Dietary Energy Value of Medium-chain Triglycerides

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ABSTRACT

As a fat source in our diet, medium-chain triglycerides (MCTs) result in lower fat deposition when compared by 2 methods to long-chain triglycerides. Using data from 10 animal studies, the calculated energy loss during utilization of MCTs was 16%, resulting in a net energy value (NEV) of 6.97 kcal/g. The NEV calculated from the molecular composition of 9 MCTs with widely varying caprylic:capric fatty acid ratios was 6.72 ± 0.16 kcal/g. For 5 MCTs with completely defined fatty acid compositions, the NEV was 6.80 ± 0.15 kcal/g. Establishing the NEV for dietary MCTs at 6.8 kcal/g is proposed.

Key Words: medium-chain triglycerides, energy value, net energy coefficient, dietary fat, calories

INTRODUCTION

MEDIUM-CHAIN TRIGLYCERIDES (MCTS) ARE EDIBLE OILS, composed primarily of caprylic (C_8) and capric (C_{10}) fatty acids esterified with glycerol. MCTs have been used for many years as a safe food ingredient in a number of nutritional products, i.e., baked goods, cheeses, energy supplements, confections and frostings, snack foods, and food and fruit coatings (Gottschlich, 1992, Shils et al., 1994). They are also used as an energy source in several infant formulas and total hyperalimentation diets. It is well documented that feeding diets, wherein a fat source of long-chain triglycerides (LCTs) was replaced with MCTs, to laboratory animals and humans resulted in decreased body weight gain and reduced fat deposition (Baba et al., 1982; Bach et al., 1989; Contaldo et al., 1985; Crozier et al., 1987; Harkins and Sarett, 1968; Hashim and Tantibhedyangkul, 1987; Hill et al. 1989). Such results have lead to the suggestion that replacing traditional sources of dietary fat, which are composed primarily of LCTs, with MCTs would yield food with lower caloric content. Therefore, MCTs could be used as a tool in the control of weight gain or fat deposition in man. Support for this use can also be found in popular consumer literature (Sheats and Greenwood-Robinson, 1992). A review of the safety of medium-chain triglycerides has been prepared and is in press (Traul et al., 2000). Therefore, we have chosen not to present a discussion of that information here.

The mechanism for the reduced degree of fat deposition has been extensively studied and reviewed (Bach and Babayan, 1982; Chanez et al., 1991; Harkins and Sarett, 1968; Hashim et al., 1960; Hashim and Tantibhedyangkul, 1987). One key source of information showing a reduced caloric value for MCTs is the lower gross energy value determined by heat of combustion measured with bomb calorimetric methods (Bach and Babayan, 1982; Babayan, 1988; Lee and Chiang, 1994). The gross energy content of MCTs is 8.3 Kcal/g vs 9 Kcal/g for fat or LCTs. When used in food for animals and humans, however, research studies show that the useable energy value of MCTs is actually less than the gross energy value. The lower useable energy value for MCTs (and the medium chain fatty acids derived from these triglycerides) is related to the fact that they are readily absorbed, are metabolized extensively, and are not deposited in adipose tissue as are LCTs. There is a high energy loss during metabolism and utilization of MCTs (increased thermogenesis) (Baba et al., 1982; Hill et al., 1989; Freund and Weinster, 1966; Johnson and Cotter, 1986; Lavau and Hashim, 1978). This energy loss suggests that the useable energy value for MCTs in food is less than the useable energy value of dietary fat composed of long chain fatty acids. Although some studies have accounted for these energy losses in defining a useable energy value, there does not appear to be a generally recognized dietary energy value for MCTs.

This article reviews the available information to show, by 2 methods of calculation, that the useable energy value for MCTs in foods should be 6.8 Kcal/g instead of the 8.3 Kcal/g gross energy value cited above.

