Medium-chain Triglycerides with Maltodextrin Increase Fat Oxidation during Moderate-intensity Exercise and Extend the Duration of Subsequent High-intensity Exercise

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Abstract: Medium-chain triglycerides (MCT) are useful for increasing fat utilization during exercise. The highest rate of fat oxidation during submaximal exercise tends to precede the lactate threshold in untrained adults. In our previous study, blood lactate concentration was more than 4 mmol/L (onset of blood lactate) in recreational athletes during exercise at a workload corresponding to 60% peak $\dot{V}O_2$, which was below ventilation threshold. In the present study, we investigated the effect of 2 week of ingestion of food containing 6 g MCT on substrate oxidation during moderate-intensity (50% peak $\dot{V}O_2$) exercise and high-intensity (70% peak $\dot{V}O_2$) exercise in recreational athletes. For comparison, two experimental trials were conducted after participants had been administered isoenergetic test foods (MCT-supplemented food with mainly maltodextrin-containing carbohydrate (MCT + CHO) or CHO) for 2 weeks, with a washout period between trials. Participants were instructed to perform cycle ergometer exercise at a workload corresponding to 50% peak $\dot{V}O_2$ for 40 min followed by a workload corresponding to 70% peak $\dot{V}O_2$ until exhaustion. Fat oxidation was significantly increased in the MCT + CHO trial (13.3 ± 2.7 g/40 min, mean $\pm$ SD, $p < 0.05$) during moderate-intensity exercise and the duration was extended significantly (23.5 ± 19.4 min, $p < 0.05$) during subsequent high-intensity exercise, compared with that observed in the CHO trial (fat oxidation; 11.7 ± 2.8 g/40 min, duration; 17.6 ± 16.1 min). In conclusion, continuous ingestion of 6 g MCT with maltodextrin could increase fat oxidation during moderate-intensity exercise and extend the duration of subsequent high-intensity exercise in recreational athletes, compared with the ingestion of isoenergetic maltodextrin alone.

Key words: medium-chain triglycerides, exercise, recreational athlete, maltodextrin

1 INTRODUCTION

Dietary fat intake is independently associated with the maximal capacity for fat oxidation during exercise¹⁾, and the capacity to oxidize fat during exercise is related to daily fat oxidation²⁾. To ensure that increases fat utilization during high-intensity exercise, (1) fasting or ingestion of a short-term (1–3 day) high-fat diet, (2) ingestion of a high-fat pre-event meal (+ heparin) or intralipid infusion, and (3) consumption of medium-chain triglycerides (MCT) during exercise have been proposed^{3,4)}. However, these approaches have failed to increase exercise capacity, although in-

crease fat oxidation during exercise. Recent studies have investigated the effect of long-term adherence to a ketogenic low-carbohydrate, high-fat diet and of ingestion of ketone salts and esters during moderate- or high-intensity exercise. These approaches can be expected to make better use of fat as a fuel during exercise^{5,6)}. A high-fat diet (particularly a ketogenic diet) can substantially increase fat oxidation during exercise^{7–9)}. A study reported that ingestion of large amounts (approximately 30 g per hour) of MCT increased the amount of energy derived from fatty acids, reduced carbohydrate oxidation, and improved perfor-

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mance in a 40-km cycling time-trial undertaken after 2 hours of submaximal exercise¹⁰). However, the findings of the studies that have explored divergent macronutrient intakes using fat loading may not be applicable to the habitual dietary patterns that have been reported for most of the general population^{11–13}).

In a study among recreational athletes, the ingestion of small amounts (6 g) of MCT for 2 weeks suppressed the increase in blood lactate concentration and rating of perceived exertion (RPE) during moderate-intensity exercise and extended the duration of subsequent high-intensity exercise, compared with the ingestion of long-chain triglycerides (LCT, rapeseed oil and soybean oil, 7:3 (w/w))¹⁴. A previous study in animals performing moderate-intensity exercise indicated that a single ingestion of MCT-containing food did not extend swimming time to exhaustion whereas continuous ingestion of MCT increased the swimming duration¹⁵. MCT are composed of fatty acids containing mainly 8 to 10 carbon atoms¹⁶. MCT are readily and completely hydrolyzed by pancreatic lipase to free fatty acids and glycerol via 2-monoacylglycerol. Absorbed medium-chain fatty acids (MCFA) are mostly transported directly to the liver via the portal vein¹⁷. MCFA can be transported across the mitochondrial membrane without carnitine and are more easily degraded by β -oxidation than long-chain fatty acids¹⁸.

