

Effect of Ingestion of Medium-Chain Triacylglycerols on Moderate- and High-Intensity Exercise in Recreational Athletes

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Summary Medium-chain triacylglycerols (MCT) are known to hydrolyze readily and completely to fatty acids and to be metabolized more easily by β -oxidation than long-chain triacylglycerols (LCT). Therefore, we investigated the effect of 2 wk of ingestion of food containing a small amount (6 g) of MCT on energy metabolism during moderate-intensity exercise and high-intensity exercise in recreational athletes. For comparison, the subjects were administered food containing MCT or LCT for 14 d, and were instructed to perform cycle ergometer exercise at a workload corresponding to 60% peak $\dot{V}O_2$ for 40 min followed by a workload corresponding to 80% peak $\dot{V}O_2$ until exhaustion. Blood lactate concentration, $\dot{V}O_2$, $\dot{V}CO_2$, and rating of perceived exertion (RPE) were measured at rest and during exercise. The exercise time to exhaustion at a workload corresponding to 80% peak $\dot{V}O_2$ was significantly ($p < 0.05$) longer in the MCT trial (10.2 ± 7.6 min; mean \pm SD) than in the LCT trial (5.8 ± 3.3 min). Blood lactate concentration and RPE during exercise were significantly ($p < 0.05$) lower after ingestion of MCT-containing food. Fat oxidation rate was higher and carbohydrate oxidation rate was lower during exercise in the MCT trial than in the LCT trial, but the differences were not significant. These results indicate that the ingestion of MCT-containing food may suppress utilization of carbohydrate for energy production because of increased utilization of fatty acids for generating energy. In conclusion, our data suggest that short-term ingestion of food containing a small amount of MCT suppresses the increase in blood lactate concentration and RPE during moderate-intensity exercise and extends the duration of subsequent high-intensity exercise, at levels higher than those achieved by ingestion of LCT-containing food.

Key Words medium-chain triacylglycerols (MCT), moderate-intensity exercise, recreational athlete, exhaustion, duration time

The major fuels used during moderate- to high-intensity exercise are carbohydrate and fat (1–3). Carbohydrate is mainly stored in the muscles and liver in the form of glycogen and is used for aerobic and anaerobic exercise depending on exercise intensity. Fat is stored in the form of triglycerides and is utilized at rest as well as during aerobic exercise (2, 3). During aerobic exercise, fat oxidation in muscle mitochondria generates a large proportion of the required energy (1, 2). Moreover, an increase in the fat utilization capacity leads to a decrease in the ability to utilize carbohydrate. Thus, an increase in fat utilization capacity is associated with resistance to fatigue (4, 5). In fact, well-trained athletes have an increased fat utilization capacity (6, 7).

Methods to increase fat utilization capacity have been investigated in the light of not only training (8) but also diet (9, 10) modifications. Previous studies (11, 12) have reported that prolonged consumption of a high-fat diet does not improve performance in time trials or total power output, suggesting that ingestion of long-chain fatty acids does not affect exercise performance. In con-

trast, medium-chain triacylglycerol (MCT) is a food component that is expected to enhance exercise performance (13). In a previous animal study (14), trained or untrained mice that were fed MCT-containing food for a long period demonstrated a significantly longer swimming time than mice that were fed food containing long-chain triacylglycerol (LCT). Furthermore, a previous study on humans (15) reported that ingestion of a beverage containing 4.3% MCT+10% carbohydrate during 2 h of exercise at 60% peak $\dot{V}O_2$ increased the finishing time in a subsequent simulated 40-km cycling time trial, to levels higher than those brought about by the ingestion of a carbohydrate solution alone. In the same study, it was also demonstrated that the ingestion of a large amount (~ 85 g) of MCT-containing food during steady-state exercise resulted in an improved time-trial performance in athletes. However, it is not practical to ingest a large amount of MCT-containing food in the routine diet. Moreover, despite numerous investigations on (16–22) the effect of the ingestion of MCT-containing food in athletes, little is known about the effect of a large intake of MCT-containing food in recreational athletes.

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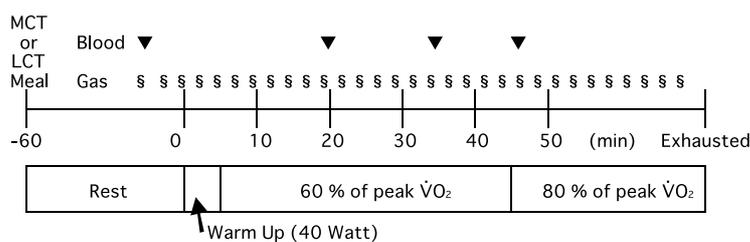


Fig. 1. Experimental design.