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CALCULATIONS & RESULTS

Energy value determination from feeding studies

Consumption of significant levels of medium-chain triglycerides results in a change in body composition, wherein a reduction in fat deposition or accumulation occurs. In animal experiments, MCT-containing diets result in a reduced weight gain compared to LCT-containing diets (Crozier et al., 1987; Geliebter et al., 1982; Baba et al., 1982). A major portion of this reduced weight gain is a reduction in fat deposition. A portion of the reason for lower fat deposition is the increased thermogenesis (heat increment) or thermic effect of the food following consumption. The thermic effect of food is the increase in heat production following food consumption, which reflects the energy costs of nutrient utilization, i.e., energy is expended to metabolize the food components. For example, protein is recognized has having a larger heat increment than either carbohydrate or fat. (Kleiber, 1975) Although protein has a gross energy value of 5.65 kcal/g, the useable dietary energy is 4 kcal/g. The difference is the heat energy lost during metabolism to produce urea, formed to excrete nitrogen (1.30 kcal/g) (Krebs, 1964), and other energy loss from incomplete oxidation of carbon and hydrogen that are used in the synthesis of other molecules. Similar losses occur during MCT metabolism. It has been speculated that heat is generated during the rapid oxidation of the short chain fatty acids during ketosis wherein energy is expended to produce ketones for utilization by peripheral tissues (Crozier et al., 1987). It is suggested that the useable energy content of MCTs should be based on the energy available after subtracting the obligatory heat energy losses during metabolism.

The thermic effects of MCT diets have been demonstrated in a number of animal and human studies. This effect can be quantified by calculating a net energy efficiency coefficient (NEC) (thermic effect or heat increment). This is a comparison of the amount of energy deposited in animals fed a diet in which the fat is composed of MCTs to the amount deposited in animals fed a diet containing LCTs. This calculation involves multiplying the amount energy deposited in body fat in the MCT-fed animals compared to the LCT-fed animals (1 minus % reduction in fat content) by the relative gross energy value of LCTs and MCTs (9 kcal/g for LCTs divided

Table 1—Energy values for MCTs calculated from comparing body weight gain and body fat deposition in rats fed isocaloric levels of long-chain triglycerides or medium-chain triglycerides

Composition of MCT, C8:C10 % ratio	Percentage calories from fat in diet	Net energy coefficient[a]	Energy value kcal/g for MCT	Reference
62.5 : 37.3	70	0.79	6.52[b]	Crozier et al., 1987
Est. 75 : 25	45	0.87 (weight gain basis)	7.32[b]	Geliebter et al., 1983
Est. 75 : 25	45	0.83 (fat gain basis)	6.92[b]	Geliebter et al., 1983
Est. 75 : 25	50	0.92 (weight gain basis)	7.82[b]	Baba et al., 1982
Est. 75 : 25	50	0.79 (fat gain basis)	6.52[b]	Baba et al.,1982
66.7 : 29.7	40	0.87	7.3	Ranhotra et al., 1994
75 : 25	40	0.79	6.5	Ranhotra et al., 1994
71.1 : 26.9	40	0.82	6.8	Ranhotra et al., 1994
71.1 : 26.9	30	0.84	7.0	Ranhotra et al., 1995
71.1 : 26.9	20	0.83	7.0	Ranhotra et al., 1995
Mean ± SD	n = 10	0.835 ± 0.040	6.97 ± 0.40[c]	

[a]Net Energy Coefficient is the relative energy retention by animals fed MCT compared to those fed LCT. Calculation = [(1 – % change) × 9kcal / 8.3kcal/g].
[b]Energy value for MCT calculated from regression equation derived from Ranhotra et.al. studies. (Y = 10X – 1.38)
[c]Because this is a mean of mean values, the SD is shown only to emphasize the relatively small degree of variation around the mean.

by 8.3 kcal/g for MCTs). This value could be corrected for the percent absorption of MCTs (98%, Kaunitz et al., 1958). However, no correction was done for our calculations because more recent data (Ranhotra et al., 1994, 1995) suggest that the absorption of MCTs is greater than 99%. Crozier et al. (1987) fed adult rats isocaloric diets in which fat was composed of either an MCT oil or of LCTs for 44 d. The results showed a 28% lower weight gain in the MCT fed animals compared to the LCT-fed animals. This resulted from a 27% decrease in energy retention primarily as a result of less fat deposition. The comparative NEC derived from MCT compared to LCT was determined to be 0.79 calculated by [(1 − 0.27) × 9/8.3 kcal/g].

