

## Review Article

# The application of medium-chain fatty acids: edible oil with a suppressing effect on body fat accumulation

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The bulk of fatty acids found in our diets consists of long-chain fatty acids (LCFA), which are molecules containing 12 or more carbon atoms. In contrast, medium-chain fatty acids (MCFA) are composed of 8-10 carbon atoms, and are found in palm kernel oil, among other types of foods. MCFA have attracted attention as being part of a healthy diet, because they are absorbed directly into the portal vein, transported rapidly to the liver for  $\beta$ -oxidation, and thus increase diet-induced thermogenesis. In contrast, long-chain triacylglycerols are absorbed via the intestinal lymphatic ducts and transported by chylomicrons through the thoracic duct into the systemic circulation. Because medium-chain triacylglycerols (MCT) containing solely MCFA have a few disadvantages when used for deep frying, we have developed a new kind of triacylglycerol product: medium- and long-chain triacylglycerol (MLCT). MLCT is produced by lipase-catalyzed enzymatic transesterification. Long-term clinical trials have demonstrated that MLCT and MCT result in less body fat accumulation in humans. MLCT oil has been approved as FOSHU (Food for Specified Health Use) for use as cooking oil with a suppressing effect on body fat accumulation.

**Key Words:** medium-chain fatty acids, medium-chain triacylglycerols, palm kernel oil, medium and long-chain triacylglycerols, body fat accumulation

## INTRODUCTION

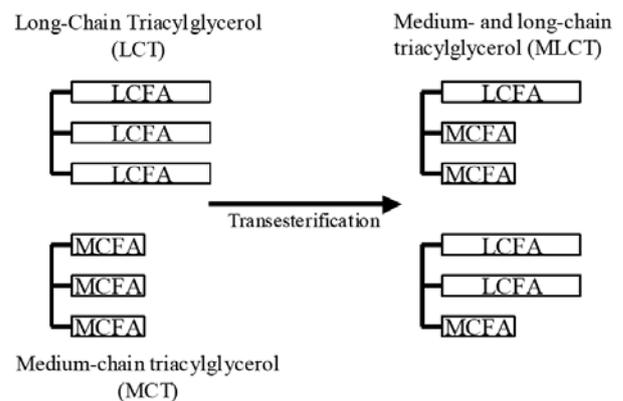
There are many types of fatty acids composing triacylglycerol due to differences in the numbers of double bonds and carbons (Table 1). Usually, ingested fatty acids are mostly long-chain fatty acids (LCFAs) composed of 12 or more carbons, but a small amount of medium-chain fatty acids (MCFAs) with 8-10 carbons is also ingested. MCFAs are markedly different from long-chain fatty acids with regard to physical properties, digestion/absorption, biodegradation, and body fat accumulation. This paper reviews the physiological function of MCFAs along with the study results of newly developed medium- and long-chain triacylglycerols (MLCTs).

### Medium-chain fatty acids (MCFAs)

MCFAs are contained in triacylglycerol in general foods. For example, 100 g of butter and fresh cream contains about 3 and 2 g of MCFAs, respectively, and cow and breast milk fat also contain it at about 1-3%. Palm kernel and coconut oils contain about 7% and 14%, respectively, and these are the main sources of medium-chain fatty acids used for foods.

Medium-chain triacylglycerol (MCT) is a colorless, transparent, tasteless, odorless, and low-viscous 'water-like' liquid oil at normal temperature. MCT was introduced to clinical nutrition in the 1950s for the dietary treatment of malabsorption syndromes because of its rapid absorption and solubility<sup>1</sup>: MCT is used as an oil material of liquid diets after surgery, energy supply source for patients with renal diseases, and solvent of drugs. Its utilization as an edible oil started in the 1970s, and it is currently used as an

additive for foods, base material of pigments, and mold and lubricating oil in food production. These utilize the characteristics of MCT: high melting property, high stability, colorless, and odorless.



**Figure 1.** Manufacture of medium- and long-chain triacylglycerol (MLCT) by transesterification. LCFA, long-chain fatty acid; MCFA, medium-chain fatty acid.

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**Table 1.** The classification of the fatty acid and representative fatty acid.

	Saturated fatty acids	Monounsaturated fatty acids	Polyunsaturated fatty acids
Short-chain (C2 ~ 6)	acetic acid, butyric acid (vinegar, butter)	-*	-
Medium-chain (C8 ~ 10)	caprylic acid, capric acid (breast milk, palm oil)	-	
Long-chain (Above C12)	palmitic acid, stearic acid (beef tallow, lard)	oleic acid (olive oil)	linoleic acid (corn oil), linolenic acid (flaxseed oil), EPA and DHA (fish oils)

Examples of food containing abundant fatty acids are shown in parentheses.

\*Not present or rarely present in nature.

