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Structured Lipids: A Unique Designer Lipid

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Abstract

Structured lipids (SLs) generally refer to any fats that are modified or restructured from natural oils and fats or fatty acids primarily containing short or medium chain fatty acids and preferably essential fatty acids. The function and properties of structured lipids depend on the type of fatty acids moieties present and the position of their attachment to the backbone. Availability of SLs tightly relates to the new discoveries and collection of evidence in nutritional and functional studies. Production of SLs can be done by either chemical or enzymatic inter-esterification or synthesis depending on what products are needed. Randomized SLs can be produced by both methods. However, SLs with defined structures can only be produced by the enzymatic method with specific lipases. On the other hand, functions of SLs with respect to the consideration of medium chain fatty acids or PUFA have gained wide recognition. A number of products, largely with randomized structure, are available for different applications. SLs have potential applications in the delivery of energy and PUFA to persons suffering from malabsorption. Academic research has demonstrated a number of potential aspects from nutritional or biochemical points of view. With the potential perspectives in mind, technological development has already made the possibility of SL synthesis into production level with reasonably acceptable product standards.

Keywords: *Lipids, fatty acids, malabsorption, triacylglycerols*

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INTRODUCTION

Structured lipids chemically consist of medium chain fatty acids and select long chain fatty acids attached to a glycerol backbone. The function and properties of structured lipids depend on the type of fatty acids moieties present and the position of their attachment to the backbone. Long chain fatty acids are chosen for particular functional properties they impart to the final product or for their biological function after ingestion. Medium chain fatty acids are chosen as a readily available source of energy that, in general, does not contribute to fat storage.

Structured lipids (SL) are defined as triacylglycerols (TAG) restructured or modified to change the fatty acid composition and/or their positional distribution in glycerol molecules by chemical or enzymatic processes. Structured lipids (SLs) generally refer to any fats that are modified or restructured from natural oils and fats or fatty acids there from, primarily containing short or medium chain fatty acids and preferably essential fatty acids. The oils are targeted to have special functionality or nutritional properties for edible or pharmaceutical purposes. This definition, in fact, covers all oils and fats containing short/medium chain fatty acids, whether produced by either chemical or enzymatic methods. The chain length of fatty acids is normally defined as long chain (more than 12), medium chain (8–12), and short chain (less than 8).

Structured lipids have been discussed for more than a decade. The applications of SLs were initiated from the applications of medium chain triacylglycerol (MCT) in clinical treatment of fat malabsorption. Due to the nutritional requirements of essential fatty acids, natural vegetable oils containing essential fatty acids are often blended with MCT for medical applications. However, the physical mixtures of MCT and long chain triacylglycerol (LCT) are metabolized differently and result in the retention of the original absorption rates of the MCT and LCT. This led to the development of inter-esterified products between MCT and LCT.

History

The term "structured lipids" or "designer lipids" was first introduced in 1980s. During the initial period, researches in structured lipids focused on producing medium chain triacylglycerol (MCT) for pre-term infant, parenteral and enteral nutrition to address metabolic disorder. As MCT can be rapidly absorbed, it can provide instant energy to patients with metabolic disorder. Over time, the area of research in food-related structured lipids have expanded rapidly to include baking and confectionary fats, cocoa butter substitute, human milk fat substitute, healthy cooking and salad oil and many more. In fact, today, the area of structured lipids has expanded beyond food application to include usage as biofuels, plasticizers, lubricants and ingredients in various cosmetics and pharmaceutical products.

WHAT ARE STRUCTURED LIPIDS?

In a broad sense, structured lipids (SLs) are lipids that have been chemically or enzymatically modified from their natural biosynthetic form. In this definition of SLs, the scope of lipids includes triacylglycerols (TAGs) (the most common types of food lipids) as well as other types of acylglycerols such as diacylglycerols, monoacylglycerols, and glycerol-phospholipids (phospholipids). The term modified means any alteration in the structure of the naturally occurring lipids. In a narrower sense and in many cases, SLs are specifically defined as TAGs that have been modified by incorporation of new fatty acids, restructured to change the positions of fatty acids, or the fatty acid profile, from the natural state.