Similar results were obtained by Geliebter et al. (1983) for a study wherein MCT-oil-fed rats gained 20% less body weight and possessed 23% less weight in fat depots than LCT-fed (corn oil) rats. The NEC values for MCT in this study were 0.87 based on weight gain and 0.83 based on a fat gain basis. Also, Baba et al. (1982) observed NEC values of 0.92 on a weight gain basis and 0.79 on a fat gain basis in rats administered diets containing isocaloric levels of MCT oil or LCT oil (corn oil) (Table 1).

Recently, Ranhotra et al. (1994, 1995) determined the useable energy value of MCTs by measuring the changes in body composition in 5 groups of rats fed a diet containing 20%, 30%, 40%, 40%, and 40% of dietary calories from MCTs for 3 weeks. The latter 3 diets contained MCTs with different ratios of $C_8 : C_{10}$. The comparative isocaloric diets were a positive control diet, which contained LCT (bakers shortening) and the negative control diet, which contained mineral oil that has no nutritional value. Results of these studies provide an absolute measurement of the amount of energy deposited from the fat in the LCT and MCT diets because the total energy deposited can be corrected for the amount of energy deposited by animals receiving the diet containing non-absorbed fat (mineral oil). The energy value equaled the ratio of the dietary energy consumed to the relative increase in fat deposited for the LCT-fed animals times the ratio of the relative carcass energy deposit divided by the weight, in grams, of the MCT fed animals. The energy values for the 5 MCTs were 7.3, 6.8, 6.5, 7.0, and 7.0 kcal/gram providing a mean of 6.92 ± 0.264.

Net energy values calculated from net energy coefficients

Using the data from Ranhotra et al. (1994, 1995), the net energy coefficient values for 3 different sources of MCTs fed at 40% of calories were calculated to be 0.87, 0.82, and 0.79, while the values for MCTs fed at 20% of calories was 0.83 and at 30% of calories was 0.84. The mean ± SD of the NEC values from the 10 animal studies described above was 0.835 ± 0.040. Using these values, a linear regression equation was calculated to describe the relationship of net energy coefficients and net energy values ($Y = 10X – 1.38$). This equation was then used to predict the net energy values for the MCTs fed in the earlier 5 animal dietary studies described above. The results of the calculations and the mean energy values of the MCTs are presented in Table 1. The mean ± SD net energy value for these studies was 6.97 ± 0.40. (While this is a mean of mean values, the SD is shown only to emphasize the relatively small degree of variation around the mean.)

Calculated energy value of MCTs based on molecular composition

To determine the net energy of MCTs based on their molecular composition, we chose 9 MCT products (Table 2) that had a wide range of $C_8 : C_{10}$ percentage ratios (ranging from 4.3 : 95.2% to 83 : 11%), including the MCTs used in the above feeding studies.

The net energy value of 1 g of each representative MCT can be calculated by multiplying the weight fraction of each component fatty acid, glycerol, and water by their respective gross energy value and correcting the gross energy for the degree of absorption and the efficiency (NEC) with which each component is utilized for energy in the body.

The steps involved in this calculation include:

1. Determine the average fatty acid molecular weight in the triglyceride by adding the mole fraction of the fatty acids in the different MCTs. The values for the 9 MCTs are presented in Table 2.

2. Determine the average molecular weight of the triglyceride by summing the 3 average fatty acid molecular weights plus the molecular weight of glycerol and subtracting the molecular weight of 3 moles of water.

3. Determine the weight fraction of each component in 1 gram of the triglyceride by dividing each component by the molecular weight of the triglyceride.

4. The gross energy of each component is determined by multiplying the weight fraction of each component by the kcal/gram of each component. (C_6 caproic 7.19, C_8 caprylic 7.91, C_{10} capric 8.46, C_{12} lauric 8.86, glycerol 4.31, and water 3.21 kcal/g) (Damalski, 1972).

