Dietary Fats and Adipose Tissue Fatty Acid Composition

SAMI A. HASHIM

Department of Medicine, St. Luke's-Roosevelt Hospital Center and Institute of Human Nutrition, Columbia University, Amsterdam Avenue at 114th Street, New York, New York 10025

INTRODUCTION

The fat in human and other mammalian adipose tissue is virtually all in the form of triglycerides located inside individual adipocytes. In prenatal life, the white adipose tissue appears between 26 and 30 weeks of gestation. A typical fat cell develops in the fetus, exhibiting a large sudanophilic droplet with the nucleus pushed toward the circumference of the cell (35). Maternal diet has little influence on the fatty acid composition of the adipose tissue of the fetus, since the newborn adipose tissue has no resemblance to the mother's dietary or body fat (3, 29). Thus, during intrauterine life there is little transplacental transfer of fatty acids, and the fetus synthesizes mostly saturated fatty acids from carbohydrate precursors, such as glucose, or from certain amino acids.

The average human newborn infant has 500 g of fat located in 4 billion adipocytes, each containing 0.12 μg of fat (42). In contrast, the non-obese adult has 30 billion adipocytes with 0.5 μg of fat per cell, and the obese adult may harbor 1 trillion adipocytes, each containing 0.6 to 1.2 μg of fat (34). Thus, considerable increase in adipocyte number must occur from infancy to adulthood. Some increase occurs during the first 2 years of life, with the greater increase appearing between ages 8 and 15 and adulthood (12, 13, 16, 18, 25, 36, 42). There are sex differences in the ultimate attainment of cellularity between adolescence and early adulthood, females reaching 25% and males 15 to 20% of body weight as fat (42).

The considerable amount of fat in the human diet, including mother's milk, has a modifying effect on the composition of adipose tissue postnatally. Whereas adipose tissue cellularity does not proliferate appreciably in the neonatal period, its composition can be profoundly influenced by diet during the first 3 months to 1 year of life. In an attempt to clarify the changes that occur in adipose tissue composition during early postnatal growth, a brief account of dietary fat and fat digestion, absorption, and transport will be made. Dietary fat in early neonatal life contains long-chain and medium-chain triglycerides. Considerable data have accumulated to suggest that the long-chain, but not the medium- or short-chain triglycerides, in the diet are important determinants of adipose tissue composition. Also, there is some evidence to suggest that medium-chain fats depress lipogenesis, have a reductive effect on adipose fat stores, and are useful in the management of certain types of hyperlipidemia in infants and children.

ADIPOSE TISSUE PHYSIOLOGY

The adipose tissue is capable of mobilizing its fat content into the circulation in the form of free fatty acids (FFA). Thus, the composition of circulating FFA in turn reflects the composition of adipose tissue fatty acids. The usual dietary fats, composed mainly of long-chain fatty acids, are powerful inhibitors of lipogenesis in both liver and adipose tissue (30, 37, 41). Paradoxically, in the presence of positive energy balance, dietary fat is deposited in adipose tissue while fat deposition from endogenous, nonfat sources diminishes. Thus, by analyzing the pattern of adipose tissue fatty acids or the plasma FFA patterns, it is possible to draw certain conclusions regarding the mean fatty acid composition of the diet.

During the past 3 decades, evidence has been obtained to indicate that the adipocytes of adipose tissue release FFA in response to a variety of metabolic, hormonal, and nutritional influences (6, 17, 19, 22, 60). In adult humans, in contrast to liver and growing rat adipose tissue, the adipocytes appear to synthesize little FFA (21, 49). An increase in plasma FFA is found during starvation (9, 17, 24, 43, 48) and in blood-draining areas rich in adipose tissue (17). Concurrently, plasma glycerol concentration increases—an indication that complete hydrolysis of adipose tissue triglyceride takes place prior to FFA and glycerol mobilization (39, 44, 59).