METHOD OF PRODUCTION

Structured lipids can be produced through chemical, enzymatic or chemo-enzymatic pathway. Each pathway has its own advantages and disadvantages. Chemical catalysts triumphed in terms of their relatively cheaper price as compared to biocatalysts. Nevertheless, the overall production cost today between the two different pathways does not differ much due to the increasing affordability of biocatalysts. This has also taken into account of the harsher reaction conditions and additional purification steps commonly required for chemical reactions. Biocatalysts; on the other hand, have the upper hand of offering specificity in producing compounds with a specific structure. In fact, industrial scale enzymatic inter-esterification and transesterification plants have been built globally for manufacturing of various products including margarine fats, human milk fat substitutes and biofuels. In certain cases, a chemo-enzymatic pathway is required for production of structured lipid. This is mainly due to the nature of the raw materials which are unsuitable for enzymatic reaction such as highly acidic substrate. A chemical reaction will then proceed in order to modify the substrates into an intermediate compound which can be subjected to enzymatic reaction.

Solvent engineering is a common feature in production of structured lipid especially in cases whereby solubility of substrates is a problem. For example, organic solvents can be used to enhance the miscibility of hydrophilic glycerol and hydrophobic lipid to increase the reaction rate in glycerolysis. Nevertheless, due to growing awareness for green processes and products, various strategies have been developed to replace organic solvents. One of such strategies is to use the environmental friendly green solvents namely the ionic liquids. Aside from facilitating the solubility of different substrates, ionic liquid can sometimes contribute to higher reaction rate and better reaction efficiency.

Production of Structured Lipids

Sources of Fatty Acids for Structured Lipid Synthesis

SLs have been developed to optimize the benefit of fat substrate mixtures. A variety of fatty acids are used in the synthesis of SLs, taking advantage of the functions and properties of each to obtain maximum benefits from a given SL. These fatty acids include SCFAs, MCFAs, poly unsaturated fatty acids (PUFAs), saturated LCFAs, and monounsaturated fatty acids.

The component fatty acids and their position in the TAG molecule determine the functional and physical properties, the metabolic fate, and the health benefits of the SL. It is therefore appropriate to review the function and metabolism of the component fatty acids.

Short-Chain Fatty Acids

The SCFAs range from C2:0 to C6:0. They occur ubiquitously in the gastrointestinal tract of mammals, where they are the end products of microbial digestion of carbohydrates. In the human diet, SCFAs are usually taken in during consumption of bovine milk, which has a TAG mixture containing approximately 5–10% butyric acid and 3–5% caproic acid. Butyric acid is found in butterfat, where it is present at about 30% of the TAG. SCFAs, also known as volatile fatty acids, are more rapidly absorbed in the stomach than MCFAs because of their higher water solubility, smaller molecular size, and shorter chain length [1–3].

Being hydrophilic, SCFAs have rates and mechanisms of absorption that are clearly distinguishable from those of lipophilic LCFAs. SCFAs are mainly esterified to the sn-3 position in the milk of cows, sheep, and goats. Under normal conditions, the end products of all carbohydrate digestion are the three major straight chain SCFAs: acetate, propionate and butyrate. SCFAs are generally found in smaller proportions except with diets containing high levels of sugar. Microbial proteolys is followed by de-amination also produces SCFA. Using synthetic TAGs, Jensen *et al*. have shown that human pancreatic gastric lipase can preferentially hydrolyze sn-3 esters over sn-1 esters in the ratio of 2:1 [4]. This enzyme has also shown some hydrolytic specificity for SCTs and MCTs, although later studies reported *in vitro* optimal conditions for the hydrolysis of LCFAs by gastric lipase. Pancreatic lipase has been reported to attack only the primary ester group of TAG, independent of the nature of fatty acid attached.

