Adipose tissue expansion and the development of obesity: influence of dietary fat type

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Recent studies indicate that the prevalence of obesity in adults has increased by 30% or more in the past decade, with increases in both genders and in all ethnic and racial populations and age groups. Obesity is associated with many chronic diseases and alterations in physiologic function including cardiovascular disease, hypertension, diabetes mellitus, gallbladder disease and certain types of cancer. Much attention regarding dietary influences on obesity development or prevention has focused on high fat diets. Many studies have confirmed that high fat feeding leads to an expansion of adipose tissue mass through an increase in fat cell size and/or number and to the subsequent development of obesity. However, there is little definitive information on the effect of type of dietary fat, especially palm oil, on adipose tissue cellularity and the development of obesity. These studies were designed to determine whether dietary fat of different sources vary in their ability to produce obesity and to begin to elucidate the mechanism by which such divergence occurs. Male Osborne-Mendel rats were fed either a low fat (15% calories) or one of three high fat diets (65% calories) for 12 weeks. The predominant fat source in the high fat diets was either soybean oil, tallow, or palm-olein (a fraction of palm oil). Final body weight was not influenced by fat level or type; however, percent carcass lipid and fat pad weight were higher in soybean oil and tallow fed rats than in low fat and palm-olein fed rats. Fat pad specific increases in cell size and cell number were observed for tallow and soybean oil fed compared to low fat and palm-olein fed rats. Serum triglycerides were higher in the tallow and palm-olein fed rats compared to low fat fed rats; no significant effects of dietary fat type on serum cholesterol were observed. These results indicate that palm-olein, unlike tallow and soybean oil, were comparable to a low fat diet concerning fat pad weight, body composition and adipose tissue cellularity when fed for twelve weeks as 65% of energy intake. The lower fat storage in the palm-olein fed rats is perhaps associated with a slower rate of triglyceride uptake and/ or a reduced fat cell proliferative capacity. The influence of dietary fat type on the proliferative capacity of the pre-adipocytes and on the production of a local or systemic adipogenic factor is being determined in subsequent studies.

Key words: Palm oil, fat cell sizes, fat cell number, rats

Introduction

Obesity is associated with many chronic diseases and alterations in physiologic function including cardiovascular disease, hypertension, diabetes mellitus, gallbladder disease and certain types of cancer[1]. Obesity is a major public health problem in the United States and Europe and is becoming increasingly important in many other areas of the world[2]. The prevalence of obesity in adults in the U. S. has increased by 30% or more in the past decade, with increases in both genders and in all ethnic and racial populations and age groups[3]. It is now estimated that over one third of the adult population in the US are obese[3]. Obesity is likewise very common in Europe, with a prevalence of considerably greater than 10% based on ninetieth percentile body mass indices[4]. Recent studies indicate a strong correlation between the increasing prevalence of obesity and diet-related chronic diseases in many developing countries including China, Pacific Island populations and Brazil[5-7].

The etiology of human obesity is quite complex, involving genetic, metabolic, behavioral and environmental factors. Although obesity is believed to have a strong genetic component[8], the increased incidence of obesity in specific population groups undergoing Westernization indicates the importance of dietary and lifestyle changes in the manifestation of this disease[5,6]. Among dietary factors, both total energy intake and fat intake are significantly correlated with body mass index in these population groups[5]. However, increased intake of fat energy is associated with a greater per unit increase in body mass than is increased intake of energy from non-fat sources. Therefore, much attention regarding dietary influences on obesity development or prevention has focused on high fat diets.

Many animal studies have confirmed that high fat feeding leads to an expansion of adipose tissue mass through an increase in fat cell size and/or number and to the subsequent development of obesity[9-15]. Hyperphagia[9,10] and decreased energy expenditure (via changes in diet induced thermogenesis)[11] are believed to be contributing factors to the development of high fat diet induced obesity, while changes in adipose tissue cellularity influence the reversibility of this condition[12,13]. It is thought that once the peak capacity for storing lipid is reached in high fat fed animals, increases in fat cell number are triggered[12]. These changes in fat cell number are permanent, as substitution of the high fat diet with a low fat diet leads to a reduction in body weight and fat cell size but not in fat cell number[12,13]. Recent evidence indicates that changes in adipose cellularity during the development of obesity in high fat fed rats may be associated with the appearance of a locally produced factor(s) capable of stimulating adipose cell proliferation[16].