MCT is composed of fatty acids containing 8 to 10 carbon atoms (23). MCT is readily and completely hydrolyzed to free fatty acid (FFA) and glycerol via 2-monoacylglycerol by pancreatic lipase. Absorbed medium-chain fatty acid (MCEFA) is mostly transported directly to the liver via the portal vein (24). MCEFA can be transported across the mitochondrial membrane without carnitine and is more easily degraded by β -oxidation than long-chain fatty acid (25). Moreover, ingestion of MCT-containing food during exercise increases the amount of energy derived from fatty acids and reduces carbohydrate oxidation (14, 15). The aims of this study were to investigate the effect of short-term ingestion of a food containing a small amount (6 g) of MCT on fat and carbohydrate utilization, to determine the rate of perceived exertion (RPE) during moderate-intensity exercise and duration of high-intensity exercise in recreational athletes. Exercise time to exhaustion was measured when subjects exercised at a workload corresponding to 80% peak $\dot{V}O_2$ following a 40-min exercise at a workload corresponding to 60% peak $\dot{V}O_2$.

METHODS

Subjects. This study was carried out in accordance with the revised version of the Declaration of Helsinki 1994 (2000) and was approved by the Ethics Committee of Japan Women's College of Physical Education. The subject selection criteria were as follows: (1) fairly constant lifestyle pattern, (2) undertaking continuous exercise, and (3) being available for a 2-wk dietary intervention trial. The subjects comprised 1 man and 7 women aged between 21 and 28 y, belonging to a physical education college. Informed consent was obtained from each subject. Before the start of the study, the medical history of each subject was recorded, and the systolic and diastolic blood pressures and body weight were measured. To determine the peak $\dot{V}O_2$, each subject was asked to perform incremental cycling (Aerobike 75XLII, Combi, Tokyo, Japan) until volitional fatigue before starting test-food consumption.

Test food. Test food provided to the subjects consisted of a baked meal containing 414 kcal of energy, 4.8 g of protein, 67.6 g of carbohydrate, and 14.4 g of fat (including either 6 g of MCT [MCT meal] or 6 g of LCT [LCT meal]). The MCT contained 74% caprylic (C8) and 26% capric (C10) fatty acids.

Pre-experimental protocol. This study was carried out in a double-blind, crossover manner. The subjects were examined on 2 occasions separated by a washout period of 14 d. The subjects were asked to ingest a test

food (MCT or LCT meal) and to record their consumption each day for 13 d. They were instructed to maintain their physical activity at a fixed level and to record their activity time for 13 d. They were also asked to record all meals consumed from days 9 to 13 and to abstain from hard exercise, alcohol, and tobacco from day 12 to day 13.

Experimental trial. On day 14, the subjects were asked to report to the laboratory at 9:20 am and were queried about their condition using an interview sheet. Their body weights were recorded after an overnight fast, and their systolic and diastolic blood pressures were measured in the sitting posture. At 9:30 am, the subjects were asked to ingest the test food. At 10:30 am, after a 5-min warm-up at a fixed workload of 40 W, the subjects started exercise at a pedaling frequency of 50–60 rpm and at a workload corresponding to 60% peak $\dot{V}O_2$ for 40 min. Then, the workload was increased to a level corresponding to 80% peak $\dot{V}O_2$, and they continued cycling until exhaustion (i.e. they stopped pedaling or their pedaling frequency was maintained at 3 times below 50 rpm) (Fig. 1). The bicycle ergometer workload was controlled using computer software (AT Windows, Minato Medical Science, Osaka, Japan). To simulate a trial environment in the laboratory, we ensured that each subject was encouraged to a similar extent by the same investigator in each trial.

