Caloric Availability of SALATRIM in Rats and Humans

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SALATRIM is a reduced-calorie fat substitute composed of structured triacylglycerols. These structured triacylglycerols are composed of long-chain fatty acids (predominantly stearic) and short-chain aliphatic acids (acetic, propionic, and/or butyric). It has been demonstrated in rat studies and in a clinical study that SALATRIM with various combinations of these aliphatic acid and fatty acid side chains delivers fewer calories per gram than conventional triacylglycerols such as corn oil. The reduced calories are accounted for by the lower caloric value of the short-chain aliphatic acids and limited absorption of the stearic acid which is freed by enzymatic hydrolysis in the gastrointestinal tract. In caloric availability studies with rats SALATRIM was found to deliver between 4.5 and 6.0 kcal/g. In the human clinical study between 27.6 and 36.5% of the stearic acid in SALATRIM was shown to be absorbed, resulting in an apparent caloric availability of between 4.7 and 5.1 kcal/g. Although subjects consuming SALATRIM exhibited an increased excretion of fecal fat and stearic acid, they did not excrete higher levels of calcium, magnesium, or zinc. These results show that SALATRIM exhibits similar caloric reduction in both rats and humans.

INTRODUCTION

In the Western diet up to 40% of the calories are supplied by fat. The U.S. Surgeon General has recommended that no more than 30% of the dietary calories should be derived from fat (U.S. Department of Health and Human Services, 1988). Thus, there has been increased interest by consumers in lower fat products, which has stimulated efforts by food manufacturers to provide products with reduced calories from fat. Fat is frequently associated with higher quality and greater sensory satisfaction in foods. The food industry has attempted to deal with this conundrum by providing fats with reduced caloric availability. SALATRIM materials represent one approach toward a low-calorie fat. SALATRIM is a triacylglycerol containing a mixture of long-chain and short-chain aliphatic acids randomly distributed on the three positions of the glycerol molecule. The long-chain fatty acids are typically contributed by starting materials rich in stearic acid such as highly hydrogenated soy or canola oil. The short-chain aliphatic acids on SALATRIM are typically acetic, propionic, or butyric acid either alone or in combination. Each SALATRIM triacylglycerol contains at least one long- and one short-chain acid. Because of the random distribution of fatty acids on SALATRIM, each preparation contains multiple molecular species. The short/long-chain fatty acid ratio (S/L ratio molar basis) is a convenient way to further describe various SALATRIM preparations (Softly et al., 1994).

It has been shown that stearic acid is poorly absorbed as the free fatty acid. Carroll (1957), Clarke et al. (1977), and Mattson et al. (1979) have demonstrated that stearic acid esterified on the 1- and 3-positions of the glycerol molecule has limited bioavailability. The stearic acid in the poorly hydrolyzed 2-position of the glycerol appears to be almost completely absorbed, presumably as the monoglyceride. Therefore, in a fat where stearic acid occurs in the more readily hydrolyzed 1- or 3-position of the glycerol molecule, free stearic acid should be produced, which would pass through the gastrointestinal tract with minimal absorption. Fats high in stearic acid such as tallow and cocoa butter have previously been shown to provide fewer calories than a typical vegetable oil such as corn oil (Finley et al., 1994a,b). On the basis of heats of combustion, it is known that short-chain fatty acids such as acetic, propionic, and butyric are lower in caloric value than medium- or long-chain fatty acids (*CRC Handbook*, 1992–1993).

In SALATRIM we have combined the advantages of the low caloric value of the short chains with the poor absorption of stearic acid to produce a triacylglycerol with significantly reduced calories compared to conventional fats such as corn oil. We have tested this hypothesis with several variations of SALATRIM in rats and confirmed the findings in a human clinical trial. These studies are the basis of this paper.

METHODS AND MATERIALS

SALATRIM preparations were produced through interesterification of either hydrogenated soybean oil or hydrogenated canola oil with triesters of the desired short-chain aliphatic acids (triacetin, tripropionin, or trubutyrin) (Klemann et al., 1994). The short- to long-chain ratios (S/L) of fatty acids on the triacylglycerols of SALATRIM were determined by acid composition of the product according to the method of Henderson et al. (1994). Detailed compositions of SALATRIM family members are reported by Huang et al. (1994) and Softly et al. (1994).