There is little definitive information on the effect of type of dietary fat on adipose tissue cellularity and the development of obesity. Alterations in dietary fat type have been shown to influence membrane composition, function and metabolic processes in many tissues[17-27]. Kirtland *et al*[14] observed that long-term feeding of high fat diets (20%) containing beef drippings vs. maize oil had no influence on body weight gain or adipose tissue cellularity in guinea pigs. More recently, Shimomura *et al*[28] reported a decreased accumulation of body fat in rats fed safflower oil vs. beef tallow

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associated with similar weight gain throughout the dietary treatment. In contrast, Pan *et al*[29] observed a decreased weight gain with long-term feeding of high fat diets containing tallow as compared to safflower oil or olive oil. The effect of diet on total body lipid composition was not determined in that study. Both Su and Jones[30] and Hill *et al*[31], reported a reduction in energy accumulation in rats fed fish oil but no differences in energy accumulation between rats fed the other dietary fat types (olive oil vs. beef tallow and lard vs. corn oil, respectively). Shillabeer and Lau[32], reported differences in body and fat pad weights and in fat cell diameter between rats fed different high fat diets as compared to chow-fed rats; however, differences between rats fed various types of dietary fat (beef tallow, safflower oil) were observed only when the diets were fed at restricted levels.

Long-term studies of the effect of different types of dietary fats on the development of obesity have generally not included palm oil, one of the world's most widely consumed oils[33]. Palm oil is a partially saturated oil containing equal amounts of saturated and unsaturated fatty acids. Palm-olein, a modified fraction of palm oil, contains more unsaturated than saturated fatty acids. Recent research indicates that palm oil, unlike other partially saturated dietary fats, does not raise plasma cholesterol levels[34-36]. Palm oil has also been shown to decrease tumor development during cancer-induction in several animal studies[35-37]. Although much research has been done on the potential beneficial effects of palm oil on serum lipids and tumor suppression, there is little information concerning the relationship between palm oil consumption and obesity, another major chronic disease. A few studies have reported no differences in final body weight[17,38,39] epididymal fat pad weight[17] or fat cell diameter[17] between rats fed palm oil as compared to several other types of dietary fats; however these studies were all of fairly short duration (four weeks or less). This study was undertaken therefore, to determine the effect of longer-term feeding of diets containing high levels of various types of dietary fat, including palm-olein, on lipid accretion and adipose cellularity in Osborne-Mendel rats. In subsequent studies we hope to discern whether variations in lipid accretion associated with the various types of dietary fat are due to alterations in endogenous production of local adipogenic factors.

Methods

Twenty-seven male Osborne-Mendel rats (125g body weight) were purchased from the Genetic Resource Division of NIH (Washington, DC, USA). After a three-day acclimatization period, rats were randomly allocated to one of four diet groups: Low Fat, Soybean Oil, Tallow, or Palm-Olein. The low fat diet contained 15% calories as fat, whereas the three high fat diets contained 65% calories as fat (Table 1). All diets contained 20% calories as protein and adequate vitamins and minerals. Non-lipid diet ingredients were purchased from United States Biomedical Co. (Cleveland, OH; USA). Source and approximate fatty acid composition of fats and oils used in diet formulation are presented in Table 2. Diets were prepared weekly, stored at 4° C and fed *ad libitum*. Body weight and food intake measurements were recorded at least three times weekly. Spillage was taken into account. As problems were experienced with the acceptance of the somewhat liquid high fat diets, the initial diet formulation was modified after one week. Fiber content of the high fat diets was increased to 17.9 g/ 100 g (Table 1). Rats remained on the reformulated diets for an additional eleven weeks. Data from the compositional analysis of diet samples (via bomb calorimetry at the Poultry Research Laboratory, Dept Poultry Sci, University of Georgia, Athens, GA; USA) taken during week seven of the study are also given in Table 1.

