 ± 11.1#	−31.6 ± 3.0*
		12	132.0 ± 10.8#	−32.6 ± 0.5	130.6 ± 10.8#	−48.8 ± 5.1*
	<23	0	114.5 ± 12.6		106.7 ± 11.4	
		4	102.6 ± 11.7#	12.0 ± 2.1	99.5 ± 11.7#	−7.2 ± 11.9
		8	101.9 ± 15.7#	−12.6 ± 4.2	91.8 ± 12.4#	−14.9 ± 2.9
		12	88.5 ± 13.2#	−26.0 ± 4.2	86.8 ± 12.0#	−19.9 ± 3.7
Visceral fat area, cm2	≥23	0	84.7 ± 5.5		87.1 ± 7.2	
		4	74.2 ± 4.5#	−10.5 ± 2.6	76.2 ± 5.7#	−10.9 ± 2.7
		8	69.3 ± 5.1#	−15.4 ± 2.5	68.7 ± 5.8#	−18.3 ± 3.3
		12	62.7 ± 4.5#	−22.0 ± 2.8	61.9 ± 5.5#	−25.2 ± 3.3
	<23	0	44.2 ± 6.9		58.4 ± 5.1	
		4	44.6 ± 7.1	0.3 ± 2.0	55.9 ± 5.0	−2.5 ± 1.8
		8	40.3 ± 7.7	−4.0 ± 2.8	49.1 ± 4.3#	−9.2 ± 2.6
		12	38.5 ± 6.3#	−5.7 ± 1.4	41.9 ± 3.5#	−16.4 ± 2.6*

[1] Values are means ± SEM, n = 26 (MCT, BMI ≥ 23), 30 (LCT, BMI ≥ 23), 15 (MCT, BMI < 23), 7 (LCT, BMI < 23). Significantly different from the initial value: # $P < 0.05$

[2] Four-, 8-, and 12-wk value minus 0- wk value.

TABLE 5

Concentration of lipids in serum, total ketone bodies and hepatic enzymes in men and women consuming either long-chain triacylglycerol (LCT) or medium-chain triacylglycerol (MCT) diets for 12 wk[1]

