Plasma clearance of chylomicrons from butterfat is not dependent on saturation: studies with butterfat fractions and other fats containing triacylglycerols with low or high melting points[1–3]

Cam T Phan, Bok-Cheng Mortimer, Ian J Martins, and Trevor G Redgrave

ABSTRACT

Background: Dietary fats influence plasma lipids, and changes in the clearance and metabolism of postprandial lipoproteins can affect atherosclerosis. Butterfat is considered hypercholesterolemic but contains a multitude of constituent fatty acids.

Objectives: We determined triacylglycerol and cholesteryl ester clearances of lymph chylomicrons derived from butterfat, fractions of butterfat, and other dietary fats.

Methods: Radiolabeled lymph chylomicrons resulting from the intestinal absorption of different fats were reinjected into recipient rats to measure plasma clearance. Plasma clearance of [^{14}C]triacylglycerol was used as an indicator of chylomicron lipolysis whereas clearance of [^{3}H]cholesteryl ester was used as an indicator of chylomicron remnant removal.

Results: [^{3}H]Cholesteryl ester clearance was slower from chylomicrons derived from a solid, high-saturated-butterfat fraction than from whole butterfat, but clearance of chylomicrons from other fractions did not correlate with the fractions' saturated fatty acid contents. Clearance of cholesteryl esters in chylomicrons derived from cocoa butter, palm oil, and butterfat was slower than clearance of cholesteryl esters in chylomicrons derived from safflower oil. Hepatic uptakes of cholesteryl esters were generally lower for chylomicrons from all butterfat fractions, cocoa butter, and palm oil.

Conclusions: In contrast with minor effects on the lipolysis of chylomicron triacylglycerols, chylomicron remnant removal was strongly influenced by the type of dietary fat, with slower cholesteryl ester clearances for saturated fats with higher melting points. However, remnant removal and hepatic uptake of chylomicrons from whole butterfat and fractions of butterfat were not correlated with fat saturation. The mechanisms of this apparent paradox remain unknown but may be attributable to acyl arrangements in the lipid classes of chylomicrons that influence the association with apolipoproteins and receptors and hence remnant removal. *Am J Clin Nutr* 1999;69:1151–61.

KEY WORDS Chylomicrons, chylomicron remnants, butterfat, saturated fatty acids, dietary fats, plasma clearance, cholesteryl ester, triacylglycerol, rats

INTRODUCTION

Numerous studies have shown the effect of diets with various fat contents on plasma lipid profiles (1–5), but few have examined the actual metabolism of the absorbed dietary fats. Dietary fats affect plasma concentrations of cholesterol (1, 5, 6) and can influence coronary artery disease and atherosclerosis (7–9). In atherosclerosis, the accumulation of lipids in arterial walls is probably linked to aspects of lipoprotein metabolism. Zilversmit (10) first proposed atherogenesis as a postprandial phenomenon; additionally, several lipid-related disorders have impaired chylomicron and chylomicron remnant metabolism (11, 12). The cholesterol-rich chylomicron remnant particle easily penetrates arterial tissues and can be found in fatty lesions (13, 14). Plasma triacylglycerol and cholesterol concentrations can also be affected by persisting concentrations of exogenous lipoproteins that are not removed by the liver.

Dietary saturated fats in general raise total and LDL cholesterol (1, 4). However, not all saturated fatty acids affect plasma lipid concentrations similarly (15–17). Lauric acid (12:0) and myristic acid (14:0) are considered more hypercholesterolemic than palmitic acid (16:0) (2, 18). Myristic acid is the most hypercholesterolemic (2, 3, 17, 19), whereas the effects of palmitic acid are dependent on the inclusion of cholesterol in the diet (18). Stearic acid (18:0) is neutral (3), although large amounts in the diet cause reductions in both LDL and HDL cholesterol (20). The mono- and polyunsaturated fatty acids, such as oleic (18:1) and linoleic acids (18:2), are prevalent in most foods and are hypocholesterolemic (4, 8, 18). Butterfat is the most complex dietary fat in terms of fatty acid and triacylglycerol composition. It contains high concentrations of oleic and palmitic acids, along with significant amounts of lauric, myristic, and stearic acids and a host of other fatty acids (21).

[1] From the University of Western Australia, Department of Physiology, Nedlands, Perth, Australia.

[2] K Versteeg and the Dairy Research and Development Corporation provided the butterfat and the butterfat fractions along with the details of their composition, ASH Ong and the Malaysian Palm Oil Promotion Council provided the palm oil and palm oil subfractions, and the Confectionery Manufacturers of Australasia provided the cocoa butter.

[3] Address reprint requests to CT Phan, Department of Physiology, University of Western Australia, Nedlands, Perth, Western Australia 6907. E-mail: ctphan@cyllene.uwa.edu.au.

Received May 7, 1998.

Accepted for publication January 7, 1999.

Postprandial chylomicrons are produced from enzymatic hydrolysis and reesterification of dietary lipids and reflect the lipid composition of the diet. Intestinal absorption rates of dietary fatty acids vary according to their hydrocarbon chain lengths, degree of saturation, and position on the triacylglycerol molecule (22–24). It is therefore probable that the composition and size of postprandial chylomicrons varies over time after the ingestion of food. We showed previously that the metabolism of lipid emulsions mimicking lymph chylomicrons can be influenced by the types of fatty acids and lipids present (25–29) and the acyl arrangement of the fatty acids on the triacylglycerol molecule (25, 27, 30).

The aim of the present study was to compare the metabolism of chylomicrons produced in rats fed whole butterfat and fractions of butterfat. Chylomicrons derived from other dietary fats were then compared with those derived from butterfat. The other dietary fats were selected to represent "high-melting" triacylglycerols (those with a high melting point: cocoa butter, palm oil, and palm stearin) and "low-melting" triacylglycerols (those with a low melting point: safflower oil, olive oil, and palm olein) and to test the hypothesis that fats containing triacylglycerols with a higher melting point produce chylomicrons that are less readily metabolized than those produced by fats containing triacylglycerols with a lower melting point.

MATERIALS AND METHODS

Materials

Safflower oil and olive oil were obtained from local grocery stores. Cocoa butter was kindly supplied by the Confectionery Manufacturers of Australasia Ltd (Camberwell, Australia). Palm oil, palm olein, and palm stearin were gifts from the Malaysian Palm Oil Promotion Council. Butterfat and butterfat fractions were obtained from the Dairy Research and Development Corporation (Melbourne, Australia). Radiolabeled [1-^{14}C]palmitic acid and [7(*n*)-^{3}H]cholesterol were purchased from Amersham (Sydney, Australia).

Preparation of chylomicrons

Animal care was in accordance with the Animal Experimentation and Ethics Committee of The University of Western Australia. Male Wistar rats (260–280 g body wt) were obtained from the Animal Resource Centre (Murdoch, Australia). While the rats were anesthetized (60 mg pentobarbitone/kg body wt intraperitoneally, NEMBUTAL; Boehringer Ingelheim Pty Ltd, Artarmon, Australia), the abdominal cavity was exposed by a midline incision and the main mesenteric lymph duct was located (31). The duct was cannulated with a precoated siliconized (Aquasil; Pierce Chemical Co, Rockford, IL), clear polyvinyl tubing with an internal diameter of 0.5 mm (Critchley Electrical Products Pty Ltd, Auburn, Australia). The tubing was passed under the inferior vena cava and various organs to exit through the right abdominal muscle wall. A polyethylene tube with an internal diameter of 0.58 mm was similarly inserted into the pyloric region of the stomach and threaded through to lie within the duodenum. The tubing was externalized through a hole made in the left abdominal muscle wall above the spleen and secured within the stomach by a purse string suture. One milliliter water was injected into the stomach to facilitate the flow of lymph. The rat was then placed in a cage and the stomach tubing was attached to a peristaltic pump (Minipuls 2; Gilson, supplied by John Morris Scientific Pty Ltd, Perth, Australia) set to deliver ≈2 mL saline/h. The animal was then allowed to recover overnight with drinking water given ad libitum.

