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ORIGINAL ARTICLE

Medium- and Long-Chain Triacylglycerols Reduce Body Fat and Blood Triacylglycerols in Hypertriacylglycerolemic, Overweight but not Obese, Chinese Individuals

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Abstract In contrast to the consumption of long-chain triacylglycerols (LCT), consumption of medium- and long-chain triacylglycerols (MLCT) reduces the body fat and blood triacylglycerols (TAG) level in hypertriacylglycerolemic Chinese individuals. These responses may be affected by BMI because of obesity-induced insulin resistance. We aimed to compare the effects of consuming MLCT or LCT on reducing body fat and blood TAG level in hypertriacylglycerolemic Chinese subjects with different ranges of BMI. Employing a double-blind, randomized and controlled protocol, 101 hypertriacylglycerolemic subjects (including 67 men and 34 women) were randomly allocated to ingest 25–30 g/day MLCT or LCT oil as the only cooking oil for 8 consecutive weeks. Anthropometric measurements of body weight, BMI, body fat, WC, HC, blood biochemical variables, and subcutaneous fat area and visceral fat area in the abdomen were measured at week 0 and 8. As compared to subjects with BMI 24–28 kg/m^2 in the LCT group, corresponding subjects in the MLCT group showed significantly greater decrease in body weight, BMI, body fat, WC, ratio of WC to HC, total fat area and subcutaneous fat area in the abdomen, as well as blood TAG and LDL-C levels at week 8. Based upon our results, consumption of MLCT oil may reduce body weight, body fat, and blood TAG and LDL-C levels in overweight hypertriacylglycerolemic Chinese subjects but may not induce these changes in normal or obese hypertriacylglycerolemic subjects.

Keywords Medium-and long-chain triacylglycerols · Body fat · Blood triacylglycerols · Hypertriacylglycerolemia · Overweight · Chinese · Long-chain triacylglycerols

Abbreviations

ALT	Alanine aminotransferase
AST	Aspartate aminotransferase
BMI	Body mass index
HC	Hip circumference
HDL-C	High-density lipoprotein-cholesterol
LCT	Long-chain triacylglycerols
LDL-C	Low-density lipoprotein-cholesterol
MLCT	Medium- and long-chain triacylglycerols
SFA	Subcutaneous fat area
TAG	Triacylglycerols
TFA	Total fat area
VFA	Visceral fat area
WC	Waist circumference
WHR	Ratio of waist circumference to hip circumference

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Introduction

The prevalence of being overweight or obese has increased by 40.7 and 97.2%, respectively, in mainland China since 1992 [1]. This trend will undoubtedly increase the incidence of chronic diseases such as hypertension, diabetes, stroke and coronary heart disease. The total medical cost

that can be attributed to being overweight and obese was estimated at 21.11 billion Chinese Renminbi (RMB) Yuan and accounted for 25.5% of the total medical costs for the four chronic diseases, or 3.7% of the total national medical costs, in 2003 [2]. The high economic burden of being overweight or obese suggests an urgent need to develop effective interventions for preventing and controlling overweightedness and obesity. Hypertriacylglycerolemia is an independent risk factor for cardiovascular disease [3, 4]. There is a suggestion that choosing the right type of dietary fat could be an effective strategy for preventing weight gain or fat deposition and reducing the blood levels of triacylglycerols (TAG) under an appropriate dietary regimen [3, 5].

Ordinary dietary fats are mainly long-chain triacylglycerols (LCT) composed of long-chain fatty acids with carbon numbers ranging from 14 to 18. In contrast, medium-chain triacylglycerols (MCT), composed of fatty acids with carbon numbers of 8–12, are found in palm oil and coconut oil, which are minor components of a normal diet. However, the carbon numbers of MCT used in our study were 8–10. Because MCT are hydrolyzed more rapidly and metabolized more completely than are LCT, rapid oxidation prevents deposition of fat [6]. For these reasons, MCT may be useful in dietary therapy. Animal studies have shown that consumption of MCT decreases body weight and the amount of fat deposited [7]. Dietary MCT also reduce body fat accumulation in healthy men and women [8]. Furthermore, ingestion of 18 g/day MCT has been shown to decrease body weight and waist circumference (WC) in moderately overweight humans with type 2 diabetes mellitus [9].

MCT are difficult to use as cooking oil because of a low smoke point and foam generation on being mixed with other vegetable oils or in frying. A new oil composed of medium- and long-chain triacylglycerols (MLCT) in the same glycerol molecule range produced by a transesterification technique has been developed recently as a cooking oil [10]. Our previous studies indicated that MLCT reduced body fat and blood TAG in Chinese hypertriacylglycerolemic subjects [11]. However, whether body mass index (BMI) affects the response in these hypertriacylglycerolemic Chinese individuals is unknown.

Elevated levels of free fatty acids (FFA) in the blood commonly seen in obese persons are associated with the expansion of adipose mass and insulin resistance. Blood cytokines such as leptin, plasminogen activator inhibitor-1 (PAI-1), tumor necrosis factor-α (TNF-α), and interleukin-6 (IL-6) levels were often increased in obese subjects. These are thought to promote insulin resistance [12]. Insulin resistance might hinder any increase in fat oxidation and induce difficulties in the reduction of body fat and TAG in obese subjects. These observations prompted us to investigate the response to MLCT consumption in subjects with different BMI categories.

