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Effects of a structured lipid, Captex, and a protein-based fat replacer, Simplesse, on energy metabolism, body weight, and serum lipids in lean and obese Zucker rats

Casimir C. Akoh, Kimberly D. Long,* William P. Flatt,* Barbra S. Rose,* and Roy J. Martin*

*Department of Food Science and Technology, and *Foods and Nutrition, The University of Georgia, Athens, GA USA*

The effects of a structured lipid, Captex 810D, and a protein based fat replacer, Simplesse®, on the energy metabolism of 8-week-old female lean and obese Zucker rats were measured for 14 days. Body weight gain and serum lipids and glucose were also measured after 4 weeks on the experimental diets. Zucker rats were divided into six groups (n = 9) as follows: lean control (LC), obese control (OC), lean Captex (LX), obese Captex (OX), lean Simplesse (LS), and obese Simplesse (OS). Heat production was measured using open circuit respiration chambers (Oxymax animal calorimeters). Average dry matter (DM) intake (g/kg$^{0.75}$/d) during the respiration trials (two 24-hour periods) was significantly less (P < 0.05) in the OX and OC groups than in the OS group (31.9 ± 1.6 and 33.1 ± 1.5 SE, respectively, vs. 40.1 ± 4.2 SE). Gross energy (GE) was 5.2 and 4.7 kcal/g DM for the control and the Captex diets, respectively. Metabolizable energy density (ME, kcal/g DM) for Simplesse diets were significantly different from the ME in the control and Captex diets. ME density was less in the OS due to greater urine energy excretion (polyuria) in that group. ME intake (kcal/kg$^{0.75}$/d) was similar for all groups (169.0 ± 4.0 SE) when expressed on a metabolic body size basis, with the intake of the OX being 163.8 ± 6.9 SE. Heat production or energy expenditure (kcal/kg$^{0.75}$/d) of the OX group was significantly higher than the OC group (85.2 ± 2.8 SE vs. 76.0 ± 2.9 SE), but the OC group was not significantly different from the OS group (76.9 ± 2.9 SE). Experimental diets did not affect heat production in lean rats.

A phenotypic effect was observed in serum glucose, triglycerides, cholesterol, and high density lipoprotein (HDL) cholesterol concentrations between lean and obese rats. Obese rats consuming the Simplesse diet had significantly lower glucose concentrations than the Captex and the corn oil control groups (16.3 ± 3.8 vs. 20.1 ± 4.8 and 20.7 ± 2.1 mmol/L, respectively). Serum triglycerides (5.61 ± 0.55 mmol/L vs. 4.27 ± 0.81 and 4.21 ± 0.91 mmol/L) and total cholesterol concentrations (3.96 ± 1.09 mmol/L vs. 3.18 ± 0.49 and 3.33 ± 0.51 mmol/L) in the obese rats on the Simplesse diet were greater than the Captex and the control groups. Obese rats had higher HDL cholesterol concentrations than the lean rats but no difference due to diet was observed in either rats.
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Introduction

Reduced calorie and low-fat products are a growing segment of the food industry. With increasing awareness of the effects of obesity on overall general health, wellness, and longevity, the need to lower fat and calorie content of foods has become a primary concern of the food industry and the

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Address correspondence to Dr. Casimir C. Akoh, Department of Food Science and Technology, Food Science Building, The University of Georgia, Athens, GA 30602-7610, USA.
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public. The emergence of fat replacers to lower the caloric and fat content of food has brought new challenges to the nutritional market and has raised questions regarding the mechanisms by which these fat replacers react in the body. Fat replacers are divided into two main groups: fat mimetics and fat substitutes. They are also classified as carbohydrate-based, protein-based, and lipid-based fat replacers or combinations thereof.[1,2] The protein-based and carbohydrate-based replacers are widely regarded as fat mimetics. These fat mimetics are not fats; they are either proteins or carbohydrates that were physically or chemically processed to mimic the properties and functions of fats in food systems. Fat substitutes are believed to be compounds that physically and chemically resemble triacylglycerols (TAGs). Several lipid-based synthetic low calorie or zero calorie fat substitutes belong to the fat substitute group. A good example is Olestra®, or Olean® [chemical name is sucrose fatty acid polyester (SPE)], which was originally developed by Procter & Gamble Co. (Cincinnati, OH) to replace edible fats and oils in the diet.[3]

Simplesse (NutraSweet Kelco Co., San Diego, CA), a protein-based fat mimetic, and Captex 810D (Abitec Corporation, Columbus, OH), a lipid-based fat substitute, structured lipid (SL), have the potential for use in food formulations. Simplesse is formulated by a patented microparticulation process from whey protein and provides 4 kcal/g. It can be used in baked goods, dairy products, and salad dressings but not for frying. Captex is produced by a chemical interesterification process. It contains both medium chain and long chain fatty acids and is considered a reduced calorie fat or SL. SLs can improve fat utilization in patients with high energy requirements, such as cystic fibrosis or pancreatic and fat malabsorption disorder. They are used mainly in total parenteral nutrition (TPN) and enteral nutrition.[4,5] Oxidation of SL is more rapid than for normal TAGs. SLs have modified absorption rates.[6] SLs such as Captex may lead to increased heat production and decreased storage in tissues. Other commercially available SLs are Caprenin, produced by Procter & Gamble Co., which consists of $C_{8:0}$–$C_{10:0}$–$C_{22:0}$, and Benefat™, originally produced as Salatrim by Nabisco Foods Group (East Hanover, NJ) and now marketed by Cultor Food Science (New York, NY), which consists of short-chain ($C_{2:0}$–$C_{4:0}$) and long chain ($C_{18:0}$) fatty acids. The caloric content of Caprenin and Benefat is approximately 5 kcal/g compared with 9 kcal/g for regular TAGs.[4,5,7]

This study was to determine if the fat replacers Simplesse and Captex can alter the energy metabolism, body weight, and serum factors in lean and obese Zucker rats, a genetic model of obesity. The Zucker rat may be an ideal model for testing dietary effects on obesity. We recently used this model to show that the fat substitute Olestra will result in lowered body weights in obese animals.[8] It is our contention that genetic predisposition to obesity also makes individuals more sensitive to diet induced obesity. We report for the first time a comparison between Simplesse and Captex diet consumption in Zucker rats.