On the same day, 0.30 g of a test fat was placed into a vial and mixed with solutions of 0.333 MB_2 (9 μCi) [1-^{14}C]palmitic acid and 1.48 MB_2 (40 μCi) [7(*n*)-^{3}H]cholesterol in toluene and ethanol, respectively. The solvents were evaporated under nitrogen and the lipids were vacuum desiccated overnight. The next day, the radiolabeled lipid mixture was injected via the gastric tube into the duodenum of the cannulated rat. Thirty minutes after injection, the lymph produced from the intestine was collected at ≈24–28 °C into a vial containing 0.1 mL 0.4 mol EDTA/L, pH 7.4. Lymph collected over 6 h was centrifuged (1600 × *g* for 10 min at room temperature) to remove cells and fibrin. The lymph was then diluted to 14 mL with a solution of 1.006 kg NaCl/L and then 0.14 kg KBr/L of lymph was added to increase the density to 1.10 kg/L. After it was degassed in vacuo, the lymph was layered under a discontinuous density gradient consisting of 6-mL volumes of 1.065, 1.040, 1.020, and 1.006 kg NaCl/L solutions, respectively. The gradients were then centrifuged at 20 °C in an SW28 rotor at 131 000 × *g* for 75 min in a Beckman Optima Ultracentrifuge (Beckman Instruments Australia Pty Ltd, Gladesville, Australia) (30). The fatty layer at the top of the tube (chylomicrons) was harvested into plastic graduated tubes. Reduced glutathione (50 mg/L) was added and the tubes were mixed by gentle inversion. Argon was flushed into the tube, which was then sealed and stored in the dark at 20–25 °C until used in the clearance studies within 24 h.

Clearance studies

Healthy male Wistar rats (270–280 g body wt) were anesthetized with pentobarbitone and the neck region and the carotid artery were exposed. Siliconized polytetrafluoroethylene tubing with an internal diameter of 0.4 mm (Small Parts Inc, Miami Lakes, FL) was used to cannulate the carotid artery while a siliconized clear vinyl tubing (Critchley Electrical Products Pty Ltd) with an internal diameter of 0.5 mm was used to cannulate the jugular vein (25). The tubings were threaded through the loose outer skin at the back of the neck and connected to syringes filled with non-heparin-treated physiologic saline. The animals were left to recover from being anesthetized in individual cages for ≤4 h until fully awake.

An aliquot of the labeled chylomicron solution (≈6 mg triacylglycerol) was injected into the jugular vein and blood samples were collected from the carotid cannula at set time points over 30 min. Blood samples were centrifuged in a Biofuge 13 minicentrifuge (Heraeus Sepatech, supplied by Foss Electric Australia Pty Ltd, Perth, Australia) at ≈14 000 × *g* for 3–4 min at room temperature. Plasma obtained from each centrifuged blood sample was added to plastic scintillation tubes containing 5 mL scintillant (Emulsifier-safe; Packard Instrument BV Chemical Operations, Groningen, Netherlands). The radioactivity was then counted in a liquid scintillation spectrometer (Beckman LS6500; Beckman Instruments Australia Pty Ltd). The rats were killed at 30 min with a lethal dose of pentobarbitone. The spleen and liver were then excised and lipids in the whole spleen and in 1 g weighed whole liver were extracted with 30 mL chloroform:methanol (2:1, by vol). The radioactivity in a sample of nitrogen-dried lipid extract was measured in 5 mL scintillant.

TABLE 1
Characteristics of the 4 butterfat fractions studied[1]

Butterfat fraction	Physical state at room temperature	Saturated fatty acid content	Solid fat content
		% of total	*% at 20°C*
1	Liquid	39.2	0
2	Solid	59.0	54.2
3	Liquid	47.7	10.4
4	Liquid	49.0	21.5

[1] Determined by pulsed nuclear magnetic resonance. Results were calculated as percentage of total fat.

Apolipoprotein B-48 and triacylglycerol concentrations in lymph

Apolipoprotein (apo) B-48 and triacylglycerol outputs in the collected lymph were measured as described previously (32). Briefly, the lymph was delipidated with ethyl ether and quantified on a sodium dodecyl sulfate gel against standards containing known amounts of pure apo B-48 (32). The gels were then scanned on an Epson Scanner 4000 (Epson Australia Pty Ltd, Chatswood, Australia) and the image was analyzed by using the SCAN ANALYSIS program (Biosoft, Milltown, NJ). Triacylglycerols were extracted from chylomicrons with chloroform:methanol (2:1, by vol) and separated from other lipids by thin-layer chromatography with 0.2-mm thick silica gel plates. The plate was run in a solvent system containing petroleum spirits 40–60:diethyl ether:formic acid (90:10:1, by vol) (32). Triacylglycerols were then scraped from the plates and analyzed by the chromotropic acid method (33).

Statistics

Results are given as means ± SEMs. Fractional clearance rates were calculated by fitting monoexponential curves by least-squares procedures on the percentage of radioactivity remaining in the plasma between 3 and 12 min after injection of the radiolabeled chylomicrons. The INSTAT software package (GraphPad Software, San Diego) was used with analysis of variance (ANOVA) performed on all data followed by Tukey-Kramer procedures. Statistical significance was accepted for probability values of $P < 0.05$.

RESULTS

Degree of saturation in the butterfat fractions

The characteristics of the 4 butterfat fractions produced by the process of crystallization at reduced temperatures (34) are given in **Table 1**. Fraction 2 was solid at room temperature and contained the highest percentage of long-chain saturated fatty acids. Fraction 1 had the lowest percentage of saturated fatty acids. The solid fat content was determined by pulsed nuclear magnetic resonance (35).

Plasma clearance of chylomicrons derived from different fats and oils

The plasma clearance of [^{14}C]triacylglycerol was used to indicate the rate of lipolysis of chylomicron particles by lipoprotein lipase plus the removal of residual remnant triacylglycerols from the circulation by the liver. The [^{3}H]cholesteryl ester label remains within the core of the remnant particle and thus its clearance from plasma was used to indicate the hepatic clearance of chylomicron remnants. The rate of lipolysis, or the lipolysis index, was calculated by subtracting the remnant particle clearance rate from the triacylglycerol clearance rate.

Shown in **Figure 1** are the [^{14}C]triacylglycerol and [^{3}H]cholesteryl ester clearance curves for chylomicrons derived from butterfat and the 4 butterfat fractions. About 90% of the triacylglycerol label was removed from plasma within 12 min whereas the disappearance of cholesteryl ester was delayed, with 90% removed by ≈30 min. The disappearance of the triacylglycerol label was rapid within the first 3 min but was not always the same for each chylomicron sample. The fractional clearance rate was thus calculated for the (sampling) period between 3 and 12 min after injection of the chylomicron sample to capture clearance during the more rapid removal period. The triacylglycerol fractional clearance rates for the different types of butterfat chylomicrons were significantly different ($P < 0.002$, ANOVA). Post hoc Tukey-Kramer tests indicated that triacylglycerols in chylomicrons derived from butterfat fraction 2 were cleared significantly more slowly than triacylglycerols in chylomicrons derived from whole butterfat ($P < 0.05$), fraction 4 ($P < 0.05$), and fraction 3 ($P < 0.01$).

The amount of [^{3}H]cholesteryl ester remaining in the plasma at 30 min for chylomicrons from fraction 2 (≈30%) was 20% higher than the values obtained for the other 3 fractions or for whole butterfat. The [^{3}H]cholesteryl ester clearance rates for the different types of butterfat chylomicrons were significantly different ($P < 0.0001$, ANOVA). Additionally, individual Tukey-Kramer comparisons indicated that [^{3}H]cholesteryl ester in chylomicrons derived from fraction 2 was cleared significantly more slowly than that in chylomicrons derived from either whole butterfat and fraction 1 ($P < 0.05$) or fractions 3 and 4 ($P < 0.001$). Chylomicrons from fraction 3 had the fastest [^{3}H]cholesteryl ester clearance rate ($P < 0.01$ when compared with chylomicrons from both whole butterfat and fraction 1 and $P < 0.001$ when compared with chylomicrons from fraction 2).

The clearance of [^{14}C]triacylglycerol and [^{3}H]cholesteryl ester in chylomicrons derived from olive oil, palm oil, safflower oil, and cocoa butter was measured and plotted against that of butterfat chylomicrons (**Figure 2**). Plasma clearance rates of [^{14}C]triacylglycerol were not significantly different for chylomicrons from any of the oils and fats tested. However, [^{3}H]cholesteryl ester clearance rates of the different chylomicrons were significantly different ($P < 0.02$, ANOVA). Additionally, Tukey-Kramer post hoc tests on pairs of chylomicron samples showed that [^{3}H]cholesteryl ester in chylomicrons derived from both butterfat and palm oil was cleared significantly more slowly than [^{3}H]cholesteryl ester in chylomicrons from safflower oil ($P < 0.05$). No significant differences were found in the clearance rates of either [^{14}C]triacylglycerol or [^{3}H]cholesteryl ester between chylomicrons derived from safflower and olive oils.