The working group on obesity in China suggested that BMI values of 24–28 kg/m^2 and ≥28 kg/m^2 indicated overweight and obesity, respectively, in Chinese individuals [13]. We analyzed our previous data based on the BMI categories to elucidate whether overweight individuals responded differently to MLCT consumption than did obese individuals.

Materials and Methods

Study Design and Subjects

The study was carried out in accordance with the Helsinki Declaration and was approved by the Ethics Committee of the Chinese People's Liberation Army General Hospital. The study procedures were fully explained to all subjects, who gave their informed consent before the start of the study. The study was a double-blind, randomized clinical trial involving 76 men and 36 women with hypertriacylglycerolemia values of 1.7–4.5 mmol/L. All subjects had no history of diabetes, hypertension, renal and hepatic disease, or gastrointestinal disease and were not receiving any medication. The study population was randomly allocated to receive MLCT or LCT oil by random numbers assigned by the providers of the MLCT and LCT oil, who also encoded the oils with matching random numbers. Neither the subjects nor the researchers of this study knew which subject was receiving which oil during the study. Before starting the study, dietary energy intake for each individual was calculated using the Harris–Benedict equation. Food choice and amount for each subject were suggested by experienced dietitians and doctors by face-to-face communication. Recommended daily carbohydrates were about 55–60% of total daily calorie intake, and mainly came from complex carbohydrate of the starch food group, such as cereals and tubers. Ready-to-eat cereal products such as biscuits, crackers, instant noodles, etc. containing higher fat and/or higher refined sugar and alcoholic beverage were not allowed to be eaten during the study period. Recommended daily fats were about 25–30% of total energy intake, MLCT or LCT oil, as the only cooking oil, was to be consumed at a rate of 25–30 g/day, which was about 12–15% of the total daily energy intake, other types oil such as coconut were not allowed to be used during our study. Other fat mainly came from balanced foods such as egg, milk, lean red meat and white meat. These recommended foods provide balanced nutrients. The dietary regimen was maintained at relatively fixed energy and nutrients intake. In addition, both the time and the intensity of physical activity for

each subject were well controlled. A manual on the study was distributed to all subjects, in which all subjects were specifically advised how to maintain healthy bodily activity and to take moderately intensive exercise daily throughout the trial. The recommended activities were walking (4–5 km/h), housework, babysitting, and bicycle-riding (8–10 km/h), etc.

The subjects were instructed to record their physical activity intensity, duration and method for 3 days and the intake of the type and quantity of food for 3 days each week (including one weekend day) at baseline (week 0) and at weeks 2, 4, 6 and 8. The physical activities included walking (4–5 km/h), housework, childcare, and bicycle riding (8–10 km/h). The diaries were collected weekly to confirm that subjects were following the instructions, and if not, the subjects were advised to drop out of the study. Daily intake of energy, fat, protein, and carbohydrates was calculated from the food record on the basis of the China Food Composition Tables published in 2002.

Anthropometric and Biochemical Measurements

Anthropometric variables were measured by trained investigators. Body weight and height were measured to the nearest 0.1 kg and 0.1 cm. WC was measured at the umbilical level. Hip circumference (HC) was measured at the level of the greatest posterior protuberance. Both WC and HC were measured to the nearest 0.1 cm with the subject in a standing position, and the ratio of WC to HC (WHR) was calculated. All measurements were taken at baseline and at week 8.

Blood samples were taken in the morning after 12 h of overnight fasting at baseline and week 8. Levels of aspartate aminotransferase (AST), alanine aminotransferase (ALT), blood glucose, total cholesterol (TC), TAG, high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) were measured using a 7600-automated system (Hitachi, Tokyo, Japan).

Measurement of Body Fat and Abdominal Fat Area by Computed Tomography (CT)

The measurements were carried out after 12 h overnight fasting at baseline and at week 8. Body fat was measured by use of a BCA-2A body composition analyzer (Tongfang, Qinghua, Beijing, China). Subjects underwent CT [Pro 16 CT (GE, USA)] scanning at the umbilical level at the Chinese People's Liberation Army General Hospital. Visceral fat area (VFA) and subcutaneous fat area (SFA) were obtained from the CT images as described in [14]. Blood sampling, anthropometric measurements and CT scanning were performed on the same day.

Test Oils

The test oils of MLCT and LCT were supplied by The Nisshin Oillio Group (Tokyo). The fatty acids and TAG compositions of MLCT and LCT are listed in Table 1 and the same as those in a previous report [10]. In MLCT, the concentration of medium-chain fatty acids (MCFA), C8:0 and C10:0, was 13% of total MLCT oil weight (Table 1).

