Specialty Lipids and Their Biofunctionality

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Medium Chain Triglycerides and Structured Lipids

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Lipids are an essential component of our body composition and necessary in our daily food intake. Conventional fats and oils are composed of glycerides of long chain fatty acids and are designated as long chain triglycerides (LCT). Body fat as well as the fats and oils in our daily intake fall into this category. In enteral and parenteral hyperalimentation, we can identify such LCT fats and oils. Soy, corn, safflower and sunflowerseed oils are typical of the LCT oils.

In the search for alternative noncarbohydrate fuels, medium chain triglycerides (MCT) are unique and have established themselves in the areas of malabsorption syndrome cases and infant care and as a high energy, rapidly available fuel. Structure lipids with a MCT backbone and linoleic acid built into the triglyceride molecule have been developed to optimize the triglyceride structure that is best for patients, particularly the critically ill. Structured lipids with built-in essential fatty acid components or other polyunsaturated fatty acids promise greater flexibility in patient care and nitrogen support.
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Recent years have brought a renewed interest in lipids and their role in the metabolic and dietetic applications in health care of hospitalized patients as well as the public at large (1-33; Shah, N.M., and Iber, F.L., private communication).

This symposium focuses on a specific, unique segment of the lipid picture: the medium chain triglycerides (MCT) and structure lipids prepared from them.

A review and summary is presented here to lay the groundwork for the papers that follow. Each presentation supplements the broad picture that is evolving from the animal and human research that is progressing at various universities and laboratories.

REVIEW AND DISCUSSION

Fats and oils of animal, vegetable and marine origin have a fatty acid spectrum that ranges from C_2-C_{24}, with variations in not only physical and chemical characteristics but also in isomers and positional structure in the triglyceride molecule. Most fats and oils are composed of long chain fatty acids and are termed long chain triglycerides (LCT). Dairy fat, meat fat and vegetable oils fall into this category (Table 1).

The lauric fats, however, are composed primarily of fatty acids of C_{14} chain length and shorter. Coconut and palm kernel oils are typical of this class of lauric fats. They represent the main source of the C_8-C_{10} acids required for synthesis of MCT (Table 2).

MCT are different from all of the fats and oils we conventionally use. Where conventional fats and oils are absorbed via the lymphatic system and are carnitine-dependent for chylomicron formation and transport, MCT are absorbed via the portal system, are not carnitine-dependent and do not require chylomicron formation. The metabolic pathways of the MCT and LCT distinguish the unique aspects of the MCT (Tables 3 and 4; Fig. 1).

Aside from the transport difference, MCT demonstrate certain additional characteristics of considerable advantage. Whereas lipids generally are slowly absorbed and metabolized and energy is expended to oxidize and utilize them as fuel or building blocks, MCT are absorbed and

TABLE 1

Typical Long Chain Triglyceride Oils

	Type of oil				
Fatty acid	Corn	Peanut	Safflower	Soybean	Sunflowerseed
Lauric					0.5
Myristic		0.1	0.1	0.1	0.2
Palmitic	12.2	11.6	6.5	11.0	6.8
Palmitoleic	0.1	0.2		0.1	0.1
Margaric		0.1			
Stearic	2.2	3.1	2.4	4.0	4.7
Oleic	27.5	46.5	13.1	23.4	18.6
Linoleic	57.0	31.4	77.7	53.2	68.2
Linolenic	0.9			7.8	0.5
Arachidic	0.1	1.5	0.2	0.3	0.4
Gadoleic		1.4			
Eicosadienoic		0.1			
Behenic		3.0		0.1	
Lignoceric		1.0			

TABLE 2

Typical Lauric Fats and Oils

	Type of oil				
Fatty acid	Babassu	Coconut	Cohune	Palm kernel	Tacum
Caproic	0.4	0.5	0.3	0.3	0.2
Caprylic	5.3	8.0	8.7	3.9	2.9
Capric	5.9	6.4	7.2	4.0	2.3
Undecanoic			0.1		
Lauric	44.2	48.5	47.3	49.6	51.8
Myristic	15.8	17.6	16.2	16.0	22.0
Palmitic	8.6	8.4	7.7	8.0	6.8
Stearic	2.9	2.5	3.2	2.4	2.3
Oleic	15.1	6.5	8.3	13.7	9.3
Linoleic	1.7	1.5	1.0	2.0	2.4
Arachidic	0.1	0.1		0.1	

TABLE 3

Medium Chain Triglyceride Oil Specifications

Free fatty acids (as oleic)	0.05% max
Saponification value	345–355
Iodine value (Wijs)	1.0 max
Acetyl value	5.0 max
Setting point	−5 C
Color (Lovibond)	10 yellow/1.0 red
Unsaponifiables	0.5 max
Fatty acid composition	
C_6	1–2%
C_8	65–75%
C_{10}	25–35%
C_{12}	2% max

metabolized as rapidly as glucose while having better than twice the caloric density of protein and carbohydrate. They are easily oxidized and utilized as fuel and energy, with little tendency to deposit as body fat. For a quick, high energy source, MCT are outstanding.