The [^{14}C]triacylglycerol and [^{3}H]cholesteryl ester plasma clearance curves of chylomicrons derived from palm oil and its 2 fractions, palm olein and palm stearin, are shown in **Figure 3**. There were no significant differences in [^{14}C]triacylglycerol or [^{3}H]cholesteryl ester clearance rates for palm oil chylomicrons and chylomicrons from either fraction.

The fractional clearance rates of [^{14}C]triacylglycerol and [^{3}H]cholesteryl ester in chylomicrons from all the fats and oils studied are shown in **Table 2**. ANOVAs were performed on the clearance rates of all the different types of chylomicrons fol-

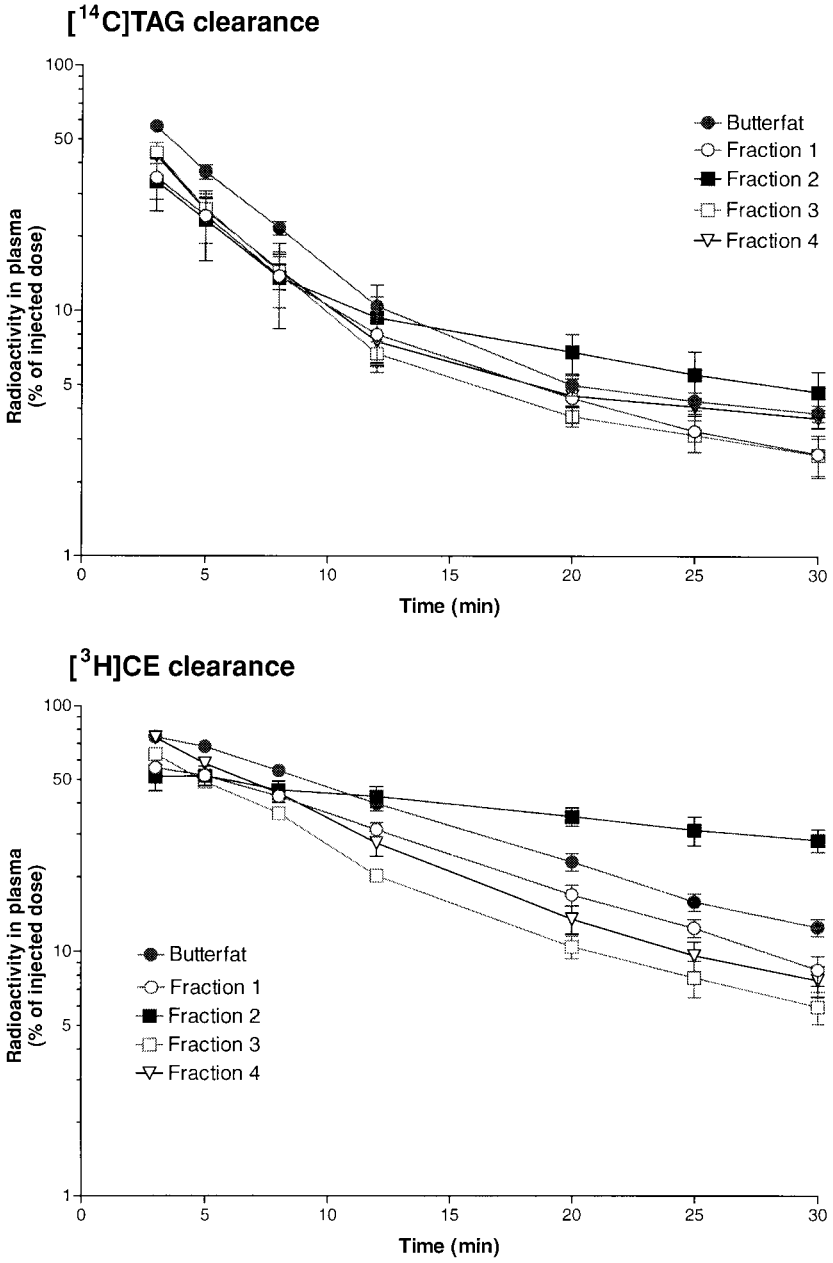

FIGURE 1. Mean (±SEM) plasma clearance of [^{14}C]triacylglycerol (TAG) and [^{3}H]cholesteryl ester (CE) in chylomicrons produced from a bolus injection of whole butterfat or 1 of 4 butterfat fractions. n = 5 rats. Fractional clearance rates (calculated for each fat between 3 and 12 min) were significantly different for the clearance of both [^{14}C]TAG ($P < 0.002$) and [^{3}H]CE ($P < 0.0001$, ANOVA). [^{3}H]CE clearance was slowest for chylomicrons from fraction 2 compared with all other fractions and whole butterfat ($P < 0.05$).

lowed by Tukey-Kramer post hoc tests on individual pairs of chylomicron. (*See* the preceding paragraphs for statistical analyses of the individual groupings of fats and oils.) [^{14}C]Triacylglycerol clearance rates were significantly different among the different types of chylomicrons: the [^{14}C]triacylglycerol clearance rate of chylomicrons derived from butterfat fraction 2 was significantly slower than that of chylomicrons derived from either safflower oil or palm olein. [^{3}H]Cholesteryl ester clearance rates also differed significantly. Chylomicrons derived from butterfat fraction 2 had the slowest [^{3}H]cholesteryl ester clearance rate, which was significantly different from that for all other types of chylomicrons except those derived from palm oil, whole butterfat, and fraction 1. Butterfat fraction 3 and safflower oil tended to have the fastest [^{3}H]cholesteryl ester clearance rates. Tukey-Kramer post hoc tests indicated no significant differences in the clearance rates of [^{14}C]triacylglycerol and [^{3}H]cholesteryl ester in chylomicrons from safflower or olive oil. Likewise, there were no significant differences between the clearance rates of [^{14}C]triacylglycerol and [^{3}H]cholesteryl ester in chylomicrons from whole butterfat or fraction 1. A significant difference was seen when ANOVAs were performed on the lipolysis index for all chylomicron types. However, comparisons