Therefore, due to the positional and chain length specificity of the lipase, SCFAs attached to the sn-3 position of TAGs are likely to be completely hydrolyzed in the lumen of the stomach and small intestine. SCFAs are useful ingredients in the synthesis of low-calorie SLs such as Benefat because from heats of combustion, SCFAs are lower in caloric value than MCFAs and LCFAs. Examples of caloric values of SCFAs are as follows: acetic acid, 3.5 kcal; propionic acid, 5.0 kcal; butyric acid, 6.0 kcal; and caproic acid, 7.5 kcal.

Medium-Chain Fatty Acids and Triacylglycerols

MCTs contain C6:0 to C12:0 fatty acids esterified to glycerol backbone. MCTs serve as an excellent source of MCFAs for SL synthesis. MCTs are used for making lipid emulsions either alone or by blending with LCTs for parenteral and enteral nutrition. MCTs are liquid or solid at room temperature, and their melting points depend on the fatty acid composition. MCTs are used as carriers for colors, flavors, vitamins, and pharmaceutical. MCFAs are commonly found in kernel oils or lauric fats; for example, coconut oil contains 10–15% C8:0 to C10:0 acid and is a raw material for MCT preparation. MCT is synthesized chemically by direct esterification of MCFA and glycerol at high temperature and pressure, followed by alkali washing, steam refining, molecular distillation, and further purification.

Enzymatically, MCTs have been synthesized with immobilized *Mucormiehei* lipase in a solvent-free system. MCFAs have a viscosity of about 25–31 cP at 20°C and a bland odor and taste; as a result of the saturation of the fatty acids, they are extremely stable to oxidation. MCTs have a caloric value of 8.3 kcal compared with 9 kcal for LCTs. This characteristic has made MCTs attractive for use in low-calorie desserts. MCTs may be used in reduced-calorie foods such as salad dressings, baked goods, and frozen dinners [5–7].

MCTs have several health benefits when consumed in mixtures containing LCTs. Toxicological studies on dogs have shown that consuming 100% MCT emulsions leads to the development of adverse effects in dogs, which include shaking of the head and vomiting and defecation, progressing to a coma. It was theorized that these symptoms arose from elevated plasma concentration of MCFA or octonoate. Some advantages of MCFA and MCT consumption include the following:

(1) MCFAs are more readily oxidized than LCFAs;

(2) Carnitine is not required for MCT transport into the mitochondria, thus making MCT an ideal substrate for infants and stressed adults
(3) MCFAs do not require chylomicron formation;
(4) MCFAs are transported back to the liver directly by the portal system.

MCTs are not readily re-esterified into TAGs and have more than twice the caloric density of proteins and carbohydrates, yet can be absorbed and metabolized as rapidly as glucose, whereas LCTs are metabolized more slowly. Feeding diets containing 20 and 30% lipid concentrations in weight maintenance studies indicate that MCTs may be useful in the control of obesity. MCTs appear to give satiety and satisfaction to some patients. Thermogenesis of MCT may be a factor in its very low tendency to deposit as depot fat [8].
Some reports suggest that MCTs can lower both serum cholesterol and tissue cholesterol in animals and man, even more significantly than conventional polyunsaturated oils. However, a study by Cater *et al.* showed that MCTs indeed raised plasma total cholesterol and TAG levels in mildly hyper-cholesterolemic men fed MCT, palm oil, or high oleic acid sunflower oil diets.

A suggested mechanism for the cholesterol-raising ability of MCTs is as follows: acetyl CoA, which is the end product of MCT oxidation, is resynthesized into LCFAs; the LCFAs then mix with the hepatic LCFA pool; and the newly synthesized LCFA may then behave like dietary LCFA. In addition, the C8:0 may serve as precursor for de novo synthesis of LCFAs such as C14:0 and C16:0, which were detected in the plasma TAG. There were no differences in the high-density lipoprotein (HDL) cholesterol concentrations among the subjects. Evidence is pointing against the advisability of using MCTs in weight control because the level of MCTs (50%) required to achieve positive reduction is unlikely in human diet.