### Digestion, absorption, and metabolism of MCT

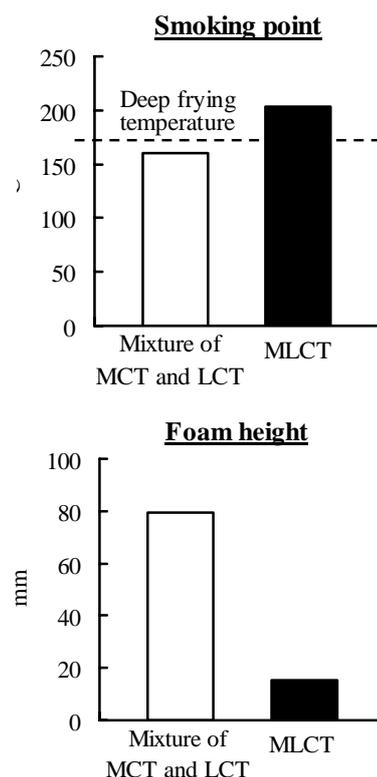
Compared to long-chain triacylglycerol (LCT), MCT is easily digested and absorbed. LCT is hydrolyzed at the 1,3 ester bond of glycerol to mainly 2-monoacylglycerol by pancreatic lipase in the small intestine. 2-Monoacylglycerol and fatty acids are dissolved in micelles and absorbed by small intestinal mucosa cells. In contrast, MCT is completely hydrolyzed to fatty acids and glycerol by pancreatic lipase, and rapidly absorbed. Even when pancreatic juice secretion is reduced due to diseases, MCFAs are digested and absorbed relatively well.

LCFAs absorbed from the small intestine are re-synthesized to triacylglycerol in small intestinal mucosa cells, form chylomicrons, released into the circulation via the lymph vessels, and transported to peripheral tissues (adipose tissue and muscle). In contrast, MCFAs are not readily re-synthesized to triacylglycerol. They are mostly bound with albumin as free fatty acids, transferred into portal blood, and transported to the liver, where MCFAs are transported to mitochondria and rapidly degraded by oxidation. In an experiment using rat liver sections, MCFAs were degraded to carbon dioxide at a rate more than 10 times faster than LCFAs, and only about 1/20 was utilized for lipid synthesis.<sup>2</sup>

### Suppression of body fat accumulation by MCT

Obesity, in which body fat is excessively accumulated, is likely to be accompanied by many diseases, such as diabetes, hyperlipidemia, and hypertension. In recent years, obesity is considered to be a preparatory state of various lifestyle-related disorders.

MCT is less accumulated as body fat than general edible oil which consisted in LCT in laboratory animals<sup>3</sup>, suggesting that MCT prevents obesity, being useful for the prevention of lifestyle-related disorders. However, the suppression of body fat accumulation by MCT had not been fully clarified in humans. Thus, we performed a large-scale study on the body fat accumulation-suppressing effect of MCT in humans. A double-blind study was performed in healthy subjects under strict dietary management.<sup>4</sup> Seventy-eight subjects slightly fatter than the average (mean BMI=24.7) ate bread containing 14 g of the test oil daily as breakfast. A total of more than 10,000 lunches and suppers were prepared so that the subjects ate identical meals for 12 weeks. Eating between meals and beverages were also controlled, and the subjects were strictly controlled to ingest 2200 kcal/day containing 60 g of lipids. For body fat measurement, the air

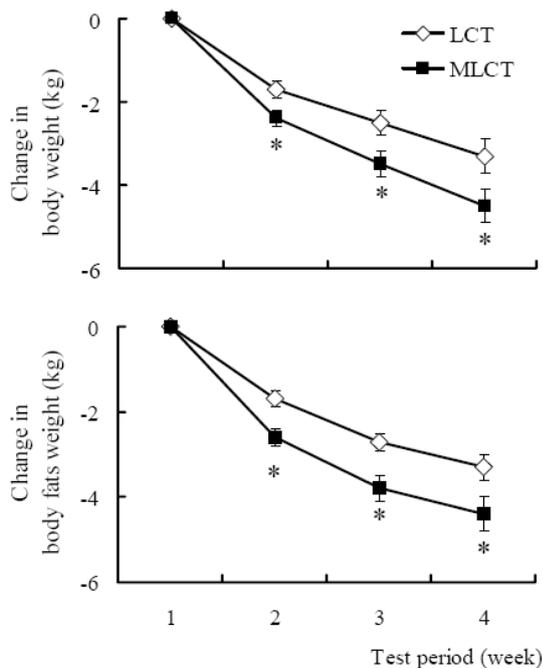


**Figure 2.** Improvement of smoking point and foaming property by transesterification. Medium- and long-chain triacylglycerol (MLCT) is a transesterified oil of medium-chain triacylglycerol (MCT) and long-chain triacylglycerol (LCT). The smoking point was measured using a Cleveland Open Cup Flash Point Tester. In the foam height test, the oil sample was added into a test tube with an inner diameter of 28 mm, and heated to 160°C. A 1-cm potato cube was added, and the height of foams generated (maximum value) was measured.

