Energy Value of Medium-Chain Triglycerides in Muffins Fed to Rats

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Cereal Chem. 71(6):553-556

ABSTRACT

This study was designed to determine the energy values of three commercially available medium-chain triglycerides (MCTs), using young rats as the test model. These MCTs, with slightly different C-8 to C-10 fatty acid ratios, replaced shortening in a muffin formula and represented, through muffins added to the diet, 40% of total dietary energy. The increase observed in rats' carcass energy due to MCTs fed over a three-week period formed the basis of calculating energy values. Rats fed MCTs deposited significantly ($P < 0.05$) less fat in their carcass than did those fed a conventional fat (baker's shortening). Primarily because of this, calculations showed that the MCTs tested had an average energy value of 6.9 ± 0.4 cal/g, a value about one-fourth lower than that of conventional fats. All MCTs were slightly better digested than the baker's shortening.

Medium-chain triglycerides (MCTs), developed in the 1950s, have been primarily utilized in nutritional formulations as an energy source for individuals with disorders of fat assimilation. MCTs naturally occur in commercially significant amounts in milk fat, palm kernel oil, and coconut oil. Coconut oil is usually the source for commercially prepared MCTs, which are essentially composed of C-8 (caprylic) and C-10 (capric) fatty acids.

MCTs are absorbed bypassing the lymphatic system (lymphatic system transports conventional long-chain triglycerides [LCTs]), going through the portal vein, and being transported directly to the liver (Bach and Babayan 1982). Rapidly oxidized in the liver, MCTs are, thus, metabolized more like carbohydrates than like conventional fat. As such, they may show a caloric value lower than that of conventional fats. It has also been reported that MCTs are less effectively incorporated into tissue lipids, therefore limiting the storage of body fat (Lavau and Hashim 1978, Geliebter et al 1983).

The heat of combustion (gross energy) for MCTs, also called MCT oils, is reported as 8.3 cal/g (Bach and Babayan 1982, Babayan 1991). However, there is a paucity of information on how well this energy is utilized; the usable energy value of MCTs may be lower than 8.3 calories. It is also difficult to make a valid comparison of MCTs versus LCTs for their effect on body fat deposition, as several studies conducted with rats (Wiley and Leveille 1973, Lavau and Hashim 1978, Chanez et al 1991) did not equalize caloric intake from MCTs and LCTs. The study reported here was undertaken to address these questions. Young rats were used as the test model because they allow relatively simple whole-body analysis (the basis of the method used here).

MCT oils were tested as added to a food product—muffins. Being saturated fats, MCTs show a high degree of oxidative stability. MCT oils also show excellent solubility and solvency characteristics. The current food uses of MCTs include solvents for colors and flavors; antistick, moisture-barrier, or release agents for bakery products and candies; and ingredients in gloss-enhancing coatings. MCTs can also serve as the fat ingredient in full-fat, reduced-fat, or low-fat bakery products. Reduced-calorie foods such as peanut butter have been prepared with MCTs. Due to their extremely low viscosity, MCTs may also be suited as spray oil for use in cereals, crackers, and other snacks.

MATERIALS AND METHODS

Test Fats

Partially hydrogenated soybean oil (baker's shortening), a commercial USP-grade heavy mineral oil, and three commercial sources of MCT oils (Table I) were tested. Mineral oil and MCT oils are odorless, tasteless, clear liquids.

Muffin Preparation

Test fats were used at the 22.3% level in muffin formula. Besides water, the other formula ingredients included flour (46.5%), sugar (25.5%), nonfat dry milk (2.8%), baking powder (1.9%), salt (0.5%), and dry egg white (0.5%). Baked muffins were air-dried, finely ground, and stored frozen until analyzed for proximate components (Table II).

Test Diets

Two control (shortening- and mineral oil-based) and three test (MCT-based) diets were prepared using finely ground muffins (Table III). Except for a minor contribution from flour, test fats were the only source of fat in the muffins. In the test diets, muffins provided 95% of the total fat, with the other 5% resulting from soybean oil included as a source of essential fatty acids. Calories

[1]American Institute of Baking, Manhattan, KS.

TABLE I
Percent Fatty Acid Composition of Medium-Chain Triglycerides Tested[a]

Fatty Acid	Medium-Chain Triglyceride CX[b]	NB[c]	DL[d]
Caprylic acid	66.7	71.1	75.0
Capric acid	29.7	26.9	25.0
Other acids	3.6	2.0	0.0

[a]Based on suppliers' information.
[b]Captex 200 from Karlshamns, Columbus, OH.
[c]Neobee M-5 from Stepan Co., Maywood, NJ.
[d]Delios S from Henkel Corp., La Grange, IL.