The highest rate of fat oxidation during sub-maximal exercise has been reported to occur between 40% and 65% of peak $\dot{V}O_2$ ^{19–21}, and the lactate threshold (LT) and maximal fat oxidation rate tend to coincide¹. However, in the previously cited study investigating the ingestion of 6 g MCT¹⁴, when recreational athletes adhered to an MCT diet for 14 days, the blood lactate concentration was approximately 4 mmol/L after 20 min of exercise at a workload corresponding to 60% peak $\dot{V}O_2$. In addition, significant increases in fat oxidation and suppression of carbohydrate degradation were not observed during moderate-intensity exercise compared to those observed on adherence to an LCT diet. In untrained adults, the highest rate of fat oxidation during submaximal exercise tends to precede the LT²². Therefore, the exercise intensity at which recreational athletes maximize fat oxidation may be lower than trained athletes, and the exercise-intensity indicating a significant effect of ingestion of MCT on fat oxidation during exercise may be lower than that reported in the study using trained athletes. Moreover, dietary carbohydrate (CHO) intake is also independently associated with the maximal capacity for fat oxidation during exercise¹, and a 2-week high-carbohydrate diet can reduce fat oxidation during exercise²³. In the present study, we investigated the effect on fat oxidation during exercise after a 2-week ingestion of 6 g MCT in comparison with CHO and not LCT.

Thus, the aim of the present study was to investigate the effect on fat oxidation during 40 min of exercise at a work-

load corresponding to 50% peak $\dot{V}O_2$, and the duration of subsequent exercise at a workload corresponding to 70% peak $\dot{V}O_2$ in recreational athletes consuming MCT-supplemented food with mainly maltodextrin-containing carbohydrate (MCT + CHO) for 2 weeks, in comparison with a trial when ingested isoenergetic maltodextrin.

2 MATERIAL AND METHODS

2.1 Participants

The present 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 participant selection criteria were as follows: (1) fairly constant lifestyle pattern, (2) undertaking continuous exercise, and (3) being available for a 2-week dietary intervention trial. Participants comprised eight women aged between 20 and 24 years, belonging to a physical education college. Informed consent was obtained from each participant. Before the start of the study, the medical history of each participant was recorded, and systolic and diastolic blood pressure and body weight were measured. To determine the peak $\dot{V}O_2$ using a respiratory gas analyzer (AE-300S; Minato Medical Science, Osaka, Japan), each subject was asked to perform incremental cycling (Aerobike 75XLII; Combi, Tokyo, Japan) until volitional fatigue set in before starting test-food consumption. The participants' physical characteristics are shown in Table 1.

2.2 Test food

Test foods provided to participants consisted of a jelly drink containing 332 kcal of energy, 0 g of protein, 67.6 g of carbohydrate, and 6 g of fat (MCT + CHO meal) or 332 kcal of energy, 0 g of protein, 83.1 g of carbohydrate, and 0 g of fat (CHO meal). The MCT contained caprylic (C8) and capric (C10) fatty acids. Test foods were provided by Coca-Cola Tokyo Research & Development Company, Limited.

2.3 Pre-experimental protocol

The present study was carried out in a double-blind, crossover manner (Fig. 1). Participants were examined on two occasions, separated by a washout period of 2 weeks.

Table 1 Physical characteristics of participants.

Characteristics (n = 8)	
Height, cm	159 ± 8.3
Body weight, kg	57.3 ± 7.2
Body mass index, kg/m ²	22.7 ± 2.1
Peak $\dot{V}O_2$, ml/kg/min	40.1 ± 4.3

Values are means ± standard deviation.