Table 1 Diet formulations for control, Simplesse, and Captex diets

Ingredient	Control (g/kg)	Simplesse (g/kg)	Captex (g/kg)
Casein	200	200	200
DL methionine	3	3	3
Cornstarch	450	450	450
Sucrose	100	100	100
Celufil[1]	50	50	50
Corn oil	150	50	50
Simplesse	NA	100	NA
Captex 810D	NA	NA	100
Minerals[2]	35	35	35
Vitamins[3]	12	12	12
kcal/g	4350	3850	4280

[1]Celufil is a nonnutritive bulk of fine mesh cellulose.
[2]AIN mineral mixture 93G (iron omitted) contains the following compounds (g/kg): calcium carbonate, 357.0; potassium phosphate (monobasic), 196.0; potassium citrate monohydrate, 70.78; sodium chloride, 74.0; potassium sulfate, 46.6; magnesium oxide, 24.3; zinc carbonate, 1.65; manganous carbonate, 0.63; cupric carbonate, 0.31; potassium iodate, 0.01; sodium selenate, 0.01025; ammonium paramolybdate, 0.00795; sodium meta-silicate, 1.45; chromium potassium sulfate, 0.275; lithium chloride, 0.0174; boric acid, 0.0815; sodium fluoride, 0.0635; nickel carbonate hydroxide, tetrahydrate, 0.0318; ammonium vandate, 0.0066; sucrose, 226.776. Adapted from Reeves et al.[33]
[3]AIN vitamin mixture 93G (vitamin E omitted) contains the following (g/kg): nicotinic acid, 3.0; calcium pantothenate, 1.6; pyridoxine HCl, 0.7; thiamin HCl, 0.6; riboflavin, 0.6; folic acid, 0.2; d-biotin, 0.02; vitamin B_{12} (0.1% in mannitol), 2.5; vitamin A palmitate (500,000 U/g), 0.8; vitamin D_3 (cholecalciferol, 500,000 U/g), 0.2; vitamin K (phylloquinone), 0.075; sucrose, 989.705. Adapted from Reeves et al.[33]
NA, not applicable.

Materials and methods

Animals

We randomly separated 54 female lean (Fa/?; n = 27) and obese (fa/fa; n = 27) Zucker rats from our colony into six diet groups (n = 9) as follows: lean control (LC), obese control (OC), lean Captex (LX), obese Captex (OX), lean Simplesse (LS), and obese Simplesse (OS). The diet composition, adapted from Grossman et al,[8] is given in *Table 1*. The animals were approximately 8-weeks-old and weighed 227 ± 6 g and 388 ± 13 g SE (standard error) for lean and obese rats, respectively. Animal care and use were carried out in accordance with the Institutional Animal Care and Use Committee guidelines of the University of Georgia. Animals were housed in individual hanging wire cages and had free access to food and water. Room temperature was maintained at approximately 23 ± 2°C and the room light was 12 hr/d of light (0700–1900 hr) and dark cycle. During acclimatization, the rats were fed *ad libitum* a nonpurified diet (Rat Chow 5012, Ralston Purina, St. Louis, MO) for the first 8 weeks. Simplesse and Captex constituted 10% and corn oil 5% by weight, respectively, of the experimental diets. The fatty acid profile (mol%) of Captex 810D as specified by the manufacturer (Abitec Corporation, Columbus, OH) is as follows: $C_{6:0}$ 0.4, $C_{8:0}$ 12.2, $C_{10:0}$ 11.5, $C_{16:0}$ 4.7, $C_{18:0}$ 3.7, $C_{18:1n-9}$ 12.6, $C_{18:2n-6}$ 53.6, $C_{18:3n-3}$ 0.2, and $C_{20:0}$ 0.2. The rats were then split into groups and normalized for body weight. The start of the experimental diet usage was staggered for each group to accommodate the same number of days on diet and in the respiration chambers. Diets were fed *ad libitum* for a period of 4 weeks and samples of diets, feces, and urine were analyzed for percent moisture, nitrogen, and gross energy (kcal). These data were used to calculate the gross energy and metabolizable energy

(ME) of the diets. Animals were weighed every day, including when they were placed in the respiration chambers for calorimetry measurements. Diet intake and water consumption were measured. After 4 weeks on the diets, animals were anesthetized after overnight fast with a combination of ketamine and rompum. Blood was collected by heart puncture in heparin containing tubes and delivered to Athens Regional Medical Center for analysis of serum lipids and glucose using Boehringer Mannheim Hitachi 911 automatic system (San Jose, CA). Rats were sacrificed by carbon dioxide (CO_2) inhalation. The livers were removed, weighed, and stored in a freezer (−96°C) for fatty acid analysis. The blood data were based on 4 weeks while the metabolism and respiration data were based on measurements made during the last 14 days.

Calorimetry analysis

Respiration trials using an Oxymax Deluxe Calorimetry System (ten respiration chambers) (Columbus Instruments Inc., Columbus, OH) were conducted during two consecutive 24-hour periods at the end of the study, after the rats had been on the diets for 1 week in the chambers. A mass flow controller was used to measure gas volume and air flow for each chamber. CO_2 concentrations of incoming air and exhaust gas were determined with an infrared gas analyzer. Oxygen (O_2) concentration was determined using an Oxymax oxygen sensor battery system, based on limited diffusion air battery. The following parameters were measured: oxygen consumption and carbon dioxide production (liters), respiratory exchange ratio (RER), and heat production (kcal). Metabolic body size (MBS) of each rat was estimated based on Kleiber's[9] rationale ($kg^{0.75}$). Energy expenditure or heat production calculations were based on the Brouwer[10] equations. However, for the rats in which there was no detectable methane produced and the equation for energy expenditure or heat production reduced to HP = 3.820 O_2 + 1.150 CO_2, where HP is kcal; O_2 is the number of liters of O_2 consumed; and CO_2 is the number of liters of CO_2 produced.

Fatty acid composition of liver

Fatty acid composition of the diet and liver from each rat were determined with a Hewlett Packard (Hewlett Packard, Avondale, PA) 5890 Series II gas chromatograph (GC) equipped with a flame ionization detector. The lipids were extracted, methylated, and analyzed as described previously.[11]

Statistics

Data were analyzed using the Statistical Analysis System[12] package. Differences between means ($P < 0.05$) were determined by analysis of variance with post hoc Duncan's new multiple range tests.