TABLE II
Composition (%) of Air-Dried Muffins

	Ingredient				
			Medium-Chain Triglyceride		
Component	Shortening	Mineral Oil	CX[a]	NB[b]	DL[c]
Moisture	4.4	6.4	5.7	4.6	5.1
Protein	6.3	6.2	6.5	6.5	6.5
Ash	1.8	1.7	1.7	1.7	1.8
Fat	23.7	23.1	23.1	23.1	23.1
Dietary Fiber	1.5	1.6	1.4	1.6	1.6
Carbohydrates[d]	62.3	61.0	61.6	62.5	61.9

[a]Captex 200 from Karlshamns, Columbus, OH.
[b]Neobee M-5 from Stepan Co., Maywood, NJ.
[c]Delios S from Henkel Corp., La Grange, IL.
[d]Calculated by difference.

from fat in the test diets averaged 40.4 ± 0.4% (Table III). All diets were complete in nutrients required by the rat (NRC 1978).

Animals and Feeding

Fifty-four male, weanling rats of the Sprague-Dawley strain were obtained from Harlan Sprague-Dawley (Indianapolis, IN) and housed individually in mesh-bottomed stainless steel cages in a temperature- and humidity-controlled environment. They were randomly assigned to five groups (10 rats per group) for the three-week study period. A group of four rats was sacrificed just before the start of the experiment (day 0) to obtain baseline carcass energy values. As the experiment progressed, rats were allowed to consume increasingly higher, but identical, amounts of the diets. Deionized water was offered ad libitum. Except for rats fed the mineral oil-based muffins, total fecal collection was made (throughout the study) on each rat fed the other four diets. Mineral oil-fed rats showed anal leakage of the oil which made fecal collection impractical; anal leakage also necessitated occasional washing and drying of the rats.

Carcass Sampling

At the end of the study, all rats were sacrificed under ether, and their gut contents were removed and discarded. The carcasses were weighed and individually autoclaved (121°C, 15 psi, 1.5 hr) in excess water, freeze-dried, and then finely ground. Suitable aliquots of the finely ground carcasses were taken for analysis.

TABLE III
Composition (%) of Test Diets[a]

	Diet				
	SH	MO	CX	NB	DL
SH	80.2	...	...	...	...
MO	...	82.3	...	...	...
CX	...	...	82.3	...	...
NB	...	...	...	82.3	...
DL	...	...	...	...	82.3
Casein	5.3	5.3	5.2	5.2	5.2
Gluten	6.3	6.3	6.2	6.2	6.2
Cellulose	0.1	...	0.1	...	...
Constants[b]	5.8	5.8	5.8	5.8	5.8
Cornstarch	2.3	0.3	0.4	0.5	0.5

[a]Each diet contained 20% fat (including 1% from soybean oil) and 14% protein. Calories from fat ranged between 40.0 and 40.7% for all diets. SH = shortening; MO = mineral oil; CX = Captex 200 from Karlshamns, Columbus, OH; NB = Neobee M-5 from Stepan Co., Maywood, NJ; DL = Delios S from Henkel Corp., La Grange, IL.

[b]1% vitamin mix, 3.5% mineral mix, 1% soybean oil, and 0.3% dl-methionine.

Analysis and Statistics

Muffins and carcasses were analyzed for moisture, protein (Kjeldahl), fat (muffins and feces: ether-extract method; carcass: acid-hydrolysis method), and ash using standard methods (AACC 1983). Body weight was considered in calculating total moisture in the carcass. Total dietary fiber in muffins was determined by the method of Prosky et al (1992). Carbohydrate values in muffins (Table II) and glycogen values in carcasses (Table IV) were calculated by difference by subtracting the sum of components analyzed from 100. Data were subjected to analysis of variance. Mean comparisons were made with Duncan's multiple range test (SAS 1982).

RESULTS AND DISCUSSION

Test Fats and Muffins

Conventional fats provide about 9 cal of energy per gram (Reeves and Weihrauch 1979). Mineral oil, a petroleum-derived product, provides no energy. As in a similar study recently reported (Ranhotra et al 1994), shortening and mineral oil were again used as the positive and negative controls, respectively, to assess the energy values. MCT oils tested represent three commercial preparations, and they contained caprylic acid as the major (66.7–75.0%) component (Table I). Muffins were made with all five fat sources. On a scale of 100, muffins made with MCT oils scored between 69 and 70, as compared to a value of 84 for muffins made with baker's shortening. Scores were based on external and internal characteristics, including taste and aroma. No attempt was made to optimize the quality of MCT-containing muffins.