The flux of plasma FFA appears to reflect the contribution to the energy needs from adipose tissue. The flow of FFA from adipose tissue is under hormonal and neural regulation. The rate of FFA release from adipose tissue reflects hydrolysis (lipolysis) of the stored triglycerides by a hormone sensitive lipase (HSL). Lipolytic hormones, such as catecholamines, ACTH, and glucagon stimulate and insulin inhibits FFA release by regulating the activity of HSL (4). When the organism is starved, is cold, is stressed or exercised, more FFA are mobilized from adipose tissue to meet the increased energy demand (15, 17, 26, 44, 45). When the organism eats a mixed meal, there is a rapid fall in plasma FFA, reflecting diminished mobilization of FFA from adipose tissue. Thus, under metabolic conditions favoring deposition (positive energy balance), fatty acids are taken up by adipose tissue from circulating chylomicrons (recently ingested long-chain fat) and from circulating lipoproteins, particularly very low-density lipoproteins (VLDL). Such a deposition of circulating chylomicrons and lipoproteins is mediated by the enzyme lipoprotein lipase (LPL). The activity of LPL is hormonally controlled, probably by insulin, and changes with the energy balance (15, 47). Since the fatty acids in chylomicrons and lipoproteins are in the form of lipid esters, the entry of fatty acids into the adipose tissue takes place after hydrolysis of the ester bonds. The fatty acids entering adipose tissue under the influence of LPL as a transporting catalyst are esterified to triglyceride by use of glycerophosphatase derived from the metabolism of glucose. The free glycerol released is returned to the circulation, since it cannot be phosphorylated in adipose tissue (47). Under physiologic conditions of intermittent calorie repletion and fasting, a dynamic state of fatty acid deposition (uptake or synthesis) and mobilization occurs in the adipose tissue. Thus, the two processes of deposition and mobilization are determinants of the fatty acid composition of adipose tissue.
The overwhelming proportion of dietary fats consists of naturally occurring triglycerides of which the constituent fatty acids are predominantly long chain. The carbon skeleton of these long-chain fatty acids is even numbered and varies in chain length from 12 to 24 carbon atoms. The edible triglycerides are derived from such sources as lard and marine animal tissues, animal milk, bird fats, fruit flesh, and seed fats. The American diet derives 40 to 45% of its caloric content from fat (triglyceride). The fatty acid composition of the usual diet is comprised principally of oleate (50%), palmitate (20%), stearate (5%), linoleate (15%), longer-chain fatty acids up to C24, including polyenoic acids other than linoleate (7%), and medium- and short-chain fatty acids below laurate and down to butyrate (3%). However, the complexity of naturally occurring mixed triglycerides is illustrated by the fact that more than 150 different fatty acids have been isolated from them. Most of these occur in small quantities as part of the triglyceride structure.

Two major variables affecting the physicochemical properties of fatty acids are chain length and degree of unsaturation. These properties profoundly affect the digestion, absorption, physiologic transport, and metabolism of the fat. It has been established that butterfat and coconut oil are endowed with medium- and short-chain fatty acids. For example, coconut oil, of which laurate (C12:0) constitutes approximately 50% of its component fatty acids, may contain 10–14% medium-chain fatty acids, principally octanoate (C8:0) and decanoate (C10:0).

In recent years, it has become possible to synthesize triglycerides containing fatty acids shorter than laurate in sufficiently large quantities for feeding purposes in man and experimental animals. Specifically, medium-chain triglyceride (MCT) preparation, composed predominantly of octanoic and decanoic acids, has been made available by the fat and oil industry. Also, triglycerides, such as trioc-tanoin, in which all three positions of the glycerol moiety are occupied by one type of medium-chain fatty acid, have been synthesized. It should be emphasized that although C8:0 and C10:0 fatty acids do appear in naturally occurring mixed triglycerides, the pure MCT preparations have been derived synthetically or semi-synthetically. In the latter situation, the component fatty acids are split off their natural triglyceride (coconut or milk fat), extracted, and subsequently purified prior to re-esterification with glycerol to form MCT. The final product (MCT), a light yellow liquid fat with a melting point of −5°C, is made up entirely of saturated fatty acids ranging in chain length from C6 to C12.

A typical MCT preparation contains 75% C8:0, 23% C10:0, and 1% of either C6:0 or C12:0. Its specific gravity is 0.93 g/ml, and its energy yield by bomb calorimetry is approximately 8.2 kcal per gram. The fatty acids in MCT are designated “medium” chain. In contrast, semi-synthetic long-chain triglycerides, composed principally of saturated long-chain fatty acids, differ markedly in their physicochemical characteristics from naturally occurring mixed triglycerides, which contain varying moieties of monoenoic or polyenoic long-chain fatty acids. The presence of the unsaturated acids in the triglyceride structure together with the saturated long-chain acids invariably results in the lower melting point of the
fat. Similarly, the presence of medium- and short-chain fatty acids in a mixed triglyceride structure also renders a lowering influence on the melting point of the fat.