Rat studies for caloric availability were conducted as previously described by Finley et al. (1994a,b), estimating the caloric availability of SALATRIM compared to a corn oil standard (Mazola Oil CPC, Englewood Cliffs, NJ), which was assumed to deliver 9 kcal/g. The results are based on the mean body weight gain for 14 days of rats fed diets containing SALATRIM compared to the mean body weight gain of rats fed diets containing various levels of corn oil. A balance study was conducted with rats to establish the extent of absorption of stearic acid. SALATRIM 23SO was added to NIH-07 diet (Ziegler Brothers, Gardners, PA) (5, 10, 15% of diet). A control diet was prepared by adding 10% corn oil to the NIH-07 diet. Young adult male rats were acclimatized in metabolic cages with the diets for 5 days, followed by 5 days of fecal collection. The animals were presented with 75% of their anticipated daily consumption of diet to assure complete consumption of diet. Each day the feces were collected, weighed, and frozen. Fecal samples were homogenized, and the stearic acid in the feces was determined according to AOCS Method Ce 1-62 (AOCS, 1990).

The human clinical study was a noncrossover 1-day exposure to either SALATRIM or a similar level of control (coconut oil,

0021-8561/94/1442-0495$04.50/0

Table 1. Study Design for Human Clinical Study[a]

day	control[b] group, 18 subjects	test[c] group, 17 subjects
1–7	basal diet + control	basal diet + control
8–14	basal diet + control	basal diet + test
15–23	basal diet + control	basal diet + control

[a] Fat carrier materials were ice cream, cookies, and bonbons. [b] Control, coconut oil. [c] Test, Salatrim 23CA lot 14.

Karlsham, Columbus, OH) after exposure to SALATRIM, preceded by a 7-day pretrial and followed by a 10-day posttreatment with the control material (coconut oil). A total of 35 subjects completed the study (18 control, 17 test), with one subject dropping out due to personal reasons. All subjects were confined in a clinical environment for the 24-day study at GMBA Besselaar Clinic, Madison, WI. Subjects were normal healthy individuals ranging in age from 21 to 67 years. They were assigned to either an 1800 kcal/day diet or a 2500 kcal/day diet based on sex, body weight, and age. During the study the subjects received a well-balanced basal diet designed to deliver 16% of the calories from protein, 47% of the calories from carbohydrate, and 37% of the calories from fat. The 1800 and 2500 kcal/day groups received approximately 1.4 and 2.0 g of stearic acid per day, respectively, from basal diets. In addition to the meals, the subjects received supplements of sandwich cookies (the filling in each cookie delivered 5 g of fat), ice cream (which delivered 15 g of fat per serving), and bonbons (which delivered 5 g of fat in the center per serving). The fat in the products was either the control coconut oil or SALATRIM 23CA, which was prepared by interesterification of triacetin, tripropionin, and hydrogenated canola oil in an 11:1:1 ratio (Klemann et al., 1994). Those subjects on the 1800 kcal/day diet received 45 g/day of control or test fat, those on the 2500 kcal/day diet received 60 g/day of control or test fat. The schedule for the presentation of the products to the subjects is shown in Table 1. Fecal samples for each subject were collected and pooled for the last 3 days of each 7-day test period. The fecal samples were homogenized and sampled for analysis. For each sample total fat, stearic acid, calcium, magnesium, and zinc were measured. Total fat in feces was determined by the acid hydrolysis AOAC Method 922.06 (AOAC, 1990); the coefficient of variation (CV) was 1.74%. Stearic acid was determined from fatty acid analysis according to AOCS Method Ce 1-62 (AOCS, 1990) with a CV of 3.83%, and minerals were determined by inductively coupled plasma atomic emmission spectroscope (ICP) according to AOAC Method 984.27 (AOAC, 1990) with CVs of 1.54, 0.75, 1.75 for calcium, magnesium, and zinc, respectively. Complete details of the clinical and safety aspects of the study were reported by Finley et al. (1994a,b). The protocol for the clinical study was approved by the Besselaar institutional review board prior to initiation of the studies.