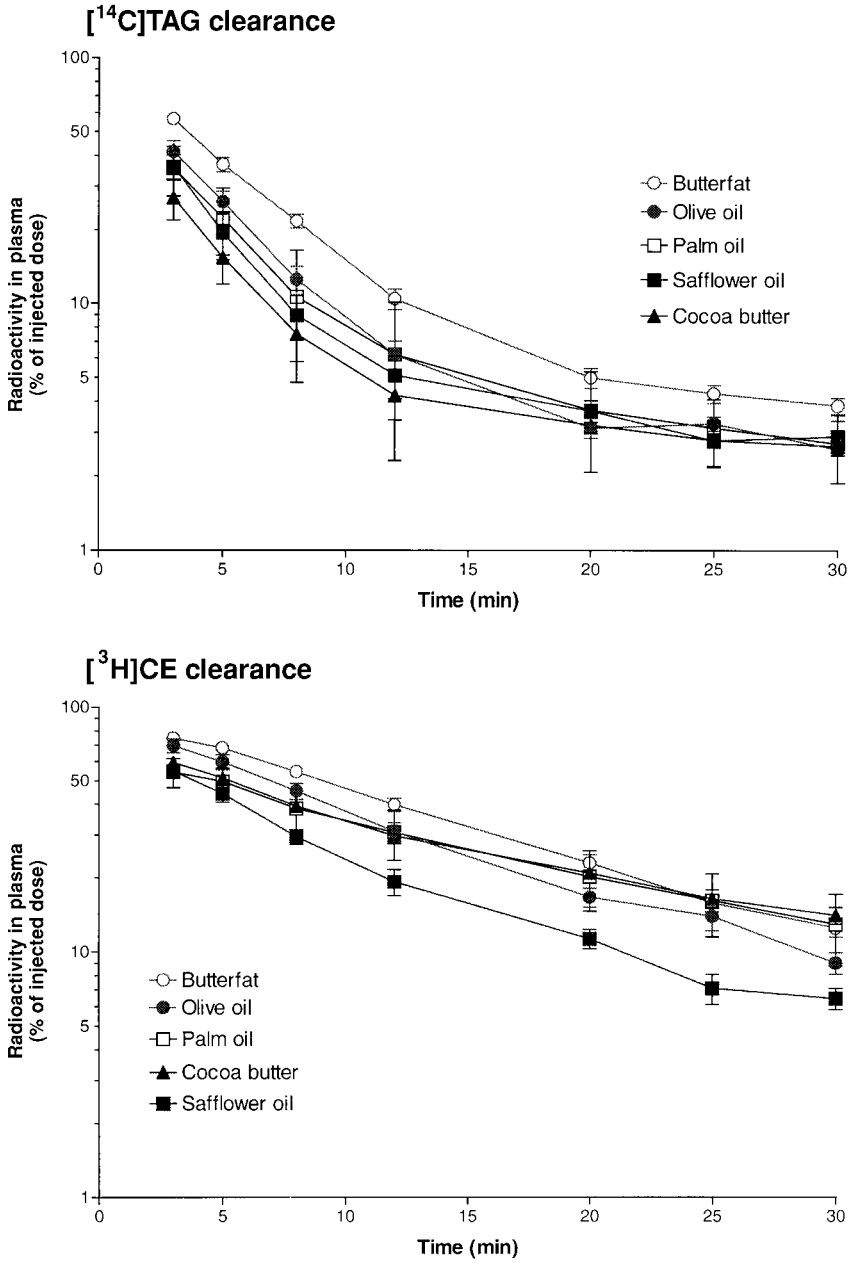

FIGURE 2. Mean (±SEM) plasma clearance of [^{14}C]triacylglycerol (TAG) and [^{3}H]cholesteryl ester (CE) in chylomicrons produced from a bolus injection of whole butterfat, olive oil, palm oil, safflower oil, or cocoa butter. n = 5 rats. Fractional clearance rates (calculated for each fat between 3 and 12 min) were significantly different for the clearance of [^{3}H]CE only ($P < 0.02$, ANOVA). [^{3}H]CE clearance was slower for chylomicrons from butterfat and palm oil than for chylomicrons from safflower oil ($P < 0.05$ for both).

with Tukey-Kramer tests indicated no significant differences between individual pairs of chylomicrons.

Organ uptake of chylomicrons derived from the different fats and oils

The liver is the major site for receptor-mediated removal of remnant particles, whereas uptake by other (scavenger) mechanisms is indicated by uptake in the spleen. Radiolabeled triacylglycerol and cholesteryl ester taken up by both the liver and the spleen at the end of 30 min are summarized in **Table 3**. Uptakes of both labels were significantly different between all chylomicron types in both organs. Liver uptake of [^{14}C]triacylglycerol was highest for chylomicrons derived from olive oil and cocoa butter and lowest for chylomicrons derived from whole butterfat, fractions 1 and 4, and palm oil. The liver uptake of [^{3}H]cholesteryl ester was lowest for chylomicrons derived from fraction 2 (except when compared with chylomicrons from palm oil and cocoa butter). When the butterfat data were isolated, liver uptakes of [^{3}H]cholesteryl ester were significantly lower for chylomicrons from all fractions than for those from whole butterfat ($P < 0.01$ for fraction 2 and $P < 0.05$ for fractions 1, 3, and 4).

Spleen uptakes of [^{14}C]triacylglycerol and [^{3}H]cholesteryl ester were all < 3% of the injected dose. Uptake of both labels was

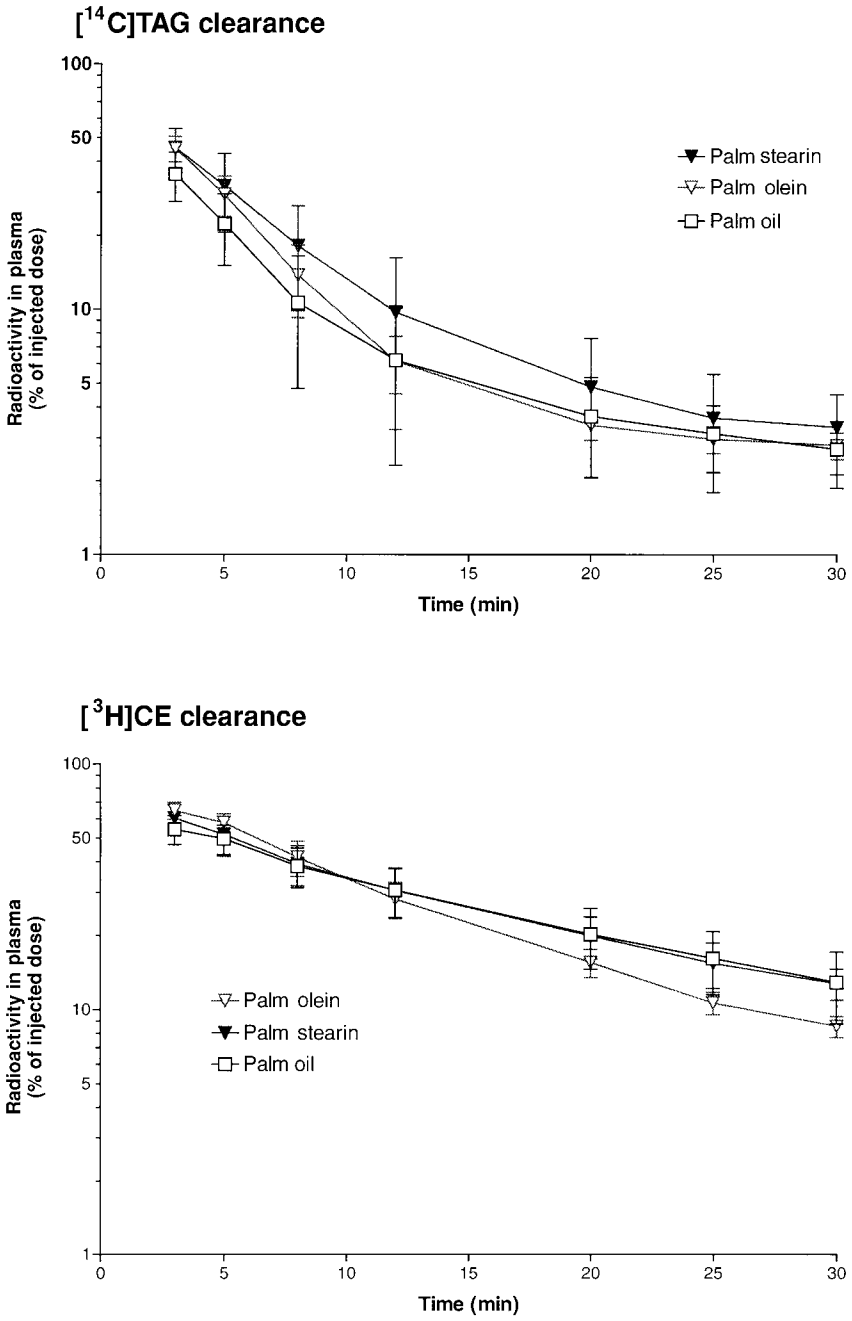

FIGURE 3. Mean (±SEM) plasma clearance of [^{14}C]triacylglycerol (TAG) and [^{3}H]cholesteryl ester (CE) in chylomicrons produced from a bolus injection of whole palm oil, palm stearin, or palm olein. n = 5 rats. There were no significant differences in either [^{14}C]TAG or [^{3}H]CE clearance between chylomicrons derived from the 3 fats.

highest for chylomicrons from cocoa butter whereas uptake for chylomicrons from whole butterfat tended to be lowest. Tukey-Kramer post hoc tests performed on the data for chylomicrons from whole butterfat and fractions of butterfat only indicated that spleen uptakes of both [^{14}C]triacylglycerol and [^{3}H]cholesteryl ester were higher for chylomicrons from fraction 2 than for chylomicrons from whole butterfat ($P < 0.05$ and $P < 0.01$, respectively). Uptake of [^{3}H]cholesteryl ester was also higher for chylomicrons from fraction 2 than for those from fraction 1 ($P < 0.05$), whereas a higher spleen uptake of [^{14}C]triacylglycerol was found for chylomicrons from fraction 3 than for those from whole butterfat ($P < 0.01$).