An SL containing MCFA and linoleic acid bound in the TAG is more effective for cystic fibrosis patients than safflower oil, which has about twice as much linoleic acid as the SL. It appears that mobility, solubility, and ease of metabolism of MCFAs were responsible for the health benefits of the SL in these cases. In the SL, MCFAs provide not only a source of dense calories but also potentially fulfill a therapeutic purpose.

Omega-6 Fatty Acids: A common n-6 fatty acid is linoleic acid (18:2n-6). Linoleic acid is mainly found in most vegetable oils and in the seeds of most plants except coconut, cocoa, and palm nuts. Linoleic acids have a reducing effect on plasma cholesterol and an inhibitory effect on arterial thrombus formation. The n-6 fatty acids cannot be synthesized by humans and mammals and are therefore considered EFAs. The inability of some animals to produce 18:2n-6 is attributed to the lack of a D12 desaturase, required to introduce a second double bond in oleic acid. Linoleic acid can be desaturated further, and elongated to arachidonic acid (20:4n-6), which is a precursor for eicosanoid formation.

Essentiality of fatty acids was reported by Burr and Burr in 1973. It is suggested that 1–2% intake of linoleic acid in the diet is sufficient to prevent biochemical and clinical deficiency in infants. Adults consume enough 18:2n-6 in the diet and deficiency is not a problem. The absence of linoleic acid in the diet is characterized by scaly dermatitis, excessive water loss via the skin, impaired growth and reproduction, and poor wound healing. Nutritionists have suggested a 3–4% content of n-6 fatty acids in SLs to fulfill the EFA requirements of SLs.

Omega-3 Fatty Acids: They are also known as EFAs because humans like all mammals, cannot synthesize them and therefore must obtain them from their diets. The n-3 fatty acids are represented by linolenic acid (18:3n-3), which is commonly found in soybean and linseed oils and in the chloroplast of green leafy plants. Other polyunsaturated n-3 fatty acids (n-3 PUFAs) of interest in SL synthesis are eicosapentaenoic acid, 20:5n-3 (EPA), and docosahexaenoic acid, 22:6n-3 (DHA), which are commonly found in fish oils, particularly fatty fish. Children without enough n-3 PUFAs in their diet may suffer from neurological and visual disturbances, dermatitis, and growth retardation. Therefore, n-3 PUFAs such as DHA must be included in their diet and in SL

design. SLs containing n-3 PUFAs and MCFAs have been synthesized chemically by hydrolysis and random esterification of fish oil and MCTs. They have been shown to inhibit tumor growth and to improve nitrogen balance in Yoshida sarcoma-bearing rats. We have successfully used lipases as biocatalysts to synthesize position-specific SLs containing n-3 PUFAs with ability to improve immune function and reduce serum cholesterol concentrations. EPA is important in preventing heart attacks primarily due to its antithrombotic effect.

Omega-9 Fatty Acids: The n-9 fatty acids or monounsaturated fatty acids are found in vegetable oils such as canola, olive, peanut, and high-oleic sunflower as oleic acid (18:n-9). Oleic acid can be synthesized by the human body and is not considered an EFA. However, it plays a moderate role in reducing plasma cholesterol in the body. Oleic acid is useful in SLs for fulfilling the LCT requirements.

Long-Chain Saturated Fatty Acids

Generally, saturated fatty acids are believed to increase plasma cholesterol levels, but it has been claimed that fatty acids with chains 4–10 carbon atoms do not raise cholesterol levels. Stearic acid (18:0) has also been reported not to raise plasma cholesterol levels. TAGs containing high amounts of LCFAs, particularly stearic acid, are poorly absorbed in man, partly because stearic acid has a melting point higher than body temperature; they exhibit poor emulsion formation and poor micellar solublisation. The poor absorption of saturated LCTs makes them potential substrates for low-calorie SL synthesis.