**ABSORPTION OF LONG-CHAIN FATS**

In recent years, significant advances have been made in understanding the basic processes of digestion, absorption, and transport of long-chain triglycerides (LCT). This presentation deals only with certain salient features of the subject in an attempt to render a contrast with the medium-chain triglycerides. Intestinal digestion of ingested LCT involves physicochemical intraluminal events with resulting hydrolysis of the emulsified LCT into fatty acids and β-monoglycerides under the influence of pancreatic lipase in the presence of bile (8, 31, 33, 46, 54). The hydrolytic products, i.e., fatty acids and monoglycerides, enter into a mixed bile salt micellar solution. Despite differences in the micellar solubilization of unsaturated and saturated monoglycerides at body temperature, the former being considerably more soluble than the latter, the bile salt micelle is likely to contain mixed monoglycerides, with the unsaturated monoglycerides predominating due to the nature of the chemical structure of naturally occurring triglycerides. Thus, mixed monoglycerides may possess high micellar solubility at body temperature. Due to their lack of ionization, the solubility of monoglycerides in the micelle is not influenced by pH. In contrast, free fatty acids in the lumen of the intestine are made more easily soluble in the micelle when some degree of ionization is facilitated by the presence of a near neutral pH aided by pancreatic bicarbonate. It is from mixed micelles of bile salts, monoglycerides, and free fatty acids that the latter two pancreatic lipase-catalyzed products of LCT emulsions are absorbed into the mucosa of intestine. The exact nature of the fat absorption process from the micelle is unknown. However, there is evidence that long-chain fatty acids are absorbed by diffusion (46), a process not requiring energy. The transformation of the hydrolytic products of digestion of LCT emulsion (oil phase) into a micellar solution (aqueous phase) in which the bile salts are the major surfactants is an important prerequisite for fat absorption. In humans, in the absence of disease, such a transformation is facilitated by sufficient amounts of pancreatic lipase, appropriate intestinal pH, and bile salts in concentrations above the critical micellar concentration (8). In disease states resulting in disturbances of the intraluminal events involved in LCT digestion and micellar solubilization of the split fatty acids and monoglycerides, fat malabsorption may ensue despite the existence of a healthy intestinal mucosa. However, when the mucosa is diseased, steatorrhea will also develop, despite apparently normal intraluminal conditions for LCT hydrolysis and micellar solubilization of its hydrolytic products. It should be emphasized that LCT hydrolysis will not occur to any significant extent in the absence of pancreatic lipase.

The absorbed long-chain fatty acids and monoglycerides are resynthesized into triglycerides by the mucosal cells. Studies have indicated that the intestinal mucosal synthesis of triglycerides proceeds along pathways similar to those defined for hepatic triglyceride synthesis (33). Small amounts of phospholipid, cholesterol, and protein are incorporated with the triglycerides into the chylomicrons
CLINICAL SECTION: SAMI A. HASHIM

(emulsion) which range in diameter from 350Å to 0.5 μm. Although triglyceride synthesis by the intestinal mucosa has been delineated, the steps involved in the elaboration of chylomicrons are unknown. In any event, after their formation, the chylomicrons are discharged into the intestinal lacteals from which they drain into the thoracic duct and ultimately the systemic circulation. The composition of the chylomicrons varies with the nature of ingested fat. Studies in humans, rats, and dogs, have shown that the chylomicrons consist of 85–93% triglyceride, 7–11% phospholipid, 1.5–4.5% cholesterol (ester and free), and 1.9–2.5% protein. Immunochemical and chemical studies (51) reveal that the chylomicrons contain virtually all of the proteins of the lipoproteins. However, the exact nature of chylomicron proteins remains unknown.

In summary, ingested long-chain triglycerides are emulsified and transformed by pancreatic lipase to free fatty acids and β-monoglycerides. The split products are solubilized at the normal intestinal pH into mixed bile acid micelles from which they are absorbed by diffusion. The intestinal mucosa resynthesizes the absorbed fat into triglycerides. A new process of emulsification begins and a system is elaborated for the transport of the fat out of the mucosa into the lacteals. The products of such a transport system are the chylomicrons. In abetalipoproteinemia in man, chylomicron formation is impaired due to a deficiency in the synthesis of the chylomicron proteins (32). Patients with this disorder invariably exhibit steatorrhea. Similarly, suppression of chylomicron formation and fat malabsorption have been induced in the rat by administration of inhibitors of protein synthesis, such as puromycin (52).