5. The net energy contribution of each component is determined by correcting the gross energy for the digestibility coefficient and the net energy coefficient of each component. It has been established that the degree of absorption, or digestibility coefficient, for long chain fatty acids (C_{12} to C_{18}) is 94% (Merrill and Watt, 1955), while the digestibility coefficient for medium chain fatty acids (C_6 to C_{10}) is practically 100% (Ranhotra et al., 1994, 1995). The mean net energy coefficient, calculated from the 10 animal studies reported in Table 1, is 0.84. This value is used to calculate the net energy value of the $C_6 – C_{10}$ fatty acids. The net energy coefficient for C_{12} fatty acids, glycerol, and water was 1.0.

6. The net energy value of the triglyceride is the sum of the net energy values of each component. The net energy calculated for the MCTs are shown in Table 3. It was assumed that the composition of each MCT evaluated was 100% triglyceride.

For all 9 MCTs, with $C_8 : C_{10}$ percentage ratios varying from 4.3 : 95.2 to 83 : 11, the calculated net energy values range from 6.49 to 7.01 with a mean value of 6.72 ± 0.16 kcal/g. When we excluded the 4 MCTs that had a small percentage of undetermined "other fatty acids", the net energy values calculated for the 5 MCT

Table 2—Summary of fatty acid distribution and molecular weights of representative medium chain triglyceride products

	Fatty acid composition								Avg. fatty acid mol. wt.
	C6:0		C8:0		C10:0		C12:0		
Sample[a]	FA Wt. Fraction	Mole fraction (10^{-3})	FA Wt. Fraction	Mole fraction (10^{-3})	FA Wt. Fraction	Mole fraction (10^{-3})	FA Wt. Fraction	Mole fraction (10^{-3})	1/ total mole fraction
1	N.S.	N.S.	0.625	4.34	0.373	2.17	N.S.	N.S.	153.61
2	N.S.	N.S.	0.750	5.21	0.250	1.45	N.S.	N.S.	150.07
3	N.S.	N.S.	0.711	4.94	0.269	1.56	N.S.	N.S.	153.85
4	N.S.	N.S.	0.667	4.63	0.297	1.73	N.S.	N.S.	157.23
5[b]	0.03	0.026	0.830	5.76	0.110	0.64	0.025	0.13	147.28
6[b]	0.03	0.026	0.630	4.38	0.310	1.80	0.025	0.13	152.21
7[b]	0.01	0.009	0.630	4.38	0.310	1.80	0.050	0.25	153.37
8[b]	0.01	0.009	0.460	3.19	0.480	2.79	0.050	0.25	158.23
9[b]	N.S.	N.S.	0.043	0.30	0.952	5.54	0.005	0.03	170.36

[a]Examples of MCT products with different fatty acid distribution: 1 = Crozier et al. (1987); 2 = Captex 300, Geliebter et al. (1983) and Delios S, Ranhotra et al. (1994); 3 = Neobee M-5, Ranhotra et al. (1995); 4 = Captex 200, Ranhotra et al. (1994); 5 = Neobee M5 (high C8); 6 = MCT (low C8); 7 = Neobee 1053 (low C10); 8 = MCT (high C10); and 9 = Neobee 1095 (very high C10).
[b]Samples with complete fatty acid profile identified.
N.S. = Not specified.

products, for which the amounts of other fatty acids were known, yielded a mean energy value of 6.80 ± 0.15 kcal/g.

The net energy values for the above calculation as well as from the calculations in the feeding studies are summarized in Table 4.

DISCUSSION

FEEDING DIETS CONTAINING MCTS INSTEAD OF LCTS AS THE source of fat in the diet have been shown to reduce weight gain and fat deposition in laboratory animals and in humans. This is due to (1) the lower gross energy density of the component fatty acids and (2) the inefficient utilization of energy from medium chain fatty acids. The mechanism for the reduced fat deposition is believed to be due to rapid direct absorption, lack of direct deposition into fatty tissue, and increased energy loss during metabolic utilization (thermogenic effect). All of these effects support the hypothesis that the true energy value used to calculate the caloric energy contribution of MCT in a diet is less than the 9 kcal/g conventionally used for dietary fats, which are composed of long-chain triglycerides, and is less than the gross energy value of 8.3 kcal/g determined by direct calorimetry for MCTs.