Results

The composition of the diets and the diet analysis in terms of gross energy and ME are summarized in *Table 1* and *Table 2*, respectively. Simplesse, a low calorie (~4 kcal/g) protein-based fat replacer,[13,14] when included in the diet at the same level (10% by weight) as Captex, a SL (~8.3 kcal/g),[4,14] or corn oil (~9 kcal/g), resulted in a diet that was significantly lower ($P < 0.05$) in gross energy density (4.7 kcal GE/g DM) as well as ME density (4.3 kcal ME/g DM) than the Captex and control diets. The ME of the Simplesse group was significantly different from Captex and control for both lean and obese rats. Polyuria was evident in five of the nine obese rats that consumed the Simplesse diet. The Simplesse diet was higher in nitrogen (3.98%) compared with the Captex (3.28%) and corn oil control (3.16%) diets, which resulted in greater urinary nitrogen and energy losses.

Table 2 Diet analysis

Diet	Moisture (%)	Gross energy (kcal/g DM)	Metabolizable energy (kcal/g DM)	
			Lean	Obese
Control	5.11	5.21	4.85	4.75
Simplesse	5.45	4.68	4.28[1]	4.13[1]
Captex	5.16	5.14	4.76	4.77

[1]Simplesse group significantly different from Captex and control groups, $P < 0.05$. Metabolizable energy (ME) = gross energy minus fecal and urinary energy.
DM, dry matter basis.

Figure 1 and *Figure 2* show the body weight and daily ME intake of lean and obese female Zucker rats, when they were given free access to the diets. Obese Zucker rats fed the Simplesse diet consumed significantly less ME (kcal ME/d) than those fed Captex or corn oil, and the daily weights reflected the lower energy intake throughout the study. Many of the differences, however, could be attributed to the lower energy density of the diet (4.13 kcal/ME/g DM) due to urinary energy losses in the obese group. No significant differences in ME intake or body weight were observed in the lean Zucker rats. Overall, the obese rats showed higher rates of body weight gain than the lean rats. In lean rats, diet had no effect on body weight. In obese rats, the Simplesse diet resulted in significantly ($P < 0.05$) lower body weight gain than the Captex and control diets. For any given day, the obese rats on the Simplesse diet had significantly different body weights compared with the obese rats on Captex and control diets.

Figure 3 and *Figure 4* illustrate the total ME intake and total heat production per 24 hours of each of the six groups of female Zucker rats fed *ad libitum*. Phenotype (lean vs. obese) had a highly significant effect ($P < 0.01$) on energy intake and daily heat production. The food intake, measured as daily dry matter (g DM/d) or as ME (kcal ME/d) during the respiration trials, was less for the obese Captex (95.4 ± 1.5) and obese Simplesse (92.9 ± 3.4) groups compared with the obese control (99.1 ± 3.8) group (*Figure 3*). Obese rats consuming the Captex diet lost more energy as heat (49.8 ± 0.2 kcal/d) than the Simplesse (41.8 ± 1.4 kcal/d) or the corn oil control (45.1 ± 1.8 kcal/d) groups (*Figure 4*). The average ME intake during the respiration trials was 61.4 kcal ME/d for lean rats and 95.8 kcal ME/d for obese rats. Heat production was 20.3 kcal/d for lean rats and 45.6 kcal/d for obese rats. Thus, the energy balance during the respiration trials would be 41.1 kcal/d for lean rats and 50.2 kcal/d for obese rats. Body weights increased in each group, but this may not accurately reflect changes in body composition during this short period of time. No medium chain fatty acids were found in the livers of the Captex-fed animals. This finding supports the statement that the medium chain fatty acids in Captex are readily oxidized more directly than are the longer chain fatty acids in the corn oil