ABSORPTION OF MEDIUM-CHAIN FATS

The physiologic events that occur in the intestinal lumen and mucosa after oral administration of MCT have received much attention by a number of investigators. The advent of MCT as a clinically useful fat has stimulated studies of its digestion and mode of absorption. Results of studies of duodenal perfusion of emulsified lipids in the rat under a steady state of maximum absorption indicated that the small intestine had a fourfold capacity to absorb trioctanoin compared with long-chain triglycerides (5). Also, it was found that bile diversion in rats did not affect the rate of absorption or hydrolysis of trioctanoin (14). Very little triglyceride remained in the intestinal lumen in control and bile-diverted animals. The animals absorbed mostly medium-chain fatty acids (MCFA). However, some evidence was presented that in the absence of bile, a small amount of MCT is absorbed as triglyceride. Under conditions of diversion of pancreatic juice, the medium-chain fat was present predominantly in triglyceride form in the intestinal lumen and mucosa. However, over 94% of the labeled lipid was present in the free fatty acid form in portal venous blood, indicating extensive mucosal hydrolysis of MCT. It is emphasized that under normal conditions, there is extensive intraluminal hydrolysis of MCT, and absorption of this fat seems to occur in the form of free fatty acid. There is evidence that very little, if any, MCT-derived monoglyceride is allowed to remain in the intestinal lumen under the influence of pancreatic lipase. Unlike long-chain fatty acids, the absorbed MCFA do not appear to be esterified to any significant extent in the intestinal mucosa. Rather,
they diffuse rapidly into the capillaries and are transported into the portal vein as free fatty acids bound to albumin. The virtual lack of chylomicron formation after absorption of MCFA has been related to the efficient absorption of these fatty acids in patients with abetalipoproteinemia.

Studies in humans have contributed to our understanding of the mechanism of absorption of MCT (2). A striking reduction in steatorrhea occurred when MCT was first substituted for a mixed LCT in the diet of a patient with severe pancreatogenous steatorrhea. These studies have been widely confirmed and extended. A remarkable finding was the demonstration that MCT was absorbed well in patients with total pancreatectomy. The patients were fed [14C]trioctanoin and excretion of 14CO2 in the expired air was measured. There was good absorption and subsequent utilization of the octanoate moiety of MCT. Thus, there is considerable clinical evidence that MCT, in contrast to LCT, is absorbed in the absence of pancreatic lipase. This fact led to studies of an intestinal mucosal hydrolytic system for MCT in the rat (23, 50). Indeed, a MCT hydrolase system was demonstrated in the rat intestine. When [14C]trioctanoin was introduced into intestinal loops, 58% of the dose was absorbed after 10 min. At the end of this time, the lipid in the intestinal lumen still was exclusively triglyceride, whereas 11% of the label in the mucosa was in the form of free fatty acid and the rest in triglyceride. Examination of the lipid in the portal vein revealed that over 97% of the lipid label was in the form of free fatty acid. Furthermore, hydrolysis of [14C]trioctanoin was demonstrated in intestinal mucosal homogenates; and, the greatest specific activity was found in the microsomal fraction. The mucosal hydrolytic system for MCT was shown to be distinct from pancreatic lipase, which also hydrolyzes MCT extensively in the intestinal lumen under normal circumstances.

Further evidence for efficient absorption of MCT, despite diminution of available bile acids in the intestinal lumen, was obtained in subjects with cholestyramine-induced steatorrhea. Cholestyramine, a bile acid-binding polymer resin, in large doses (30 g per day) induced steatorrhea in normal subjects ingesting LCT. It was observed that MCT in the diet abolished cholestyramine-induced steatorrhea when substituted in isocaloric amounts for LCT (61). Concurrent measurement of fecal bile acid output showed that MCT did not interfere with the ability of cholestyramine to sequester the bile acids. Thus, while the bile acids were being prevented from participating in the intestinal intraluminal events of digestion, MCT absorption continued at a more efficient rate than long-chain triglyceride absorption. In general, studies in humans indicate that MCT is absorbed efficiently under conditions adverse to the absorption of LCT.