Test Diets

Air-dried muffins contained 23.1–23.7% fat (Table II). They were incorporated in test diets at a substantial (80.2–82.3%) level to provide slightly excessive energy from fat, which averaged 40.4 ± 0.4% (Table III).

Growth Response and Body Composition

All rats were fed the same amount (194 g) of total diet during the three-week test period (Table IV). By week 3, their body weights differed significantly ($P < 0.05$) between groups, which

TABLE IV
Body Weight Gain, Body Composition, and Fat Digestibility Responses for Three-Week Study[a]

	Diet[b]				
	SH	MO	CX	NB	DL
Diet intake, g	194	194	194	194	194
Body weight, g[c]					
Week 1	59 ± 3 a	38 ± 2 b	59 ± 3 a	58 ± 2 a	58 ± 2 a
Week 2	95 ± 4 a	61 ± 3 b	95 ± 3 a	93 ± 5 a	92 ± 3 a
Week 3	126 ± 3 a	75 ± 3 c	122 ± 4 b	121 ± 4 b	120 ± 3 b
Body weight, g[d]	121 ± 4 a	71 ± 3 c	116 ± 3 b	116 ± 4 b	115 ± 3 b
Body composition, g[e]					
Fat	19.6 ± 1.6 a	1.8 ± 0.2 d	15.8 ± 2.2 b	14.6 ± 2.0 bc	13.8 ± 0.9 c
Protein	21.0 ± 0.9 a	13.8 ± 0.6 b	20.3 ± 0.5 a	20.4 ± 0.8 a	20.6 ± 0.5 a
Ash	3.5 ± 0.2 b	2.4 ± 0.2 c	3.7 ± 0.1 a	3.6 ± 0.2 ab	3.6 ± 0.1 ab
Water	77.0 ± 2.6 a	52.9 ± 2.7 b	76.2 ± 1.4 a	76.9 ± 2.6 a	76.1 ± 2.1 a
Glycogen	0.1 ± 0.2 c	0.2 ± 0.1 c	0.4 ± 0.1 b	0.4 ± 0.2 b	0.6 ± 0.1 a
Apparent fat digestibility					
Fat intake, g	38.8 ± 0.0	38.8 ± 0.0	38.8 ± 0.0	38.8 ± 0.0	38.8 ± 0.0
Fat excreted, g	0.6 ± 0.1 a	...	0.2 ± 0.0 b	0.2 ± 0.1 bc	0.1 ± 0.1 c
Fat digested, %	98.5 ± 0.1 c	...	99.5 ± 0.0 b	99.6 ± 0.1 ab	99.6 ± 0.1 a

[a]Values are averages ± SD for 9–10 rats per diet. Within a line, averages not sharing a common letter are significantly different ($P < 0.05$).

[b]SH = shortening; MO = mineral oil; CX = Captex 200 from Karlshamns, Columbus, OH; NB = Neobee M-5 from Stephan Co., Maywood, NJ; and DL = Delios S from Henkel Corp., La Grange, IL.

[c]Initial (day 0) body weight: 36 ± 3 g.

[d]Gut contents discarded.

[e]Body composition of rats sacrificed at day 0: Fat, 1.3 g; protein, 5.3 g; ash, 0.9 g; water, 20.2 g; and glycogen, 0.1 g (carcass energy, 33 calories).

TABLE V
Calculating Energy Value of Medium-Chain Triglycerides (MCTs)[a]

	Diet[b]				
	SH	MO	CX	NB	DL
Fat consumed, g	38.8	38.8	38.8	38.8	38.8
Total carcass energy, cal[c]	261 ± 15 a	72 ± 3 d	225 ± 20 b	215 ± 19 bc	209 ± 9 c
Increase in carcass energy					
Net increase, cal[d]	228 ± 15 a	39 ± 3 d	192 ± 20 b	182 ± 19 bc	176 ± 9 c
Relative increase, cal[e]	189	...	153	143	137
Energy value, cal/g[f]					
Captex	...	...	7.3	...	...
Neobee	...	...	...	6.8	...
Delios	...	...	...	...	6.5

[a]Values are averages ± standard deviation for 9–10 rats per diet. Within a line, averages not sharing a common letter are significantly different ($P < 0.05$).
[b]SH = shortening; MO = mineral oil; CX = Captex 200 from Karlshamns, Columbus, OH; NB = Neobee M-5 from Stephan Co., Maywood, NJ; and DL = Delios S from Henkel Corp., La Grange, IL.
[c]Based on compositional data in Table IV.
[d]Total carcass energy minus baseline (day 0) carcass energy (33 cal).
[e]Relative to diet MO.
[f]Energy value = A/B × C/D, where A = shortening consumed (g) × calories (9) per gram of shortening; B = relative increase in carcass energy (calories) due to shortening; C = relative increase in carcass energy (calories) due to MCTs; D = MCTs consumed (g).