During week seven on the study, total daily energy expenditure was determined using a computer controlled indirect calorimeter (OXYMAX, Columbus, Instruments, Columbus, OH; USA). Ten automated open circuit respiration chambers were used to measure air flow using a mass flow controller, carbon dioxide concentrations using an infrared gas analyzer and oxygen concentration using an Oxymax sensor battery. Chamber temperatures were also recorded throughout each 24-hour monitoring period. Average oxygen consumption, average daily carbon dioxide production, respiratory quotient and average heat production were subsequently determined.

Table 1. Composition of the experimental diets.

	Low fat	High fat soybean oil	High fat tallow	High fat palm-olein
	g/ 100 g diet			
Casein	19.5	27.5	27.5	27.5
Cornstarch	53.6	17.5	17.5	17.5
Sucrose	10.0	3.2	3.2	3.2
Fat:				
Soybean oil	6.85	41.8	6.8	6.8
Other	------	------	35.0	35.0
Fiber	5.0	5.0 (17.9)*	5.0 (17.9)*	5.0 (17.9)*
Minerals†	3.5	3.5	3.5	3.5
Vitamins†	1.0	1.0	1.0	1.0
L-Cysteine	0.3	0.3	0.3	0.3
Choline chloride	0.25	0.25	0.25	0.25
Caloric density** (cal/ g)	4389	5941	6191	6028
% dry matter**	93.7	97.7	97.4	97.4

*After 1 week on feeding, high fat diets were reformulated so as to improve texture and acceptability. Fiber was the only component altered. Revised values for fiber and caloric density are given in parenthesis.
†AIN-76 mineral and vitamin mixtures (AIN 1977).
**Compositional analysis of diet samples via bomb calorimetry (Poultry Research Laboratory, Dept Poultry Sci, University of Georgia).

After twelve weeks on the experimental diets, rats were killed by decapitation between 0900 and 1100 hours. Blood was collected, stored on ice and centrifuged at 2500 x g for 30 minutes to obtain serum. Serum was stored at -20° C until used for assay of: total cholesterol (Cholesterol 20 kit #352-20; Sigma Chemical Co, St Louis, MO; USA), triglycerides (Triglyceride-Int kit #336-10; Sigma Chemical Co, St Louis, MO; USA), glucose (Glucose Trinder kit #315-10; Sigma Chemical Co, St Louis, MO; USA) and insulin (^{125}I-Insulin ImmuChem radioimmunoassay kit; ICN Biomedicals, Costa Mesa, CA; USA).

Table 2. Fatty acid composition of the oils and fats used in the experimental diets.

	Soybean oil*	Tallow†	Palm-olein§
	(% of total fatty acids)		
Saturated	14	50	46
Monounsaturated	25	35.7	43
Polyunsaturated	60	14.3	11

Values based on product specifications and compositional analysis data furnished with individual products. *ICN Biochemicals (Cleveland, OH); †Wilsey A/V Fry Shortening (City of Industry, CA); §Fuji Vegetable Oil, Inc (Savannah, GA)

Inguinal, retroperitoneal and epididymal fat pads were dissected completely and weighed. Triplicate samples of each pad (40-60 mg) were taken for cell size and number analysis. The samples were rinsed thoroughly with isotonic saline, weighed and fixed with osmium tetroxide in 50 mM collidine-HCl buffer as described by Cartwright[40], prior to electronic counting on a Coulter ZM particle analyzer according to the method of Hirsch and Gallian[41]. Use of this technique allowed determination of both cell size distribution and total fat pad cell number.

Table 3. Food intake and body weight gain of Osborne-Mendel rats fed a low fat diet or one of three high fat diets for 12 weeks.

	Low-fat	High fat soybean oil	High fat tallow	High fat palm-olein
Initial body weight (g)	141 ± 3.8	138 ± 3.5	138 ± 3.5	137.5 ± 3.5
Body weight gain (g)	299 ± 11	322 ± 10.2	315 ± 10.2	306 ± 10.2
Total food intake (g)	1781 ± 39[a]	1193 ± 36[b]	1310 ± 36[b]	1181± 36[b]
Total food intake (Kcal)	7816 ± 215[a]	7086 ± 199[b]	8112 ± 199[a]	7120 ± 199[b]
Estimated digestible energy (Kcal)	7042 ± 176[a]	5678 ± 163[b]	6323 ± 163[c]	5605 ± 163[b]

Values represent least squares mean ± SEM for 6-7 rats per diet group. Estimated digestible energy intake for the 12 week dietary period is based on digestible dry matter determinations of 90.10, 80.12, 77.95 and 78.73% for the low fat, soybean oil, tallow and palm-olein diets, respectively. Values within a row with different superscripts are significantly different ($p < 0.05$).