Statistical Analysis

Data were expressed as means ±SD. The general linear model (GLM) was used to test almost all data except for a chi-square test for gender distribution. In our GLM analysis, fixed factors were BMI and oil, a random factor was gender, covariate was age. The full factorial model, which included main effects and factors interaction, was used in our study. If a significant difference was detected, comparisons of means were performed by Student's t test between the two groups and by a paired t test between the initial and final values in the same group. All analyses involved use of SPSS v10.0 for Windows (SPSS Inc.,

Table 1 Fatty acid and triacylglycerols compositions of LCT and MLCT oil

Fatty acid	LCT (g/100 g total weight)	MLCT (g/100 g total weight)
8:0	ND	9.7
10:0	ND	3.3
16:0	6.2	3.8
16:1	0.2	0.2
18:0	2.5	1.7
18:1	48.8	51.2
18:2	30.2	18.4
18:3	9.4	9.0
20:0	0.6	0.6
20:1	1.1	1.2
22:0	0.4	0.3
22:1	0.2	0.3
24:0	0.2	0.1
24:1	0.2	0.2
Total	100	100
Triacylglycerols		
L, L, L	100.0	55.1
L, L, M	ND	35.2
L, M, M	ND	9.1
M, M, M	ND	0.6
Total	100.0	100.0

L long-chain fatty acids, *M* medium-chain fatty acids, *LCT* long-chain triacylglycerols, *MLCT* medium- and long-chain triacylglycerols, *ND* not detected

Chicago, IL, USA). The level of significant difference was set at $P < 0.05$.

Results

Subjects

Among the subjects, one had a traffic accident, one had a cerebral infarction, two were not willing to consume the specified oil and seven were unable to consume the oil for consecutive days (three were out of town on business and four were on vacation). Thus these eleven subjects were excluded from our study, and 101 subjects were enrolled finally in the study. There were 34 men and 16 women left in the LCT group, and 33 men and 18 women in the MLCT group at the end of the study. No gender distribution differences were noted between the two groups. The characteristics of the groups at the beginning of the study are shown in Table 2.

Intakes of Energy, Protein, Fat, Carbohydrate and Physical Activity Time and Gender Distribution

GLM analysis revealed that there was no significant difference in daily intake of total energy, protein, fat and carbohydrate or daily physical activity time among all the subgroups at baseline and week 8 ($P > 0.05$). In addition, chi-square analysis showed that there was no significant difference in gender distribution among all subgroups (Table 3).

Table 2 Characteristics of subjects consuming long-chain triacylglycerols (LCT) or medium- and long-chain triacylglycerols (MLCT) oil at baseline

Index	LCT ($n = 50$)	MLCT ($n = 51$)
Age (year)	53.2 ± 13.0	54.2 ± 12.5
Male (%)	34 (68.0%)	33 (64.7%)
Height (cm)	165.9 ± 8.8	166.5 ± 6.7
Body weight (kg)	71.5 ± 9.0	72.0 ± 11.4
BMI (kg/m^2)	25.9 ± 2.4	25.9 ± 3.3
Body fat weight (kg)	17.2 ± 4.4	17.4 ± 5.8
Body fat (%)	24.2 ± 6.2	23.9 ± 5.7
ALT (U/L)	25.5 ± 14.3	25.3 ± 14.9
AST (U/L)	22.1 ± 6.2	23.7 ± 8.9
Glucose (mmol/L)	5.1 ± 0.9	5.4 ± 1.0
TC (mmol/L)	5.2 ± 0.9	5.2 ± 0.8
TAG (mmol/L)	2.6 ± 0.7	2.7 ± 0.8

ALT alanine aminotransferase, *AST* aspartate aminotransferase, *BMI* body mass index, *TC* total cholesterol, *TAG* triacylglycerols

Anthropometric Measurements

GLM analysis showed that the oil had an effect, but the BMI no effect. As compared with their initial levels, body weight, BMI and WC decreased significantly in subjects with different BMI categories in the MLCT group. HC and WHR were lowered significantly in subjects with BMI 24–28 kg/m^2 in the MLCT group. WHR decreased significantly in subjects with BMI ≥28 kg/m^2 in the MLCT group ($P < 0.05$; Table 4). However, no similar changes in these indices were observed in the LCT group.

BMI × oil interaction was found using GLM analysis, further analysis revealed that there were greater decreases in the changes of body weight, BMI, WC and WHR in subjects with a BMI 24–28 kg/m^2 in the MLCT group as compared to their corresponding controls in the LCT group ($P < 0.05$; Table 4 and Fig. 1).

Body Fat Composition

GLM analysis showed that the oil has effects, but the BMI no effect. When compared with their baseline, body fat weight, TFA and SFA decreased significantly in subjects with BMI 24–28 kg/m^2 in MLCT group, but TFA and VFA increased in the same BMI category in the LCT group. Body fat weight and TFA was lowered significantly in subjects with a BMI <24 kg/m^2 in the MLCT group, however, VFA increased in the same BMI category in the LCT group ($P < 0.05$; Table 5).

BMI × oil interaction was found using GLM analysis, further analysis revealed the extent of decreases in changes and change rates of body fat weight, TFA and SFA in subjects with a BMI 24–28 kg/m^2 were greater in the MLCT group than those in corresponding subjects in the LCT group ($P < 0.05$; Table 5).