RESULTS

The fatty acid composition and the observed caloric availability (Table 2) for several SALATRIM preparations illustrate differing SALATRIM structures which yield functional compounds with reduced caloric value. The CA series, prepared from hydrogenated canola oil, exhibit lower caloric availability than the SO series reported here, which are prepared from hydrogenated soy oil. The soy preparations contain 9.1% palmitic acid, which is readily metabolized and contributed in part to the higher caloric value of SALATRIM prepared from hydrogenated soy oil.

SALATRIM preparations are produced from a series of starting materials with differing short- and long-chain acid sources. Modification of the S/L ratio affords products with a variety of physical properties for specific food applications. In Table 3 the caloric availabilities of SALATRIM preparations produced with a range of short-chain acids and differing S/L ratios are presented. The results illustrate the range of caloric availability one can anticipate from SALATRIM prepared with differing short-chain acids. From the data in Table 3 it can be seen that a wide variety of SALATRIM formulations can be prepared, all of which exhibit significant reductions in caloric availability ranging from 4.3 kcal/g for SALATRIM 3CA to 5.7 kcal/g for SALATRIMs 34CA and 234CA, as compared to the 9 kcal/g expected from corn oil.

Stearic acid excretion in the feces of rats further confirms the hypothesis that SALATRIM provides fewer calories as a result of the poor absorption of stearic acid. The results in Table 4 illustrate that the stearic acid in feces of rats increases as the level of SALATRIM in the diet increases. The mean caloric availability, based on recovered stearic acid in the feces, is 4.2 kcal/g.

Ultimately, SALATRIM will serve as a low-calorie fat substitute in a variety of food products. The fecal fat and stearic acid excretion during the last 3 days of each exposure period of the human clinical study is shown in Table 5. From the data it can be seen that during SALATRIM exposure (week 2) the increases in stearic acid excretion for the 1800 and 2500 kcal/day groups are 7.1 and 12.4 g/day and the increases in total fecal fat are 8.7 and 15.8 g/day, respectively (therefore, the increase in fecal fat is mostly from stearic acid). The observed increase in stearic acid supports the hypothesis that SALATRIM provides fewer calories because stearic acid is poorly absorbed.

Stearic acid accounts for 57% of the weight of SALATRIM 23CA. In Table 6 we report the recovery of stearic acid in the feces and the contribution of the stearic acid which was absorbed to the apparent caloric availability of SALATRIM. The 1800 and 2500 kcal/day diet groups absorbed 72.4 and 63.5% stearic acid, respectively. From these data the percent absorption of stearic acid can be calculated for the two test groups and those values used to calculate the apparent caloric availability of SALATRIM. The caloric availability of SALATRIM is assumed to be the total energy from the stearic acid absorbed and all of the non-stearic acid components of the mixture. On the basis of these assumptions we calculate the human caloric availability to be 5.1 and 4.7 for the 1800 and 2500 kcal/day groups, respectively. The mean of 4.9 kcal/g agrees well with the 4.5 kcal/g for the same material in rat studies. The higher values are reflected in the higher absorption of stearic acid in clinical studies.

Mattson et al. (1959) has suggested that stearic acid forms a soap with calcium or magnesium in the gastrointestinal tract and that the soaps pass through the system with limited absorption. Our analytical procedure for stearic acid did not differentiate the free fatty acids and soaps. However, because of the potential for soap formation, we analyzed for calcium, magnesium, and zinc in the feces to assure that if soap formation occurs, it exhibits no impact on the mineral balance of the subjects. The results of these analyses are found in Table 7. From the table it can be seen that during the SALATRIM exposure period (week 2), when stearic acid levels in the feces are elevated, there was no significant increase in calcium, magnesium, or zinc in the feces. When the concentrations of minerals and stearic acid are compared on a milliequivalent basis, there is more than enough of the metal ions to neutralize the stearic acid.