Table 4. Energy expenditure parameters of Osborne-Mendel rats fed a low fat diet or one of three high fat diets.

	Low-fat	High fat soybean oil	High fat tallow	High fat palm-olein
Oxygen consumption (Liter/ day)	10.1 ± 0.76	10.7 ± 0.7	10.1 ± 0.7	10.6 ± 0.7
CO_2 production (Liter/ day)	9.4 ± 0.7	8.4 ± 0.66	7.7 ± 0.66	8.3 ± 0.66
CO_2/ O_2 (Respiratory Quotient)	0.93 ± 0.16[a]	0.78 ± 0.15[b]	0.76 ± 0.15[b]	0.78 ± 0.15[b]
Heat production (kcal/ day)	50 ± 3.8	51 ± 3.5	48 ± 3.5	51 ± 3.5

Measurements were made over two 24-h periods during week seven of the study. Values represent least squares means ± SEM for 6-7 rats per diet group. Values within a row with different superscripts are significantly different ($p < 0.05$).

Table 5. Body composition of Osborne-Mendel rats fed a low fat diet or one of three high fat diets for 12 weeks.

	Low-fat	High fat soybean oil	High fat tallow	High fat palm-olein
Carcass weight (g)	400 ± 11	413 ± 9.8	407 ± 9.8	398 ± 9.8
Protein (%)	17.5 ± 0.7	16.3 ± 0.65	17.4 ± 0.65	16.6 ± 0.65
Lipid (%)	11.3 ± 0.79[a]	15.1 ± 0.73[b]	14.3 ± 0.73[b]	11.6 ± 0.73[a]
Ash (%)	1.72 ± 0.16[a]	1.13 ± 0.15[b]	1.42 ± 0.15[a]	1.43 ± 0.15[a]
Water (%)	69.4 ± 0.93[a,b]	67.5 ± 0.86[a]	67.1 ± 0.86[a]	70.4 ± 0.86[b]

Values represent least squares means ± SEM for 6-7 rats per diet group. Values within a row with different superscripts are significantly different ($p < 0.05$).

The remainder of the fat pads were returned to the carcass. The carcass (minus the GI tract) was stored for subsequent determination of carcass composition according to the method of Harris and Martin[42]. Briefly, frozen carcasses were autoclaved in individual sealed beakers for one hour at 121°C. When cool, each carcass was ground in a blender with water. The slurry was homogenized and samples of the homogenate taken for water, ash and fat analyses. Water content was determined by the difference in weight of the triplicate aliquots of the homogenate before and after drying to a constant weight (85°C for 48 hours). Ash was analyzed by subsequent ashing of the same samples in a furnace at 600°C for 12 hours. Additional aliquots of homogenate were analyzed for lipid content. Lipid was determined gravimetrically after extraction of the homogenate with chloroform:methanol and evaporation of the extract to a constant weight. Protein was estimated by subtracting the weight of lipid and ash from that of the dry matter.

Statistical Analysis

The effect of diet treatment on food intake, body weight gain, energy expenditure, body composition, and adipose tissue cellularity was determined on a personal computer using the SuperANOVA program (Abacus Concepts, Berkeley, CA; USA). Comparison between the means was accomplished using the Least Squares Means procedure[43]. Differences were considered statistically significant at the $p < 0.05$ level.