Blood Biochemical Variables

GLM analysis showed that the oil had effects, but the BMI no effect. When compared to their baseline, a significant decrease in blood TAG and an increase in HDL-C in subjects with a BMI 24–28 kg/m^2 in the MLCT group were observed; however, blood TAG, LDL-C and TC levels were significantly higher in the same BMI category subjects in the LCT group; LDL-C and TC increased significantly in subjects with a BMI <24 kg/m^2 in the LCT group. Blood TAG levels decreased significantly in subjects with a BMI ≥ 28 kg/m^2 in the MLCT group ($P < 0.05$; Table 6).

BMI × oil interaction was found by using GLM analysis, further analysis revealed that the extent of decreases in changes and change rates in blood TAG and LDL-C were greater in subjects with a BMI 24–28 kg/m^2 in the

Table 3 Mean intake of energy, protein, fat, and carbohydrates, mean physical activity time and gender distribution in subjects consuming LCT or MLCT oil

	Time	LCT ($n = 50$)			MLCT ($n = 51$)		
		BMI <24 kg/m^2 $n = 16$	BMI 24–28 kg/m^2 $n = 17$	BMI ≥28 kg/m^2 $n = 17$	BMI <24 kg/m^2 $n = 19$	BMI 24–28 kg/m^2 $n = 20$	BMI ≥28 kg/m^2 $n = 12$
Energy (kcal/day)	Baseline	1803.7 ± 281.3	1773.9 ± 253.7	1762.9 ± 218.9	1746.8 ± 164.2	1811.0 ± 233.8	1843.2 ± 191.6
	1–8 week	1760.0 ± 108.2	1786.2 ± 130.9	1724.4 ± 137.9	1767.5 ± 100.8	1758.0 ± 103.2	1727.1 ± 95.4
Protein (g/day)	Baseline	62.61 ± 14.03	58.84 ± 14.76	59.30 ± 12.28	60.87 ± 10.17	64.11 ± 14.11	59.99 ± 10.00
	1–8 week	60.91 ± 6.80	61.59 ± 4.80	60.32 ± 4.29	62.96 ± 6.92	60.67 ± 8.16	62.00 ± 7.67
Fat (g/day)	Baseline	51.07 ± 8.69	50.37 ± 10.62	51.11 ± 8.59	51.42 ± 7.63	52.31 ± 8.14	51.29 ± 8.72
	1–8 week	51.98 ± 3.86	52.14 ± 3.39	51.45 ± 2.43	51.77 ± 5.74	51.93 ± 5.26	51.06 ± 4.26
Carbohydrates (g/day)	Baseline	263.98 ± 54.42	261.23 ± 42.80	256.60 ± 43.73	251.06 ± 22.09	263.99 ± 32.86	269.20 ± 42.45
	1–8 week	252.40 ± 21.33	257.99 ± 26.18	246.42 ± 33.49	252.16 ± 15.28	251.00 ± 17.39	245.54 ± 11.49
Protein (% of total energy)	Baseline	13.75 ± 2.08	13.09 ± 2.05	13.38 ± 2.20	13.95 ± 1.43	14.11 ± 1.65	13.25 ± 1.72
	1–8 week	13.74 ± 1.17	13.66 ± 0.55	13.90 ± 1.00	14.15 ± 1.04	13.63 ± 1.27	14.20 ± 1.10
Fat (% of total energy)	Baseline	25.51 ± 3.90	25.52 ± 4.06	26.19 ± 3.76	27.39 ± 3.26	25.96 ± 2.96	23.71 ± 3.94
	1–8 week	26.72 ± 1.97	26.30 ± 2.01	27.04 ± 2.60	26.24 ± 2.43	26.67 ± 2.24	26.58 ± 1.67
Carbohydrates (% of total energy)	Baseline	58.61 ± 5.69	59.13 ± 5.80	58.19 ± 5.79	56.72 ± 3.07	58.02 ± 4.09	60.32 ± 4.79
	1–8 week	57.33 ± 2.87	57.86 ± 2.46	57.08 ± 3.44	57.10 ± 2.84	57.58 ± 3.02	57.29 ± 2.47
Physical activity time (min/day)	Baseline	104.90 ± 42.24	122.82 ± 43.72	129.49 ± 49.84	125.26 ± 37.91	116.25 ± 30.55	113.61 ± 41.82
	1–8 week	118.93 ± 25.83	114.07 ± 16.99	130.09 ± 27.75	123.50 ± 19.41	124.80 ± 20.65	119.41 ± 20.97
Gender distribution	Male	11 (68.8%)	12 (70.6%)	11 (64.5%)	13 (68.4%)	13 (65.0%)	7 (58.3%)
	Female	5 (31.2%)	5 (39.4%)	6 (35.5%)	6 (31.6%)	7 (35.0%)	5 (41.7%)

There were no significant differences among all subgroups, $P > 0.05$

Table 4 Changes in anthropometric measurements in the two groups consuming LCT or MLCT oil with different body mass indexes at baseline (week 0) and week 8