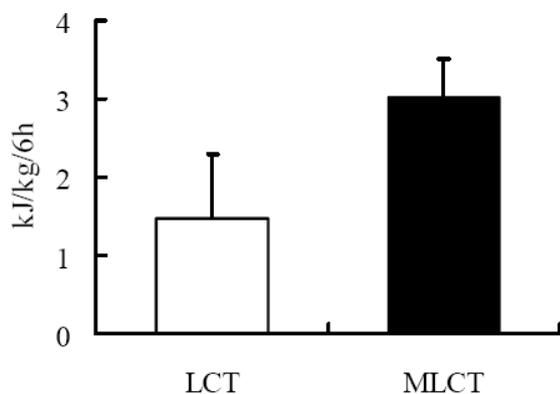
displacement method was used for accuracy. In the subjects with a BMI of 23 or higher (slightly fat), the body weight loss was larger in the MCT ingestion group than in the common edible oil ingestion group.

### Medium- and long-chain triacylglycerol (MLCT)

As described above, MCT suppressed body fat accumulation in not only laboratory animals but also humans. However, its general use has been limited because MCT has a low smoking point (about 140°C), easily foams during deep frying, and is expensive. Aiming at the development of oil with superior nutritional properties of MCFAs and applicability for heating as cooking oil for domestic use, we developed MLCT. MLCT represents



**Figure 3.** Medium- and long-chain triacylglycerol (MLCT)-induced changes in body weight and body fat amount in humans<sup>8</sup>. Eighty-two healthy subjects ate bread containing MLCT or long-chain triacylglycerol (LCT) for 12 weeks as breakfast under strict dietary control. The values are presented as the means  $\pm$  SE. \* $p < 0.05$ .



**Figure 4.** Increase in energy expenditure after long-chain triacylglycerol (LCT) or medium- and long-chain triacylglycerol (MLCT) ingestion<sup>10</sup>. Fifteen healthy females ingested LCT or MLCT, and energy expenditure was measured for 6 hours. The values are presented as the means  $\pm$  SE. \*\* $p < 0.01$ .

triacylglycerol containing medium- and long-chain fatty acids in the molecule, and is prepared by mixing MCT and LCT and enzymatic transesterification (Fig. 1).<sup>5</sup> Conversion to MLCT elevated the smoking point and markedly reduced foaming, which broadened the use range of MCFAs (Fig. 2).

#### Suppression of body fat accumulation by MLCT

We investigated the body fat accumulation-suppressing effect of MLCT in animals and humans. When body fat was measured after feeding rats an MLCT diet for 6 weeks, the body fat amount was smaller than that in the soybean oil diet control group.<sup>6</sup> When healthy male subjects ingested a liquid diet containing 20 g of soybean or

MLCT oil per day for 3 weeks, in addition to usual meals, and body fat was measured before and after the experiment. The body fat amount increased in the soybean oil group, but did not change in the MLCT group.<sup>7</sup>

To confirm the body fat accumulation-suppressing effect of MLCTs, a large-scale long-term nutrition study was performed similarly to the MCT evaluation study.<sup>8</sup> Diets of 82 healthy subjects were strictly controlled under a double-blind condition for 12 weeks: They ate bread containing MLCT or vegetable oil daily as breakfast. Lunch and dinner were standardized, and eating between meals was also controlled (Fig. 3). Body weight loss was larger in the MLCT group than in the LCT group (Fig. 3). On abdominal subcutaneous and visceral fat measurement by CT, the body fat amount was reduced more in the MLCT group than in the LCT group.<sup>9</sup> Energy expenditure was also investigated in healthy young women. Energy expenditure increased after MLCT ingestion, compared to soybean oil ingestion (Fig. 4),<sup>10</sup> suggesting that an MLCT-induced increase in energy expenditure is one mechanism of the suppression of body fat accumulation.

To investigate the safety of MLCT, a 4-week ingestion study (42 g/day) was performed in 10 healthy males and females. No negative influence on liver or renal function was noted, confirming the high safety level of MLCT11). MLCT oil, confirmed to be less accumulated as body fat and safe, was approved as a FOSHU (food for specified healthy use) in 2002, and has been widely sold in Japan.

#### CONCLUSION

MCT is rapidly digested and absorbed, and suppresses body fat accumulation. However, MCT has disadvantages: low smoking point and foaming in deep frying. We developed MLCT by enzymatic transesterification, and solved these problems. MLCT also suppressed body fat accumulation by increasing energy expenditure.

MCFAs are contained in breast milk, being a nutrient that humans ingest from birth. Conversion to MLCT broadened the use range, which may attract more attention to MCFA function.

#### AUTHOR DISCLOSURES

Hiroyuki Takeuchi, Seiji Sekine, Keiichi Kojima and Toshiaki Aoyama, no conflicts of interest, except that this paper is authored from The Nisshin OilliO Group, Ltd.

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