Results

As shown in Table 3, body weight gain throughout the twelve week period of *ad libitum* feeding was unaffected by either the level or type of dietary fat. Cumulative food intake, on a per gram basis, was significantly greater in the low fat fed group as compared to the three high fat fed groups. However, after correction for differences in the caloric density of the diets (given in Table 1) total caloric consumption was significantly greater in the low fat and high fat tallow fed groups as compared to the high fat soybean oil and high fat palm-olein fed groups. Digestibility determinations conducted during week seven of the feeding trial indicated a significantly higher digestiblity of the low fat diet (90.1 ± 0.4% digestible dry matter) as compared to the three high fat diets (80.1 ± 0.5, 78.0 ± 1.5 and 78.7 ± 0.9% digestible dry matter for the soybean oil, tallow and palm-olein diets, respectively). Corrections for differences in digestibility of the various diets resulted in a greater estimated digestible energy intake for the twelve week dietary period for the low fat fed group as compared to the high fat fed groups. Among the high fat fed groups, the estimated digestible energy intake was significantly higher for the tallow fed as compared to the soybean oil and palm-olein fed rats.

Indirect calorimetry for determination of total daily energy expenditure during week seven of the study indicated no significant effect of level or type of dietary fat on daily oxygen consumption, CO_2 production or heat production (Table 4). As expected, the respiratory quotient was significantly higher for the low fat fed rats as compared to the three high fat fed groups. However, there were no differences in respiratory quotient among the three high fat fed groups.

Despite the minimal effects of diet on body weight gain, food intake and energy expenditure, significant differences in carcass composition were observed between the dietary groups (Table 5). An approximate 25-34% increase in carcass lipid was observed in rats fed the high fat soybean oil and tallow diets as compared to those fed the low fat diet. However, percent carcass lipid was not increased in the rats consuming the high fat palm-olein diet for twelve weeks. Carcass protein was similar in all four dietary groups. Percent carcass ash was lower in the rats fed the high soybean oil

Table 6. Fat pad weights and cellularity parameters of Osborne-Mendel rats fed a low fat diet or one of three high fat diets for 12 weeks.

	Low-fat	High fat soybean oil	High fat tallow	High fat palm-olein
Inguinal fat pad				
Fat pad weight (g)	7.35 ± 0.61^{a}	10.42 ± 0.56^{b}	9.36 ± 0.56^{b}	7.71 ± 0.56^{a}
Cells /pad (x 10^6)	18.90 ± 3.11^{a}	30.73 ± 2.88^{b}	22.90 ± 2.88^{ab}	19.08 ± 2.88^{a}
Average cell volume (pl)	153 ± 16.1	160 ± 14.9	178 ± 14.9	135 ± 14.9
Epididymal fat pad				
Fat pad weight (g)	6.83 ± 0.78^{a}	10.11 ± 0.72^{b}	10.47 ± 0.72^{b}	7.96 ± 0.72^{a}
Cells /pad (x 10^6)	16.39 ± 3.31	25.27 ± 3.06	25.58 ± 3.06	22.54 ± 3.06
Average cell volume (pl)	220 ± 12.2^{a}	238 ± 11.3^{a}	215.5 ± 11.3^{ab}	184 ± 11.3^{b}
Retroperitoneal fat pad				
Fat pad weight (g)	5.83 ± 0.88^{a}	9.14 ± 0.81^{b}	8.69 ± 0.81^{b}	5.96 ± 0.81^{a}
Cells /pad (x 10^6)	18.15 ± 3.37	22.09 ± 2.85	14.17 ± 3.07	13.60 ± 3.07
Average cell volume (pl)	204 ± 16.7^{ab}	246 ± 14.1^{a}	234.9 ± 12.0^{a}	178 ± 16.4^{b}

Values represent least squares means ± SEM for 6-7 rats per diet group. Values within a row with different superscripts are significantly different ($p < 0.05$).

Table 7. Serum metabolite and insulin concentrations of Osborne-Mendel rats fed a low fat diet or one of three high fat diets.

	Low-fat	High fat soybean oil	High fat tallow	High fat palm-olein
Total cholesterol (mg/dL)	71 ± 6.3^{a}	90 ± 5.9^{b}	94 ± 5.9^{b}	89 ± 5.9^{b}
Triglycerides (mg/dL)	66 ± 12.33^{a}	$93 \pm 11.4^{a,b}$	23 ± 11.4^{b}	124 ± 11.4^{b}
Glucose (mg/ dL)	126 ± 5.6	126 ± 5.2	141 ± 5.2	143 ± 5.2
Insulin (μU/ mL)	42 ± 9.5	46 ± 8.8	28 ± 8.8	34 ± 8.8