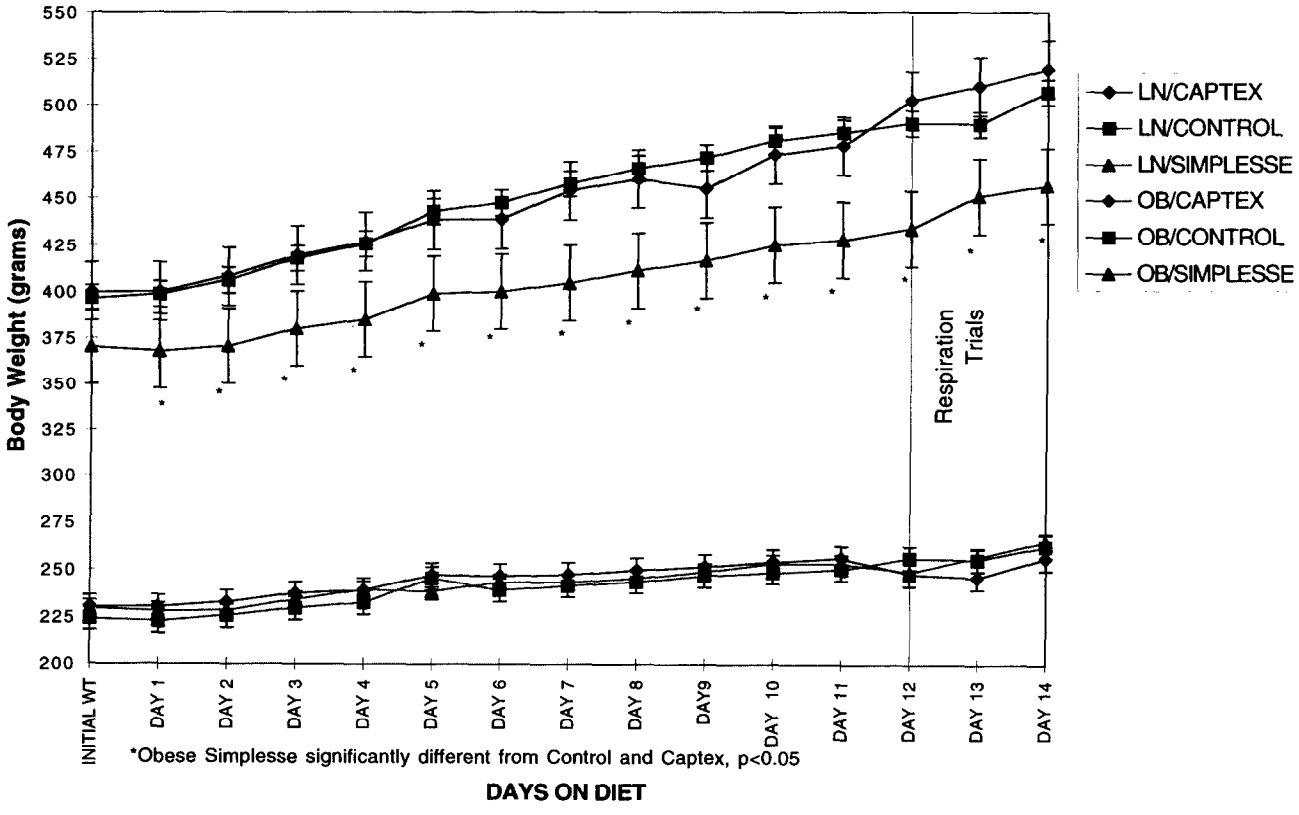

Figure 1 Daily body weight of control, Simplesse, and Captex diets in lean (LN) and obese (OB) female Zucker rats during the last 14 days of the experiment. *Obese Simplesse group significantly different from control and Captex groups, $P < 0.05$.

and result in greater heat production rather than being deposited in the adipose or liver tissue.

Figure 5 shows that during the respiration trials conducted at the last 48 hours of the experiment, the ME intake per unit MBS (kcal ME/kg$^{0.75}$/d) was similar for all groups, regardless of diet or phenotype (169.0 ± 4.0 SE). The obese rats fed the Captex diet consumed 163.8 ± 6.9 SE kcal ME/MBS. *Figure 6* shows that the heat production per unit MBS of obese rats fed the SL, Captex diet (85.2 ± 2.8 SE) was significantly higher ($P < 0.05$) than those of the obese control (76.0 ± 2.9 SE) or the obese Simplesse fed (76.9 ± 2.9 SE) groups. These results indicate that the medium chain fatty acids ($C_{6:0}$ to $C_{10:0}$) in Captex were used as a readily available source of energy and produced heat rather than depositing in the adipose tissue or liver in the obese Zucker rats. This was not the case for lean female Zucker rats, in which there were no significant differences due to dietary treatment in either the ME intake or heat production per unit MBS.

Serum lipids and glucose concentrations of lean and obese female Zucker rats fed the control, Simplesse, and Captex diets are reported in *Table 3*. A phenotypic effect was observed in all serum parameters [glucose, triglycerides, cholesterol, and high density lipoprotein (HDL) cholesterol] between lean and obese, with the obese rats having significantly ($P < 0.05$) higher values than the lean rats. Obese rats consuming the Simplesse diet had significantly lower glucose concentrations (16.3 ± 3.8 mmol/L) than the Captex and the corn oil control groups (20.1 ± 4.8 and 20.7 ± 2.1 mmol/L, respectively). There were no significant differences in glucose levels among the lean groups consuming the three diets with the exception of the Captex group, in which the animals tended to have slightly lower glucose levels than did the control and Simplesse groups. The serum triglycerides in the obese rats fed the Simplesse diet (5.61 ± 0.55 mmol/L) were significantly different from the Captex (4.27 ± 0.81 mmol/L) and the control (4.21 ± 0.91 mmol/L) groups. Lean rats consuming the Simplesse diet had significantly greater triglyceride concentrations than did the control group but not the Captex group. The total cholesterol concentration in the obese rats that consumed the Simplesse diet (3.96 ± 1.09 mmol/L) was significantly greater than the Captex (3.18 ± 0.49 mmol/L) and control (3.33 ± 0.51 mmol/L) groups. However, the lean rats consuming Captex (1.63 ± 0.16 mmol/L) and the Simplesse (1.84 ± 0.44 mmol/L) diets showed no statistically different total cholesterol concentrations. Both the Simplesse and Captex diets raised the HDL cholesterol of the lean animals but the differences were not statistically significant at the tested level. The obese animals showed no difference in HDL cholesterol due to diet although HDL cholesterol in the Captex group was slightly lower than that in the Simplesse group. The total cholesterol/HDL cholesterol ratio was not significantly different between the lean and obese animals consuming the Captex and control diets. However, a slightly elevated ratio was observed in the

