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Increased adipose tissue lipolysis after a two-week high-fat diet in sedentary overweight/obese men

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Abstract

Background/Objectives—The purpose of this study was to determine if a high fat diet would result in a higher lipolytic rate in subcutaneous adipose tissue than a lower fat diet in sedentary non-lean men.

Subjects/Methods—Six participants (healthy males: 18-40 yrs old: body mass index 25-37 kg/m²) underwent two weeks on a high-fat or well-balanced diet of similar caloric content (approx. 1600 kcal) in randomized order with a ten-day washout period between diets. Subcutaneous abdominal adipose tissue lipolysis was determined over the course of a day using microdialysis after both two-week diet sessions.

Results—Average interstitial glycerol concentrations (index of lipolysis) as determined using microdialysis were higher following the high-fat diet ($210.8 \pm 27.9 \mu\text{M}$) than following a well-balanced diet ($175.6 \pm 23.3 \mu\text{M}$; $P = 0.026$). There was no difference in adipose tissue microvascular blood flow as determined using the microdialysis ethanol technique.

Conclusions—These results demonstrate that healthy non-lean men who diet on the high-fat plan have a higher lipolytic rate in subcutaneous abdominal adipose tissue than when they diet on a well-balanced diet plan. This higher rate of lipolysis may result in a higher rate of fat mass loss on the high-fat diet; however, it remains to be determined if this higher lipolytic rate in men on the high-fat diet results in a more rapid net loss of triglyceride from the abdominal adipose depots, or if the higher lipolytic rate is counteracted by an increased rate of lipid storage.

Keywords

blood flow; glucose; fatty acids; glycerol; insulin; ketones; microdialysis

INTRODUCTION

Obesity is a severe growing problem in the United States. From 1976 to 2000, the incidence of obesity in adults has skyrocketed from 15 to 31 percent. These individuals are at high risk for heart disease, diabetes, and other health related issues. Seshadri et al. suggested that both environment and genetics play a role in this growing epidemic. Abundant resources and “office” jobs have exacerbated the problem. The United States is not alone in this dilemma. In Asia, developing nations are beginning to see the rise of obesity (Seshadri P & Iqbal, 2006). Many attempts have been made to address this rise in obesity, with diet and exercise being the commonly recommended solutions (Melanson K et al, 2004).

In today’s hectic society, time is too often not allotted for exercise. Dieting is therefore often chosen by many individuals as the only practical means of addressing obesity. There are a variety of diets that are readily available to the general public. Popular diets for reducing caloric intake include low-fat diets, very-low fat diets, moderate-fat/ low-calorie diets, and low-carbohydrate/ high-protein diets (Baker B, 2006).

The most common traditional diet emphasizes limiting of fat consumption to 20%-30% of daily caloric intake. The majority of daily calories consumed are therefore from carbohydrates (Baker B, 2006). Most of these diets involve increased consumption of fruits, vegetables and whole grains while limiting foods high in saturated fat and simple sugars (Burke V et al, 2007). The alternative diet plan is a low carbohydrate diet (LCD) in which consumption of carbohydrates is restricted, typically to 20-60 g. The majority of caloric intake is therefore from fats and lipids (Last & Wilson, 2006).

There is some indication that fatty acids, such as those derived from dietary fats, can directly alter lipolysis within adipose tissue. Beta adrenergic receptor (β -AR) stimulation by catecholamines, most notably epinephrine and norepinephrine, results in increased intracellular cAMP levels, ultimately increasing lipolysis. Conversely, α 2-adrenergic receptors (α 2-ARs) act in opposition to β -ARs in the presence of catecholamines. Adipocytes predominantly express α 2-ARs over β -ARs, resulting in suppressed lipolysis under resting conditions. Gesta. et al. (2001) have shown that free fatty acids act to inhibit α 2-AR activity, thereby increasing lipolysis, although the mechanism for this is not entirely known. Surprisingly, the effect of diet composition on in-vivo lipolysis is poorly understood, despite the importance of fatty acids released from subcutaneous adipose tissue on whole body substrate use (Gesta S et al, 2001).

The purpose of this study was to determine if a high fat diet would result in a higher lipolytic rate in subcutaneous adipose tissue than a lower fat diet in sedentary men. The diets compared were two weeks of either a well-balanced diet or a high fat, high protein diet of similar caloric content. It was hypothesized that lipolysis, as indicated by interstitial glycerol concentrations, would be higher during a high fat diet than a well-balanced diet. Local blood flow was also monitored to verify that any differences in interstitial glycerol were not due to differences in blood flow.

METHODS

Participant characteristics

Participants were selected with the criteria of being sedentary (no purposeful exercise training or continuous exercise >1 time per week for >20 min per session as determined by questionnaire) healthy non-lean males ages 18-40 with body mass indices of >25 kg/m² and no prior history of diabetes, kidney, liver disease or cardiovascular disease.