Indeed, Nabisco foods group used this property of stearic acid to make the group of low-calorie SLs called Salatrim which consist of short-chain aliphatic fatty acids and LCFAs, predominantlyC18:0. Caprenin, a SL produced by Procter & Gamble, contains C22:0, which is also poorly absorbed. A SL containing two behenic acids and one oleic acid has been used in the food industry to prevent chocolate bloom and to enhance fine crystal formation of palm oil and lard products.

AVAILABILITY

Availability of SLs tightly relates to the new discoveries and collection of evidence in nutritional and functional studies. Production of SLs can be done by either chemical or enzymatic inter-esterification or synthesis depending on what products are needed. Randomized SLs can be produced by both methods. However, SLs with defined structures can only be produced by the enzymatic method with specific lipases, especially in large quantities.

For most SL products for nutritional applications, PUFA and medium chain fatty acids are most important fatty acids to be considered. To combine these two types of fatty acids into SLs, natural or other available sources of different fatty acids are needed for the production. In some productions, the specific location of a fatty acid is necessary to obtain specific products and properties.

For randomized SLs, the easy way will be by implementing chemical inter-esterification between two oils with required fatty acid compositions. However, lipase-catalyzed reactions between two oils are also on the way with balanced cost.

The advantages of enzyme approaches are indeed tremendous, including

(i) Efficacy of lipases under mild reaction conditions;
(ii) Utility in “natural” reaction systems and products;
(iii) Reduced environmental pollution;
(iv) Availability of lipases from a wide range of sources;
(v) Ability to improve lipases by genetic engineering. With the increasing attention of environmental protection and the customer demands of ‘green’ products, the inter-esterification between two oils with lipases is moving into industrial scale, especially for the products with nutritional considerations.

Research focus on production technology has been largely on SLs with defined structures or the application of enzyme technology, since chemical methods are mature in reality. Many excellent overall reviews on the enzymatic

production or synthesis have been published. Technology has been advanced to the stage of pilot or even industrial operation in large quantities. However, commercial SLs, especially with defined structures, are not readily available, largely because the benefits and applications of SLs are not convincing enough to lead to a successful application.
On the other hand, functions of SLs with respect to the consideration of medium chain fatty acids or PUFA have gained wide recognition. A number of products, largely with randomized structure, are available for different applications.

SYNTHESIS OF STRUCTURED LIPIDS

Chemical Synthesis

Chemical synthesis of SLs usually involves hydrolysis of a mixture of MCTs and LCTs and then re-esterification after random mixing of the MCFAs and LCFAs has occurred, by a process called trans-esterification (ester interchange). The reaction is catalyzed by alkali metals or alkali metal alkylates. This process requires high temperature and anhydrous conditions. Chemical transesterification results in desired randomized TAG molecular species, known as SLs, and in a number of unwanted products, which can be difficult to remove. The SL product consists of one (MLL, LML) or two (LMM, MLM) MCFAs, in random order, and small quantities of pure unreacted MCTs and LCTs.

The starting molar ratios of the MCTs and LCTs, and the source or type of TAG, can be varied to produce new desired SL molecules. Coconut oil is a good source of MCTs, and soybean and safflower oils are excellent sources of (n-6)-containing fatty acids for SL synthesis. Isolation and purification of the products is tedious because of unwanted coproducts. SLs are also produced by physical blending of specific amounts of MCTs and LCTs, except there is no exchange or rearrangement of fatty acids within the same glycerol backbone. When consumed, the blend will retain the original absorption rates of the individual TAG. Positional specificity of fatty acids on the glycerol molecule is not achieved by chemical transesterification, and this is a key factor in the metabolism of SLs.

STRUCTURED LIPIDS: ASPECTS OF NUTRITIONAL STUDIES

The degradation process of oils and fats in human body is region specific and ideally results in the formation of *sn*-2 monoacylglycerols (MAGs) and free fatty acids. Free fatty acids liberated from dietary lipids during digestion are metabolized more rapidly if they are medium or short chain, whereas long chain fatty acids can be absorbed directly in the form of MAGs. This implies that the fatty acids located at the *sn*-2 position may have different metabolic paths compared to those at the 1,3-positions. This is important when considering the possible advantages of tailor-made fats with particular triacylglycerol structures. This issue has been in an intensive discussion and the interest has largely accelerated the development of enzyme technology for the production of regio-specifically defined products [9].