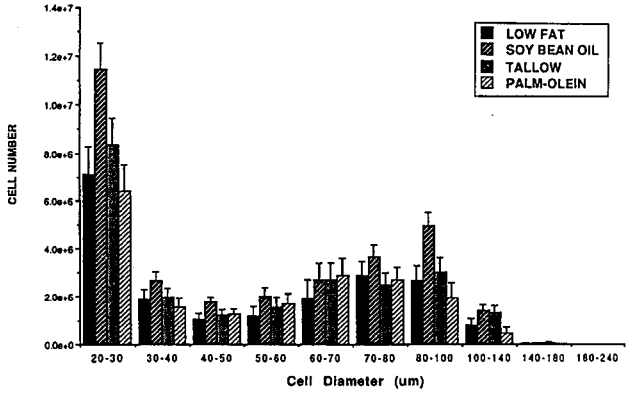
Values represent least squares means ± SEM for 6-7 rats per diet group. Values within a row with different superscripts are significantly different ($p < 0.05$).

diet as compared to the other three dietary groups. Percent carcass water was significantly higher in the high fat palm-olein fed rats as compared to rats fed the other two high fat diets.

Consistent with effects of dietary treatment on total carcass lipid, significantly greater weights of the inguinal, epididymal and retroperitoneal fat pads were observed in rats fed the high fat soybean oil and tallow diets as compared to those fed the low fat or the high fat palm-olein diets (Table 6). Inguinal fat pad weight was increased by 41 and 27% respectively for the high fat soybean oil and tallow fed rats as compared to the low fat fed group. Weights of the epididymal and retroperitoneal fat pads were likewise increased (by 49-57%) in rats fed the high fat soybean oil and tallow diets as compared to the low fat fed controls. The increased fat pad weights were associated with changes in both cell size and number. In the inguinal fat pad, a significant increase in total fat cell number was observed in rats fed the high fat soybean oil diet as compared to the low fat fed controls. This increase was attributed to a greater number of cells in both the smallest (20-30 μm) and in several larger (80-100 and 100-140 μm) size ranges (Figure 1). Average cell size in the inguinal fat pad was greatest for the high fat tallow fed group; however, this was not found to be statistically significant (Table 6). Epididymal fat cell number tended to be increased in the rats fed the high fat soybean oil and tallow diets as compared to the low fat fed controls (P=0.06 and 0.053, respectively). As for the inguinal fat pad, the numbers of cells in both the smallest (<40 μm) and in the 80-140 μm size ranges were greater in the epididymal fat pads of the high fat soybean oil and tallow fed rats as compared to the those of the low fat fed animals (data not shown). In this fat pad, average cell volume was significantly lower in rats fed the high fat palm-olein diet as compared to those fed the low fat or high fat soybean oil diets. No apparent differences in cell number relative to diet-ary treatments were observed for the retroperitoneal fat pad. However, average fat cell size was found to be significantly smaller in retroperitoneal fat pads from the high palm-olein fed rats as compared to those of the other high fat fed groups.

As shown in Table 7, total serum cholesterol concentrations were significantly lower in Osborne-Mendel rats fed the low fat diet for twelve weeks as compared to those fed any of the high fat diets. Serum cholesterol concentrations did not differ according to type of fat fed in the high fat diets. Serum triglycerides were increased approximately two-fold in rats fed the high fat tallow and palm-olein diets as compared to those fed the low fat diet. Serum glucose and insulin concentrations were not influenced by the level or type of fat fed during this twelve-week study.

Figure 1. Cell size distribution in inguinal fat pad of Osborne-Mendel rats fed a low fat diet or one of three high fat diets for 12 weeks. Samples of adipose tissue were fixed in osmium tetroxide and cell size and number were deter-mined by Coulter Counter analysis. Values are least squares means ± SEM for 6-7 rats per diet groups. A significantly greater number of cells were observed in the 20-30 μm and 80-140 μm size ranges for the rats fed the high fat soybean oil diet as compared to the low fat fed controls ($P < 0.05$).