We have approached the determination of an energy value in 2 ways. First, we analyzed data from comparative studies in rats; second, we carried out calculations of net energy values based on molecular composition. The net energy value of MCTs determined by both methods, 6.97 ± 0.40 kcal/g and 6.80 ± 0.15 kcal/g are in agreement, and the rat data are consistent with values determined in other animals species and humans.

Lee and Chiang (1994) determined energy values in neonatal pigs fed a liquid diet containing MCTs. A metabolizable energy value of 7.87 kcal/g for MCT was reported. However data were not presented to permit calculation of NEC or net energy values. The net energy of MCT compared to LCT in 7-day-old chicks, determined by Furuse et al. (1992) and Mabayo et al. (1992), showed that the available energy of MCTs is about 74% that of LCTs. This shows a heat increment or energy loss during utilization of 26% in the young chicken, which is higher than the 16% energy loss observed in the rat studies.

Contaldo et al. (1985) fed healthy male volunteers a test meal supplemented with 1300 kcal of either MCT or LCT (corn oil) after overnight fasting and measured resting metabolic rate (RMR) over for a 6 hr period after the meal. The NEC was 0.90 with no difference between obese or lean subjects. Seaton et al. (1986) fed 7 healthy male volunteers a test emulsion containing 48 g of MCT oil or 45 g of corn oil and measured RMR for 6 hr. The NEC in this study was 0.82. Hill et al. (1989) fed healthy male volunteers an MCT containing test meal at 1.5 × energy required (1000 kcal/

Table 3—Summary of net energy value calculations for various medium-chain triglycerides based on composition

MCT product [a]	Fatty acid	Fatty acid weight fraction	MCT weight fraction	Caloric[b] density contribution /gram	Energy value of MCT (kcal/g)
1	C8:0	0.625	0.577	3.834	
	C10:0	0.373	0.344	2.445	
	Glycerol		0.188	0.802	
	Water		(0.110)	(0.353)	6.73
2	C8:0	0.750	0.691	4.591	
	C10:0	0.250	0.230	1.630	
	Glycerol		0.188	0.810	
	Water		(0.111)	(0.356)	6.68
3	C8:0	0.711	0.657	4.365	
	C10:0	0.269	0.249	1.769	
	Glycerol		0.184	0.793	
	Water		(0.108)	(0.347)	6.58
4	C8:0	0.667	0.617	4.100	
	C10:0	0.297	0.275	1.954	
	Glycerol		0.181	0.780	
	Water		(0.106)	(0.340)	6.49
5	C6:0	0.030	0.028	0.169	
	C8:0	0.830	0.764	5.076	
	C10:0	0.110	0.101	0.718	
	C12:0	0.025	0.023	0.192	
	Glycerol		0.186	0.802	
	Water		(0.109)	(0.350)	6.61
6	C6:0	0.030	0.028	0.169	
	C8:0	0.630	0.582	3.867	
	C10:0	0.310	0.286	2.032	
	C12:0	0.025	0.023	0.192	
	Glycerol		0.186	0.797	
	Water		(0.109)	(0.350)	6.71
7	C6:0	0.010	0.009	0.054	
	C8:0	0.630	0.582	3.867	
	C10:0	0.310	0.286	2.032	
	C12:0	0.05	0.046	0.383	
	Glycerol		0.185	0.797	
	Water		(0.109)	(0.350)	6.78
8	C6:0	0.010	0.009	0.054	
	C8:0	0.460	0.426	2.831	
	C10:0	0.480	0.445	3.162	
	C12:0	0.05	0.046	0.383	
	Glycerol		0.180	0.776	
	Water		(0.105)	(0.337)	6.87
9	C8:0	0.043	0.040	0.266	
	C10:0	0.952	0.886	6.296	
	C12:0	0.005	0.005	0.042	
	Glycerol		0.168	0.724	
	Water		(0.099)	(0.318)	7.01

