Physiological Effects of Medium-Chain Triglycerides: Potential Agents in the Prevention of Obesity[1]

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ABSTRACT Medium chain fatty acids (MCFA) are readily oxidized in the liver. Animal and human studies have shown that the fast rate of oxidation of MCFA leads to greater energy expenditure (EE). Most animal studies have also demonstrated that the greater EE with MCFA relative to long-chain fatty acids (LCFA) results in less body weight gain and decreased size of fat depots after several months of consumption. Furthermore, both animal and human trials suggest a greater satiating effect of medium-chain triglycerides (MCT) compared with long-chain triglycerides (LCT). The aim of this review is to evaluate existing data describing the effects of MCT on EE and satiety and determine their potential efficacy as agents in the treatment of human obesity. Animal studies are summarized and human trials more systematically evaluated because the primary focus of this article is to examine the effects of MCT on human energy metabolism and satiety. Hormones including cholescytokinin, peptide YY, gastric inhibitory peptide, neurotensin and pancreatic polypeptide have been proposed to be involved in the mechanism by which MCT may induce satiety; however, the exact mechanisms have not been established. From the literature reviewed, we conclude that MCT increase energy expenditure, may result in faster satiety and facilitate weight control when included in the diet as a replacement for fats containing LCT. J. Nutr. 132: 329–332, 2002.

KEY WORDS: • medium-chain triglycerides • satiety • energy expenditure • obesity

Fats varying in fatty acid chain lengths are metabolized differently (1–8). Medium-chain triglycerides (MCT),[3] containing 6–12 carbon fatty acids, differ from long-chain triglycerides (LCT), which have fatty acids of > 12 carbons, in that they are absorbed directly into the portal circulation and transported to the liver for rapid oxidation (1). LCT, however, are transported via chylomicrons into the lymphatic system, allowing for extensive uptake into adipose tissue. Therefore, it has been hypothesized that the rapid metabolism of MCT may increase energy expenditure (EE), decrease their deposition into adipose tissue and result in faster satiety. The objective of the present article is to review literature concerning the effects of MCT on EE, fat deposition and food intake as a means to establish the potential efficacy of MCT in the prevention of obesity in humans.

Effect of MCT on Energy Expenditure. Animal trials studying the effects of MCT vs. LCT consumption on lipid and energy metabolism have shown that body weight (BW) is reduced with MCT consumption compared with LCT consumption and that feed efficiency is thus reduced (9–11). In a study in which rats infused with MCT gained one third of the weight gained by those infused with LCT, Lasekan et al. (9) concluded that replacing LCT with MCT over long periods could produce weight loss without decreasing energy intakes.

Human studies have mainly compared the effects of MCT vs. LCT in single-meal or single-day experiments. Scalfi et al. (3) evaluated the effects of a single mixed meal containing MCT on postprandial thermogenesis and examined possible differences in the thermic response between lean and obese men. Subjects consumed a meal containing 15% of energy from protein, 55% from carbohydrate and 30% from fat, in the form of corn oil (CO) and animal fat or MCT oil (56% octanoate, 40% decanoate) in random order. Energy expenditure measurements were conducted before and for 6 h after consumption of the meal. Total EE was 48 and 65% greater in lean and obese individuals, respectively, after MCT compared with LCT consumption. Similar results were obtained by Seaton et al. (4) comparing the effects of MCT or CO on EE after a single meal. Energy expenditure peaked at 16% above baseline after MCT consumption compared with 5% for CO.

Dulloo et al. (5) investigated the thermogenic effects of low-to-moderate amounts of MCT consumption in healthy adult men. Subjects were required to spend 24 h in a respiratory chamber on four separate occasions; during that time, diets differed in the ratio of MCT:LCT (0:30, 5:25, 15:15, 30:0) provided as added fat. The diet was given at a level 1.4 times energy requirements and the 30 g of added fat was distributed evenly across all meals. The authors found that EE between 0800 and 2300 h increased by 45, 135 and 265 kJ with 5, 15 and 30 g of MCT in the diet, respectively. Mean 24-h EE also increased by 162 and 475 kJ with 15 and 30 g of MCT in added fat, respectively. Thus, the greater effects of MCT than LCT on EE are evident not only in the few hours after the meal but for a much longer time.