The interest in short or medium chain fatty acids is obvious. There are more easily released from oils and fats. The activity of pancreatic lipase has been extensively examined using *in vitro* conditions. The lipase will be active towards fatty acids located in the *sn*-1,3 positions. A number of SLs have been synthesised and tested as substrates by *in vitro* hydrolysis with pancreatic lipase. Jandacek *et al*. demonstrated that the SLs, 8:0/18:2/8:0 and 8:0/18:1/8:0, were hydrolysed as rapidly as MCT and more rapidly than oils with long chain fatty acids in all positions of the triacylglycerols (TAG) [10]. For randomly inter-esterified fats containing 8:0 and 10:0 as well as 18:2n-6, hydrolysis decreased with increasing contents of 18:2n-6, indicating the higher lipase activity towards medium chain fatty acids. Minor amounts of plasma medium-chain fatty acids and no improved time trial performance after consuming specifically defined SLs were observed in a recent study.

The absorption of SLs has been studied using well-defined oils or inter-esterified fats. Ikeda *et al*. examined the thoracic lymph absorption of SLs [11]. They concluded that SLs would be better than MCT or LCT in the treatment of malabsorption. Tso *et al*. made the similar conclusion with a rat model of fat malabsorption [12]. Jensen *et al*. compared a specifically structured oil with 18:2n-6 at the

sn-2 position and 8:0 and 10:0 at the *sn*-1,3 positions and the same oil in a randomised form [4]. They found that the lymph TAGs had the highest levels of 18:2n-6 after intake of the specific SL compared to the randomised SL. Jensen *et al*. compared a randomly inter-esterified fat manufactured from MCT and fish oil versus the equivalent mixture of the two fats for lymph absorption in a canine model [4]. They found higher transport of medium chain fatty acids from the randomised fat compared with the physical mixture.

Christensen *et al*. examined the specific SL and the randomised ones and found more rapid absorption of 20:5n-3 and 22:6n-3 from the former and more rapid absorption of 10:0 from the latter [13]. This confirmed the importance of the conservation of the *sn*-2 position for n-3 polyunsaturated fatty acids (PUFA). Effect of SLs containing medium-chain fatty acids and linoleic acid on clearance rate in serum of triaclglycerols in rats was studied. The authors demonstrated that the structural differences in triacylglycerols containing medium-chain fatty acids and linoleic acid could alter the rate of lipid clearance in serum of rats.

The intestinal absorption of specifically defined SLs was examined and indicated that the medium-chain fatty acids from SLs, in addition to absorption into the portal blood as free fatty acids, are absorbed by the same pathway as the conventional long-chain triacylglycerols, that is, they are hydrolyzed into free fatty acids, absorbed and activated into CoA, and reacylated into triacylglycerols in the enterocyte. The chain length of medium chain fatty acids in the primary positions of SLs seems to have no effect on the maximal intestinal absorption of long-chain fatty acids in the *sn*-2 position in the rat model, whereas the distribution of fatty acids between the lymphatics and the portal vein reflects the chain length of the fatty acid.

SLs have potential applications in the delivery of energy and PUFA to persons suffering from malabsorption. This has been convincingly demonstrated in animal models. Jandacek *et al*. applied an irrigated intestinal loop model to examine the absorption of fats [10]. They found that 8:0/18:2n-6/8:0 was better absorbed than 18:1/18:2n-6/18:1. Christensen *et al*. demonstrated higher lymphatic transport of 18:2n-6 from a specifically structured fat compared to a randomised fat or the blended fat [13]. A recent study shows that structured lipids improved fat absorption in normal and malabsorbing rats [14]. The study demonstrated improved hydrolysis and absorption of the specific oil compared with the other oils examined both in rats with normal absorption and in rats with malabsorption.