DISCUSSION

The hypothesis that SALATRIM provides fewer biologically available calories than other triacylglycerols is based on two principles. First, short-chain aliphatic acids which provide fewer calories than long-chain fatty acids and glycerol, which provides 4.3 kcal/g, make up a significant proportion of the molecular weight of SALATRIM. Because of the preponderance of medium- and

Table 2. Weight Percent Fatty Acids, S/L Ratio,[a] and Caloric Availability of Various SALATRIM Preparations Based on 14-Day Rat Studies

	SALATRIM[b] (lot no.)				
	4CA (A006)	23CA (A014)	32CA (A015)	23SO (A023)	23SO (A024)
C2:0	0	22.5	1.6	19	19.3
C3:0	0	3.2	30	3.4	3.3
C4:0	34.0	0	0	0	0
C16:0	0.3	3.0	3.3	9.1	9.1
C18:0	58.2	66.3	59.4	67.1	66.8
C18:1	1.7	1.0	2.3	0.4	0.4
C20:0	1.6	2.9	2.5	0.6	0.6
C22:0	0.7	1.1	0.9	0.4	0.4
S/L	1.08	1.61	1.80	1.31	1.33
pred energy,[e] kcal/g	8.80	8.94	8.75	9.00	8.99
actual kcal/g	5.4 ± 0.7[c]	4.5 ± 0.4[d]	4.6 ± 0.3[d]	5.7 ± 0.63[d]	6.0 ± 0.2[d]

[a] S/L ratio determined from fatty acid composition. [b] 4CA, butyric/hydrogenated canola SALATRIM; 23CA, acetic/propionic (11:1)/hydrogenated canola; 32CA, acetic propionic (1:11)/hydrogenated canola; 23SO, acetic/propionic (11:1)/hydrogenated soy. [c] Mean of 13 determinations ± standard deviation. [d] Mean of three determinations ± standard deviation. [e] Based on *Heat of Fusion of Components CRC Handbook* (1992–1993).

Table 3. S/L Ratio and Caloric Availability of SALATRIM Preparations

SALATRIM type	short-chain source	avail. energy,[b] kcal/g	obsd S/L ratio	caloric avail., kcal/g
3CA[a]	tripropionin	8.91	1.23	4.7
3CA	tripropionin	8.87	1.34	4.3
3CA	tripropionin	8.63	2.16	5.7
34CA	tripropionin tributyrin	8.81	1.29	4.8
34CA	tripropionin tributyrin	8.75	1.46	4.8
34CA	tripropionin tributyrin	8.64	2.06	5.6
234CA	triacetin tripropionin tributyrin	8.83	1.45	5.2
234CA	triacetin tripropionin tributyrin	8.78	1.60	5.3
234CA	triacetin tripropionin tributyrin	8.64	2.06	5.7

[a] Hydrogenated canola oil was long-chain fatty acid source for all SALATRIM samples. [b] Calculated from *Heat of Combustion CRC Handbook* (1992–1993).

Table 4. Caloric Value, Stearic Acid, and Fecal Stearic Acid in Rats for SALATRIM

test fat	g of stearic acid consumed/day	g of stearic acid in feces/day	caloric value, kcal/g
10% corn oil	0	0.04 ± 0.01	9.0
5% SALATRIM	0.56	0.40 ± 0.12	4.2
10% SALATRIM	1.03	0.67 ± 0.18	4.3
15% SALATRIM	1.49	1.01 ± 0.10	4.2

Table 5. Total Fat and Stearic Acid Content of Human Feces (Grams per Day)

diet		week 1	week 2	week 3
control[a] 1800 kcal/day	fat	3.7 ± 1.2	3.3 ± 1.0	3.4 ± 0.6
	stearic	0.4 ± 0.2	0.3 ± 0.1	0.4 ± 0.1
test[b] 1800 kcal/day	fat	3.9 ± 1.0	12.4 ± 4.4	3.4 ± 0.8
	stearic	0.3 ± 0.1	7.6 ± 2.7	0.3 ± 0.2
control 2500 kcal/day	fat	6.2 ± 1.8	6.3 ± 2.4	7.0 ± 3.7
	stearic	0.9 ± 0.5	0.8 ± 0.6	1.0 ± 0.8
test 2500 kcal/day	fat	5.6 ± 1.6	21.1 ± 4.3	4.9 ± 1.8
	stearic	0.7 ± 0.4	12.3 ± 3.3	1.0 ± 1.4