Most results (3–5) from single-day experiments indicated that replacing LCT for MCT in the diet could produce weight loss after prolonged consumption. However, when Flatt et al. (6) compared diets rich in MCT, LCT and low in fat, they concluded that a low fat diet was more prudent when aiming for weight loss. However, MCT consumption resulted in greater EE at several time points compared with the low fat diet.

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[3] Abbreviations used: BW, body weight; CCK, cholecystokinin; CO, corn oil; DVZ, Devazepide; EE, energy expenditure; FO, fish oil; GIP, gastric inhibitory peptide; LCFA, long-chain fatty acids; LCT, long-chain triglycerides; MCFA, medium-chain fatty acids; MCT, medium-chain triglycerides; PYY, peptide YY; SCFA, short-chain fatty acids; SCT, short-chain triglycerides; TEF, thermic effect of food; TG, triglycerides.

Few trials have been conducted over longer periods. One of those studies examined energy balance during the overfeeding of liquid formula diets containing MCT (61% octanoate, 32% decanoate) or LCT (32% oleate, 51% linoleate) for 7 d (7). EE was measured on d 1 and 6 for 10–15 min every 30 min for 6 h after meal consumption. The thermic effect of food (TEF) was identified as 8% of ingested energy after MCT consumption compared with 5.8% after LCT consumption on d 1. After 6 d, TEF was 12 and 6.6% of ingested energy with MCT and LCT consumption, respectively, indicating that the difference in EE between MCT and LCT persists even after a week of overfeeding.

The study of longest duration (14 d) published to date (8) sought to determine whether fatty acid chain length influenced EE and substrate oxidation in women. Subjects consumed a controlled, weight maintenance diet containing 40% of energy as fat, either in the form of butter and coconut oil (MCT; 38.9% of fatty acids contained chains with <16 carbons) or beef tallow. Energy expenditure was measured before and for 5.5 h after breakfast. Postprandial total EE after MCT consumption was greater than after LCT consumption on d 7 but not d 14. The authors concluded that the effects of MCT consumption on EE may be transient.

All animal studies (9–11) and most human studies (3–5,7,8) have shown that MCT consumption increases EE compared with a meal containing LCT. Investigators who found the greatest differences also concluded that MCT could be used in the treatment or prevention of human obesity (3–5). However, the studies conducted to date have been short, ranging from a single meal (3–6) to several days (7,8). Whether effects of MCT on EE and RQ are long lasting and result in actual measurable and sustainable changes in body composition of humans remain to be established.

Effect of MCT on Fat Deposition. Given that feed efficiency studies in animals and energetic studies in humans indicate enhanced EE after MCT consumption (3–11), additional work has examined whether increased EE translates into decreased fat mass. In animals consuming MCT, BW were lower, fat depots smaller (12–15) and adipocyte size smaller (12,13) with MCT compared with LCT consumption. These results led the authors to conclude that MCT could potentially prevent (13) or control (15) obesity in humans. However, MCT consumption was not observed by Hill et al. (16) to cause greater weight loss than lard, CO or fish oil (FO). Body adipose tissue during the first 3 mo was not different among groups but after 6 mo, the group fed FO had less body fat than all other groups. Although both FO and MCT feeding resulted in small fat cells, only FO feeding was associated with inhibition of cell proliferation.

Only one study evaluated the ability of MCT to facilitate weight reduction in humans (17). Obese women (n = 16) consumed MCT (58% octanoate, 22% decanoate) or LCT (soy oil) in random order for either 4 wk if they were inpatients or 12 wk if they were outpatients, at a level of 191 kJ/d. There were no differences in weight loss or rate of weight loss between diet treatments. A liquid diet containing 24% of energy as MCT failed to increase the rate of weight loss compared with LCT. This lack of agreement with animal trials and EE experiments may have been due to the low fat content of the diets (1.5 g of total fat/d, of which 1.2 g was treatment fat) or to gender differences in the effects of MCT. Differences detected in EE with MCT and LCT consumption are considerably greater in males than females. When data are extrapolated from trials conducted in men (3–5,7), average EE was ~460 kJ/d greater with MCT than with LCT consumption, with a peak difference between treatments of 669 kJ/d (7). In contrast, data from White et al. (8), who studied women, found differences in EE of 138 kJ/d between MCT and LCT consumption. Our own work with overweight women also revealed a difference in EE of ~188 kJ/d (18). From these preliminary data, it appears that women respond less readily to treatment with MCT than men.