Lipid profiles in rats were found to be significantly affected after intake of highly purified SLs containing medium chain fatty acids and linoleic acid with specific locations The results indicated that the feeding of highly purified LML types could effectively improve serum and liver lipid profiles and that MLM types might be a preferable substrate for the pancreas and contribute to energy supply in rats (M= medium chain fatty acids and L= long chain fatty acids).

Following the absorption of the *sn*-2 MAG, a resynthesis of TAGs for chylomicron production takes place in the intestinal cells. After intake of a normal TAG from fats containing long chain fatty acids, the pool of fatty acids absorbed from the intestine will be used for the resynthesis of TAGs. This process is stereospecifically-favouring acylation at the *sn*-1 position For SLs, medium chain fatty acids will be released but more will be transferred to the portal vein and thus not be available for the resynthesis of TAGs.

The fatty acids for resynthesis of TAGs must then be derived from the endogenous pools, i.e. either from the bile phospholipids or from the fatty acids transported to the intestine from liver or adipose tissue with VLDL, and the availability of fatty acids may in fact limit the absorption and intestinal resynthesis of TAGs, indicating a low fat accumulation in the body. Effect of SLs on serum triacylglycerol levels and body fat in college athletes was studied. The study shows that SLs, compared with soybean oil, may have the potential to prevent hypertriglyceridemia and obesity caused by consumption of a high-fat diet.

Uptakes of both PUFA and medium chain fatty acids will be favourable in several cases. In animal models of burn patients it has been demonstrated that healing and tissue regeneration was favoured by intake of the SL derived from MCT and fish oil. This can be attributed both to the increased demand for PUFA for tissue regeneration and to the intake of medium chain fatty acids, which, during absorption, will be directed towards the liver for oxidation and thereby spare the protein from utilisation for energy. Protein-sparing effects on protein and energy metabolism in the hypercatabolic state was also studied in a low dose endotoxin rat model with chemically defined SLs containing omega 3 or 6 fatty acids at the *sn*-2 position. Considerably different performance has been seen for SLs with different structures.

In parenteral nutrition the fats are given as an emulsion and the purpose is to provide PUFA and fat-soluble vitamins. The metabolism of SLs given as emulsions has been examined. Higher fractional clearance rate for the SLs was found, indicating that this was removed more rapidly from the circulation than the other emulsions. This agreed with similar findings for drug delivery systems based on SLs.

The applications of emulsions will include total parenteral nutrition treatment of extensive burn wounds, where largest gains in body weight, greatest positive nitrogen balance and highest energy consumption was reported following the intake of an emulsion from SLs. In postoperative patients randomised SLs were rapidly metabolised compared with conventional emulsions for total parenteral nutrition. Also in infusion treatment of animals with implanted tumours, it has been observed that tumour growth was slowed down and muscle tissue restored in rats by feeding randomised SLs. SLs based on fish oil may have potential applications in the situation of rejection of transplants, endotoxic shock, and chronic and progressive inflammation by cancer.

The use of SLs in clinical nutrition for now can be primarily concluded as providing energy as well as PUFA. We may add the purpose of directing the distribution of the components of the SLs towards different tissues in the body following absorption. In cases of normal absorption the purpose of applying SLs may be:

(i) To increase the rate of uptake of PUFA for tissue regeneration;
(ii) To supply rapidly absorbed energy from medium chain fatty acids;
(iii) To reduce the energy density of the fat through the lower energy content of medium
(iv) Chain fatty acids;
(v) To direct the fatty acids towards the hepatic tissue for oxidation and to minimise
(vi) deposition in the adipose tissue;
(vii) To provide fatty acids for immunosuppression using n-3 fatty acids from fish oils.