Gas exchange, blood, and RPE measurements. After 5 min of rest and during exercise, $\dot{V}O_2$, and carbon dioxide production ($\dot{V}CO_2$) were measured continuously (AE-300S, Minato Medical Science). From respiratory measurements ($\dot{V}O_2$ and $\dot{V}CO_2$), respiratory exchange ratio (R), and fat and carbohydrate oxidation rates were calculated as follows (16, 17):

$$R = \dot{V}CO_2 / \dot{V}O_2$$

$$\text{Fat oxidation rate} = 1.695 \dot{V}O_2 - 1.701 \dot{V}CO_2$$

$\text{Carbohydrate oxidation rate} = 4.585 \dot{V}CO_2 - 3.226 \dot{V}O_2$
At rest (10:20 am) and during exercise (after 20 and 35 min at a workload corresponding to 60% peak $\dot{V}O_2$ and after 45 min at a workload corresponding to 80% peak $\dot{V}O_2$), blood samples were collected from the finger tip to measure the concentrations of blood glucose (Ascensia Breeze, Bayer Medical, Tokyo, Japan) and blood lactate (Lactate Pro, Arkley, Kyoto, Japan), and RPE was calculated using Borg's scale (26).

Statistical analysis. The data obtained from this study were expressed as mean \pm standard deviation (SD). Wilcoxon's signed-rank-sum test was used to compare the mean values of the dietary intake and activity time before the 2 experimental trials and the exercise

Table 1. Physical characteristics of the subjects.

Characteristics (n=8)	
Height, cm	162.8±5.3
Body weight, kg	58.9±8.2
Body mass index, kg/m ²	22.2±2.3
Peak $\dot{V}O_2$, mL/kg/min	44.7±4.4

Values are means±SD.

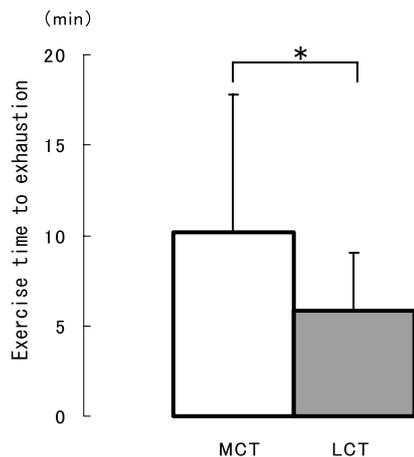


Fig. 2. Exercise time to exhaustion at a workload of 80% peak $\dot{V}O_2$ during cycling, and after cycling at a workload of 60% peak $\dot{V}O_2$ for 40 min after ingestion of a MCT or LCT meal for 14 d. Values are means±SD. Clear squares (□): MCT; solid squares (■): LCT. *Statistically significant difference from the value in the LCT trial ($p<0.05$).

time to exhaustion at a workload corresponding to 80% peak $\dot{V}O_2$ from the 2 experimental trials. The data for gas exchange, concentrations of blood glucose and lactate, and RPE obtained from the 2 experimental trials were compared using 2-factor (time and meal) analysis of variance (ANOVA) with repeated measures. When significant differences were observed, a comparison of mean values of each time was carried out by Wilcoxon's signed-rank-sum test to examine the differences in treatment effects between the 2 test meals. All statistical analyses were performed with SPSS for Windows (version 14J; SPSS Japan, Tokyo, Japan). The significance level for all comparisons was set at $p<0.05$.

RESULTS

All subjects complied with the prescribed pre-experimental instructions and completed the experimental trials. Therefore, data analyses were performed for all the 8 subjects. The subjects' physical characteristics are shown in Table 1.

Diet and physical activity before the experimental trial

Means of dietary intake per day during the 5 d before each experimental trial were 1,855±477 kcal of energy, 58.0±19.2 g of protein, 65.4±22.3 g of fat, and 250.7±63.0 g of carbohydrate in the MCT trial; and 1,860±519 kcal of energy, 52.6±18.6 g of protein,