These unique features of MCT have been recognized and utilized over the years. Oral supplementations and enteral feeding formulas of MCT products are available for use in a variety of areas, including care of infants, epileptic children and cystic fibrosis patients and for intestinal resection (35–37). For such established areas of MCT use, the practice has been to physically mix 15–20% of a highly polyunsaturated vegetable oil (to insure essential fatty acid requirements) with the MCT oil (38).

In the area of parenteral nutrition, we have been limited for many years to lipid emulsions based on soybean oil and now safflower oil (Table 5). Both are LCT types of lipid and pose a number of problems.

The current practice of using lipid emulsion in a total parenteral nutrition (TPN) regimen has been based on the need for a noncarbohydrate source for fuel and energy and the need to satisfy essential fatty acid requirements and/or deficiencies. LCT supply caloric needs and alleviate essential fatty acid deficiency. They have, however, shown a tendency to deposit as fat (a large proportion of the infused lipid) rather than to satisfy immediate fuel requirements. LCT lipid emulsions also are too slow in clearing from the blood and oxidize too slowly to supply fuel and energy.

At present, there is controversy over the optimum feeding regimen for the critically ill patient. An all-carbohydrate TPN system may promote visceral protein attraction and obligatory hepatic lipogenesis. There is no consensus, however, that lipid emulsions composed of LCT are optimal. There is concern that these emulsions are less than ideal because of a relative carnitine deficiency that occurs in sepsis, which blocks their entry into the mitochondria for β-oxidation. Numerous additional studies have shown reduced clearance of these emulsions in the critically ill patient and increased potential for elongation, desaturation and deposition in the liver and other organs.

In contrast, MCT have been shown to have a carnitine-independent entry into the mitochondria, to have a more rapid β-oxidation and to be less likely to undergo elongation and deposition (39–42). Emulsions composed

TABLE 4

Rationale for Use of Medium Chain Triglycerides (MCT)

Physicochemical characteristics	Physiologic considerations	Potential therapeutic applications
MCT present more interfacial surface for enzyme action/unit time	Intraluminal enzymatic hydrolysis of AMCT is more rapid and complete than LCT	Decreased intraluminal concentrations of pancreatic lipase (pancreatic insufficiency, cystic fibrosis) Decreased small-bowel absorptive surface (intestinal resection)
Greater water solubility of MCT hydrolysis products	Bile salts are not required for dispersion in water	Decreased intraluminal concentrations of bile salts (intrahepatic and extrahepatic biliary-tract obstruction, chronic parenchymal liver disease)
Smaller molecular size of MCT vs LCT	Small amounts of MCT may enter intestinal cell without prior hydrolysis	Pancreatic insufficiency
Shorter chain length of fatty acids derived from MCT	More efficient penetration of diseased mucosal surface	Nontropical sprue, tropical sprue
Small molecular size and lower pK of fatty acids derived from MCT	Intramucosal metabolism of MCFA different from LCFA: Decreased affinity for esterifying enzymes Decreased affinity for activating enzymes Minimal reesterification of MCFA to MCT No chylomicron formation	Abeta-lipoproteinemia Hypobeta-lipoproteinemia
Greater water solubility of MCFA	Different routes of transport of MCT vs LCT: Portal transport of MCT (as MCFA) Lymphatic transport of LCT (as chylomicrons)	Lymphatic obstruction (lymphomas) Intestinal lymphangiectasia