[a] Control, coconut oil. [b] Test, SALATRIM 23CA lot 14.

long-chain fatty acids in conventional triacylglycerols, glycerol and short-chain acids normally do not significantly dilute the caloric density of triacylglycerols. Acetic acid and proionic acid are not normally found in triacylglycerols

Table 6. Stearic Acid Absorption and Caloric Availability of SALATRIM 23CA Lot 14

	1800 kcal/ day diet	2500 kcal/ day diet
SALATRIM fed/day, g	45	60
stearic acid fed/day, g	27.4	34.2
stearic acid in feces/day, g	7.6	12.3
stearic acid absorption, %	72.4	63.5
kcal/g from stearic acid portion[a]	3.90	3.44
kcal/g from non-stearic acid portion	1.23	1.23
kcal/g SALATRIM	5.1	4.7

[a] kcal/g stearic acid = % absorption × 9.5 kcal/g × % stearic acid in SALATRIM.

Table 7. Milliequivalents per Day of Calcium, Magnesium, Zinc, and Stearic Acid Excretion in Feces during Last 72 h of Each Exposure Period

	stearic acid	calcium	mag-nesium	zinc	total cation
week 1					
1800 kcal control[a]	1.2 ± 0.9	54 ± 9	24 ± 4	0.38 ± 0.08	78
1800 kcal test[b]	1.0 ± 0.4	51 ± 8	23 ± 4	0.4 ± 0.08	74
2500 kcal control	3.1 ± 1.9	58 ± 15	30 ± 8	0.5 ± 0.11	89
2500 kcal test	2.5 ± 1.3	56 ± 12	27 ± 5	0.5 ± 0.09	83
week 2					
1800 kcal control	0.8 ± 0.5	45 ± 13	20 ± 5	0.3 ± 0.1	66
1800 kcal test	26.7 ± 9.5	45 ± 13	21 ± 7	0.4 ± 0.12	67
2500 kcal control	3.1 ± 2.0	59 ± 17	32 ± 12	0.53 ± 0.17	82
2500 kcal test	43.2 ± 11.5	60 ± 11	30 ± 5	0.5 ± 0.1	90
week 3					
1800 kcal control	1.1 ± 0.6	48 ± 10	22 ± 5	0.4 ± 0.09	70
1800 kcal test	1.1 ± 0.6	54 ± 12	24 ± 5	0.5 ± 0.09	78
2500 kcal control	3.3 ± 2.7	70 ± 24	36 ± 18	0.6 ± 0.24	107
2500 kcal test	3.5 ± 5.0	49 ± 12	24 ± 6	0.5 ± 0.12	73

[a] Control, coconut oil. [b] Test, SALATRIM 23CA lot 14.

but constitute substantial portions of some SALATRIM triacylglycerols. Butyric acid is found in butterfat, where it is present in about 30% of the triacylglycerols in the mixture (Hawke and Taylor, 1983). In butterfat, butyric acid is generally present in a triacylglycerol with two long-chain fatty acids; therefore, the butyric acid which contributes 6.0 kcal/g compared to 9.5 kcal/g for long-chain fatty acids does not significantly lower the caloric density of the triacylglycerol mixtures.

In SALATRIM, short-chain aliphatic acids can occupy any of the three positions on the triacylglycerol molecule, making the short-chain acids and glycerol a significant proportion of the molecular weight of the triacylglycerol. In this case the caloric contributions of the acetic acid (3.5 kcal/g), propionic acid (5.0 kcal/g), butyric acid (6.0 kcal/g), and glycerol (4.3 kcal/g) (*CRC Handbook*, 1992–1993)

can significantly reduce the total caloric value of the triacylglycerol.

The second principle contributing to the lower caloric value of SALATRIM is the presence of stearic acid as a major portion of the long-chain fatty acids. When stearic acid is hydrolyzed from the triacylglycerol, it is poorly absorbed (Carroll, 1957; Clarke et al., 1977; Mattson et al., 1979). The only stearic acid which is well absorbed is the stearate which remains esterified to glycerol and is absorbed as a monoglyceride. Henderson et al. (1994) have developed a model which allows estimation of caloric availability based on the fatty acid composition and random distribution of acids in the SALATRIM structure.