The malabsorptive disorders in which MCT has been shown to be an effective mode of therapy (2) can be classified as those involving the gastrointestinal tract, the pancreas, the biliary system, or a metabolic derangement associated with malabsorption. These include tropical sprue, pediatric and adult celiac disease, infant prematurity, postgastrectomy, blind loop syndrome, resection of small intestine, biliary atresia, hepatic cirrhosis, chronic pancreatitis, cystic fibrosis, congenital abetalipoproteinemia, and diabetic steatorrhea. The use of MCT in the treatment of protein-losing enteropathy and malabsorption associated with lym-
phangiectasia has been reported. When the disorder occurs in early life, it may reflect congenital malformation of the lymphatic system, wherein patients may exhibit edema, chylous ascites, and chylothorax.

TRANSPORT OF MEDIUM-CHAIN FAT

Experimental studies of animals fed medium- and short-chain triglycerides and of patients with chyluria, chylothorax, and other abnormal chylous fistulas showed that the component fatty acids could not be recovered in the lymph, depot fat, or extrahepatic tissues (7, 27). From these and other experiments, the inference was made that since the short- and medium-chain fatty acids were absent from the lymph, they were transported via the portal venous system after absorption. However, the extent and mode of transport of MCT were not clear, and only recently have studies been concerned with digestion, absorption, transport, and utilization of MCT preparations (2). Experiments in dogs with in-dwelling catheters in the portal and hepatic veins have provided direct evidence for portal venous transport of MCFA following intestinal instillation of 14C-labeled and nonlabeled MCT (28). In this way, it was possible to assess transport in portal vein and hepatic metabolism of MCFA following intestinal absorption of their parent triglycerides. Following ingestion of 14C-labeled MCT, radioactivity was recovered in the portal vein as free fatty acid. In contrast, virtually all the radioactivity in simultaneously obtained hepatic vein samples was present in the aqueous nonlipid fraction. The radioactivity in the aqueous fraction of hepatic vein plasma was in carbon dioxide, and to a lesser extent ketones, and other aqueous metabolites. The studies indicate hepatic transformation of MCFA into energy, carbon dioxide, and other water-soluble metabolites, and confirm earlier studies reporting extensive MCFA metabolism in the liver. Thus, those MCFA reaching the liver do not subsequently appear in significant quantities as FFA or fatty acid esters in hepatic venous blood. Despite the extensive metabolism in the liver, the extrahepatic tissues, if given the opportunity, as in physiologic hepatectomy, appear capable of oxidizing [14C]octanoate into 14CO2 (57). The small amounts of octanoate-derived two-carbon fragments that escape complete oxidation of CO2 in the liver can be used for elongation of pre-existing fatty acids (53).

Evidence from cannulation studies of the thoracic duct indicates that less than 3% of orally administered MCT are transported via the chylomicrons, depending on the carbon chain of the MCFA. For example, considerable proportions (7–19%) of orally administered tridecanoin (C10) are transported via the rat chyle (7). In contrast, more recent studies have shown that less than 1% of orally administered tripelargonin (C9) was transported via the rat chyle in triglyceride form (40). However, administration of polyenoic LCT mixed with tripelargonin enhanced up to threefold the quantity of pelargonate transported as triglyceride in chyle. Figure 1 summarizes in a schematic fashion the chylous and portavenous modes of transport of naturally occurring even-numbered fatty acids.

Animals fed MCT as a major source of dietary fat display only small quantities of MCFA in their adipose tissue. However, by circumventing the liver and feeding even- and odd-numbered MCT preparations to rats with portacaval anastomoses, it is possible to "shunt" the transport of MCFA to the peripheral circulation (62).
In this way appreciable quantities of odd- and even-numbered MCFA were deposited in the adipose tissue.

It is of considerable interest that correlation between the melting point of even-numbered fatty acids and their chain length shows a sharp rise in the melting point as the fatty acid lengthens from medium to long chain. It appears that nature has two ways of lowering the melting point: (a) by shortening the chain length of the fatty acid, and (b) by introducing double bonds in the structure of long-chain fatty acids. There are no data relative to unsaturated MCFA. Theoretically, these should possess extremely low melting points. When the odd-carbon fatty acids are plotted on the same curve, a line almost parallel to the even-carbon fatty acids is obtained. Again, no information is available as regards the melting point or physiologic behavior of unsaturated odd-carbon fatty acids.