Fig. 1 Pre-experimental protocol. The present study was carried out in crossover manner. The participants were examined on two occasions, separated by a washout period of 2 weeks. Participants were asked to ingest a test food (MCT + CHO or CHO meal) and to record their consumption each day for 13 days. Participants were instructed to maintain their physical activity at a fixed level and to record their activity duration for 13 days. Participants were also asked to record all meals consumed from days 9 to 13 and to abstain from strenuous exercise, alcohol, and tobacco on days 12 and 13.

Fig. 2 Experimental Design. At time -60, participants were asked to ingest the test food. At time 0, after a 5-min warm-up at a fixed workload of 40 watt, participants started to exercise at a pedaling frequency of 50–60 rpm and at a workload corresponding to 50% peak $\dot{V}O_2$ for 40 min. At time 45, the workload was then increased to a level corresponding to 70% peak $\dot{V}O_2$, and participants continued cycling until exhaustion. Blood sampling (▼) was conducted at time -5, 20, 30, 40 and 50 min. Gas sampling (§) was continuously conducted from time -5 min to exhaustion.

The participants were asked to ingest a test food (MCT + CHO or CHO meal) and to record their consumption each day for 13 days. They were instructed to maintain their physical activity at a fixed level and to record their activity duration for 13 days. They were also asked to record all meals consumed from days 9 to 13 and to abstain from strenuous exercise, alcohol, and tobacco on days 12 and 13.

2.4 Experimental trial

The present experimental study was conducted according to the protocols of our previous study (Fig. 2)¹⁴. On day 14, participants were asked to report to the laboratory at 9:20 am, where they were queried about their condition using an interview sheet. Each participant's body weight was recorded after an overnight fast, and systolic and diastolic blood pressure was measured with the participant in the sitting posture. At 9:30 am, the participants were asked to ingest the test food to avoid hunger during exercise. At 10:30 am, after a 5 min warm-up at a fixed workload of 40

watt, the participants started to exercise at a pedaling frequency of 50–60 rpm and at a workload corresponding to 50% peak $\dot{V}O_2$ for 40 min. The workload was then increased to a level corresponding to 70% peak $\dot{V}O_2$, and participants continued cycling until exhaustion (i.e., they stopped pedaling or their pedaling frequency was maintained at 3 times below 50 rpm). The bicycle ergometer (Aerobike 75XLII) workload was controlled using a computer software (AT Windows; Minato Medical Science, Osaka, Japan). To simulate a trial environment in the laboratory, we ensured that each participant was encouraged to a similar extent by the same investigator in each trial.

2.5 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). From respiratory measurements ($\dot{V}O_2$ and $\dot{V}CO_2$), the respiratory exchange ratio (RER) and fat and carbohydrate oxidation rates were calculated as follows^{24, 25}.

$$\text{RER} = \dot{V}\text{CO}_2 / \dot{V}\text{O}_2$$

$$\text{Fat oxidation rate} = 1.695 \dot{V}\text{O}_2 - 1.701 \dot{V}\text{CO}_2$$

$$\text{Carbohydrate oxidation rate} = 4.585 \dot{V}\text{CO}_2 - 3.226 \dot{V}\text{O}_2$$

At rest (10:20 am) and during exercise (after 20, 30 and 40 min at a workload corresponding to 50% peak $\dot{V}\text{O}_2$ and after 50 min at a workload corresponding to 70% peak $\dot{V}\text{O}_2$), blood samples were collected from the finger-tip to measure concentrations of blood glucose (Ascensia Breeze; Bayer Medical, Tokyo, Japan) and blood lactate (Lactate Pro; Arkley, Kyoto, Japan), and RPE was calculated using the Borg scale, which ranges from 6 to 20²⁶⁾.