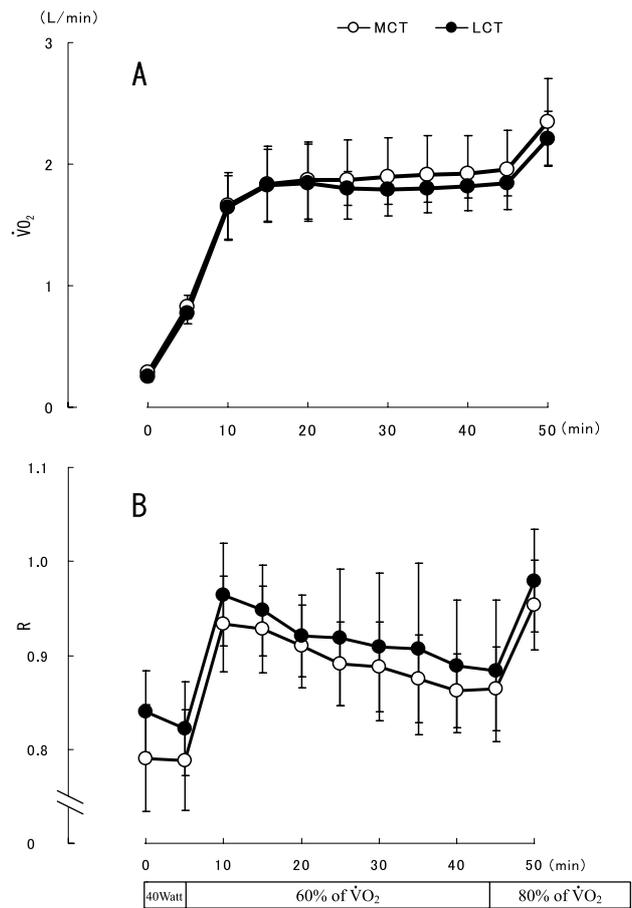


Fig. 3. (A) Oxygen uptake ($\dot{V}O_2$) and (B) respiratory exchange ratio (R) before and during cycling after ingestion of a MCT or LCT meal for 14 d. There were no statistically significant differences between the values for the MCT and LCT trials.

65.6±23.8 g of fat, and 255.9±58.5 g of carbohydrate in the LCT trial. Mean physical activity time per day during the 13 d of the pre-experimental period was 83.4±96.9 min and 74.4±60.1 min in the MCT and LCT trials, respectively. There were no significant differences in pre-experimental dietary intake and physical activity time between the MCT and LCT trials.

Experimental trial

When the subjects consumed either of the 2 test foods for 14 d, the exercise time to exhaustion at a workload corresponding to 80% peak $\dot{V}O_2$ was significantly longer in the MCT trial (10.2±7.6 min) than in the LCT trial (5.8±3.3 min) (Fig. 2). Throughout the experimental trial, $\dot{V}O_2$ showed no significant difference between the 2 trials (Fig. 3A). Values of R were lower in the MCT trial than in the LCT trial throughout the experimental period, but did not differ significantly between the 2 experimental trials (Fig. 3B). Fat oxidation rates were consistently higher in the MCT trial than in the LCT trial, but not to a significant degree (Fig. 4A). Carbohydrate oxidation rates were slightly lower in the MCT trial than in the LCT trial, but not significantly (Fig. 4B). Data on concentrations of blood glucose and lactate and RPE obtained before and during

the 2 experimental trials are shown in Table 2. There were no significant differences in the blood glucose concentrations between the 2 experimental trials. Blood lactate concentration and RPE were significantly lower in the MCT trial than in the LCT trial at 20 min of exercise during a workload corresponding to 60% peak $\dot{V}O_2$ (Table 2).

DISCUSSION

In this study, we investigated the effect on duration of subsequent exercise at a workload corresponding to

80% peak $\dot{V}O_2$ (high intensity) after 40 min of exercise at a workload corresponding to 60% peak $\dot{V}O_2$ (moderate intensity) when recreational athletes ingested a small amount (6 g/d) of MCT for 2 wk. Exercise time to exhaustion at high-intensity exercise recorded for subjects who ingested MCT-containing food was longer than that of subjects who ingested LCT-containing food. However, many previous studies (16–22) on the effect of MCT on exercise performance have failed to find any significant influence. A few of such studies investigated the effect of mainly a single oral dose of MCT on the day of the exercise. Some of them (27, 28) investigated the effect of ingestion of MCT-containing food for 1–2 wk on high-intensity exercise. In fact, a previous study on animals performing moderate-intensity exercise indicated that a single ingestion of MCT-containing food did not extend swimming time to exhaustion, while continued ingestion of MCT increases this duration (14). Further, Van Zyl et al. (15) found a significant improvement in the time-trial performance of high-intensity exercise after repeated ingestion of MCT during exercise at moderate intensity for 2 h. In effect, the subject ingested a large amount (~85 g) of MCT. Thus, continued daily ingestion of MCT might extend the duration time of moderate-intensity exercise and of the following high-intensity exercise. The onset of fatigue changes according to dietary intake and exercise (29). In our study, the pre-trial intake of energy sources and major nutrient and physical activity time did not differ significantly between the 2 experimental trials.