In conclusion, over the past 2 decades, with the help of the fat and oil industry, certain triglycerides containing MCFA have been prepared, and the feasibility of their use in humans as part of or as the sole source of fat in the diet has been
TABLE 1

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Molar ratios (percentage ± SD of total fatty acids)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C14:0</td>
<td>3.2 ± 0.2</td>
</tr>
<tr>
<td>C14:1</td>
<td>0.5 ± 0.3</td>
</tr>
<tr>
<td>C16:0</td>
<td>51.9 ± 3.5</td>
</tr>
<tr>
<td>C16:1</td>
<td>9.4 ± 1.1</td>
</tr>
<tr>
<td>C18:0</td>
<td>4.1 ± 0.3</td>
</tr>
<tr>
<td>C18:1</td>
<td>26.5 ± 1.9</td>
</tr>
<tr>
<td>C18:2</td>
<td>0.8 ± 0.7</td>
</tr>
</tbody>
</table>

Demonstrated. MCT has been shown to be effective in the nutritional management of a variety of absorption disorders with varying etiologies. The mechanisms whereby MCT preparations are absorbed under conditions adverse to the absorption of long-chain fats appear to be related to the following characteristics: low melting point; relatively small molecular size; a degree of finite solubility in water; lower requirement for bile acids for the formation of micellar solutions; higher partition coefficient in micellar phase of digestion; faster rate of hydrolysis in the intestinal lumen; hydrolysis in the intestinal mucosa; and portal venous route of transport in free fatty acid form. Their usefulness is related to their high caloric density, their extensive oxidative metabolism in the liver, and their relatively small rate of incorporation into lipid esters. Under normal conditions, due to their metabolic behavior in the liver, they do not appear to be stored in appreciable quantities in extra-hepatic tissues during periods of long-term administration as a substantial portion of caloric intake. Also, in recent years it has been possible to induce chylous transport of medium-chain, odd-numbered fat in successful attempts to enrich the animal with appreciable quantities of potentially glucogenic fatty acids.

MODIFICATION OF ADIPOSE TISSUE FATTY ACID COMPOSITION IN THE INFANT

The fatty acid pattern of adipose tissue of 15 full-term infants is shown in Table 1. Fat samples were obtained by needle aspiration of the subcutaneous tissue of the buttocks. The samples were analyzed by gas–liquid chromatography.

It is evident that at birth, the adipose tissue of infants contains mainly saturated (C16:0) and mono-unsaturated (C16:1 and C18:1) fatty acids. Palmitic acid (C16:0) is by far the largest constituent and accounts for over 50% of infant adipose tissue at birth. Small amounts (less than 1%) of linoleic acid (C18:2) were present, indicating some transplacental transfer of maternal fatty acid.

Infants' adipose tissue changes rapidly after birth, depending on diet. The adipose tissue fatty acids of infants fed LCT in the form of a cottonseed oil formula or an evaporated milk formula and infants who were breast fed during the first 3 months of life are shown in Table 2. It is clear that those infants fed the cottonseed oil formula rapidly incorporated linoleate in their adipose tissue such that by age
TABLE 2

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Group I (months)</th>
<th>Group II (months)</th>
<th>Group III (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>C14:0</td>
<td>3.4 ± 0.3</td>
<td>1.6 ± 2.8</td>
<td>3.6 ± 0.2</td>
</tr>
<tr>
<td>C14:1</td>
<td>0.6 ± 0.6</td>
<td>0.2 ± 0.1</td>
<td>0.2 ± 0.1</td>
</tr>
<tr>
<td>C16:0</td>
<td>53.2 ± 5.3</td>
<td>27.3 ± 0.5</td>
<td>53.0 ± 4.0</td>
</tr>
<tr>
<td>C16:1</td>
<td>9.6 ± 0.9</td>
<td>5.2 ± 0.5</td>
<td>9.3 ± 1.1</td>
</tr>
<tr>
<td>C18:0</td>
<td>4.3 ± 1.3</td>
<td>2.2 ± 0.7</td>
<td>4.4 ± 0.6</td>
</tr>
<tr>
<td>C18:1</td>
<td>26.6 ± 3.3</td>
<td>26.0 ± 4.5</td>
<td>24.4 ± 1.2</td>
</tr>
<tr>
<td>C18:2</td>
<td>0.7 ± 0.6</td>
<td>39.3 ± 2.8</td>
<td>0.7 ± 0.5</td>
</tr>
</tbody>
</table>

a Percentage ± SD.

b Adapted from Ref. 29.