Mattson et al. (1979) have shown the hydrolysis of oleate/stearate esters of triacylglycerols to be a series of reactions from triacylglycerol, first to 1,2-diacylglycerol and then to a 2-monoacylglycerol with free fatty acid released at each step. In their studies they found that when the triacylglycerol contained stearate in the 2-position, the stearate was well absorbed. Stearate in the 1- or 3-position with two oleates on the triacylglycerol was approximately 55% absorbed. When stearates are present in both the 1- and 3-positions, only about 37% of the stearate was absorbed. In these studies it was also demonstrated that increased stearate absorption was observed when the rats were on diets deficient in calcium and magnesium, because, it was proposed, the stearic acid which was not absorbed was reported to be a calcium or magnesium soap in the feces. This was first proposed by Ambrose and Robbins (1956).

The caloric availability results from the clinical study average 4.9 kcal/g compared to the 4.5 kcal/g found in the rat. From the results it is clear that in our system we observe significantly lower stearic acid absorption than proposed by Peters et al. (1991). In our clinical study stearic acid absorption averaged 68%. The results compared well with results reported by Coleman et al. (1963) when rats were fed acetostearin. Additions of linoleate to the diet improved digestibility. Essential fatty acid deficiency was observed in animals fed acetostearin as a sole source of fat in the diet. Mattson et al. (1979) reported decreased absorption of fat with increased stearic acid and concluded that long-chain saturated fatty acids of 18 carbons or greater are absorbed when on triacylglycerols with other long-chain fatty acids. While this is true for long-chain unsaturated fatty acids, our results suggest that when the non-stearic fatty acids on the triacylglycerol are short-chain fatty acids, the stearic acid is poorly absorbed. Mattson et al. (1979) observed that replacement of a portion of the stearic acid or tristearin with acetic acid improves the coefficient of absorption. The acetin fats used in this work were better absorbed as the melting point decreased. On the basis of weight gain the acetin fats containing stearic acid exhibited lower absorption (caloric availability) than acetin fats containing unsaturated fatty acids. Peters et al. (1991) have reported a low-calorie fat, Caprenin, which achieves reduced calories through inclusion of medium-chain triglycerides and behenic acid, which is essentially unabsorbed. The net caloric reduction is similar to the results reported here for SALATRIM. In the clinical trial reported here we found that slightly over two-thirds of the stearic acid is absorbed when the stearic acid source is from hydrogenated canola oil.

Improved stearic acid absorption in the presence of easily digested fatty acids such as palmitic is supported in the experiments where hydrogenated soy is utilized as the source of long-chain fatty acids (Table 2). These results agree with work done by Ambrose and Robbins (1956), who observed improved absorption of acetostearin in the presence of acetoolein. Coleman et al. (1963) showed similar results adding acetolinolein to acetostearin. The soy-based SALATRIM contained slightly over 9% palmitic acid, and the caloric availabilities were approximately 1.3 kcal/g greater than with SALATRIM prepared from hydrogenated canola. Canola oil based SALATRIM contained 3% palmitic acid. The 6% greater palmitic acid in SALATRIM prepared from soy would account for an increase of 0.54 kcal/g (0.06 × 9 kcal/g) for the material.

In our rat studies we observe a net stearic absorption of 72% in animals which were receiving adequate levels of magnesium and calcium. We therefore suggest that the SALATRIM triacylglycerols may be hydrolyzed more rapidly than the oleate/stearate triacylglycerols studied by Mattson et al. (1979). Enzymes in the upper gastrointestinal tract may hydrolyze SALATRIM, generating absorbable monoglycerides. Lingual lipase (Carey et al., 1983; Hamosh, 1984; Hamosh and Burns, 1977; Jensen et al., 1982; Nelson et al., 1977) and perhaps gastric lipase (Cohen et al., 1971) are responsible for gastric triacylglycerol hydrolysis. Lingual lipase is much more active on triacylglycerols with short- and medium-chain fatty acids than those with long-chain fatty acids (Fernando-Warnakulasurya et al., 1981; Staggers et al., 1981), and it is relatively specific for the hydrolysis of fatty acids in the 1- or 3-position on the glycerol backbone. This preferential release of short-chain acids on the SALATRIM molecule would result in the formation of mono- or diglycerides with stearic acid. The stearic acid which is released by hydrolysis is poorly absorbed, and the reduced calories of the short-chain acids, which are present in significant quantities, explain the reduction in calories provided by SALATRIM compared to conventional triacylglycerols.