[a]MCT products with different fatty acid distribution: 1 = Crozier et al. (1987); 2 = Captex 300, Geliebter et al. (1983) and Delios S, Ranhotra et al. (1994); 3 = Neobee M-5, Ranhotra et al. (1995); 4 = Captex 200, Ranhotra et al. (1994); 5 = Neobee M5 (high C8); 6 = MCT (low C8); 7 = Neobee 1053 (low C10); 8 = MCT (high C10) and 9 = Neobee 1095 (very high C10).
[b]Net energy per gram of each component determined by multiplying the MCT weight fraction/ gram by a gross energy value and corrected with the digestibility coefficient and net energy coefficient. Gross energy value, digestibility coefficient, and net energy coefficient, respectively, are for C6 fatty acid 7.19 kcal/g, 1.0 and 0.84, for C8 fatty acid 7.91, 1.0, 0.85, for C10 fatty acids 8.46, 2.0 and 0.84; for C12 fatty acid 8.86, 0.94 and 1.0; glycerol 4.31, 1.0 and 1.0 and water 3.21, 1.0 and 1.0. Damalski (1972), Merrill and Watt (1955) and Ranhotra (1994, 1995).

Table 4—Comparison of MCT net energy value calculated using animal feeding data versus net energy values calculated from molecular composition

	Net Energy Value (kcal/g)	
MCT ratios of C8 : C10	Feeding studies	Molecular composition
1. 4.3 : 95.2		7.01[b]
2. 46.0 : 48.0		6.87[b]
3. 62.5 : 37.3	6.52	6.73
4. 63.0 : 31.0		6.71[b] , 6.78[b]
5. 66.7 : 29.7	7.30	6.49
6. 71.1 : 26.9	6.80, 7.00, 7.00	6.58
7. 75.0 : 25.0	7.32, 6.92, 7.82, 6.52, 6.50	6.68
8. 83.0 : 11.0		6.61[b]
Mean SD[a]	6.97 0.40	6.72 ± 0.16 6.80 ± 0.15[b]

[a]Because this is a mean of mean values, the SD is shown only to emphasize the relatively small degree of variation around the mean.
[b]MCT products with complete fatty acid profile identified.

day) for 7 d, and the thermic responses were measured for 6 hr on the first and last day. The NEC was 0.94. These studies, conducted to measure the thermogenic effect in humans fed diets containing MCTs as the source of dietary fat, tended to underestimate the NEC or the amount of energy lost. The underestimation was due to the fact that the studies were short term and the thermic values had not returned to premeal baseline values. The thermic responses following an LCT meal had, on the other hand, returned to baseline values during the testing period. Although, these latter NEC values could not be included in our net energy value determination for MCTs, they support other data showing a lower dietary energy value for MCTs when compared to LCTs.

The data from other animals and in human studies support the fact that the net energy value of MCTs is lower than LCTs, and it is well documented that the metabolism and utilization as a energy from MCTs are similar among all species. Therefore, the rat is an acceptable model for evaluating the energy value of MCTs as a nutrient ingredient.

CONCLUSIONS

THE DIFFERENCES IN ENERGY UTILIZATION SHOW THAT HEAT increment associated with the metabolism of MCTs appears to be about 16% higher as compared to LCTs. Thus, in calculating the actual dietary energy value for MCTs, it is important to subtract the heat energy lost due to metabolic processes. The calculated mean net caloric energy value for MCTs composed of a wide range of ratios of medium chain fatty acids was 6.97 ± 0.40 kcal/g from animal feeding studies. This value is similar to the mean caloric energy value, 6.72 ± 0.16 kcal/g, calculated from the molecular composition of 9 representative MCTs. The calculated caloric energy value for 5 of those products with well-defined fatty acid composition was 6.80 ± 0.15 kcal/g. Since the latter value represents MCTs with a broad range of medium chain fatty acids, we propose that the net caloric energy value for MCTs used in diets be accepted as 6.8 kcal/g.

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MS 19990317 received 3/15/99; revised 6/17/99; accepted 8/13/99.