Lymph apolipoprotein B-48 and triacylglycerol

According to studies by Martins et al (32) and Hayashi et al (36), the amount of apo B-48 produced per chylomicron particle is constant regardless of changes in lipid load. The mass of apo B-48 measured in lymph (a measure of particle numbers) derived from either safflower oil, butterfat, or the butterfat fractions was not significantly different (**Table 4** and **Figure 4**). However, the

TABLE 2
Plasma clearance in conscious rats of [^{14}C]triacylglycerol and [^{3}H]cholesteryl ester in chylomicrons derived from different fats and oils[1]

Fat	Fractional clearance rate		Lipolysis index[4]
	[^{14}C]Triacylglycerol[2]	[^{3}H]Cholesteryl ester[3]	
	min^{-1}		
Butterfat and fractions			
Fraction 1 (n = 5)	0.16 ± 0.01^{a,b}	0.07 ± 0.00^{a,c}	0.10 ± 0.01
Fraction 2 (n = 5)	0.14 ± 0.01^{a}	0.02 ± 0.00^{a}	0.12 ± 0.01
Fraction 3 (n = 5)	0.21 ± 0.00^{a,b}	0.13 ± 0.01^{b}	0.08 ± 0.01
Fraction 4 (n = 7)	0.19 ± 0.01^{a,b}	0.11 ± 0.01^{b,c}	0.08 ± 0.02
Whole butterfat (n = 5)	0.19 ± 0.00^{a,b}	0.07 ± 0.00^{a,c,d}	0.11 ± 0.00
Low-melting dietary fats			
Safflower oil (n = 5)	0.22 ± 0.01^{b}	0.12 ± 0.01^{b,d}	0.10 ± 0.01
Olive oil (n = 5)	0.21 ± 0.01^{a,b}	0.09 ± 0.01^{b,c}	0.12 ± 0.00
Palm olein (n = 5)	0.22 ± 0.02^{b}	0.09 ± 0.01^{b,c}	0.13 ± 0.01
High-melting dietary fats			
Palm stearin (n = 5)	0.17 ± 0.03^{a,b}	0.08 ± 0.01^{b,c}	0.10 ± 0.02
Palm oil (n = 5)	0.20 ± 0.03^{a,b}	0.07 ± 0.02^{a,c}	0.13 ± 0.01
Cocoa butter (n = 5)	0.20 ± 0.01^{a,b}	0.08 ± 0.00^{b,c}	0.13 ± 0.01

[1] $\bar{x}$ ± SEM. Fractional clearance rates were calculated between 3 and 12 min postinjection of radiolabeled chylomicrons. ANOVA was performed on the combined data (11 different fats and oils) in each column, followed by post hoc Tukey-Kramer analysis on individual pairs. Means with different superscript letters are significantly different, $P < 0.05$.
[2] ANOVA for triacylglycerol clearance rates for all 11 fats and oils: $P < 0.02$; ANOVA for the 5 butterfat samples: $P < 0.002$.
[3] ANOVA for cholesteryl ester clearance rates for all 11 fats and oils: $P < 0.0001$; ANOVA for the 5 butterfat samples: $P < 0.0001$.
[4] ANOVA for lipolysis index: $P < 0.02$.

mass of triacylglycerol in lymph (a measure of volume) from whole butterfat was significantly less than that from safflower oil lymph. There were no significant differences in the lymph output of apo B-48 or triacylglycerol between whole butterfat and any of its fractions. When the ratio of triacylglycerol to apo B-48 was calculated (mass/mol) and adjusted to that of safflower oil (2.85 μg/mol apo B-48), chylomicron particles from whole butterfat and the butterfat fractions contained less triacylglycerol mass per mole apo B-48. The relative particle triacylglycerol mass of whole butterfat chylomicrons (1.29 μg/mol apo B-48) was 55% lower than that for safflower oil chylomicrons. Fractions 2 and 4 (1.61 and 1.18 μg/mol apo B-48) were 57% and 41% the mass of safflower oil chylomicron (Figure 4), whereas fractions 1 and 3 (2.12 and 2.16 μg/mol apo B-48) were ≈75% of this value.

Although triacylglycerol output may have varied, the lipid composition of chylomicrons produced from safflower oil, whole butterfat, and the 4 butterfat fractions remained essentially constant. Only the phospholipid content of chylomicrons from fraction 1 was significantly reduced compared with the content of chylomicrons from safflower oil ($P < 0.05$). More importantly, the per-

TABLE 3
Organ uptake in conscious rats of [^{14}C]triacylglycerol and [^{3}H]cholesteryl ester in chylomicrons derived from different fats and oils 30 min postinjection[1]

Dietary fat	Liver		Spleen	
	[^{14}C]Triacylglycerol[2]	[^{3}H]Cholesteryl ester[3]	[^{14}C]Triacylglycerol[4]	[^{3}H]Cholesteryl ester[5]
	% of injected dose			
Fraction 1 (n = 5)	19.5 ± 1.6^{a,c}	65.9 ± 4.3^{a,c,e}	0.7 ± 0.04^{a}	1.6 ± 0.1^{a,b}
Fraction 2 (n = 5)	19.8 ± 1.3^{a,b,c}	46.2 ± 2.7^{b,d}	1.0 ± 0.2^{a,b}	2.5 ± 0.3^{a,b}
Fraction 3 (n = 5)	21.3 ± 1.7^{a,b,c}	63.8 ± 4.0^{a,c,e}	1.0 ± 0.1^{a,b,c}	2.1 ± 0.1^{a,b}
Fraction 4 (n = 7)	17.0 ± 1.1^{a}	66.2 ± 2.9^{a,c,e}	0.7 ± 0.1^{a}	1.9 ± 0.2^{a,b}
Whole butterfat (n = 5)	17.8 ± 0.8^{a}	79.9 ± 1.2^{a}	0.4 ± 0.1^{a}	1.4 ± 0.1^{a}
Safflower oil (n = 5)	20.2 ± 1.2^{a,b,c}	75.7 ± 3.6^{a,e}	0.7 ± 0.1^{a,b}	2.1 ± 0.2^{a,b}
Olive oil (n = 5)	26.3 ± 1.2^{b,c}	80.0 ± 1.9^{a}	0.6 ± 0.04^{a}	1.8 ± 0.2^{a,b}
Palm olein (n = 5)	20.9 ± 1.1^{a,b,c}	79.9 ± 4.1^{a}	0.8 ± 0.1^{a,b}	2.0 ± 0.2^{a,b}
Palm stearin (n = 5)	25.2 ± 1.7^{b,c}	72.5 ± 5.0^{a,e}	1.6 ± 0.3^{b,c}	2.9 ± 0.2^{a,b}
Palm oil (n = 5)	17.1 ± 1.0^{a}	55.2 ± 2.7^{c,d}	1.2 ± 0.3^{a,b,c}	2.6 ± 0.6^{a,b}
Cocoa butter (n = 5)	26.3 ± 1.9^{b}	61.2 ± 2.9^{d,e}	1.9 ± 0.5^{c}	3.2 ± 0.7^{b}

[1] $\bar{x}$ ± SEM. ANOVA was performed on the combined data in each column, followed by post hoc Tukey-Kramer analysis on individual pairs. Means with different superscript letters are significantly different, $P < 0.05$.
[2] ANOVA for all liver triacylglycerol uptakes: $P < 0.0001$.
[3] ANOVA for all liver cholesterol ester uptakes: $P < 0.0001$.
[4] ANOVA for all spleen triacylglycerol uptakes: $P < 0.0001$.
[5] ANOVA for all spleen cholesterol ester uptakes: $P < 0.008$.