			LCT		MCT	
	BMI, kg/m^2	wk		Δ[2]		Δ
Triacylglycerol, mmol/L	≥23	0	1.76 ± 0.24		1.48 ± 0.18	
		4	1.50 ± 0.15	−0.26 ± 0.15	1.21 ± 0.12#	−0.27 ± 0.11
		8	1.27 ± 0.08#	−0.49 ± 0.19	1.07 ± 0.10#	−0.42 ± 0.13
		12	1.23 ± 0.12#	−0.53 ± 0.15	0.98 ± 0.10#	−0.50 ± 0.14
	<23	0	0.79 ± 0.14		1.15 ± 0.17	
		4	0.89 ± 0.18	0.10 ± 0.17	1.06 ± 0.09	−0.09 ± 0.14
		8	0.73 ± 0.13	−0.06 ± 0.07	0.92 ± 0.08	−0.23 ± 0.14
		12	0.67 ± 0.05	−0.12 ± 0.12	0.87 ± 0.07	−0.28 ± 0.17
Total cholestrol, mmol/L	≥23	0	5.50 ± 0.19		5.36 ± 0.16	
		4	4.87 ± 0.18#	−0.64 ± 0.12	4.82 ± 0.17#	−0.55 ± 0.08
		8	4.71 ± 0.15#	−0.80 ± 0.13	4.70 ± 0.16#	−0.67 ± 0.08
		12	4.73 ± 0.18#	−0.78 ± 0.13	4.64 ± 0.16#	−0.73 ± 0.10
	<23	0	4.88 ± 0.20		4.89 ± 0.22	
		4	4.25 ± 0.09#	−0.63 ± 0.18	4.41 ± 0.19#	−0.48 ± 0.13
		8	4.29 ± 0.19#	−0.59 ± 0.20	4.38 ± 0.17#	−0.52 ± 0.13
		12	4.26 ± 0.18#	−0.62 ± 0.20	4.33 ± 0.20#	−0.56 ± 0.13
Total ketone bodies, μmol/L[3]	≥23	0	51.2 ± 12.2		35.6 ± 3.1	
		4	56.8 ± 10.9	5.6 ± 6.8	58.9 ± 9.8#	23.3 ± 10.5
		8	53.2 ± 7.3	2.0 ± 15.0	91.7 ± 16.1#*	56.2 ± 16.0*
		12	63.0 ± 9.0	11.8 ± 15.1	110.6 ± 19.9#*	75.0 ± 20.6*
	<23	0	63.9 ± 29.0		41.7 ± 7.2	
		4	40.3 ± 7.3	−23.6 ± 31.3	57.1 ± 8.4	15.4 ± 12.0
		8	53.3 ± 12.3	−10.6 ± 36.0	55.0 ± 8.5	13.3 ± 10.7
		12	82.4 ± 23.5	18.6 ± 12.2	69.5 ± 21.1	27.8 ± 20.6
GOT, U/L	≥23	0	27.9 ± 2.7		28.1 ± 1.8	
		4	23.9 ± 2.3#	−4.1 ± 0.9	24.4 ± 1.4#	−3.7 ± 1.2
		8	22.4 ± 1.6#	−5.5 ± 1.5	22.8 ± 1.2#	−5.2 ± 1.2
		12	23.2 ± 1.5#	−4.7 ± 1.6	22.7 ± 1.1#	−5.4 ± 1.3
	<23	0	25.1 ± 2.7		21.3 ± 1.4	
		4	22.6 ± 1.6	−2.6 ± 1.4	18.0 ± 0.6#*	−3.3 ± 1.1
		8	22.9 ± 2.3	−2.3 ± 1.3	18.1 ± 0.8#*	−3.3 ± 1.1
		12	23.1 ± 1.8	−2.0 ± 1.6	18.2 ± 0.5#*	−3.1 ± 1.3
GPT, U/L	≥23	0				
		4	31.1 ± 5.7#	−6.1 ± 2.0	31.1 ± 4.0#	−6.2 ± 2.3
		8	27.3 ± 3.9#	−9.9 ± 3.4	27.2 ± 4.1#	−10.2 ± 2.2
		12	24.8 ± 3.7#	−12.4 ± 3.5	24.4 ± 3.1#	−12.9 ± 2.6
	<23	0	26.0 ± 6.6		22.1 ± 3.1	
		4	22.1 ± 4.2	−3.9 ± 2.8	16.9 ± 1.7#	−5.2 ± 2.4
		8	20.3 ± 3.8	−5.7 ± 3.3	16.5 ± 1.9#	−5.6 ± 2.4
		12	20.1 ± 3.8	−5.9 ± 3.3	14.9 ± 1.1#	−7.3 ± 2.6
γ−GPT, U/L	≥23	0	50.3 ± 7.9		43.6 ± 5.8	
		4	35.8 ± 6.0#	−14.5 ± 3.8	30.3 ± 3.5#	−13.3 ± 2.8
		8	31.5 ± 4.5#	−18.8 ± 4.2	26.3 ± 3.0#	−17.2 ± 3.1
		12	29.4 ± 4.6#	−20.9 ± 4.4	25.4 ± 3.1#	−18.2 ± 3.1
	<23	0	32.4 ± 6.7		34.0 ± 6.5	
		4	29.6 ± 10.4	−2.9 ± 5.8	26.1 ± 4.6#	−7.9 ± 3.1
		8	24.1 ± 5.9	−8.3 ± 2.7	23.9 ± 4.1#	−10.1 ± 3.6
		12	21.4 ± 3.9	−11.0 ± 3.7	21.1 ± 3.3#	−12.9 ± 4.0

[1] Values are means ± SEM, n = 26 (MCT, BMI ≥ 23), 30 (LCT, BMI ≥ 23), 15 (MCT, BMI < 23), 7 (LCT, BMI < 23). Significantly different from the initial value: # $P < 0.05$, significantly different from LCT diet group: * $P < 0.05$

[2] Four-, 8-, and 12-wk value minus 0-wk value.

[3] Total keton bodies include 3-hydroxbutyric acid and acetoacetic acid.