was due primarily to differences in the caloric density of the two control diets. Rats fed the MCT-based diets showed only slightly (3–5%) lower body weights than those fed the shortening-based diet (Table IV). Bray and Bray (1980) and Geliebter et al (1983) have reported a marked decrease in body weight of rats fed diets containing MCTs as opposed to LCTs. The magnitude of growth responses obtained in our study suggest that MCTs may likely provide slightly less energy than a conventional fat. However, body composition data, a more sensitive indicator, suggest a wider gap.

Fat and protein represent the major components of energy gained. In rats fed LCT-based or MCT-based diets, no significant differences were observed in carcass protein content (Table IV). This was also observed by Chanez et al (1991). In contrast, fat content differed significantly between groups. Body fat in rats fed the shortening-based (SH) diet was significantly higher ($P < 0.05$), as compared not only to rats fed the mineral oil-based (MO) diet, but also to those fed the MCT-based (CX, NB, and DL) diets (Table IV). This is strongly suggestive that MCT oils reduced body fat deposition markedly, perhaps because they are rapidly oxidized and thus stimulate thermogenesis. In studies with human subjects, this stimulatory effect of MCTs on thermogenesis has been well documented, especially when caloric intake from fat is excessive (Seaton et al 1986, Hill et al 1989, Mascioli 1991). The body's limited ability to incorporate medium-chain fatty acids into tissue lipids, and indications that medium-chain fatty acids may also inhibit *de novo* synthesis of fatty acids in adipose tissues (Bach and Babayan 1982), may have contributed to differences observed between MCTs and LCTs.

Carcasses were also analyzed for ash and water content, primarily to enable calculating glycogen values. Differences noted in values for these components have limited physiological significance in the type of study reported here.

Energy Value of MCT Oils

Total carcass energy was calculated using body composition data (Table IV) and standard conversion factors (metabolizable energy) of 4, 9, and 4 cal per gram of protein, fat, and glycogen, respectively. Total energy represents the baseline (day 0) carcass energy (33 cal) plus energy gained during the three-week test period, with differences between the two representing a net increase in carcass energy. The net increase occurred due to the feeding 194 g of total diet, which contained 38.8 g of test fat. (The minor contribution from soybean oil was disregarded).

As mineral oil, 38.8 g of fat provided no energy. However, when compared to mineral oil, shortening and MCT oils provided energy that resulted in a relative increase of 189 cal (shortening) and 137–153 cal (MCTs) (Table V). For shortening, this represents a diet energy (38.8 × 9 = 349.2 cal) to net (carcass) energy (189) ratio of 1.85:1. An equation based on this ratio (Table V) revealed that the three MCT oils provided energy appreciably lower than that of the conventional fat tested. It also became apparent that the three MCTs differed somewhat in energy value among themselves, with lower energy values being inversely related with higher caprylic acid content in MCTs (Tables I and V). This association may be meaningful, if confirmed in additional studies.

Lower energy values of MCTs likely resulted from lower body fat deposition. MCT oils were even slightly better digested than shortening (Table IV), eliminating fat digestibility as a contributory factor in lower energy values observed for MCTs. Studies reported by Okamoto et al (1982) with low-birth-weight infants lead to a similar conclusion. In that study, although infants fed MCTs showed a higher fat digestibility (as compared to infants fed cow's milk), they did not show enhanced growth response, thus, pointing to a lower (as compared to LCTs) energy value for MCTs.

Overfeeding of MCT has been suggested (Baba et al 1982, Geliebter et al 1983) as causing a reduction in body fat deposition. However, in our study, calories from MCT (40%) may be viewed as only slightly excessive; nevertheless, the effect on body fat deposition was profound. Another study is being planned to feed rats MCTs at graded levels (low to excessive) to enable arriving at a firm energy value for MCTs, which may or may not be closer to 8.3 cal/g, the heat of combustion reported for MCTs.

CONCLUSIONS

Fed to rats at 40% of the total calories, three commercial MCT oils averaged an energy value of 6.9 ± 0.4 cal/g. Compared to a conventional fat, this lower value probably resulted from MCT's ability to reduce deposition of fat in the body, through a mechanism not fully understood. MCTs are currently used as a fuel in enteral and parenteral nutrition, but, as a functional and a reduced-calorie fat, they may have food applications also.

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[Received April 7, 1994. Accepted July 11, 1994.]