	BMI (kg/m^2)	Time (week)	LCT ($n = 50$)			MLCT ($n = 51$)		
			Mean ± SD	Δ	Δ%	Mean ± SD	Δ	Δ%
Body weight (kg)	<24	0	64.53 ± 5.99			62.53 ± 5.37		
		8	63.83 ± 6.20	–0.77 ± 1.45	–1.18 ± 2.20	60.92 ± 5.06*	–1.60 ± 1.71	–2.51 ± 2.73
	24–28	0	71.32 ± 5.71			72.20 ± 8.08		
		8	70.74 ± 5.54	–0.59 ± 1.59	–0.78 ± 2.18	70.15 ± 7.57*	–2.05 ± 1.52#	–2.78 ± 2.03#
	≥28	0	79.38 ± 6.52			86.17 ± 7.56		
		8	79.18 ± 6.51	–0.21 ± 2.22	–0.21 ± 2.78	84.41 ± 8.15*	–1.75 ± 2.57	–2.06 ± 3.06
BMI (kg/m^2)	<24	0	22.24 ± 1.91			22.75 ± 1.06		
		8	22.10 ± 1.88	–0.30 ± 0.58	–1.33 ± 2.47	22.13 ± 0.89*	–0.63 ± 0.66	–2.69 ± 2.85
	24–28	0	26.07 ± 1.28			25.98 ± 1.07		
		8	25.88 ± 1.55	–0.19 ± 0.61	–0.75 ± 2.34	25.25 ± 1.18*	–0.73 ± 0.61#	–2.80 ± 2.36#
	≥28	0	30.28 ± 1.81			30.61 ± 2.08		
		8	30.13 ± 2.11	–0.14 ± 0.95	–0.49 ± 3.19	29.85 ± 2.33*	–0.76 ± 0.88	–2.51 ± 2.95
WC (cm)	<24	0	84.28 ± 6.53			82.89 ± 4.36		
		8	83.78 ± 6.44	–0.5 ± 2.75	–0.53 ± 3.31	81.94 ± 4.54*	–0.95 ± 1.05	–1.15 ± 1.28
	24–28	0	88.32 ± 5.06			90.2 ± 6.13		
		8	88.09 ± 4.86	–0.24 ± 1.13	–0.25 ± 1.29	88.85 ± 6.06*	–1.35 ± 0.86#	–1.49 ± 0.95#
	≥28	0	93.88 ± 6.24			98.25 ± 7.02		
		8	93.82 ± 5.79	–0.06 ± 1.42	–0.02 ± 1.53	97.13 ± 7.53*	–1.13 ± 1.52	–1.17 ± 1.56
HC (cm)	<24	0	94.4 ± 2.61			92.87 ± 2.92		
		8	94.2 ± 2.61	–0.20 ± 1.16	–0.21 ± 1.24	92.45 ± 2.77	–0.42 ± 1.10	–0.44 ± 1.19
	24–28	0	98.85 ± 5.56			99.40 ± 4.69		
		8	98.35 ± 5.43	–0.5 ± 1.13	–0.49 ± 1.12	98.77 ± 4.81*	–0.63 ± 0.84	–0.63 ± 0.86
	≥28	0	102.93 ± 3.81			106.35 ± 4.98		
		8	102.71 ± 4.14	–0.21 ± 0.97	–0.22 ± 0.96	106.10 ± 5.80	–0.25 ± 1.40	–0.26 ± 1.32
WHR	<24	0	0.88 ± 0.06			0.89 ± 0.04		
		8	0.88 ± 0.06	–0.00 ± 0.03	–0.31 ± 2.93	0.89 ± 0.05	–0.01 ± 0.01	–0.70 ± 1.48
	24–28	0	0.90 ± 0.06			0.91 ± 0.06		
		8	0.90 ± 0.06	0.00 ± 0.01	0.26 ± 1.52	0.90 ± 0.06*	–0.01 ± 0.01#	–0.86 ± 1.03#
	≥28	0	0.93 ± 0.06			0.91 ± 0.06		
		8	0.93 ± 0.06	–0.00 ± 0.01	–0.10 ± 1.34	0.90 ± 0.06*	–0.01 ± 0.01	–1.14 ± 1.61

Δ represents week 8 versus week 0, Δ% represents change rate against week 0

BMI body mass index, *HC* hip circumference, *WC* waist circumference, *WHR* ratio of waist circumference to hip circumference

* Different from week 0, $P < 0.05$

\# Different from LCT group, $P < 0.05$

MLCT group than those in corresponding subjects in the LCT group ($P < 0.05$; Table 6).