General Protocol

Participants randomly underwent a two-week regimen of either the high-fat or well-balanced diets. Following a one-week washout period, participants underwent a two-week period on the second diet regime. Abdominal subcutaneous adipose tissue lipolysis and microvascular blood flow were determined with a 20-24 hour microdialysis procedure under free-living conditions performed at the end of each two-week diet.

Anthropometric and resting blood pressure measurements were conducted on each participant before and at the end of each two-week diet period. Participants were asked to remove their shoes for a height measurement using a wall mounted stadiometer (Perspective Enterprises, Portage MI). Weight was recorded on a floor scale (Cardinal 708, Cardinal Scale Manufacturing Company). Participants' blood pressure was recorded to the nearest 2 mmHg using a stethoscope and sphygmomanometer. Participants' skinfold thicknesses were then measured with a Harpenden calipers at seven different anatomical sites (Chest, Mid-Axillary Line, Triceps, Subscapular, Abdominal, Suprailiac, and Thigh) (American College of Sports Medicine, 2005). Body composition was calculated (BodyComp32: version 2.235, copyright 1996-2003) using the Siri equation. The participants then began the first randomly assigned diet.

Dietary Guidelines and Records

Dietary information, designed and approved by a registered dietitian, was provided to each participant to serve as guidelines for recording nutrient intake during each of the diets. The high-fat diet was chosen as the low carbohydrate diet due to the popularity and relative simplicity of the diet. A well-balanced diet based on the USDA's Food Guide Pyramid was selected for the lower-fat diet. Diets were recorded by the participants 2 days before the microdialysis days as well as on microdialysis days. Dietary data were entered into Nutritionist Pro (version 3.040, 2007 Axxya Systems) to calculate macronutrient intake.

Preparation of Microdialysis Probes

The two microdialysis probes (CMA-20; PAES Membrane; 10 mm in length, CMA/Microdialysis AB, Stockholm Sweden) were placed in 70% Isopropyl Alcohol (Cumberland SWAN, Smyrna TN) for twenty minutes and rinsed two times, then stored overnight in sterile deionized water (B Braun Medical Inc., Irvine, CA) to remove any glycerol present on the dialysis membranes.

Microdialysis Procedure

Participants rested in a supine position on a bed for the microdialysis probe insertions. A split catheter over an 18G 1 ½ angiocatheter (Becton Dickinson & CO., Franklin Lakes, NJ) was inserted into the subcutaneous abdominal adipose tissue immediately after the skin was temporarily anesthetized using ethyl chloride cold spray (Gebauer Company, Cleveland, OH). The catheter needle was removed and a microdialysis probe was then placed through the split catheter into the participant's subcutaneous adipose tissue approximately 0.5-1.0 cm below the skin surface. A second probe was placed in a similar manner in the adipose tissue on the contralateral side of the abdomen approximately 3-5 cm from the umbilicus. Probes were fastened in place using an adhesive strip and were covered by a clear, sterile bandage (Steri-strip and Tegaderm: 3M Health Care, St. Paul, MN).

Probes were perfused with 0.9% Sodium Chloride containing 10 mM ethanol using CMA pumps (CMA 107, CMA/Microdialysis, Acton, MA) with a flow rate of either 2.0 μ L/min (for blood flow monitoring) or 0.3 μ L/min (for interstitial glycerol determination: The in-vivo recovery of glycerol, and ethanol, is nearly 100% at 0.3 μ L/min). After an hour of

equilibration, baseline dialysate samples were collected for one hour. Participants were then allowed to eat breakfast and go about their normal daily activities. Participants were instructed to change the vials every hour and to write down their food and beverage intake as well as any physical activity during the microdialysis sampling over the ensuing 24-hour period. No samples were collected during the night when the participants were sleeping, but probe perfusion continued overnight and a nighttime dialysate sample was collected in the morning upon awakening. Dialysate and perfusate samples were stored at 0 °C until analysis for ethanol (Hickner et al, 1992) and for glycerol (CMA/600 automated analyzer: Stockholm, Sweden)

Blood Collection and Analysis

Blood was drawn from an antecubital vein into six vacutainers containing either lithium heparin, K2 EDTA, or SST clot activator (Becton Dickinson & CO., Franklin Lakes, NJ). Vacutainers were rotated 7 times for mixing. The heparin and K2 EDTA vials were placed on ice. The SST vacutainer was left at room temperature for 20 minutes during clotting. All of the vacutainers were then centrifuged at 2500 * g for 15 minutes. Serum or plasma was removed and placed into cryovials for storage at -80 degrees C until analyzed.

β -hydroxybutyrate concentrations were determined in plasma using a β -hydroxybutyrate assay kit (β -hydroxybutyrate Reagent Set, Pointe Scientific, Inc. Brussels, Belgium). Plasma insulin was determined with a paramagnetic particle, chemiluminescent immunoassay (Access Immunoassay System, Beckman Coulter, Fullerton, CA). Plasma lactate and glucose were determined using an oxidation reaction (YSI model 2300 Stat Plus, Yellow Springs Instruments, Yellow Springs, OH) (Hittel et al, 2005). Insulin sensitivity and resistance was calculated from plasma insulin and glucose data according to the Homeostasis Model Assessment (Mathews et al., 1985).