Discussion

Results of this study provide further evidence that the type of fat fed in a high fat diet can influence lipid accretion, adipose tissue cellularity and the development of obesity. Notably, we observed increases in body lipid content and fat pad weight and alterations in adipose tissue cellularity in rats fed for twelve weeks diets containing high levels of either soybean oil or tallow. These

alterations were not observed with long term feeding of high palm-olein diets. Rats fed high levels of palm-olein for twelve weeks maintained a body composition, fat pad weights and adipose tissue cellularity characteristics generally similar to the low fat fed rats.

The apparent "obesity resistance" in the high palm-olein fed rats was unexpected and did not appear to be due to any readily discernible effect of the diet on digestibility, energy intake or energy expenditure. Digestibility determinations conducted during the feeding trial indicated a higher digestibilty for the low fat diet as compared to the three high fat groups. This was primarily due to the increased fiber (Cellufil) in the high fat diets. Digestibilty values for the palm-olein diet, although somewhat lower than those previously reported[44,45], were comparable to those of the other two high fat diets. Estimated total digestible energy intake, although somewhat higher in the tallow fed rats, was similar in the soybean oil and palm-olein fed groups which differed considerably in body lipid content. Likewise, daily energy expenditure as determined by indirect calorimetry was similar in the three high fat fed groups. Furthermore, total weight gain during the twelve week feeding trial was similar for all dietary groups, only the composition of gain was altered. The high fat soybean oil and tallow fed rats apparently partitioned more energy to fat storage than did the low fat and high fat palm-olein fed rats.

Measurement of metabolic indices was not included in this study. Therefore, it is difficult to predict the factors responsible for the presumed differences in nutrient partitioning between the various high fat groups. A potential mechanism associated with this effect could be a reduced rate of triglyceride clearance, secondary to reduced lipoprotein lipase activity. Several studies have indicated lower rates of post heparin plasma lipoprotein lipase activity[39,46-48] and an accompanying reduction in triglyceride clearance[39,46,47] in animals fed saturated fat as compared to unsaturated fat diets. Although these studies did not include direct comparisons of the specific dietary fats used in the present study, palm oil was included as the source of fat in two of the previous experiments. Thus, Groot *et al*[46] observed that palm oil triglycerides were catabolized slower than sunflower seed oil triglycerides; while Lai and Ney[39] found that postheparin plasma lipoprotein lipase activity was generally greater and plasma triglyceride concentrations lower with ingestion of corn oil as compared to palm oil. It is unknown whether palm-olein, a modified, less saturated form of palm oil, would behave similar to native palm oil in this regard. In addition, these studies of the influence of dietary fat on lipoprotein lipase activity measured only postheparin plasma lipoprotein lipase activity and not enzyme activity in specific peripheral tissues. Alterations in peripheral tissue enzyme activity would more likely be associated with differences in nutrient partitioning. Furthermore, as body weight and fat pad weights were lowest in the dietary group with the intermediate level of fat saturation, it may seem implausible that the apparent differences in lipid deposition could be explained primarily by alterations in triglyceride clearance secondary to dietary fat-type induced alterations in lipoprotein lipase activity. However, recent evidence indicates that the metabolic effects of dietary triglycerides depend not only on their fatty acid composition but also on the stereochemical configuration of the specific fatty acids on the triglyceride molecule[49,50]. In order to ascertain whether the differences in lipid deposition associated with the various high fat diets may indeed be accounted for by diet-induced alterations in lipoprotein lipase activity, the activity of this enzyme is being measured in selected adipose tissue depots in our on-going studies.

The increased lipid deposition observed with the high fat soybean oil and tallow diets in the present study was somewhat modest (25-35% increase in percent body fat and 27-57% increase in weight of specific fat pads) in comparison to the level of obesity (200-250% increase in carcass lipid) reported in several previous high fat feeding experiments[10-13,51]. These studies were generally conducted for a longer period of time and/or used high fat diets that were prepared by adding lard, vegetable oil or other fat to the standard chow diet. Such diets induced a greater degree of hyperphagia[10,13] than was observed with the semi-purified diets fed in the present study. It is interesting, however, that despite the lack of effect of diet on body weight and moderate influence of dietary fat type on carcass lipid, significant increases in adipose tissue cellularity were observed after only twelve weeks of feeding the high fat soybean oil and tallow diets. This alteration is important in that changes in adipose tissue cellularity are believed to influence the reversibility of the obese state[10,12,13]. Previous studies have observed that the changes in fat cell number induced by high fat feeding were permanent, as substitution of the high fat diets with low fat diets lead to reductions in body weight and fat cell size but not in fat cell number[12,13]. Thus, the increases in the number of cells in the inguinal fat pad of the soybean oil fed rats and in the epididymal fat pad of both the soybean oil and tallow fed rats reported here would be predictive of permanent alterations in adipose tissue cellularity in these models. This would lead to a permanent increase in the capacity for lipid storage and adipose tissue expansion in these animals and could thereby allow for the induction of a greater degree of obesity with longer-term feeding of the high fat diets.