3 mos, the linoleate content of adipose tissue was 39%. In contrast, the infants fed the evaporated milk formula had very little linoleate in their adipose tissue, reflecting low dietary levels of linoleate. Intermediate degrees of linoleate enrichment of adipose tissue occurred in the breast-fed infants. Thus, adipose tissue composition changes in response to diet in neonatal life is remarkably rapid.

In contrast, the adult adipose tissue composition response reflects an overall pattern of long-term intake of dietary long-chain fatty acids. In our laboratory, gas-liquid chromatographic analysis of adipose tissue (buttock) aspirates derived from 100 adult subjects consuming the typical American diet revealed the following average values expressed as percentages of total fatty acids: saturated fatty acids (C14:0, C16:0, C18:0) 29%; mono-unsaturated fatty acids (C16:1, C18:1) 58%; and polyunsaturated fatty acids (mainly C18:2) 12%. The most prevalent single fatty acid was C18:1 (oleic), accounting for approximately 45% of adipose tissue fatty acids, a value close to its prevalence (50%) of the fatty acids encountered in the American diet. To illustrate the slow rate of incorporation of the essential fatty acid linoleate (C18:2) into the adipose tissue of adults consuming a diet rich in polyunsaturated fatty acids, the proportion of linoleate in adipose tissue went from 11 to 22% in at least 3 years (10). This contrasts clearly with the rapid rate of incorporation, noted above, of linoleate, from less than 1 to 39% in 3 months, in full-term infants fed a linoleate-rich diet. Communities outside the United States consuming diets that differ in both quantities and qualities of fat show differing adipose tissue fatty acid patterns reflective of their dietary intakes (11).

MEDIUM-CHAIN TRIGLYCERIDES AND THE ADIPOSE TISSUE

Infants fed MCT as a major source of calories do not incorporate it into their adipose tissue. MCT feeding to premature infants as 40 or 80% of dietary fat in formula diets deriving 50% of their calorie content from fat resulted in striking diminution in stool volume and frequency when compared with isocaloric feeding of LCT. The absorption of fat, nitrogen, calcium, and magnesium was improved
in infants fed MCT (55, 56). The growth curves of the MCT-fed infants revealed that body weight did not differ significantly from the LCT-fed infants at any age. However, the clinical impression was that the infants fed MCT were more lean and less fat than the LCT-fed controls. Unfortunately, it was not possible to do studies of body composition on these infants.

The effect of MCT on body fat was studied in the rat (38). Three groups of rats were fed a low-fat diet, either a 55% (by energy) MCT plus 5% corn oil or a diet containing 60% LCT in the form of corn oil. The data showed that unlike LCT, MCT had a reductive effect on fat stores and, like LCT, had a depressive effect on lipogenesis, suggesting possible application of MCT in obesity control. In a recent study (20), rats were overfed with MCT- or LCT-containing diets that provided 50% calories in excess of their normal consumption. The MCT-fed rats had diminished adipocyte size and significantly smaller fat depots than the LCT-fed controls. In this study, food intake was controlled precisely by gastrostomy feeding. In a similar study, the mechanism for the reductive effect of MCT on adipose tissue was ascribed, in part, to increased metabolic rate and enhanced thermogenesis (1). Preliminary studies in our laboratory indicate that rats fed MCT-containing diets (50 and 70% of energy) at the time of weaning and extended for 28 weeks had significantly smaller adipocyte size and fat depots than the LCT-fed controls. Further work is needed to determine whether MCT feeding early in neonatal life will result in smaller adipocyte number than comparable feeding with LCT.

The clinical use of MCT in the treatment of a variety of disorders of lipid transport has been reported and summarized in a recent review (2). Since MCT does not form chylomicrons after digestion and absorption, it has been valuable in the treatment of Types I and V hyperlipidemia. Since Type I hyperlipidemia is often discovered in childhood, the advent of MCT has enabled the structuring of a diet acceptable to the child, since a low-LCT diet is hard to follow. MCT can be incorporated into such items of food as cakes, ice cream, cookies, and French-fried potatoes, and can be used as a salad oil and in frying and cooking low-fat (LCT) foods. The effect of MCT on the hyperlipidemias characterized by elevations in serum cholesterol deserves further study in humans, although studies in animals are encouraging. Finally, the feeding of MCT early in life to children born to obese parents is a subject for future investigation.

REFERENCES