2.6 Statistical analysis

The data obtained from the present study were expressed as mean $\pm$ standard deviation (SD). The Wilcoxon signed rank sum test was used to compare the mean values of dietary intake and activity duration before the two experimental trials, cumulative values of fat and carbohydrate oxidation at a workload corresponding to 50% peak $\dot{V}\text{O}_2$ and the exercise time to exhaustion at a workload corresponding to 70% peak $\dot{V}\text{O}_2$ in the two experimental trials. The data for $\dot{V}\text{O}_2$, RER, rate of fat oxidation, concentrations of blood glucose and lactate, and RPE obtained from the two experimental trials were compared using two-factor (time and meal) analysis of variance (ANOVA) with repeated measures. When a significant difference was observed without significant interaction (time and meal), a comparison of the mean values of each time was carried out using a paired *t*-test to examine the differences in treatment

effects between the two test meals. When significant interaction was observed, the Holm-Bonferroni method was used for multiple comparisons. All statistical analyses were performed using R statistical software version 3.4.3 for Windows²⁷⁾. The significance level for all comparisons was set at $p < 0.05$.

3 RESULTS

All participants complied with the prescribed pre-experimental instructions and completed the experimental trials. Therefore, data analyses were performed for all the eight participants.

3.1 Diet and physical activity before the experimental trial

The dietary intake per day during the 5 days before each experimental trial were $1,978 \pm 344$ kcal of energy, 59.5 ± 18.3 g of protein, 62.2 ± 2.1 g of fat, and 285.6 ± 63.9 g of carbohydrate in the MCT + CHO trial and $1,833 \pm 503$ kcal of energy, 53.7 ± 23.9 g of protein, 48.1 ± 8.3 g of fat, and 287.9 ± 93.7 g of carbohydrate in the CHO trial. A significant difference was observed in the fat intake between the MCT + CHO and CHO trials, influenced by the test food containing MCT.

The physical activity duration per day during the 13-day pre-experimental period was 125 ± 49 min in the MCT + CHO trial and 124 ± 55 min in the CHO trial. There was no significant difference in the pre-experimental physical activity duration between the MCT + CHO and CHO trials.

Mean body weights in the morning on the day of the experimental trial were 56.8 ± 6.9 kg in the MCT + CHO trial

Fig. 3 (A) Oxygen uptake ($\dot{V}\text{O}_2$) and (B) respiratory exchange ratio (RER) before and during cycling after ingestion of a MCT + CHO or CHO meal for 2 weeks. Values are means and error bars are standard deviation. Clear circles (○): MCT + CHO; solid circles (●): CHO. *Statistically significant difference from the value in the CHO trial ($p < 0.05$, ANOVA followed by paired *t*-test).

and 56.7 ± 7.0 kg in the CHO trial. There was no significant difference in body weight between the MCT + CHO and CHO trials.

3.2 Experimental trial

After participants had consumed either of the two test foods (MCT + CHO or CHO) for 2 weeks, $\dot{V}O_2$ showed no significant difference between the two experimental trials (Fig. 3A). Values of RER (time 0, 5, 10, 20, 30-45) were significantly lower in the MCT + CHO trial than in the CHO trial (Fig. 3B). The cumulative value of fat oxidation was significantly higher (13.7% increase) in the MCT + CHO trial than in the CHO trial, and carbohydrate oxidation was significantly lower in the MCT + CHO trial than in the CHO trial during exercise at a workload corresponding to 50% peak $\dot{V}O_2$ (Table 2). The exercise time to exhaustion at a workload corresponding to 70% peak $\dot{V}O_2$ was significantly longer in the MCT + CHO trial than in the CHO trial (Table 2). The rate of fat oxidation was significantly higher in the MCT + CHO trial than in the CHO trial during exercise at a workload corresponding to 70% peak $\dot{V}O_2$ (Table 2). Data on the concentrations of blood glucose and lactate and RPE obtained before and during the two experimental trials are shown in Table 3. There were no significant dif-

ferences in the blood glucose and lactate concentrations between the two trials. RPE was significantly lower in the MCT + CHO trial than in the CHO trial at 20 min of exercise at a workload corresponding to 50% peak $\dot{V}O_2$ (Table 3).