Discussion

In this study, consumption of MLCT oil induced significant decreases in body weight, body fat, and SFA in hypertriacylglycerolemic and overweight subjects as compared with that of LCT oil. Our results agree with those of St-Onge et al. [15], who found that consumption of a diet rich in MLCT for 28 days resulted in greater loss of adipose tissue in overweight men than did a diet rich in LCT. Our results are similar to those of Tsuji et al. [8], Nosaka et al. [16] and Kasai et al. [17]. Tsuji et al. [8] who found that a 10-g/day MLCT consumption might reduce body weight and fat in individuals with a BMI ≥23 kg/m^2 as compared with LCT consumption. Nosaka [16] found similar effects on the body composition with one-half of the MCT intake than that in the previous study. Kasai et al. [17] reported that subjects consuming the test bread, which had been made with 14 g (about 6% of total energy) of

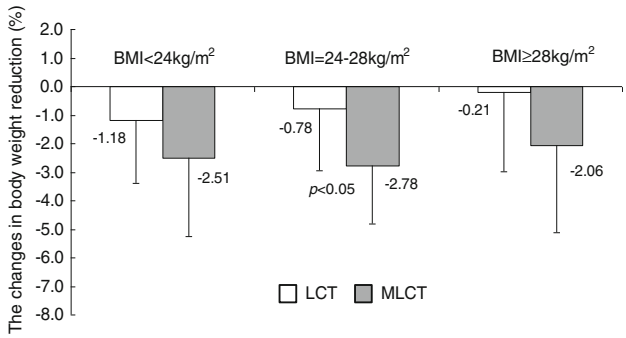

Fig. 1 The effects of LCT and MLCT on the changes in body weight reduction

MLCT containing 1.7 g MCFA had significant reduced body weight and body fat accumulation. From these results, we can suggest that an intake of 10–14 g MLCT can reduce body weight and body fat.

Yost and Eckel [18] conducted a study of the effect of an 800 kcal diet containing MCT. MCT intake did not result in greater weight loss in obese women than an isocaloric diet containing LCT. It is possible that small weight loss of MCT intake may be indistinguishable from the large weight loss effects of very low calorie diets. The study supports our finding that MLCT consumption may not be more effective at reducing fat mass in obese individuals than in overweight individuals.

Our results indicated that overweight subjects responded better to MLCT consumption than did lean or obese subjects. These different effects might be due to the metabolic difference in energy expenditure and fat oxidation in subjects with different body weights. A previous study showed that normal weight and morbidly obese subjects had similar increases in postprandial energy expenditure over resting metabolic rate value [19]; however, fat oxidation was found to be greater in normal weight subjects than in obese

Table 5 Changes in body fat in two groups consuming LCT or MLCT oil with different BMI at baseline (week 0) and week 8

	BMI (kg/m^2)	Time (week)	LCT ($n = 50$)			MLCT ($n = 51$)		
			Mean ± SD	Δ	Δ%	Mean ± SD	Δ	Δ%
Body fat weight (kg)	<24	0	15.13 ± 1.97			14.17 ± 2.32		
		8	14.44 ± 2.21	–0.7 ± 1.19	–4.53 ± 8.79	12.84 ± 1.98*	–1.33 ± 1.22	–8.98 ± 8.07
	24–28	0	18.31 ± 4.59			18.05 ± 3.17		
		8	17.77 ± 4.67	–0.55 ± 1.10	–3.21 ± 6.49	16.46 ± 3.62*	–1.59 ± 1.26#	–9.25 ± 8.34#
	≥28	0	18.31 ± 3.85			24.06 ± 6.81		
		8	18.08 ± 3.75	–0.24 ± 1.93	–0.66 ± 10.37	22.56 ± 6.81*	–1.50 ± 2.07	–6.99 ± 9.60
TFA (cm^2)	<24	0	308.14 ± 96.93			268.98 ± 45.82		
		8	315.34 ± 79.87	7.19 ± 25.02	5.05 ± 12.06	252.30 ± 41.41*	–16.68 ± 24.14#	–5.72 ± 8.44#
	24–28	0	337.55 ± 99.93			349.19 ± 82.60		
		8	359.91 ± 91.54*	22.35 ± 35.10	7.99 ± 10.99	333.73 ± 81.58*	–15.46 ± 25.22#	–4.34 ± 7.50#
	≥28	0	341.15 ± 71.88			426.73 ± 133.60		
		8	354.52 ± 70.70	13.37 ± 40.97	5.38 ± 13.53	420.17 ± 152.51	–6.56 ± 73.99	–1.95 ± 18.61
VFA (cm^2)	<24	0	123.29 ± 45.57			118.83 ± 33.89		
		8	130.67 ± 36.05*	14.73 ± 16.72	20.82 ± 29.53	112.44 ± 25.76	–6.39 ± 15.12#	–3.45 ± 12.00#
	24–28	0	135.09 ± 28.29			151.59 ± 56.08		
		8	151.43 ± 30.79*	17.66 ± 27.88	15.92 ± 24.48	152.40 ± 51.37	0.81 ± 27.51	3.49 ± 22.04
	≥28	0	160.32 ± 46.99			194.43 ± 64.65		
		8	178.28 ± 38.39	17.95 ± 34.62	17.08 ± 28.95	210.73 ± 79.28	16.29 ± 52.83	9.99 ± 29.54
SFA (cm^2)	<24	0	181.53 ± 80.85			150.14 ± 33.02		
		8	173.96 ± 74.39	–7.57 ± 15.04	–2.94 ± 9.74	139.85 ± 37.07	–10.29 ± 23.39	–6.40 ± 15.90
	24–28	0	202.43 ± 96.31			197.60 ± 61.83		
		8	208.49 ± 99.85	4.69 ± 19.06	2.27 ± 11.54	181.31 ± 67.22*	–16.29 ± 19.25#	–9.29 ± 9.77#
	≥28	0	180.81 ± 47.79			232.33 ± 98.58		
		8	176.23 ± 51.89	–4.58 ± 22.10	–2.37 ± 11.22	209.44 ± 91.42	–22.88 ± 46.76	–9.79 ± 18.25