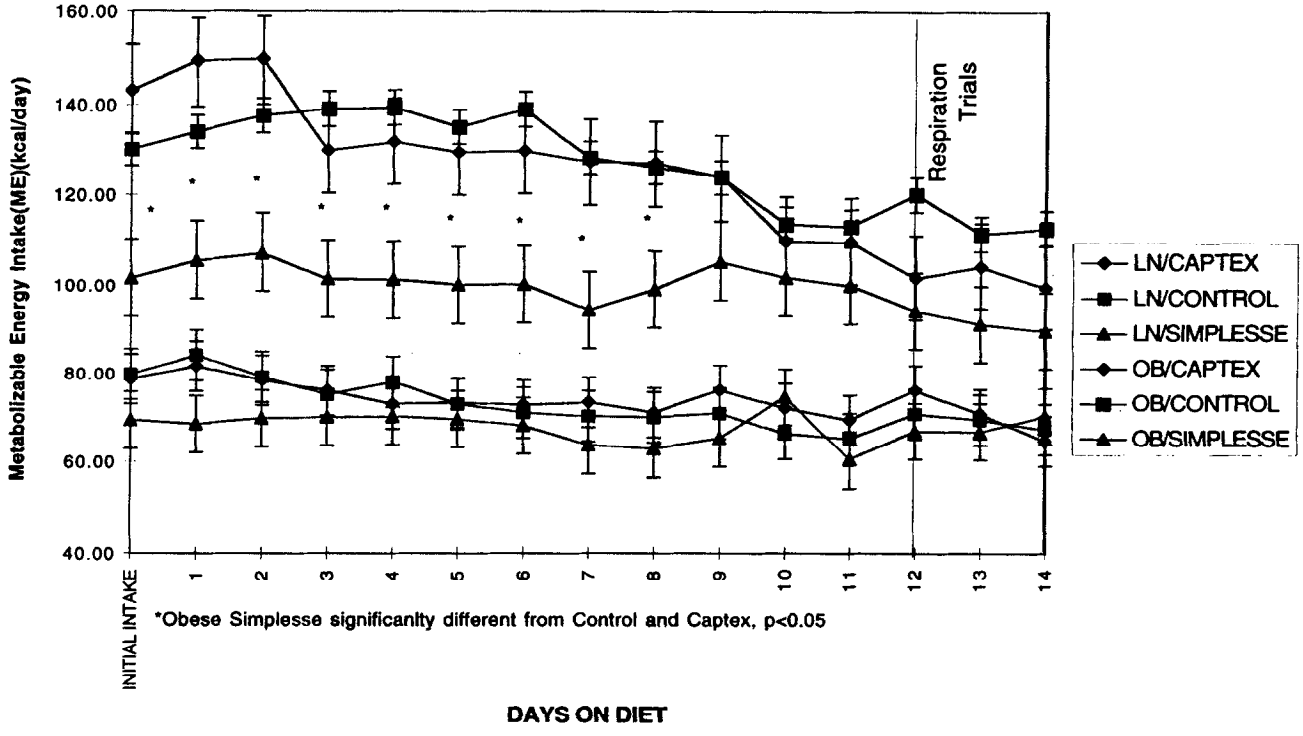

Figure 2 Daily metabolizable energy intakes (ME; kcal/d) of control, Simplesse, and Captex diets in lean (LN) and obese (OB) female Zucker rats. *Obese Simplesse group significantly different from control and Captex groups, $P < 0.05$.

Simplesse group compared with the Captex and control diet groups.

Table 4 shows the major fatty acids found in the female Zucker rat livers after 4 weeks on experimental diets. No medium chain fatty acid $C_{6:0}$ to $C_{10:0}$ was found in the liver, including in the Captex diet group. Significant differences ($P < 0.05$) were detected in $C_{16:0}$ in the Captex and control obese groups; $C_{18:0}$ in obese control and Simplesse groups; $C_{18:1n-9}$ in obese control, Simplesse, and Captex groups compared with control; and $C_{20:4n-6}$ in obese Simplesse compared with the Captex and control (lean and obese) groups. No differences were detected in $C_{22:6n-3}$ suggesting basal levels in the absence of a significant amount of the precursor, $C_{18:3n-3}$, in the diets. *Table 5* shows the body weight, liver weight, and %liver/body weight comparison for the diets groups. The obese animals had significantly higher liver and body weights than did the lean animals. However, no differences were found within the same phenotype.

Discussion

Our main goal in this study was to compare the effects of the SL, Captex, a lipid based fat replacer, and Simplesse, a protein based fat replacer, on energy metabolism and serum lipids in lean and obese female Zucker rats. Heat production was measured using open circuit respiration chambers. Our data are consistent with the well known fact that obese rats tend to gain more weight as they grow older than do lean animals.[8] Others[15–17] have reported similar results that showed that genetically obese Zucker rats are less able to maintain a constant body weight during perturbations in food intake and/or energy expenditure, while Hashim and Van Itallie[18] and Campbell et al.[19] reported that obese humans were unable to regulate their body weight as lean humans can. These diets had no effects on lean animals. In addition, as has been observed in human obesity, the obese rat has a high level of serum leptin,[20,21] indicative of resistance to anti-obesity factor. It is our contention that genetic predisposition to obesity also makes individuals more sensitive to diet-induced obesity and thus far our data support this contention. Consumption of the Captex diet resulted in increased energy expenditure or heat production in the obese rats, and thus Captex may be useful in helping to limit obesity. Simplesse may also be useful, but primarily because of reduced caloric intake by obese animals. The excessive urine excretion by obese rats raises questions about using Simplesse to limit obesity.

Serum triglycerides and total cholesterol concentrations in the obese rats on the Simplesse diet were greater than the Captex and control groups. Simplesse diet raised the total cholesterol concentrations of the lean rats, but no difference due to diet was observed when compared with the lean rats on the Captex diet. Swift et al.[22] reported that caprenin (40% of total calories) fed as a SL diet to healthy male subjects for 6 days did not alter plasma cholesterol concentration, but HDL cholesterol decreased by 14% compared with no change in levels when a long chain TAG diet was fed. However, the medium chain TAG diet was reported to raise plasma triglyceride concentration by 42% and reduce HDL cholesterol by 15%.[22] Overall, the Simplesse diet tended to raise serum triglyceride, cholesterol, and HDL