4 DISCUSSION

The aim of the present study was to investigate the effect on fat oxidation during 40 min of exercise at a workload corresponding to 50% peak $\dot{V}O_2$ in recreational athletes who ingested MCT with maltodextrin for 2 weeks. Fat oxidation at a workload corresponding to 50% peak $\dot{V}O_2$ during exercise by the participants who ingested 6 g of MCT with CHO was significantly higher than of participants who ingested isoenergetic CHO foods (13.3 ± 2.7 g/40 min vs. 11.7 ± 2.8 g/40 min, 13.7% increase). Conversely, carbohydrate oxidation at the same workload during exercise by participants who ingested MCT + CHO foods was significantly lower than of participants who ingested CHO foods. According to the evidence, the capacity to oxidize fat during exercise is related to daily fat oxidation²⁾; 2-week ingestion of 6 g MCT may be beneficial to health promotion in recreational athletes, as well as individuals beginning an

Table 2 Cumulative values of fat oxidation and carbohydrate oxidation at a workload of 50% peak $\dot{V}O_2$, and exercise time to exhaustion and rate of fat oxidation at a workload of 70% peak $\dot{V}O_2$ during cycling after ingestion of a MCT + CHO or CHO meal for 2 weeks.

Workload	Indices	MCT+CHO	CHO
50% peak $\dot{V}O_2$	Fat oxidation, g/40 min	$13.3 \pm 2.7^*$	11.7 ± 2.8
	Carbohydrate oxidation, g/40 min	$38.4 \pm 8.4^*$	42.2 ± 10.2
70% peak $\dot{V}O_2$	Exercise time to exhaustion, min	$23.5 \pm 19.4^*$	17.6 ± 16.1
	Rate of fat oxidation, mg/min	$352 \pm 95.8^{*, \dagger}$	257 ± 109

Values are means $\pm$ standard deviation. *Statistically significant difference from the value in the CHO trial ($p < 0.05$, The Wilcoxon signed rank sum test or † ANOVA followed by The Holm–Bonferroni method).

Table 3 Changes in values of blood glucose and lactate concentration and of ratings of perceived exertion before and during cycling after ingestion of a MCT+CHO or CHO meal for 2 weeks.

Workload, % of peak $\dot{V}O_2$		0	50			70
Exercise time, min		0	20	30	40	50
Blood glucose, mg/dL	MCT+CHO	128 ± 14.2	74.4 ± 9.6	77.4 ± 11.0	81.8 ± 11.7	85.4 ± 13.8
	CHO	150 ± 33.2	76.0 ± 15.0	69.1 ± 13.1	78.9 ± 16.0	82.8 ± 9.6
Blood lactate, mmol/L	MCT+CHO	2.59 ± 0.38	2.36 ± 0.67	1.93 ± 0.73	2.01 ± 0.53	4.13 ± 0.75
	CHO	3.31 ± 0.55	2.54 ± 0.72	2.43 ± 0.85	2.15 ± 0.91	3.79 ± 0.80
Ratings of perceived exertion	MCT+CHO	6.0 ± 0.0	$12.3 \pm 0.5^*$	12.8 ± 0.5	12.9 ± 0.6	15.1 ± 0.8
	CHO	6.0 ± 0.0	13.1 ± 0.8	13.4 ± 1.2	14.0 ± 1.6	15.3 ± 1.3

Values are means $\pm$ standard deviation. * Statistically significant difference from the value of CHO trial ($p < 0.05$, ANOVA followed by paired t -test).

exercise program.

In our previous study, we reported that after a 2-week ingestion of MCT versus LCT, there was no significant difference in fat oxidation ($p = 0.092$) and carbohydrate oxidation ($p = 0.125$) at a workload corresponding to 60% peak $\dot{V}O_2$. In endurance-trained individuals, the average intensity of maximal fat oxidation is at 63% $\dot{V}O_{2max}$ ²⁰. Data from a sample of endurance-trained adults suggest that there is a strong association between the fat oxidation rate and blood lactate response to incremental exercise²⁸, and the LT and maximal fat oxidation rates tend to coincide¹. However, it is difficult to identify the exercise intensity that maximizes fat oxidation because (1) there is a wide range of exercise-intensity that indicates maximum of fat oxidation (between 40% and 65% of peak $\dot{V}O_2$)²¹; (2) large inter-individual variability is observed in maximum of fat oxidation²⁰, even when measured in a sample of homogeneous participants; and (3) maximum fat oxidation has been shown to be influenced by sex, age, fitness status, and exercise modality^{20, 21, 29}.