Finally, it was noted that the increases in cellularity observed with the high fat soybean oil and tallow diets were associated with increases in the number of cells in both the smallest (20-30 μm) and in several larger (80-100 and 100-140 μm) size ranges. This observation is consistent with the "critical fat cell size" hypothesis, proposed originally by Faust *et al*[12], which suggests that once the peak capacity for lipid storage or "critical fat cell size" is reached in high fat fed animals the proliferation of adipocyte precursor cells is stimulated, triggering an increase in fat cell number. Though generally accepted, this hypothesis has not been thoroughly tested over the course of obesity development and the proposed "critical" fat cell size has never been defined. However, recent studies in our laboratory have noted increases in the total number of fat cells, associated with a bi-modal increase in number of both small and large cells, in genetic (B. Marques, unpublished data) and diet-induced[16] rat models of obesity. These changes in adipose tissue cellularity were associated with the appearance of a locally produced factor(s) capable of stimulating adipose cell proliferation[16,52]. It is unknown, however, whether or not dietary fat type could influence the endogenous production of such local adipogenic factors and thereby contribute to the alterations in lipid accretion observed with the various types of dietary fat in the present study. This possibility remains the object of our on-going investigations.

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Adipose tissue expansion and the development of obesity: influence of dietary fat type
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脂肪組織增加和肥胖症的形成: 膳食脂肪種類的影響

摘要

最近研究指出成人肥胖症發病率已增至30%，比過去十年爲多。該病發生在所有人種和年齡的男女，肥胖症與許多慢性疾病和生理功能的改變有關，它們包括心血管疾病，高血壓，糖尿病，膽囊病和某些類型的癌症. 膳食對肥胖症的形成和預防大都集中在高脂膳的研究，不少研究證實高脂喂養可使脂肪組織增加，包括脂肪細胞體積增大或數目增加，結果導致肥胖症．至于膳食脂肪種類，特別是棕櫚油對脂肪組織細胞和肥胖症形成的影響的資料不多. 該研究用以鑒定是否不同來源的膳食脂肪對產生肥胖症有不同的效果. 作者用Osborne-Mendel雄鼠爲對象，喂以低脂膳（脂肪占總能量的15%）或高脂膳（脂肪占總能量的65%）12周，高脂膳主要脂肪來源是豆油，動物油或棕櫚油酸甘油酯（一種改良的棕櫚油）. 最后體重不受膳食脂肪種類及水平的影響，但是，喂養豆油及動物油的雄鼠其尸體脂肪百分數和脂肪墊的重量均較低脂膳和棕櫚油酸甘油酯的雄鼠爲高. 作者同時觀察到脂肪墊的脂肪細胞體積和數目均較喂養低脂膳和棕櫚油酸甘油酯的雄鼠增加. 喂養動物油和棕櫚油酸甘油酯的雄鼠血清甘油三酯較喂養低脂膳的雄鼠高. 膳食脂肪種類對血清膽固醇没有明顯影響. 這些結果指出，棕櫚油酸甘油酯與動物油和豆油不同，當喂以占總能量的65%的脂肪12周后，不會影響脂肪墊的重量，身體組成和脂肪組織細胞的改變. 喂養棕櫚油酸甘油酯雄鼠脂肪的儲存減少，也許與甘油三酯的攝取緩慢和/或脂肪細胞增殖力的下降有關. 至于膳食脂肪種類對前脂肪細胞增殖能力和局部或全身脂肪形成因素的影響，有待今后的研究.