CONCLUSIONS

SALATRIM is a family of lipids containing at least one short-chain fatty acid and at least one long-chain saturated fatty acid per triacylglycerol molecule.

It has been shown that various preparations of SALATRIM exhibit significantly reduced calories compared to normal vegetable oils on the basis of the presence of significant levels of short-chain fatty acids and the poor absorption of stearic acid. Results in 14-day studies with rats have demonstrated the reduced caloric availability of SALATRIM preparations with a variety of short-chain fatty acids and S/L ratios. A clinical trial demonstrated the presence of predictable levels of stearic acid in feces. The estimates of the caloric availability from the clinical trial agree well with the caloric bioavailability observations in the rat bioassay. SALATRIM functions as a low-calorie fat substitute in rat models and in humans.

ACKNOWLEDGMENT

We thank Rick Hay, Ralph Shapiro, Gary Wnorofsky, and Kathy DeLorenzo for their scientific and technical assistance with this study.

LITERATURE CITED

Ambrose, A. M.; Robbins, D. J. Studies on Comparative Absorption and Digestibility of Acetoglycerides. *J. Nutr.* **1956**, *58*, 113–124.

AOAC. Fat in Flour—Acid Hydrolysis Method, Final Action. In *Official Methods of the Association of Official Analytical Chemists*; AOAC: Arlington, VA, 1990; Method 922.06.

AOAC. Calcium, Copper, Iron, Magnesium, Manganese, Phosphorus, Potassium, Sodium, and Zinc in Infant Formula—Inductively Coupled Plasma Emission Spectroscopic Method.

In *Official Methods of the Association of Official Analytical Chemists*; AOAC: Arlington, VA, 1990; Method 984.27.

AOCS. Fatty Acid Comparison by Gas Chromatography. In *Official Methods of the American Oil Chemists' Society*; AOCS: Champaign, IL, 1990; Method Ce 1-62.

Carey, M. C.; Small, D. M.; Bliss, C. M. Lipid Digestion and Absorption. *Annu. Rev. Physiol.* **1983**, *45*, 651–677.

Carroll, K. K. Digestibility of Individual Fatty Acids in the Rat. *J. Nutr.* **1957**, *64*, 399–410.

Clarke, S. D.; Romsos, D. R.; Leveille, G. A. Differential Effects of Dietary Methyl Esters of Long Chain Saturated and Polyunsaturated Fatty Acids on Rat Liver and Adipose Tissue Lipogenesis. *J. Nutr.* **1977**, *107*, 1170–1181.

Cohen, M.; Morgan, R. G. H.; Hofmann, A. F. Lipolytic Activity of Human Gastric and Duodenal Juice Against Medium and Long Chain Triglycerides. *Gastroenterology* **1971**, *60*, 1–15.

Coleman, R. D.; Gayle, L. A.; Alfin-Slater, R. B. A Nutritional Evaluation of Acetostearins in Rats. *JAOCS* **1963**, *40*, 737–742.

CRC Handbook of Chemistry and Physics, 73rd ed.; CRC Press: Boca Raton, FL, 1992–1993; pp 5-82–5-91.

Fernando-Warnakulasurya, G. J. P.; Staggers, J. E.; Frost, S. C.; Wells, M. A. Studies on Fat Digestion, Absorption, and Transport in the Suckling Rat. I. Fatty Acid Composuition and Concentration of Major Lipid Components. *J. Lipid Res.* **1981**, *22*, 668–674.

Finley, J. W.; Leveille, G. A.; Dixon, R. M.; Walchak, C. G.; Sourby, J. C.; Smith, R. E.; Francis, K. D.; Otterburn, M. S. Clinical Assessment of SALATRIM, a Reduced-Calorie Triacylglycerol. *J. Agric. Food Chem.* **1994a**, one of several papers in this issue.