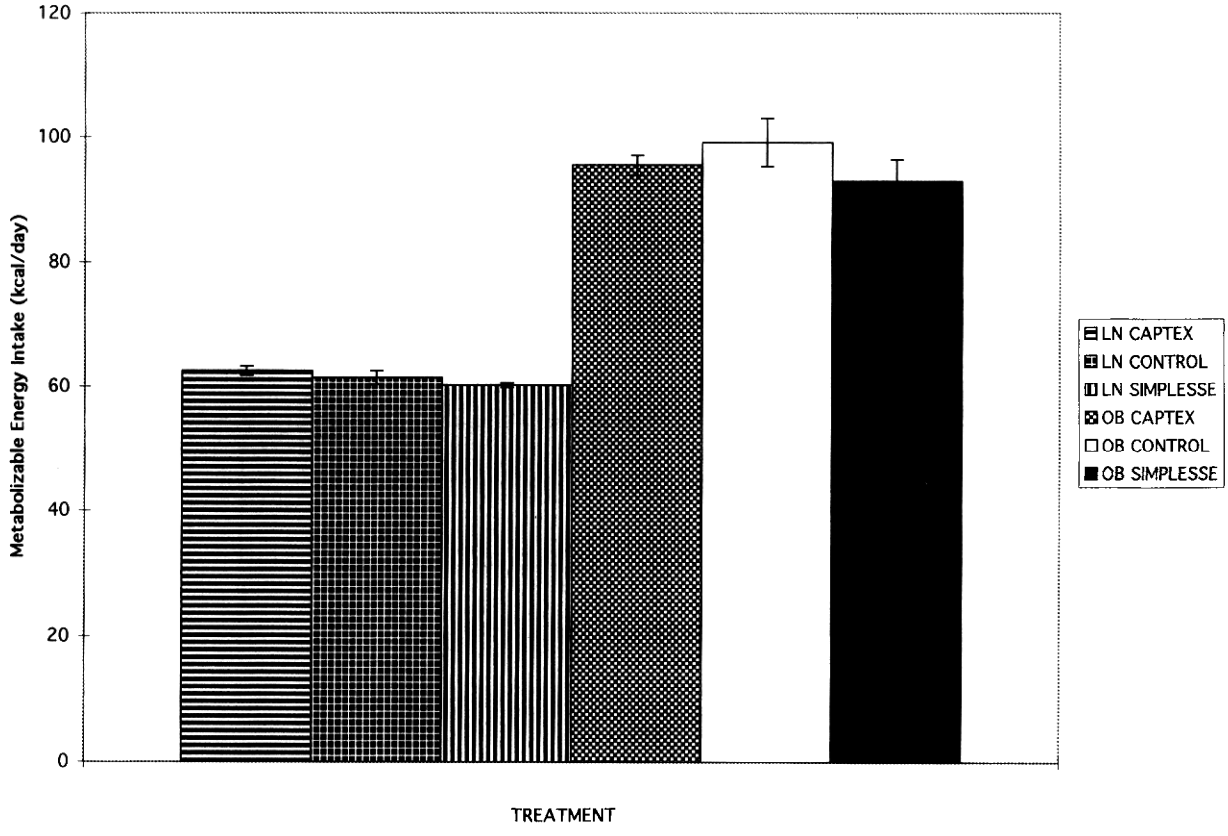

Figure 3 Metabolizable energy intake (kcal/d) during respiration trials for control, Simplesse, and Captex diets in lean (LN) and obese (OB) female Zucker rats.

cholesterol concentrations slightly more than the Captex diet. Webb et al.[23] also observed an increase in serum glucose and triglycerides, no effect on HDL cholesterol, and a decrease in total cholesterol concentrations in male and female rats fed caprenin diets (5.23–15%, w/w) for 91 days. Salatrim was found to decrease serum cholesterol concentrations in humans.[7] In another related rat study,[24] dietary Salatrim did not produce any significant effect on serum triglycerides, low density lipoprotein and HDL cholesterols, and total cholesterol when fed at 10% by weight of the diet. Nordenstrom et al.[25] found no change in serum cholesterol in healthy subjects infused with a structured triglyceride emulsion (FE 73403, Pharmacia AB, Stockholm, Sweden), but found an increase in serum triglycerides. This SL contained 27% caprylic ($C_{8:0}$) and 10% capric acid ($C_{10:0}$). Jandacek et al.[26] demonstrated that a SL containing octanoic acid ($C_{8:0}$) at the 1 and 3 positions and a long chain fatty acid in the 2-position is more rapidly hydrolyzed and efficiently absorbed compared with typical long chain TAG. They proposed that the SL may be synthesized to provide the most desirable features of long chain and medium chain fatty acids used as nutrients in cases of pancreatic insufficiency.[26] Enhanced absorption of 18:2n-6 was observed in cystic fibrosis patients fed SLs containing long chain and medium chain fatty acids.[27] McKenna and Hubbard[28] reported improved absorption of 18:2n-6 in Captex 810D in cystic fibrosis patients.

An additional objective of this study was to determine if the medium chain fatty acids from the Captex diet are stored in the liver. As reported in *Table 4*, no $C_{8:0}$ or $C_{10:0}$ were found in the liver. Mascioli et al.[29] reported that medium chain TAG was oxidized rapidly and preferentially, poorly stored into adipose tissue, and had increased thermogenesis in humans compared with long chain TAGs. The men were fed the two triglycerides enterally and parenterally as lipid emulsions. In contrast, long chain fatty acids were preferentially reesterified and stored as triglycerides in the liver and adipose tissues.[30] Significant differences were detected in $C_{16:0}$ in the Captex and control obese groups; $C_{18:0}$ in obese control and Simplesse groups; $C_{18:1n-9}$ in obese control, Simplesse, and Captex groups compared with control; and $C_{20:4n-6}$ in obese Simplesse compared with the Captex and control (lean and obese) groups. No differences were detected in $C_{22:6n-3}$, suggesting basal levels in the absence of a significant amount of the precursor $C_{18:3n-3}$ in the diets. The increase in CO_2 production and O_2 consumption support rapid oxidation and thermogenic effect of the Captex diet and other SLs.[29,30] SL emulsions containing both medium chain and long chain fatty acids in the same glycerol molecule may have clinical and metabolic advantages for stressed and/or septic patients.[31] Medium chain fatty acids may enhance the clearance of parental lipid emulsions. A SL made by reacting tripalmitin with unsaturated fatty acids using a *sn*-1,3 specific lipase was found to closely mimic the fatty acid distribution of human milk and