Δ represents 8 week versus week 0, Δ% represents change rate against week 0

TFA total fat area, *VFA* visceral fat area, *SFA* subcutaneous fat area

* Different from week 0, $P < 0.05$

Different from LCT group, $P < 0.05$

Table 6 Changes in levels of triacylglycerols, lipoproteins, hepatic enzymes, blood glucose and total cholesterol in two groups consuming LCT or MLCT oil with different BMI at baseline (week 0) and week 8

Index	BMI kg/m^2	Time (week)	LCT ($n = 50$)			MLCT ($n = 51$)		
			Mean ± SD	Δ	Δ%	Mean ± SD	Δ	Δ%
TAG (mmol/L)	<24	0	2.77 ± 0.67			2.42 ± 0.70		
		8	3.13 ± 1.33	0.36 ± 1.09	12.52 ± 37.39	2.28 ± 1.26	–0.14 ± 0.87	–8.10 ± 31.63
	24–28	0	2.58 ± 0.84			2.75 ± 0.97		
		8	3.23 ± 1.29*	0.65 ± 1.10	27.96 ± 48.08	2.18 ± 0.85*	–0.57 ± 0.86#	–17.00 ± 30.02#
	≥28	0	2.37 ± 0.67			2.90 ± 0.77		
		8	2.62 ± 0.88	0.25 ± 0.92	15.76 ± 45.77	2.13 ± 0.67*	–0.77 ± 1.10	–20.65 ± 34.17
HDL–C (mmol/L)	<24	0	1.42 ± 0.31			1.36 ± 0.22		
		8	1.38 ± 0.29	–0.05 ± 0.14	–2.72 ± 9.10	1.29 ± 0.23	–0.07 ± 0.20	–4.59 ± 15.20
	24–28	0	1.39 ± 0.37			1.26 ± 0.23		
		8	1.35 ± 0.49	–0.03 ± 0.22	–2.91 ± 14.24	1.37 ± 0.28*	0.11 ± 0.23	10.47 ± 19.14#
	≥28	0	1.35 ± 0.24			1.27 ± 0.19		
		8	1.27 ± 0.25	–0.08 ± 0.17	–5.45 ± 11.77	1.30 ± 0.34	0.03 ± 0.23	1.97 ± 16.07
LDL–C (mmol/L)	<24	0	2.78 ± 0.76			2.75 ± 0.59		
		8	3.39 ± 0.60*	0.55 ± 0.59	25.08 ± 33.32	2.86 ± 0.70	0.10 ± 0.44	4.76 ± 16.10
	24–28	0	2.56 ± 0.76			2.88 ± 0.76		
		8	2.93 ± 0.68*	0.38 ± 0.58	19.91 ± 29.46	2.83 ± 0.65	–0.05 ± 0.64#	1.29 ± 22.35#
	≥28	0	2.77 ± 0.63			3.15 ± 0.50		
		8	2.95 ± 0.64	0.18 ± 0.45	8.14 ± 19.59	2.94 ± 0.77	–0.21 ± 0.68	–6.45 ± 20.87
ALT (U/L)	<24	0	24.33 ± 13.05			19.97 ± 4.86		
		8	30.38 ± 18.85	6.06 ± 12.91	26.20 ± 53.37	21.48 ± 7.74	1.51 ± 5.27	7.22 ± 26.18
	24–28	0	22.91 ± 8.22			28.02 ± 18.76		
		8	27.6 ± 13.44	4.69 ± 14.50	28.38 ± 60.86	28.68 ± 18.67	0.87 ± 8.67	11.33 ± 38.07
	≥28	0	29.29 ± 19.38			29.03 ± 16.84		
		8	31.49 ± 18.2	2.20 ± 16.80	18.83 ± 47.22	28.93 ± 13.17	–0.1 ± 20.09	30.05 ± 105.14
AST (U/L)	<24	0	22.04 ± 5.71			21.48 ± 8.47		
		8	24.17 ± 9.54	2.13 ± 8.39	10.89 ± 38.92	19.57 ± 7.36	–1.92 ± 4.14	–7.17 ± 18.00
	24–28	0	21.26 ± 5.77			25.01 ± 9.72		
		8	20.37 ± 4.06	–0.88 ± 6.95	1.69 ± 30.42	25.59 ± 18.30	0.58 ± 17.67	6.02 ± 60.60
	≥28	0	23.02 ± 7.17			25.02 ± 8.36		
		8	23.64 ± 6.32	0.62 ± 6.50	6.91 ± 27.39	25.29 ± 13.7	0.26 ± 16.29	11.19 ± 71.58
Glucose (mmol/L)	<24	0	5.12 ± 0.86			5.01 ± 0.69		
		8	5.53 ± 1.11	0.41 ± 1.07	8.85 ± 18.16	5.18 ± 0.89	0.16 ± 0.43	3.10 ± 8.71
	24–28	0	5.30 ± 1.10			5.48 ± 0.98		
		8	5.45 ± 1.46	0.15 ± 0.76	2.44 ± 15.02	5.65 ± 1.09	0.17 ± 0.55	3.36 ± 10.12
	≥28	0	4.95 ± 0.50			5.69 ± 1.25		
		8	5.19 ± 0.56	0.24 ± 0.64	5.58 ± 13.56	5.98 ± 1.32	0.30 ± 0.60	5.57 ± 10.30
TC (mmol/L)	<24	0	5.36 ± 0.97			5.16 ± 0.80		
		8	6.03 ± 0.75*	0.67 ± 0.73	14.52 ± 18.20	5.16 ± 0.74	0.00 ± 0.40	0.53 ± 7.47
	24–28	0	5.04 ± 0.95			5.11 ± 0.83		
		8	5.50 ± 0.84*	0.45 ± 0.62	10.44 ± 14.17	5.35 ± 0.89	0.24 ± 0.57	5.33 ± 11.75
	≥28	0	5.17 ± 0.70			5.30 ± 0.81		
		8	5.39 ± 0.69	0.22 ± 0.43	4.62 ± 8.23	5.58 ± 0.54	0.29 ± 0.66	6.86 ± 14.06