TABLE 4
Percentage composition of triacylglycerol (TAG), phospholipids (PL), free cholesterol (FC), cholesteryl esters (CE), and proteins plus the total lymphatic output of apolipoprotein (apo) B-48 and TAG in chylomicrons derived from safflower oil, whole butterfat, and the 4 butterfat fractions[1]

	Lipid composition of lymph chylomicrons					Lymph output	
Fat	TAG	PL[2]	FC[3]	CE	Protein	Apo B-48	TAG[4]
			% by wt			*μg*	*mg*
Safflower oil	84.6 ± 0.5	12.9 ± 0.4[a]	0.4 ± 0.1	0.4 ± 0.0	1.7 ± 0.1	404.0 ± 20.6	278.0 ± 39.8[a]
Whole butterfat	86.3 ± 1.2	11.4 ± 1.3[a,b]	0.2 ± 0.0	0.5 ± 0.1	1.5 ± 0.1	304.8 ± 43.8	94.5 ± 17.8[b]
Fraction 1	90.0 ± 1.6	8.0 ± 1.2[b]	0.4 ± 0.1	0.4 ± 0.1	1.3 ± 0.3	376.0 ± 39.9	192.7 ± 52.6[a,b]
Fraction 2	85.9 ± 1.1	12.1 ± 1.1[a,b]	0.2 ± 0.0	0.4 ± 0.1	1.4 ± 0.1	402.4 ± 28.0	156.7 ± 23.7[a,b]
Fraction 3	88.0 ± 1.1	9.6 ± 0.6[a,b]	0.4 ± 0.1	0.5 ± 0.1	1.6 ± 0.4	383.1 ± 16.0	199.8 ± 56.6[a,b]
Fraction 4	87.6 ± 1.0	9.8 ± 0.7[a,b]	0.4 ± 0.1	0.5 ± 0.1	1.7 ± 0.2	404.9 ± 45.0	115.3 ± 13.5[a,b]

[1] $\bar{x}$ ± SEM; n = 4. Lymph chylomicrons were collected for 4.5 h; for apo B-48 and TAG from lymph, results are shown as the total mass produced over the 4.5 h. ANOVA was performed on the data in each column, followed by post hoc Tukey-Kramer analysis on individual pairs. Means with different superscript letters are significantly different, $P < 0.05$.
[2] ANOVA of PL: $P < 0.02$.
[3] ANOVA of FC: $P < 0.05$.
[4] ANOVA of lymph TAG: $P < 0.04$.

centage content of triacylglycerol was not significantly different among the different chylomicrons and was typical of postprandial chylomicron particles collected after a fat load (37, 38).

DISCUSSION

Human studies of postprandial lipid metabolism have generally been confined to measurements of circulating postprandial lipid responses to mixed meals enriched with a test fat (1, 5, 39, 40). Such noninvasive studies are of limited scope and interpretation. Animal studies may not correlate directly with humans but can be used as a basis for extrapolating possible underlying mechanisms of human postprandial lipid metabolism. We studied the metabolism of various absorbed fats in rats, detailing the plasma clearances of lymph chylomicrons derived from whole butterfat, fractions of butterfat, and safflower oil. The plasma clearances of chylomicrons were further compared between chylomicrons derived from 2 groups of dietary fats and oils, those with high-melting (or more saturated) triacylglycerols and those with low-melting (less saturated) triacylglycerols.

The physical properties of butterfat can influence its rate of absorption into enterocytes (22, 23) and its constituent fatty acids can influence not only the physical characteristics of the chylomicron particles but also their metabolism. Butterfat triacylglycerols carry predominantly long-chain saturated fatty acids (palmitic, myristic, and stearic acids) in the *sn*-1 and *sn*-2 positions with butyric acid (4:0) at the *sn*-3 position (21). With constant amounts of apo B-48 molecules produced per chylomicron particle, the intestinal absorption efficiency of whole butterfat and the butterfat fractions was less than that of safflower oil, which has a lower mass of triacylglycerol per apo B-48 molecule. More saturated fractions of butterfat also tended to have a lower relative mass of triacylglycerol per particle than other less saturated fractions.

Although the relative mass of triacylglycerol per mol apo B-48 varied, the lipid composition of each chylomicron type remained essentially constant (Table 4) and typical of chylomicrons ≥140 nm. Percentage phospholipid content increases with decreasing particle size (37, 38). Spatial differences in the configuration of specific unsaturated fatty acid species possibly altered lipid packaging and may account for the differences in phospholipid content between chylomicrons from fraction 1 and those from safflower oil.

Chylomicron particle size and, more importantly, number influence the plasma clearances of chylomicrons and chylomicron-like lipid emulsions (37, 41). Chylomicrons produced from the more complex butterfats may vary in size more than those produced from safflower oil and this variability may be a property of the fat itself. Particle volume increases with the cube of the particle diameter; therefore, larger particles contribute much more to chylomicron mass. A 30–60-fold difference in particle numbers significantly alters the clearance rates of chylomicron-like lipid emulsions (37). In the present study, differences between chylomicron preparations were minimized by the constant fat load used for the production of chylomicrons; additionally, similar doses were injected, making it unlikely that particle numbers would vary >2-fold. Furthermore, the high concentrations of saturated fatty acids in fraction 2 (the solid fraction) may have contributed to slower cholesteryl ester clearance; however, fraction 4, which was also highly saturated, exhibited significantly faster cholesteryl ester clearance by comparison. These observations indicate that factors other than saturation, particle size, or number—possibly acyl arrangements as well as constituent fatty acids—require consideration for the clearance of chylomicrons.

Around 90% of reesterified lipids are triacylglycerols (38), with the specific acyl positions of the constituent saturated fatty acids influencing plasma clearance patterns (25, 27–30). Acyl chains of phospholipids also influence the clearance of chylomicron-like lipid emulsions (42, 43). However, saturation has a greater effect on the clearance of lipid emulsions than the position of acyl chains of phospholipids. Phospholipids containing 2 saturated fatty acids reduce the triacylglycerol clearance of lipid emulsions compared with phospholipids containing only 1 saturated fatty acid, suggesting that the physical orientation of the acyl chains may affect the surface pressure of the monolayer and prevent lipolytic access to the core triacylglycerol (43). In addition, a single saturated acyl chain on triacylglycerol molecules adversely affects the surface pressure of a mixed monolayer containing triacylglycerols and phosphatidylcholine, such that fewer triacylglycerol molecules are retained within this monolayer (44). Such changes in surface properties as a result of changes in constituent fatty acids, triacylglycerol, or phospholipids may influence the association of chylomicron particles with apolipoproteins and, subsequently, chylomicron metabolism.