Effect of MCT on Food Intake and Satiety. Animal studies. Lower weight gain and decreased fat depot size with MCT feeding compared with LCT feeding in animals have been attributed to two different effects of MCT, i.e., increased EE and decreased food intake. Satiety may also be affected by fatty acid chain length of dietary fat. Bray et al. (19) observed greater feed intake when LCT were included in the diets of the rats compared with diets containing MCT. After 80 d of consuming diets containing 60% of energy from CO, MCT or a mixture of the two, rats fed the CO and the CO-MCT diets had a higher BW than those fed the MCT diet alone. Rats fed the MCT diet consumed less energy, and the authors concluded that β-hydroxybutyrate may play a role in the difference in food intake between MCT- and CO-fed rats.

Given these results, Maggio and Koopmans (20), in 1982, conducted a study to clarify the origin and the nature of the signals that terminate short-term food intake of mixed meals containing triglycerides (TG) with fatty acids of different chain lengths. Sprague-Dawley rats were intubated intragastrically and given free access to a liquid diet containing 21% of energy as fat. The TG infusions consisted of 70% TG (tributyrin, tricaprylin or triolein in different concentrations) and 30% carbohydrate. Shifting chain length from medium to long did not differentially affect food intake when the infusions were equicaloric. Therefore, the authors concluded that satiety may be related to the amount of energy ingested rather than to the physical characteristics of the specific nutrients. This was in contrast to results obtained by Denbow et al. (21) who infused intrahepatically or intubated intragastrically white leghorn cockerels with isoenergetic quantities of tributyrate, tridecanoate or trioleate and measured feed consumption. Feed consumption with SCT and MCT infusion was suppressed within 1 h after intrahepatic infusion until 180 min. However, when infusions were given intragastrically, only SCT decreased feed intake. The authors concluded that these results reflect the relatively rapid rate of digestion and absorption of short-chain fatty acids (SCFA) from the gut along with oxidation of SCFA by the liver.

Furuse et al. (22) also investigated the effects of two different levels of MCT on feed intake in rats. They further examined the capacity of endogenous cholecystokinin (CCK) to modulate feed intake with MCT. Feed intake of male Wistar rats fed diets containing CO, MCT or a 1:1 mixture of CO and MCT was determined every hour for 12 h and then at 2-h intervals for the following 12 h. In a separate trial, Devazepide (DVZ), a CCK-A receptor antagonist, was injected intraperitoneally 40 min before feeding and feed intake was measured at 1, 2, 3 and 6 h postinjection. Feed intake decreased in a dose-dependent manner with increased concentration of MCT in the diet and was enhanced 2 h after DVZ injection. After 3 h, intake of the MCT diet was less than that of the CO diet. The authors thus concluded that satiety is affected by carbon chain length in dietary TG sources.

Effect of MCT on Food Intake and Satiety. Human studies. If MCT consumption enhances satiety and decreases food intake in animals, an equivalent response might be expected in humans. Stubbs and Harbron (23) examined whether the effects of ingesting MCT can limit the hyperpha-

gia associated with high fat, energy-dense diets in humans. Six men participated in a three-phase inpatient trial in which they had free access to experimental high fat foods (61.5% of energy as fat) for 14 d. Each experimental phase differed in the amount of MCT included in the diet, i.e., low, medium or high MCT content with 20, 31 and 40%, respectively, of total energy as MCT. Subjects consumed 15.1 and 17.6 MJ less with the diet containing the most MCT compared with the diets containing the low and medium amounts of MCT, respectively, over the 14-d period. Body weights during consumption of the low and medium MCT diets increased by 0.45 and 0.41 kg, respectively, and decreased by 0.03 kg with the high MCT content diet. Food and energy intakes were thus suppressed when two thirds of the fat content of a high fat diet was derived from MCT, but BW were not affected.