MCT can exert slight weight-reducing effects. This has been confirmed in many experiments performed mainly on rats, notably obese Zucker rats (22,23), but also on other animal models (24–27). For example, Hashim et al. (4) reported that MCT-fed rats were significantly lighter and had smaller epididymal, retroperitoneal, omental and subcutaneous fat pads than did respective pair-fed LCT rats. These data correspond well to our results.

In animal studies, the observed decreases in body weight have resulted primarily from shrinkage of fat depots (4,5,28,29), leading to reduction in the relative fat content of the whole body (22,30,31). The number of adipocytes seems to be independent of alimentary fat (7) (32,33), whereas their mean size is less in MCT-fed than in LCT-fed rats. In contrast, exogenous food supply causes a transient increase in energy expenditure, i.e., the thermic effect of food. Hill et al. (34) demonstrated unequivocally that the thermic effect of food curve of healthy volunteers was delayed and did not return to the baseline value by 6 h after a normal meal containing 40% energy as MCT, in contrast to the response obtained after intake of LCT.

These conclusions, however, are far from being universally

accepted, because the promising slimming potential of MCT in humans has been poorly documented, and clinical studies supporting this concept have been rare and rather disappointing. In a study by Rath et al. (35), 24 obese women fasted for 5 consecutive days before consuming two different hypocaloric diets for 3 wk: 12 were placed on a 550-kcal (2305 kJ) regimen providing 50 g of protein and 30 g of MCT, and the others were placed on a 500-kcal (2095 kJ) regimen with 60 g of protein and 10 g of LCT as whipped cream. At the end of the experiment, body weight losses were the same in the two groups. In another clinical study, Yost and Eckel (36) placed 16 obese women on two different hypocaloric regimens [800 kcal (3352 kJ) and 30% energy as fat] for 4–12 wk. The first regimen comprised only LCT, whereas the second consisted of 6% LCT and 24% MCT. Here too, the recorded body weight losses were similar with both fats. Finally, Hill et al. (37) investigated 10 nonobese volunteers who were given a regimen providing 150% of the recommended dietary allowance for 6 d. Fats were ingested as 40% LCT or 40% MCT in a randomized, crossover design. No significant change in body weight was recorded at the end of either diet protocol.

The balance between body weight reduction and increase achieved through use of a diet seems to vary widely, indicating the balance between the two conditions needs to be substantiated more fully. For a wide variety of reasons, the positive and negative effects of MCT on body weight vary among experiments, although, ultimately, they are always rather small. Hence, there have been no reports in authoritative journals about the role of MCT in the treatment of obesity (38–40).

From the existing literature, we consider that the following two items are important. First, in general, not only intake of oil but also total energy intake affects body weight. In previous clinical trials, the actual energy intake was not reported, although the intake of oil was stipulated. In this study, we stringently controlled not only the amount of oil, but also the total energy intake under the guidance of a dietitian. Consequently, the total daily energy intake by individual subjects was almost the same during the study. Second, we believe that the hepatic lipid turnover rate in obese persons (BMI $\geq$ 23 kg/m^2) may be slower than in nonobese persons (BMI $<$ 23 kg/m^2). Therefore, we divided the data into those for subjects with a BMI over and under 23 kg/m^2 and analyzed the results separately. Consequently, we found that in subjects with BMI $\geq$ 23 kg/m^2, body weight and fat in those fed MCT were significantly lower than in those fed LCT. These results suggest that a MCT diet may tend to reduce body weight and fat in overweight persons (BMI $\geq$ 23 kg/m^2) compared with a LCT diet.

ACKNOWLEDGMENTS

We acknowledge the technical guidance and advice given by F. Yamaki, S. Masuda, K. Tsuchiya, N. Taguchi, K. Yamanouchi and M. Hosaka. We thank the Kanagawa branch of the Japan Anti-tuberculosis Association for blood sampling, and Yokohama Red Cross Hospital for measurement of fat by computed tomography.

The anthropometric and body fat measurements were conducted by N. Nosaka, O. Noguchi, F. Kubota and K. Oyama. We thank T. Noro, I. Takahashi M. Itakura and Y. Kojima for nutrition stewardship and analysis.

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