Δ represents week 8 versus week 0, Δ% represents change rate against week 0

ALT alanine aminotransferase, *AST* aspartate aminotransferase, *HDL-C* high-density lipoprotein-cholesterol, *LDL-C* low-density lipoprotein-cholesterol, *TAG* triacylglycerols, *TC* total cholesterol

* Different from week 0, $P < 0.05$

\# Different from LCT group, $P < 0.05$

subjects with MLCT consumption relative to LCT in another study [20]. Furthermore, in overweight people, those with relatively a lower body weight had the greatest increase in energy expenditure and fat oxidation [21]. Therefore, the intake of MLCT may be effective in reducing body weight and body fat with body weight not yet highly elevated.

Our results might be explained in part by a greater increase in diet-induced thermogenesis after ingesting MLCT than LCT [10, 22]. Ogawa et al. [10] conducted a study of 20 volunteers given a liquid meal containing 14 g of MLCT or LCT; intake of MLCT significantly increased diet-induced thermogenesis. With regard to the mechanism of thermogenesis, several studies have shown that MCT-fed rats had a higher oxygen consumption than LCT-fed rats after administration of norepinephrine or the sympathetic activation of brown adipose tissue [23–25]. Hence, intake of MLCT might not trigger greater diet-induced thermogenesis in obese subjects than in lean and overweight subjects.

Obesity is associated with insulin resistance [12]. Insulin resistance that is characterized by decreasing adipose tissue lipolysis and resisting increases in fat oxidation and increasing hepatic synthesis of triacylglycerols may explain in part that our results showed less response in obese subjects than in overweight subjects in body weight control after intake of MLCT. In other words, intake of MLCT did not induce greater lipolysis and fatty acid oxidation in obese subjects than in overweight subjects.

We also found that consumption of MLCT resulted in a reduced level of fasting blood TAG in hypertriacylglycerolemic and overweight subjects. The mechanism remains unclear. MCT promoting energy expenditure and fat oxidation in both liver and adipose tissue may have contributed to our results [26–29]. In addition to the effect of MCT consumption on fasting blood TAG reduction, MCT intake also induces lower postprandial TAG levels than with consumption of LCT or a soybean oil liquid diet [30, 31].

MLCT consumption did not affect blood cholesterol concentration as compared with LCT consumption; however, MLCT consumption decreased LDL-C concentration and increased HDL-C level. These results suggest that MLCT may have a protective role in the cardiovascular system. Why MLCT consumption does not affect serum cholesterol levels needs to be determined. One possible explanation is that the activity of 3-hydroxy-3-methylglutaryl-CoA, a key enzyme in cholesterol synthesis, is reduced after MLCT administration [32]. In addition, LDL receptor activity in mononuclear cells is higher with MLCT than trilaurin consumption [33].

In contrast to our results, Cater et al. [34] found that natural food supplemented with MLCT increased plasma TC, LDL and TAG levels as compared with a diet supplemented with long-chain fatty acids. The fat accounted for 53% of intake, the mean BMI was 27 ± 5 kg/m^2, and the total amount of fat intake and subject selection, as well as food composition, which may explain their conclusions. In the Temme et al. [35] study, exchanging of oleic acid with MCFA increased serum TC and LDL-C concentrations; however, the response did not differ significantly from the responses to oleic acid and myristic acid, so their conclusions need to be confirmed.

Conclusion

Intake of MLCT might help reduce body fat and levels of fasting blood TAG and LDL-C in hypertriacylglycerolemic and overweight Chinese subjects under an appropriate dietary regimen. MLCT might be useful for control of abnormal TAG metabolism and body fat accumulation in overweight subjects. However, a longer term and larger sample size clinical trial is needed to confirm the substantial effects of MLCT in overweight and hypertriacylglycerolemic individuals.

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Conflict of interest statement None of the authors have any conflicts of interest.

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