Another clinical trial (24) was designed to establish the influence of chain length and degree of saturation on food intake in normal-weight men. Breakfasts differing in the nature of the fat, i.e., olive oil, lard, MCT or a fat substitute, were served and food intakes at lunch and dinner were measured. Energy intake at lunch was lower after the MCT-containing breakfast than after all other breakfasts (3100 vs. 3715 kJ with the fat substitute, 3278 kJ with olive oil and 3798 kJ with lard) but there were no differences in food consumption at dinner.

Hormones Iinvolved in the Satiating Effect of MCT and LCT. Clinical trials (23,24) have shown that MCT consumption can lead to lower energy intakes but have not explored the underlying mechanism. More recently, research has focused on specific hormones that may be involved in the satiating effect of MCT. McLaughlin et al. (25) examined the relationship among fatty acid chain length, CCK secretion, and proximal and distal gastric motor function. Healthy volunteers (n = 15) were studied for their response to a control meal and orogastric infusion of 250 mL of a 0.05 mol/L fatty acid emulsion. Fatty acid emulsions containing fatty acids of 11 carbon chains and less did not increase plasma CCK concentrations compared with the vehicle, whereas long-chain fatty acids (LCFA) did. This study showed that the human proximal gut differentiates between fatty acid molecules; however, it does not support the role of CCK in mediating the satiating effect of MCT.

Several other studies have also reported that MCT do not stimulate CCK secretion in humans (26–28), and trials have attempted to establish which hormone is responsible for the observed effects of MCT on food intake. Barbera et al. (26) compared effects of MCT and LCT on sensations of satiety, gastric tone, gastric inhibitory peptide (GIP), pancreatic polypeptide and CCK. Subjects (n = 9) were infused with saline, LCFA (mainly oleate and linoleate) or MCFA (octanoate and decanoate) on three separate occasions in random order. LCFA infusion resulted in a greater rise in satiation than MCFA, but there was no difference between the two fats on the perception of fullness and bloating. The rise in gastric volume was also greater with LCFA infusion than MCFA infusion. Similarly, LCFA increased baseline levels of plasma CCK, GIP, neurotensin and pancreatic polypeptide compared with saline, whereas MCFA infusion did not. The authors thus concluded that MCFA induce gastric relaxation without increasing satiation or plasma levels of gut hormones. However, because Stubbs and Harbron (23) and Van Wymelbeke (24) have shown lower food intakes with diets rich in MCT, it is likely that other factors play a role in regulating energy balance with MCT consumption.

Maas et al. (27) examined effects of MCFA and LCFA on peptide YY (PYY) release to determine whether PYY, which inhibits gastric acid secretion in humans, is involved in the enterogastrone effect of MCFA. These investigators had previously observed that infusions of MCFA suppressed gastrin-stimulated gastric acid secretion without the involvement of CCK (28). Men (n = 14) were intraduodenally infused for 2.5 h with MCFA (56% octanoate, 43% decanoate), LCFA (CO) or saline in random order. The energy loads differed between MCFA and LCFA infusions, with the former providing a load of 11.6 kJ/min and the latter providing a load of 22.7 kJ/min. Both infusions increased plasma levels of PYY; however, LCFA resulted in a greater increase than MCFA infusion (10.3 vs. 2.8 pmol/L). LCFA inhibited gastrin-stimulated gastric acid secretion by 4.1 mmol/15 min compared with 2.7 mmol/15 min for MCFA. PYY is therefore involved in the enterogastrone effect of MCFA; however, MCFA are less potent at inducing PYY release than LCFA. Greater induction of PYY release by LCFA may be due to CCK discharge by LCFA because CCK has been shown to stimulate PYY secretion. Other hormones may therefore be involved in the mechanism by which MCFA inhibit gastric acid secretion. However, except for GIP, which is not released in response to MCFA, these have not been studied.