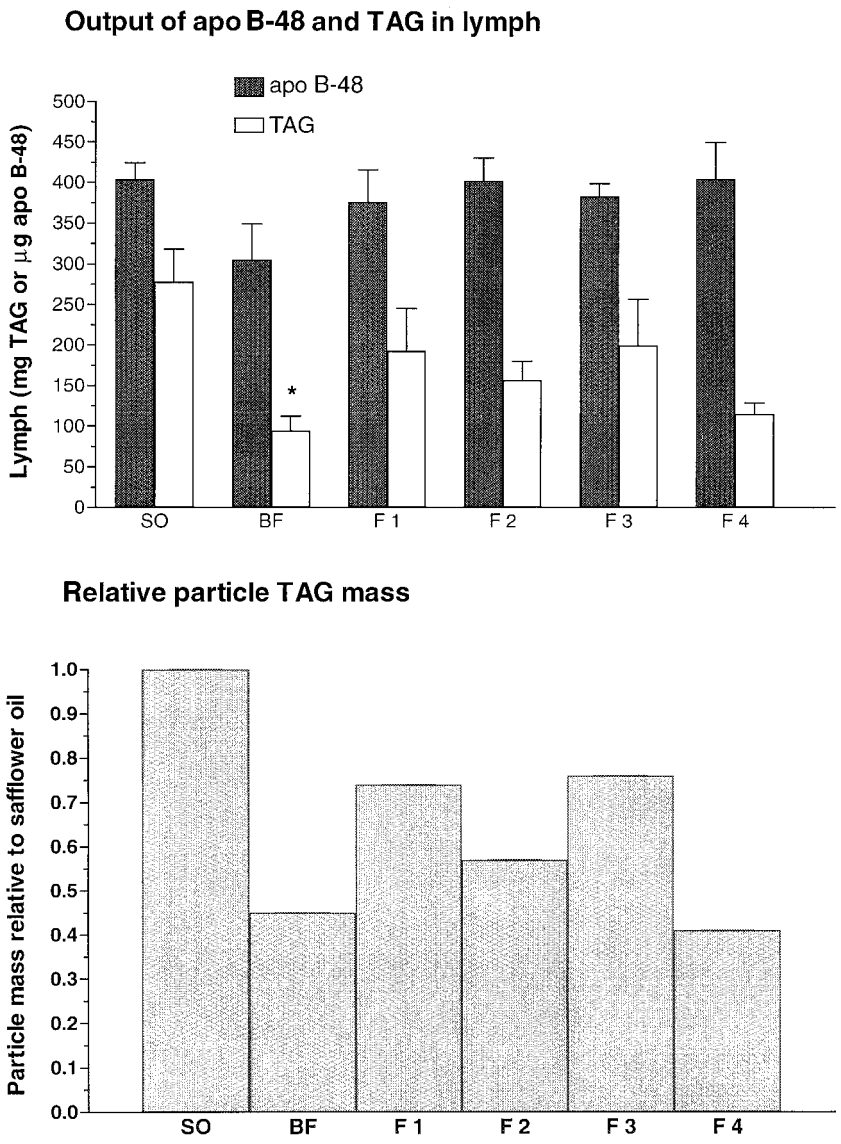

FIGURE 4. Shown in the top panel is the mean (±SEM) total apolipoprotein (apo) B-48 and triacylglycerol (TAG) output in lymph collected for 4.5 h after a bolus injection of either safflower oil (SO), whole butterfat (BF), or 1 of 4 butterfat fractions (F1–F4). Lymph TAG output was significantly different between the different fats ($P < 0.04$, ANOVA). *Significantly different from safflower oil lymph ($P < 0.05$, Tukey-Kramer post hoc analysis). Shown in the bottom panel is the mass of TAG per mole apo B-48 relative to that of safflower oil.

Hepatic uptake of cholesteryl ester was significantly reduced for all 4 butterfat fractions compared with whole butterfat. Only the solid fraction (fraction 2) had increased spleen uptake of both triacylglycerol and cholesteryl ester compared with whole butterfat. This suggests that for chylomicrons from fraction 2, use of other (scavenger) remnant removal pathways were increased as a result of reduced hepatic uptake. The mass of the chylomicron particles injected was unlikely to have been high enough to saturate the hepatic uptake process (41, 37); hence, the increased spleen uptake may indicate involvement of some physical aspect of the particle (or nature of the fraction) with hepatic uptake mechanisms. In contrast, liver uptakes of triacylglycerol and cholesteryl ester from butterfat chylomicrons were higher and comparable with those from safflower oil. Others also found increased hepatic uptakes of labeled cholesterol and oleate from butterfat chylomicron remnants compared with chylomicron remnants from olive and palm oils (45, 46). The fatty acid composition of chylomicron remnants thus affects hepatic uptake and metabolism (46). Enrichment of chylomicrons and chylomicron remnants with a wider range of unsaturated fatty acids might lead to increased rates of hepatic uptake and removal from the body via the bile (47).

The clearance rates for butterfat chylomicrons were not significantly different from those for either cocoa butter or palm oil chylomicrons. Chylomicrons from all 3 saturated fats tended to have slower cholesteryl ester clearance rates than safflower oil chylomicrons. The major saturated fatty acid in cocoa butter is stearic acid (≈35%) (3, 19, 21) and that in palm oil is palmitic acid (≈40%) (21). Cocoa butter is deemed hypocholesterolemic because of its high concentration of stearic acid (3, 48). We found that chylomicrons derived from cocoa butter and palm oil had slow cholesteryl

ester clearances and a decreased hepatic uptake of cholesteryl ester. An increase in uptake of both triacylglycerol and cholesteryl ester by the spleen was also seen with chylomicrons from cocoa butter. Conversely, chylomicrons from unsaturated olive or safflower oils were cleared quickly and rapidly removed by the liver.

In long-term dietary studies, oleic and linoleic acids were shown to influence LDL-receptor activity by affecting messenger RNA concentrations (47, 49–51). However, in the present short-term study, unsaturated fatty acids were more likely to have affected chylomicron metabolism via acyl arrangements on the triacylglycerol lipids and in other lipid classes. Triacylglycerol molecules from safflower and olive oils are typically UUU (where U is unsaturated), whereas cocoa butter is predominantly POS > SOS > POP (where P is palmitic acid, S is stearic acid, and O is oleic acid) (21, 52) and palm oil is mainly POP (21). Both cocoa butter and palm oil contain high percentages of these saturated triacylglycerols and random rearrangement of the fatty acids after digestion could result in the production of substantial amounts of disaturated triacylglycerols. Chylomicron metabolism and hepatic uptake of chylomicron remnants would thus be affected depending on the acyl position of the constituent saturated fatty acids and the presence of disaturated triacylglycerols, disaturated phospholipids, monoacylglycerols, or diacylglycerols (25, 27–30).

In summary, the metabolism of chylomicrons derived from butterfat is more complex than expected and not necessarily related to the overall saturation of the butterfat sample. With less complex fats and oils, unsaturated (low melting) oils show fast clearances with higher hepatic uptakes, whereas saturated (high melting) fats have reduced cholesteryl ester clearance and hepatic uptake of chylomicron remnants. The lipolysis index (an indication of lipolysis) was not significantly different between individual groups of chylomicrons, indicating that cholesteryl ester or remnant removal was most affected by specific dietary fats. This short-term study showed that for complex fats such as butterfat, possibilities exists for the involvement and interaction of all constituent fatty acid species in chylomicron metabolism and chylomicron remnant hepatic uptake. The mechanisms by which such a fat influences metabolism is not apparent from this study. However, the clearance patterns seen can be attributed to reesterification of dietary fatty acids into the lipid classes of chylomicrons, the physical properties and acyl arrangements of which can then influence plasma clearance. Constituent fatty acids in the various lipid classes of chylomicron particles are also postulated to influence the surface lipoprotein and hence the interactions with apolipoproteins and receptors associated with lipid metabolism. Disturbances in exogenous remnant removal will have probable consequences in relation to atherosclerosis and other lipid-related disorders.

REFERENCES

1. Kris-Etherton PM, Derr JD, Mitchell DC, et al. The role of fatty acid saturation on plasma lipids, lipoproteins, and apolipoproteins: I. Effects of whole food diets high in cocoa butter, olive oil, soybean oil, dairy butter, and milk chocolate on the plasma lipids of young men. Metabolism 1993;42:121–9.
2. Hayes KC, Pronczuk A, Lindsey S, Diersen-Schade D. Dietary saturated fatty acids (12:0, 14:0, 16:0) differ in their impact on plasma cholesterol and lipoproteins in nonhuman primates. Am J Clin Nutr 1991;53:491–8.
3. Keys A, Anderson JT, Grande F. Serum cholesterol response to changes in the diet. IV. Particular saturated fatty acids in the diet. Metabolism 1965;14:776–87.
4. Rudel LL, Haines JL, Sawyer JK. Effects on plasma lipoproteins of monounsaturated, saturated, and polyunsaturated fatty acids in the diet of African green monkeys. J Lipid Res 1990;31:1873–82.
5. Baudet MF, Esteva O, Delplanque B, Winchenne N, Jacotot B. Effects of three dietary fats on plasma lipids and lipoproteins in fasting and post-prandial humans after a short-term diet. Lipids 1980;15:216–23.
6. Lai HC, Ney DM. Corn oil, palm oil and butterfat fractions affect postprandial lipemia and lipoprotein lipase in meal-fed rats. J Nutr 1995;125:1536–45.
7. Kannel WB, Castelli WP, Gordon T, Mcnamara PM. Serum cholesterol, lipoproteins, and the risk of coronary heart disease. Ann Intern Med 1971;74:1–12.
8. Heyden S. Polyunsaturated and monounsaturated fatty acids in the diet to prevent coronary heart disease via cholesterol reduction. Ann Nutr Metab 1994;38:117–22.
9. Pronczuk A, Patton GM, Stephan ZF, Hayes KC. Species variation in the atherogenic profile of monkeys: relationship between dietary fats, lipoproteins, and platelet aggregation. Lipids 1991;26:213–22.
10. Zilversmit DB. Atherogenesis: a postprandial phenomenon. Circulation 1979;60:473–85.
11. Mamo JCL, Smith D, Yu KCW, et al. Accumulation of chylomicron remnants in homozygous subjects with familial hypercholesterolaemia. Eur J Clin Invest 1998;28:379–84.
12. Cooper AD. Hepatic uptake of chylomicron remnants. J Lipid Res 1997;38:2173–92.
13. Mamo JCL, Wheeler JR. Chylomicrons or their remnants penetrate rabbit thoracic aorta as efficiently as do smaller macromolecules, including low-density lipoprotein, high-density lipoprotein, and albumin. Coron Artery Dis 1994;5:695–705.
14. Proctor SD, Mamo JCL. Arterial fatty lesions have increased uptake of chylomicron remnants but not low-density lipoproteins. Coron Artery Dis 1996;7:239–45.
15. Hayes KC. Saturated fats and blood lipids: new slant on an old story. Can J Cardiol 1995;11:39G–46G.
16. Denke MA, Grundy SM. Comparison of effects of lauric acid and palmitic acid on plasma lipids and lipoproteins. Am J Clin Nutr 1992;56:895–8.
17. Mensink RP. Effects of the individual saturated fatty acids on serum lipids and lipoprotein concentrations. Am J Clin Nutr 1993; 57(suppl):711S–4S.
18. Pronczuk A, Khosla P, Hayes KC. Dietary myristic, palmitic, and linoleic acids modulate cholesterolemia in gerbils. FASEB J 1994; 8:1191–200.
19. Hegsted DM, McGandy RB, Myers ML, Stare FJ. Quantitative effects of dietary fat on serum cholesterol in man. Am J Clin Nutr 1965;17:281–95.
20. Dougherty RM, Allman MA, Iacono JM. Effects of diets containing high or low amounts of stearic acid on plasma lipoprotein fractions and fecal fatty acid excretion of men. Am J Clin Nutr 1995;61: 1120–8.
21. Padley FB, Gunstone FD, Harwood JL. Occurrence and characteristics of oils and fats. In: Gunstone FD, Harwood JL, Padley FB, eds. The lipid handbook. 2nd ed. London: Chapman & Hall, 1994: 47–224.
22. Ockner RK, Pittman JP, Yager JL. Differences in the intestinal absorption of saturated and unsaturated long chain fatty acids. Gastroenterology 1972;62:981–92.
23. Kalogeris TJ, Story JA. Lymph chylomicron size is modified by fat saturation in rats. J Nutr 1992;122:1634–42.
24. Greenberger NJ, Rodgers JB, Isselbacher KJ. Absorption of medium and long chain triglycerides: factors influencing their hydrolysis and transport. J Clin Invest 1966;45:217–27.
25. Mortimer BC, Holthouse DJ, Martins IJ, Stick RV, Redgrave TG. Effects of triacylglycerol-saturated acyl chains on the clearance of chylomicron-like emulsions from the plasma of the rat. Biochim Biophys Acta 1994;1211:171–80.