In recreational athletes, the blood lactate level at a workload corresponding to 60% peak $\dot{V}O_2$ in the aforementioned published study was higher (4.1 ± 1.9 mmol/L for the MCT diet and 6.1 ± 4.0 mmol/L for the LCT diet after 20 min of exercise, with a significant difference between the MCT and LCT diets, $p < 0.05$) than the LT and onset of blood lactate accumulation (4 mmol/L)¹⁴. However, the blood lactate level at a workload corresponding to 50% peak $\dot{V}O_2$ in the present study was less than 3 mmol/L, and no difference in blood lactate level was observed (MCT + CHO: 2.36 ± 0.67 mmol/L; CHO: 2.54 ± 0.72 mmol/L, after 20 min of exercise).

This difference in workload level seems to exert a large influence on recreational athletes, and it is presumed that a slight difference in the amount of fat oxidation was found in previous research¹⁴. As the relative exercise intensity increases, there is a shift from fat-based to carbohydrate-based fuels, such that the amount of carbohydrate oxidation increases, and in particular, the lactate concentration in the blood rises rapidly^{30, 31}. It is well known that fat oxidation is suppressed when blood lactate level increases²⁹.

In the present study, it was difficult to determine the exercise intensity of maximal fat oxidation in our population of college-aged, recreational athletes. However, the exercise intensity for maximal fat oxidation in recreational athletes was estimated to be lower (45% to 55% of peak $\dot{V}O_2$) than that in our previous study.

Exercise time to exhaustion at a workload corresponding to 70% peak $\dot{V}O_2$ was significantly extended with MCT ingestion (MCT + CHO: 23.5 min; CHO: 17.6 min, $p < 0.05$) as was that at a workload corresponding to 80% peak $\dot{V}O_2$ in our previous study (MCT diet: 10.2 min; LCT diet: 5.8 min, $p < 0.05$). In the present study, the blood lactate concentration rose to approximately 4 mmol/L at a workload corresponding to 70% peak $\dot{V}O_2$ in the MCT + CHO trial, which

was similar to that at a workload corresponding to 60% peak $\dot{V}O_2$ in our previous study (4.1 ± 1.9 mmol/L with the MCT diet after 20 min of exercise). However, the fat oxidation level was significantly higher at a workload corresponding to 70% peak $\dot{V}O_2$ (MCT + CHO: 352 ± 95.8 mg/min; CHO: 257 ± 109 mg/min, $p < 0.05$) when participants consumed MCT + CHO foods. Compared with the findings of a previous study in which a significant difference in blood lactate concentration was found (4.1 ± 1.9 mmol/L for the MCT diet and 6.1 ± 4.0 mmol/L for the LCT diet after 20 min of exercise, $p < 0.05$)¹⁴, the present findings suggest that the cumulative effect of a decrease in carbohydrate oxidation owing to a consistent increase in fat oxidation at a workload corresponding to 50% peak $\dot{V}O_2$ results in an increased exercise duration to exhaustion at a workload corresponding to 70% peak $\dot{V}O_2$; however, the carbohydrate oxidation level did not significantly differ.

There were several limitations in the present study: (1) participants only included women who were recreational athletes, not well-trained athletes³²; (2) the exercise protocol involved a combination of moderate- and subsequent high-intensity cycle ergometer exercise; thus, the measurement of substrate oxidation and duration is influenced by modality²⁰. It is therefore unclear whether our results would translate to alternate forms of exercise (e.g., running, swimming, and so on).

5 CONCLUSION

In conclusion, our results suggest that continuous ingestion of 6 g MCT with maltodextrin in recreational athletes for 2 weeks increases fat oxidation during exercise at a workload of 50% peak $\dot{V}O_2$ and extends the duration of subsequent exercise at a workload of 70% peak $\dot{V}O_2$, compared with the ingestion of isoenergetic maltodextrin alone.

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