Recently, Feinle et al. (29) investigated the ability of TG with fatty acids of varying chain lengths to induce gastrointestinal sensations and symptoms. Five different infusions were studied as follows: LCT (soybean oil), MCT, soy lecithin, Orlistat and sucrose polyester. LCT and MCT both increased gastric volume, with LCT causing the greater increase. All infusions resulted in increased feelings of fullness, bloating and nausea, and decreased hunger but effects were most pronounced with the LCT infusion. The authors concluded that the mechanism of action of fat in the generation of gastrointestinal symptoms required digestion of TG. Furthermore, because MCT do not release CCK, but do affect sensations of fullness, bloating and nausea, CCK-dependent and CCK-independent mechanisms must be involved.

In humans, MCFA do not stimulate CCK secretion. Therefore, CCK must not be the hormone responsible for their satiating effect (25–29). Although MCT have been shown to induce satiety and to stimulate hormone secretion, no single hormone has been found to be strongly secreted due to MCT digestion. PYY has been found to be secreted in response to MCFA, yet it is still more potently secreted in response to LCT (27).

Potential Benefits to Consumption of MCT on Body Weight. There is evidence to suggest that short-term consumption of MCT increases EE in humans (3–5,7,8) and results in decreased fat cell size and body weight accretion in animals (12–16,19). Human studies have shown that replacing dietary LCT with MCT increases daily energy expenditure from 100 (6) to 669 kJ (7) in men and 138 kJ/d (8) in women. Studies examining the satiating effect of fats of different chain lengths found that energy intake was ~1070 kJ lower when meals contained MCT than when they contained LCT as the fat source (23). Van Wymelbeke et al. (24) found that intakes were 175–698 kJ lower, depending on the chain saturation of the LCT, at the subsequent meal when MCT were substituted for LCT. Therefore, in the most optimistic scenario in which EE would be increased by 669 kJ/d (7) and intakes decreased by 698 kJ/d (23), a weight gain of 1.35 kg/mo could be avoided by replacing LCT with MCT in the diet. On the other hand, the least optimistic scenario would give an increase in daily EE of 100 kJ (6) and decreased daily food intake of 350 kJ/d (2 subsequent meals, each less by 175 kJ) (24). In this case, a weight gain of 0.45 kg/mo would be avoided (**Fig. 1**). If we

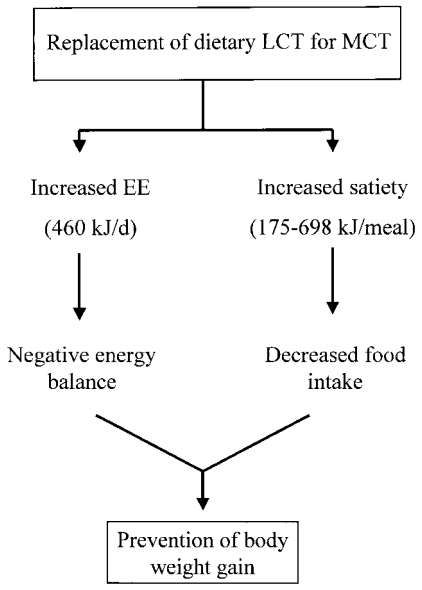

FIGURE 1 Replacement of dietary long-chain (LCT) for medium-chain triglycerides (MCT) can lead to increases in energy expenditure (EE) and satiety in humans. Energy expenditure can be increased by up to 460 kJ/d and food intake decreased by 175–698 kJ/d. The combination of increased energy expenditure and satiety can lead to prevention of body weight gain.

project these data to long-term weight balance, a negative weight balance of 5.4–16.2 kg/y would be produced. However, more work is required to establish whether prolonged consumption of MCT results in a decrease in BW or smaller weight gain compared with LCT.

In summary, research conducted to date in animals shows that replacing dietary LCT by MCT causes a rise in EE, a depression of food intake and lower body fat mass. Similarly, in humans, MCT increase EE relative to LCT consumption. Fewer studies have examined the effects of MCT on satiety but, although results vary, these also suggest decreased food intake when LCT are replaced with MCT in the diet. Therefore, greater EE and lower food intake with MCT compared with LCT suggest that replacing dietary LCT with MCT could facilitate weight maintenance in humans.

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