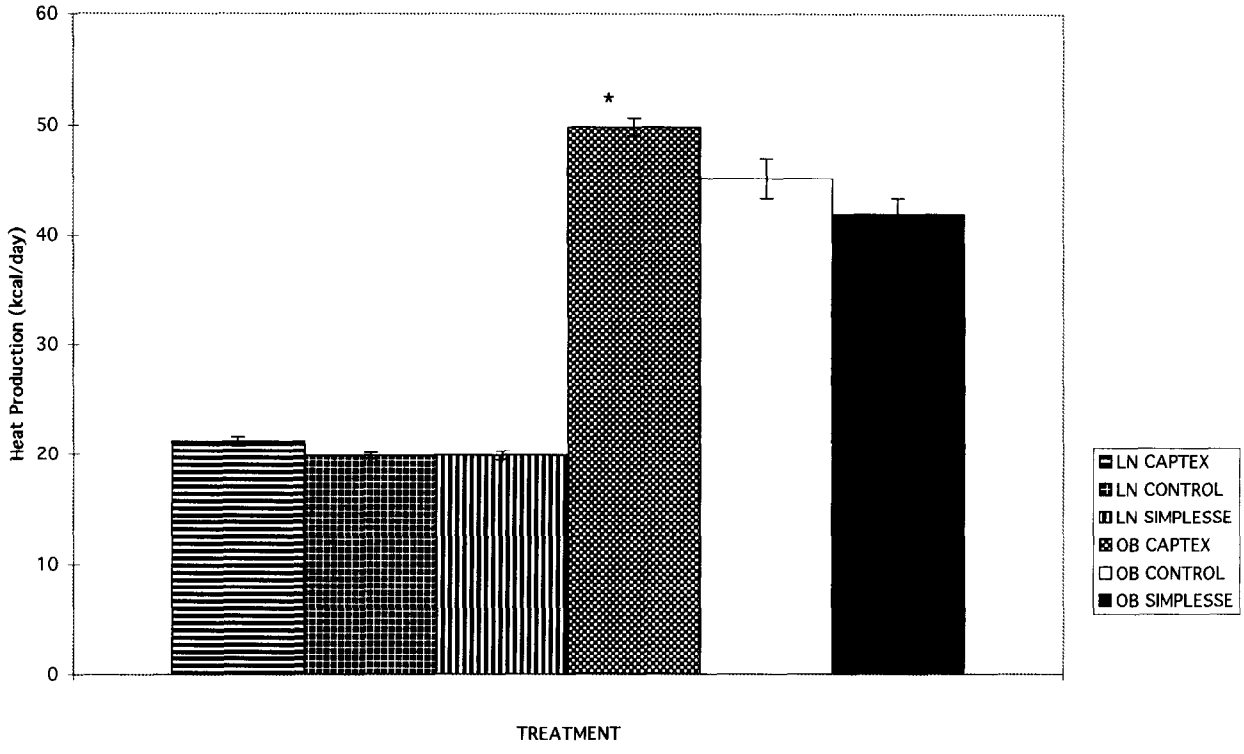

Figure 4 Heat production (kcal/d) for control, Simplesse, and Captex diets in lean (LN) and obese (OB) female Zucker rats.

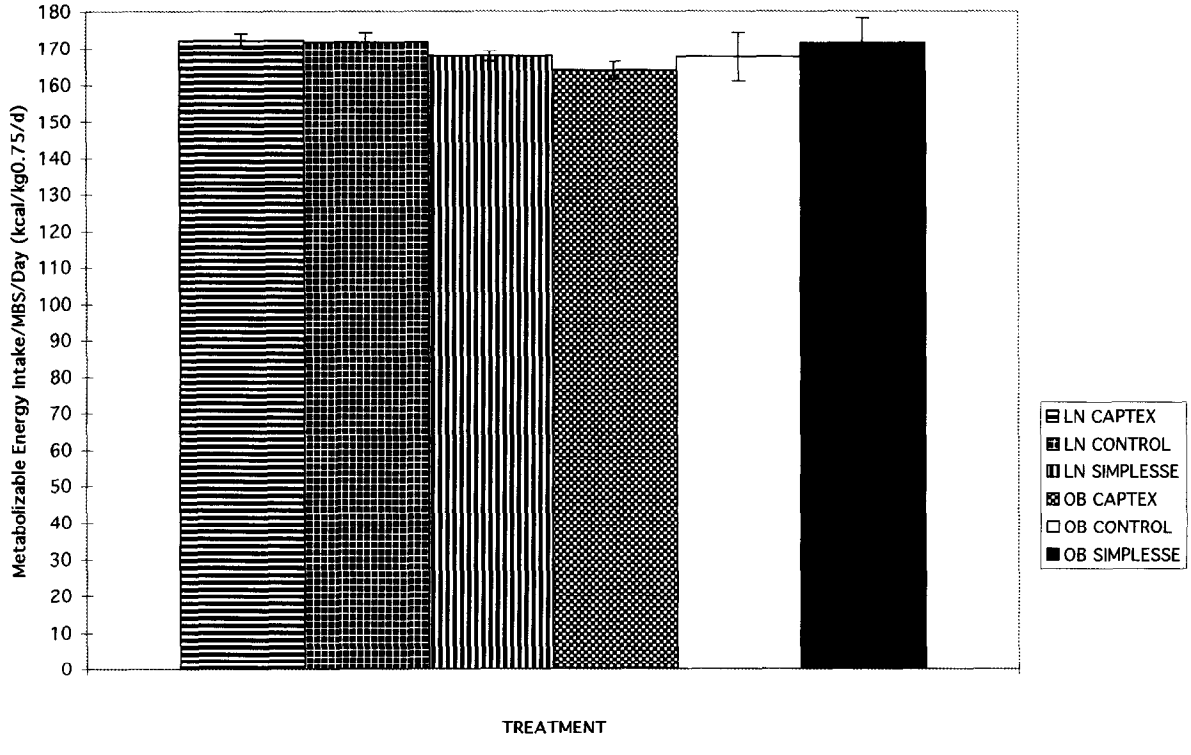

Figure 5 Metabolizable energy intake/metabolic body size (MBS)/day (kcal/kg$^{0.75}$/d) during respiration trials for control, Simplesse, and Captex diets in lean (LN) and obese (OB) female Zucker rats.