26. Mortimer BC, Tso P, Phan CT, Beveridge DJ, Wen J, Redgrave TG. Features of cholesterol structure that regulate the clearance of chylomicron-like lipid emulsions. J Lipid Res 1995;36:2038–53.
27. Mortimer BC, Kenrick MA, Holthouse DJ, Stick RV, Redgrave TG. Plasma clearance of model lipoproteins containing saturated and polyunsaturated monoacylglycerols injected intravenously in the rat. Biochim Biophys Acta 1992;1127:67–73.
28. Mortimer BC, Simmonds WJ, Cockman SJ, Stick RV, Redgrave TG. The effect of monostearoylglycerol on the metabolism of chylomicron-like lipid emulsions injected intravenously in rats. Biochim Biophys Acta 1990;1046:46–56.
29. Mortimer BC, Simmonds WJ, Joll CA, Stick RV, Redgrave TG. Regulation of the metabolism of lipid emulsion model lipoproteins by a saturated acyl chain at the 2-position of triacylglycerol. J Lipid Res 1988;29:713–20.
30. Redgrave TG, Kodali DR, Small DM. The effect of triacyl-*sn*-glycerol structure on the metabolism of chylomicrons and triacylglycerol-rich emulsions in the rat. J Biol Chem 1988;263:5118–23.
31. Waynforth HB, Flecknell PA. Specific surgical operations. In: Experimental and surgical technique in the rat. 2nd ed. New York: Academic Press, 1992:203–312.
32. Martins IJ, Sainsbury AJ, Mamo JCL, Redgrave TG. Lipid and apolipoprotein B48 transport in mesenteric lymph and the effect of hyperphagia on the clearance of chylomicron-like emulsions in insulin-deficient rats. Diabetologia 1994;37:238–46.
33. Carlson LA. Determination of serum triglycerides. J Atheroscler Res 1963;3:334–6.
34. Versteeg C. Milkfat fractionation & cholesterol removal. Food Res Q 1991;51:32–42.
35. Papalois M, Leach FW, Dungey S, Yep YL, Versteeg C. Australian milkfat survey—physical properties. Aust J Dairy Technol 1996;51:114–7.
36. Hayashi H, Fujimoto K, Cardelli JA, Nutting DF, Bergstedt S, Tso P. Fat feeding increases size, but not number, of chylomicrons produced by small intestine. Am J Physiol 1990;259:G709–19.
37. Martin IJ, Mortimer BC, Miller J, Redgrave TG. Effects of particle size and number on the plasma clearance of chylomicrons and remnants. J Lipid Res 1996;37:2696–705.
38. Redgrave TG. Formation and metabolism of chylomicrons. In: Young JA, ed. Gastrointestinal physiology IV. Baltimore: University Park Press, 1983:103–30.
39. Demacker PNM, Reijnen IGM, Katan MB, Stuyt PMJ, Stalenhoef AFH. Increased removal of remnants of triglyceride-rich lipoproteins on a diet rich in polyunsaturated fatty acids. Eur J Clin Invest 1991; 21:197–203.
40. Williams CM. Postprandial lipid metabolism: effect of dietary fatty acids. Proc Nutr Soc 1997;56:679–92.
41. Oliveira HCF, Hirata MH, Redgrave TG, Maranhao RC. Competition between chylomicrons and their remnants for plasma removal: a study with artificial emulsion models of chylomicrons. Biochim Biophys Acta 1988;958:211–7.
42. Lenzo NP, Martins I, Mortimer BC, Redgrave TG. Effects of phospholipid composition on the metabolism of triacylglycerol, cholesteryl ester and phosphatidylcholine from lipid emulsions injected intravenously in rats. Biochim Biophys Acta 1988;960:111–8.
43. Redgrave TG, Rakic V, Mortimer BC, Mamo JCL. Effects of sphingomyelin and phosphatidylcholine acyl chains on the clearance of triacylglycerol-rich lipoproteins from plasma. Studies with lipid emulsions in rats. Biochim Biophys Acta 1992;1126:65–72.
44. Redgrave TG, Ivanova MG, Verger R. The condensing effects of egg lecithin and cholesterol on triolein monolayers are inhibited by substitution of one saturated acyl chain in the triacylglycerol. Biochim Biophys Acta 1994;1211:229–33.
45. Lambert MS, Botham KM, Mayes PA. Comparison of the hepatic metabolism of chylomicron remnants derived from corn oil or butter fat. Biochem Soc Trans 1994;22:108S.
46. Lambert MS, Botham KM, Mayes PA. Variations in composition of dietary fats affect hepatic uptake and metabolism of chylomicron remnants. Biochem J 1995;310:845–52.
47. Bravo E, Ortu G, Cantafora A, et al. Comparison of the hepatic uptake and processing of cholesterol from chylomicrons of different fatty acid composition in the rat in vivo. Biochim Biophys Acta 1995;1258:328–36.
48. Grande F, Anderson JT, Keys A. Comparison of effects of palmitic and stearic acids in the diet on serum cholesterol in man. Am J Clin Nutr 1970;23:1184–93.
49. Spady DK, Dietschy JM. Interaction of dietary cholesterol and triglycerides in the regulation of hepatic low density lipoprotein transport in the hamster. J Clin Invest 1988;81:300–9.
50. Kurushima H, Hayashi K, Shingu T, et al. Opposite effects on cholesterol metabolism and their mechanisms induced by dietary oleic acid and palmitic acid in hamsters. Biochim Biophys Acta 1995;1258:251–6.
51. Salter AM, Sessions VA. LDL binding to hepatocytes isolated from hamsters fed different dietary fatty acids. Biochem Soc Trans 1993;21:150S.
52. Chaiseri S, Dimick PS. Lipid and hardness characteristics of cocoa butters from different geographic regions. J Am Oil Chem Soc 1989;66:1771–6.

The American Journal of Clinical Nutrition