Finley, J. W.; Leveille, G. A.; Klemann, L. P.; Sourby, J. C.; Ayres, P. H.; Appleton, S. Growth Method for Estimating the Caloric Availability of Fats and Oils. *J. Agric. Food Chem.* **1994b**, one of several papers in this issue.

Hamosh, M. Lingual Lipase. In *Lipases*; Borgstrom, B., Brockman, H. L., Eds.; Elsevier: New York, 1984; Chapter 2.

Hamosh, M.; Burns, W. A. Lipolytic Activity of Human Lingual Glands (Ebner). *Lab. Invest.* **1977**, *37*, 603–608.

Hawke, J. C.; Taylor, M. W. Influence of Nutritional Factors on the Yield, Composition and Physical Properties of Milk Fat. *Dev. Dairy Chem.* **1983**, *2*, Lipids, Chapter 2.

Henderson, J. J.; Petersheim, M.; Templeman, G. J.; Softly, B. J. Quantitation and Structure Elucidation of the Positional Isomers in a Triglyceride Mixture Using Proton and Carbon One- and Two-Dimensional NMR. Submitted for publication in *J. Agric. Food Chem.* **1994**, one of several papers in this issue.

Huang, A. S.; Delano, G. M.; Pidel, A.; Janes, L. E.; Softly, B. J.; Templeman, G. J. Characterization of Triacylglycerols in Saturated Lipid Mixtures with Application to SALATRIM 23CA. *J. Agric. Food Chem.* **1994**, one of several papers in this issue.

Jensen, R. G.; Clark, R. M.; deJong, F. A.; Hamosh, M.; Liao, T. H. The Lipolytic Triad: Human Lingual, Breast Milk, and Pancreatic Lipases: Physiological Implications of Their Characteristics in Digestion of Dietary Fats. *J. Pediatr. Gastroenterol.* **1982**, *1*, 243–255.

Klemann, L. P.; Aji, K.; Chrysam, M.; D'Amelia, R. P.; Henderson, J. J.; Huang, A.; Otterburn, M. S.; Yarger, R. G.; Boldt, G.; Roden, A. Random Nature of Triacylglycerols Produced by the Catalyzed Interesterification of Short- and Long-Chain Fatty Acid Triglycerides. *J. Agric. Food Chem.* **1994**, one of several papers in this issue.

Mattson, F. H.; Nolen, G. A.; Webb, M. R. The Absorbability by Rats of Various Triglycerides of Stearic and Oleic Acid and the Effect of Dietary Calcium and Magnesium. *J. Nutr.* **1979**, *109*, 1682–1687.

Nelson, J. H.; Jensen, R. G.; Pitas, R. E. Pregastric Esterase and Other Oral Lipases—A Review. *J. Dairy Sci.*, **1976**, *60*, 327–362.

Peters, J. C.; Holcombe, B. N.; Hiller, L. K.; Webb, D. R. Caprenin 3. Absorption and Caloric Value in Adult Humans. *J. Am. Coll. Toxicol.* **1991**, *10*, 357–367.

Softly, B. J.; Huang, A. S.; Finley, J. W.; Petersheim, M.; Yarger, R. G.; Chrysam, M. M.; Wieczorek, R. L.; Otterburn, M. S.; Manz, A.; Templeman, G. J. Composition of Representative SALATRIM Fat Preparations. *J. Agric. Food Chem.* **1994**, one of several papers in this issue.

Staggers, J. E.; Fernando-Warnakulasuriya, G. J. P.; Wells, M. A. Studies on Fat Digestion, Absorption, and Transport in the Suckling Rat. II. Triacylglycerols: Molecular Species, Stereospecific Analysis, and Specificity of Hydrolysis by Lingual Lipase. *J. Lipid Res.* **1981**, *22*, 675–679.

U.S. Department of Health and Human Services. *The Surgeon General's Report on Nutrition and Health*; DHHS (PHS) Publication 88-50210; U.S. GPO: Washington, DC, 1988.

Received for review August 25, 1992. Revised manuscript received December 4, 1992. Accepted January 11, 1993.[⊗]

[⊗] Abstract published in *Advance ACS Abstracts,* December 15, 1993.