Collective evidences also show that only little difference has been observed for SLs, in particular with different structures, in terms of effects on serum and liver lipid profiles in rats, on safety and tolerance parameters as well as fatty acid distribution in phospholipids of hepatic and extrahepatic tissues, on memory and learning ability, and on chylomicron metabolism. Differences in the intramolecular structure of SLs in a study did not affect pancreatic lipase activity *in vitro* or the absorption by rats of (n-3) fatty acids.One very recent study also shows that attenuated gastric distress but no benefit to performance was observed with adaptation to the SLs from interesterification of rapeseed oil and tricaprylin in well-trained male and female cyclists. Another study with ω3 fatty acids and caprylic acid but in different structures did not show marginal difference on plasma concentrations of TAG and cholesterol, when fed as part of low-fat diets to rats (Table 1) [15].

POTENTIAL AND REPORTED BENEFITS OF STRUCTURED LIPIDS

- Superior nitrogen retention,
- Preservation of reticuloendothelial system (RES) function,
- Attenuation of protein catabolism and the hypermetabolic stress response to thermal injury,

Table 1: *Commercial Structured Lipids and their Applications.*

Brands	Fatty Acids	Applications	Companies
Caprenin	8:0–10:0 (43–45%), and 22:0 (40–54%)	Ingredients for candy bars and confectionery coatings	Procter & Gamble
Salatrim/Benefat	18:0 and 2:0–4:0 (contents vary depending on food uses)	Chip baking, chocolate-flavoured coatings, baked and dairy products, dressings	Danisco
Captex	(a) containing 8:0, 10:0, 18:2n-6 or (b) containing 8:0, 10:0, 12:0 and 18:2n-6	(a) Clinical application; (b) topical creams and lotions for cosmetic industry	Abitec Corp.
Neobee	8:0, 10:0, and LCFA (n-6 and n-3) (contents vary depending on product types)	Pharmaceutical uses incorporated in nutritional or medical beverages or in snack bars	Stepan Company
Impact	Randomised high-lauric acid oil and high linoleic acid oil	Pharmaceutical uses targeted for patients who have suffered trauma or surgery, sepsis, or cancer	Novartis Nutrition
Laurical*	12:0 (40%) and the rest mainly 18:1n-9, 18:2n-6 and 18:3n-3	Confectionery coatings, coffee whiteners, whipped toppings, and centre fats	Calgene Inc.
Structolipid	Fatty acid profile, %8:0, 27; 10:0, 10; 16:0, 7; 18:0, 3; 18:1n-9, 13; 18:2n-6, 33; 18:3n-3, 5; and others, 2	Fat emulsion for intravenous nutrition, developed especially for critically ill patients as a rapid source of energy	Fresenius Kabi, Parenteral Nutrition
Healthy oil	15–20% medium chain fatty acids and rest is fatty acids from rapeseed oil, etc.	Salad oil, cooking oil, and other functional applications	Nisshin Oillio

(Xubing XU. 2005) [9]

- Enhanced absorption of the fatty acid at the sn-2 position (e.g., 18:2n-6 cystic fibrosis patients),
- Reduction in serum TAG, LDL-cholesterol, and cholesterol,
- Improved immune function,
- Prevention of thrombosis
- Lipid emulsion for enteral and parenteral feeding,
- Calorie reduction, and
- Improved absorption of other fats. *[14]*

CONCLUSION

Structured lipids as a concept development, has attracted intense interest among researchers for the last few years. Academic research has demonstrated a number of potential aspects from nutritional or biochemical points of view. With the potential perspectives in mind, technology development has already made the possibility of SL synthesis into production level with reasonably acceptable product standards. So far no industrial efforts have been claimed for the commercial production of SLs with defined structures, even though there have been considerable evidences showing the positive effects in a few aspects of functional applications. It is likely that nutritional considerations of many issues are far from convincing and remain an intensive topic in the research cycle. A general consensus for SLs remains for the effects of fatty acids in SLs rather than the effects of structure of SLs. This issue will take more years to be clarified. Intensive research programs are still moving on worldwide. A full picture of SLs in human nutrition and food functionality will emerge eventually sooner or later.

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