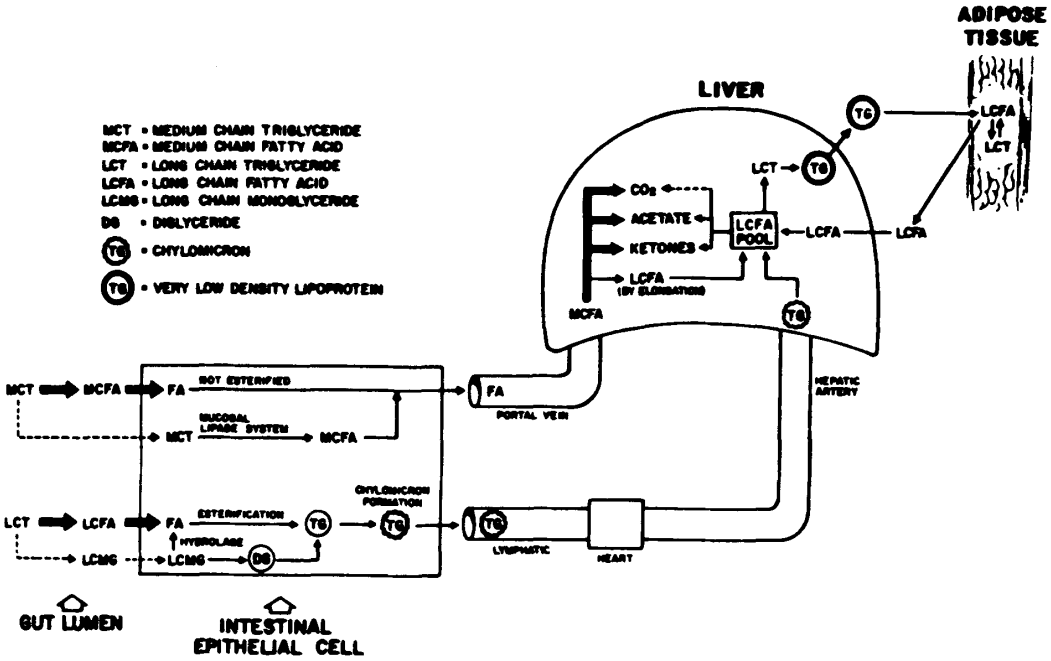

FIG. 1. Transport of medium and long chain triglycerides.

TABLE 5

Fatty Acid Composition of Oils for Parenteral Emulsions

Fatty acid	Type of oil		
	Soybean	Safflower	MCT
6:0	—	—	<2
8:0	—	—	70
10:0	—	—	30
12:0	—	—	<2
14:0	0.1	0.1	—
16:0	10.5	6.7	—
18:0	3.2	2.7	—
18:1	22.3	12.9	—
18:2	54.5	77.5	—
18:3	8.5	tr	—
20:0	0.2	0.5	—
20:1	0.9	0.5	—

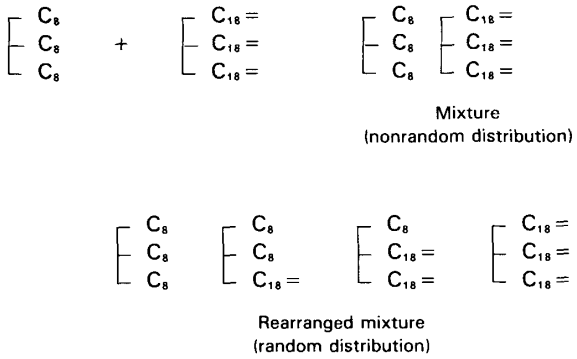

FIG. 2. Physical mix vs rearrangement.

principally of MCT may offer a unique and readily available fuel for the injured and stressed patient (43). Also, since MCT readily undergo β-oxidation, ketonemia is usually much more pronounced than with LCT emulsions. Skeletal muscle can readily burn ketone bodies for fuel and may spare the oxidation of branched chain amino acids and reduce skeletal protein catabolism (44–52).

In an effort to develop the optimum lipid structure for parenteral use, we considered structured lipids using MCT and LCT having linoleic and/or linolenic fatty acids. The resulting rearranged triglycerides have both medium chain fatty acids and a polyunsaturated fatty acid on the same glycerine molecule. Based upon the molar ratios of the MCT and the LCT with a high unsaturated fatty acid, one can obtain the structured lipid of the desired combinations (Fig. 2). We have considered further the structured lipids with an MCT backbone by adding the essential fatty acid (linoleic acid) into the triglyceride molecule at various levels (45,46).

If LCT emulsions are too slow in clearing and suffer from other drawbacks, and MCT emulsions may be too rapid in clearing and suffer from the absence of essential fatty acids, then the structured lipid with sufficient linoleic acid to satisfy essential fatty acid needs will also serve to slow down the clearance of the MCT backbone to a more acceptable level (Table 6). A structured lipid

TABLE 6

Approximate Composition of Glycerides

	Captex 810 series structured lipids (%)			
	A	B	C	D
I MCT (3 short)	62	39	15	3
II MCT (2 short, 1 long)	32	43	40	20
III MCT (1 short, 2 long)	6	16	27	44
IV LCT (3 long)	<1	2	3	34

having about 25% linoleic acid (Captex 810B) appears to be suitable for such parenteral lipid emulsion use. Preclinical and clinical testing remains to supply the needed data to validate this concept. The animal studies to date are encouraging and show certain additional benefits for the use of such structured lipids in hyperalimentation. Further investigation is warranted.

The rationale for and concept of preparing structured lipids are gaining support of research laboratories. It appears feasible that triglycerides where at least one fatty acid is a polyunsaturated fatty acid and at least one is a medium chain fatty acid can be obtained in glyceride oils. The actual format and combination of the fatty acids on the glycerine molecule will have to be investigated. Whether we shall require specific structures of high purity or can take advantage of molecular rearrangement to yield a mixture of structures will be determined by the functionality of such compositions. It appears highly probable, however, that lipid compositions of medium and long chain glycerides will advance our application of such lipids, both for the treatment of patients and the general welfare of the public.

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