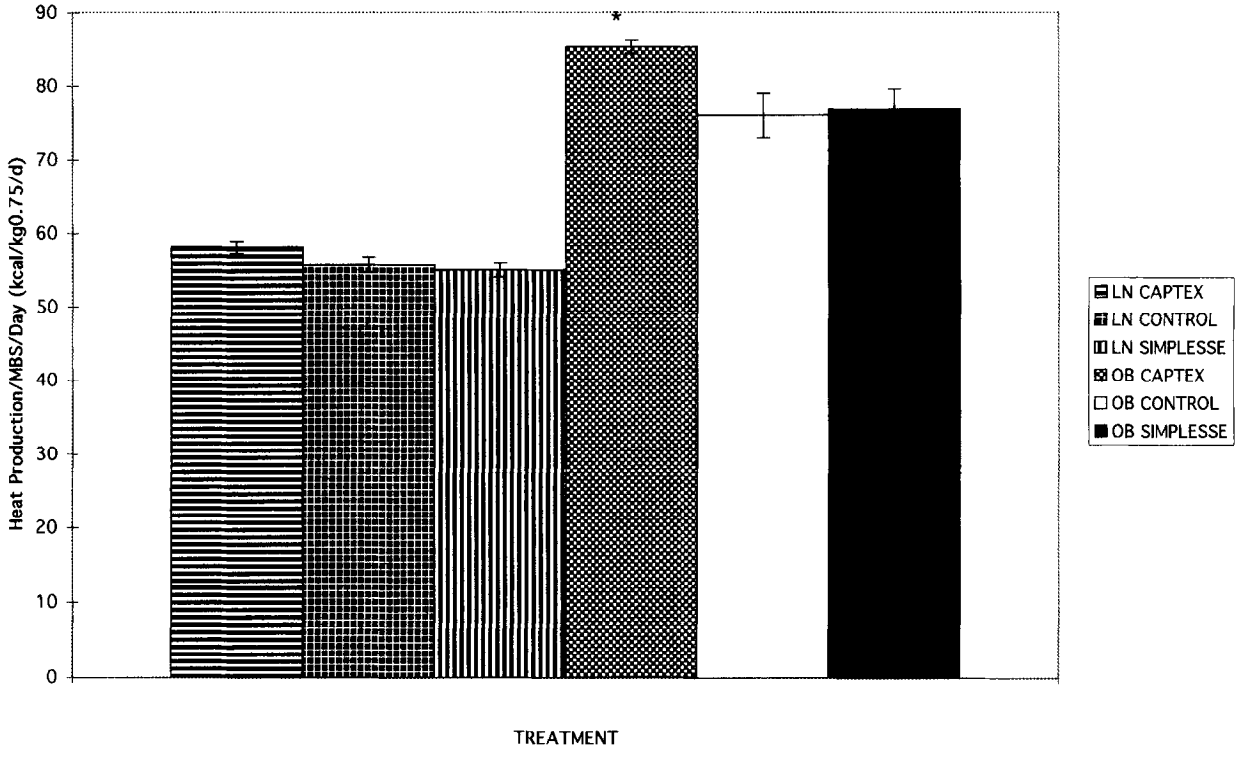

Figure 6 Heat production/metabolic body size (MBS)/day (kcal/kg$^{0.75}$/d) for control, Simplesse, and Captex diets in lean (LN) and obese (OB) female Zucker rats. *Captex diet group significantly different from control group, $P < 0.05$.

Table 3 Serum glucose and lipids of lean and obese rats on experimental diets

Serum parameter (mmol/L)	Control diet		Simplesse diet		Captex diet	
	Lean	Obese	Lean	Obese	Lean	Obese
Glucose	10.3 ± 2.9—a	20.7 ± 2.1—c	9.9 ± 4.3—a	16.3 ± 3.8—b	9.4 ± 3.4—a	20.1 ± 4.8—c
TAG	0.76 ± 0.12—a	4.21 ± 0.91—c	1.15 ± 0.53—b	5.61 ± 0.55—d	0.95 ± 0.29—ab	4.27 ± 0.81—c
Cholesterol	1.47 ± 0.18—a	3.33 ± 0.51—c	1.84 ± 0.44—b	3.96 ± 1.09—d	1.63 ± 0.16—ab	3.18 ± 0.49—c
HDL-Chol	1.20 ± 0.18—a	2.74 ± 0.62—b	1.45 ± 0.44—a	2.95 ± 1.11—b	1.34 ± 0.18—a	2.61 ± 0.57—b
Chol:HDL-Chol	1.23	1.22	1.27	1.34	1.22	1.22

Note: Values represent mean ± standard error. N = 9 in each group. Mean with different letters in a row are significantly different ($P < 0.05$).
TAG, triglyceride, HDL-Chol, high density lipoprotein cholesterol.

Table 4 Major fatty acids of Zucker rats liver after 4 weeks on experimental diets (mol%)

Fatty acid	Control diet		Simplesse diet		Captex diet	
	Lean	Obese	Lean	Obese	Lean	Obese
16:0	21.7 ± 6.2—a	24.9 ± 2.3—ab	21.9 ± 1.7—a	28.3 ± 4.5—a	19.8 ± 1.6—a	23.5 ± 2.8—b
18:0	22.8 ± 5.7—a	20.8 ± 2.0—ab	22.2 ± 3.4—a	17.7 ± 3.1—b	22.8 ± 1.9—a	23.1 ± 5.2—a
18:1n-9	10.1 ± 3.8—a	13.3 ± 2.3—ab	10.8 ± 2.2—a	16.4 ± 3.0—b	7.9 ± 1.6—a	12.3 ± 2.1—ab
18:2n-6	19.8 ± 6.5—a	13.2 ± 1.7—a	17.0 ± 2.4—a	10.2 ± 4.0—a	21.4 ± 3.1—a	12.5 ± 2.9—a
20:4n-6	18.0 ± 5.7—a	16.3 ± 2.3—a	18.8 ± 3.3—a	11.9 ± 2.9—b	20.7 ± 2.5—a	19.2 ± 4.2—a
22:6n-3	7.6 ± 3.2—a	8.7 ± 1.9—a	8.7 ± 1.9—a	8.6 ± 2.5—a	7.4 ± 1.3—a	9.4 ± 1.5—a
Others		2.8	0.6	6.9		

Note: Average of duplicate analysis. Values represent mean ± standard error. N = 9 in each group. Mean with different letters in a row are significantly different ($P < 0.05$).
No medium chain fatty acid $C_{6:0}$ to $C_{10:0}$ was found in the liver, including in the Captex diet group.

Table 5 Body weights and liver weights after 4 weeks on experimental diets

Parameter (g)	Control diet		Simplesse diet		Captex diet	
	Lean	Obese	Lean	Obese	Lean	Obese
Body weight	254.4 ± 19.5—a	500.9 ± 25.1—b	257.5 ± 14.1—a	450.7 ± 57.8—b	260.1 ± 20.4—a	493.1 ± 64.5—b
Liver weight	8.4 ± 1.2—a	16.0 ± 2.5—b	8.2 ± 0.8—a	14.3 ± 2.1—b	8.1 ± 1.0—a	15.7 ± 2.4—b
Liver/body weight (%)	3.3 ± 0.4—a	3.2 ± 0.5—a	3.2 ± 0.4—a	3.2 ± 0.2—a	3.1 ± 0.2—a	3.3 ± 0.8—a

Note: Values represent mean ± standard error. N = 9 in each group. Mean with different letters in a row are significantly different ($P < 0.05$).

is currently under commercial development for application in a infant formula under the trade name Betapol.[32]

The Captex diet resulted in increased heat production and altered energy metabolism in the obese Zucker rats. Our results support the idea that the SL, Captex may be useful in limiting obesity.

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