In this study, fat oxidation rate in the MCT trial was higher than that in the LCT trial, and carbohydrate oxidation rate in the MCT trial was lower than that in the LCT trial, but the differences were not significant (fat oxidation: $p=0.092$; carbohydrate oxidation: $p=0.125$). Ingestion of MCT-containing food might suppress the degradation of carbohydrate and increase utilization of fatty acids for energy, thus resulting in a decrease in carbohydrate utilization in the body during moderate-intensity exercise and might, thus, affect the duration of subsequent high-intensity exercise. However, blood lactate concentration and the RPE of subjects who ingested MCT-containing food were significantly lower than those of subjects who ingested LCT-containing food during moderate-intensity exercise.

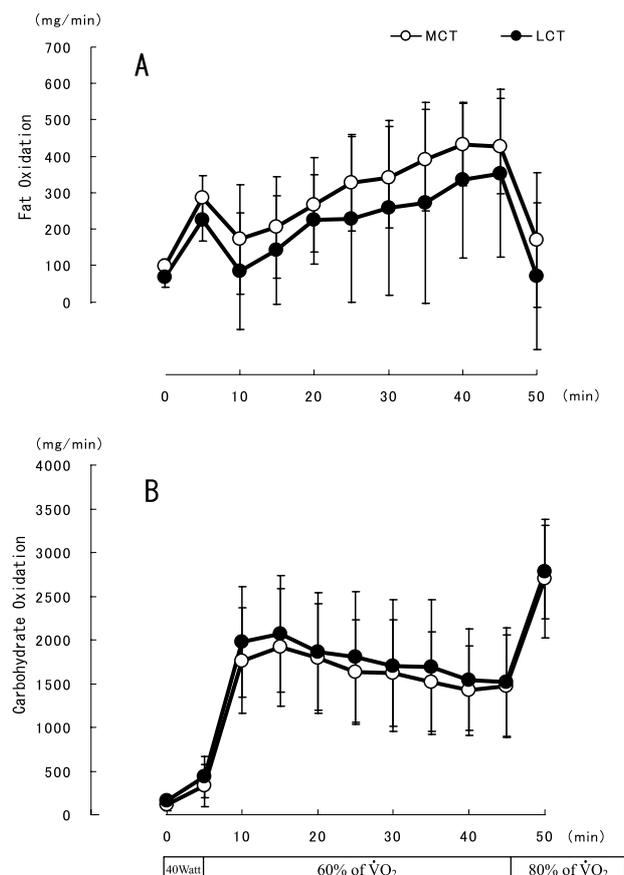


Fig. 4. (A) Fat oxidation and (B) carbohydrate oxidation before and during cycling after ingestion of a MCT or LCT meal for 14 d. There were no statistically significant differences between the values for the MCT and LCT trials.

Table 2. Changes in values of blood glucose and lactate concentration and of ratings of perceived exertion before and during cycling after ingestion of a MCT or LCT meal for 14 d.

Workload, % of peak $\dot{V}O_2$		0	60		80
Exercise time, min		0	20	35	45
Blood glucose, mg/dL	LCT	119±16	82±6	86±9	90±11
	MCT	124±24	80±11	87±13	94±16
Blood lactate, mmol/L	LCT	2.0±0.6	6.1±4.0	5.8±4.7	7.7±3.7
	MCT	1.4±0.5	4.1±1.9*	3.4±1.7	5.0±1.4
Ratings of perceived exertion	LCT	6.0±0.0	14.3±1.0	16.1±1.5	18.8±1.2
	MCT	6.0±0.0	13.6±1.1*	15.1±1.1	18.0±0.9

Values are means±SD. *Statistically significant difference from the value of LCT trial ($p<0.05$).

The relation between RPE and blood lactate concentration has been previously investigated, and an association between these parameters has been established (30, 31). Therefore, further investigations are required to clarify the mechanisms involved in fat and carbohydrate metabolism (i.e. alteration of blood ketone bodies and free fatty acid) in the body during moderate-intensity exercise when recreational athletes ingest MCT for 2 wk. Further, little is known regarding the relationship between the ingestion of MCT-containing food and change of peak $\dot{V}O_2$.

In conclusion, our data suggest that short-term ingestion of food containing a small amount of MCT suppresses the increase in blood lactate concentration and RPE during moderate-intensity exercise and extends the duration of subsequent high-intensity exercise, at levels higher than those achieved by the ingestion of LCT-containing food.

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