Serum samples for lipid profile (total cholesterol, triglycerides, and high density lipoprotein cholesterol) determination were sent to a certified analytical laboratory (Labcorp, Greenville NC) for analysis.

Statistics

Blood measures as well as 24-hour, prandial, and sedentary dialysate glycerol concentrations and ethanol outflow/inflow ratios were analyzed for significant differences between diet treatments using Student paired t-tests. Weight, BMI and percent fat data were analyzed using a two-way, treatment (HF and BAL) by time (pre and post) repeated measures ANOVA. Significance was further evaluated using Student Newman Keuls' post hoc analysis. Data are presented as mean and SEM.

RESULTS

Participant Characteristics

Participant weight, body mass index and percent fat are presented in Table 1. There were no differences between the groups before the weight loss in any of these parameters. There was a significant decrease in body weight in the high fat diet group and a trend ($P=0.08$) for weight loss in the balanced diet group. There was also a trend ($P=0.08$) for a decrease in body fat in the high fat diet group in response to the diet period.

Diet Analysis

Dietary data are presented in Table 2. Participants' overall daily caloric consumption was not different on the high-fat and well-balanced diets. Daily carbohydrate intake was higher during the well-balanced than high-fat diet ($P=0.003$). Total fat and protein intake was

higher in participants during the high-fat than well-balanced diet condition ($P = 0.025$). Daily total fiber intake was lower during the high-fat than during the well-balanced diet condition; however, the daily soluble fiber intakes did not vary with the diet condition.

Dialysate Glycerol Data

The average dialysate glycerol concentration (reflective of actual interstitial glycerol concentration at 0.3 $\mu\text{l}/\text{min}$) over 24 hours from probes perfused at 0.3 $\mu\text{l}/\text{min}$ was $210.8 \pm 27.9 \mu\text{mol}/\text{L}$ at the end of the high-fat diet. The average dialysate glycerol concentration over 24 hours was $175.6 \pm 23.3 \mu\text{mol}/\text{L}$ at the end of the well-balanced diet ($P = 0.026$ balanced vs High-fat). Participants' average dialysate glycerol concentration from probes perfused at 2.0 $\mu\text{l}/\text{min}$ was $70.3 \pm 9.5 \mu\text{mol}/\text{L}$, while the average concentration for the well-balanced diet was $56.3 \pm 9.1 \mu\text{mol}/\text{L}$ ($P=\text{N.S.}$; Table 3 and Fig. 1).

During consumption of food by participants on the high-fat diet, the average dialysate glycerol concentration from probes perfused at 0.3 $\mu\text{l}/\text{min}$ was $159.8 \pm 33.5 \mu\text{mol}/\text{L}$. The corresponding value for participants on the well-balanced diet was $149.4 \pm 24.4 \mu\text{mol}/\text{L}$ ($P = 0.54$ vs high-fat). During consumption of food by participants on the high-fat diet, the average dialysate glycerol concentration from probes perfused at 2.0 $\mu\text{l}/\text{min}$ was also not different (high-fat: $58.8 \pm 9.37 \mu\text{mol}/\text{L}$; well-balanced: $48.3 \pm 8.8 \mu\text{mol}/\text{L}$; $P = 0.68$; Table 3).

During the sedentary, non-eating periods (non-active/no caloric consumption) of the day, dialysate glycerol concentration from probes perfused at 0.3 $\mu\text{l}/\text{min}$ was $198.8 \pm 30.6 \mu\text{mol}/\text{L}$ for the high-fat diet, and $147.4 \pm 28.2 \mu\text{mol}/\text{L}$ for the well-balanced diet ($P = 0.012$). During the sedentary periods of the day, dialysate glycerol concentration from probes perfused at 2.0 $\mu\text{l}/\text{min}$ was $105.54 \pm 34.1 \mu\text{mol}/\text{L}$ for the high-fat diet participants and $53.41 \pm 9.1 \mu\text{mol}/\text{L}$ for the participants on the well-balanced diet ($P = 0.23$; Table 3).

Adipose Tissue Blood Flow

The ethanol outflow/inflow ratio is inversely related to blood flow (Hickner et al, 1992) (Fellander et al, 1996). Average ethanol outflow/inflow ratio over 24 hours from probes perfused at 2.0 $\mu\text{l}/\text{min}$ in participants on the high-fat diet was 0.60 ± 0.05 , compared to 0.70 ± 0.04 in participants on the well-balanced diet ($P = 0.20$). Ethanol data are only presented from dialysate collected from the probe perfused at 2.0 $\mu\text{l}/\text{min}$. The nearly total net movement of ethanol out of the probe over the dialysis membrane into the participant when probes were perfused at 0.3 $\mu\text{l}/\text{min}$ prohibited measurement of an accurate outflow/inflow ratio at 0.3 $\mu\text{l}/\text{min}$.

Blood Metabolites

Blood metabolite data are presented in Table 4. There were no differences in glucose, insulin, B-hydroxybutyrate, or blood lipids at the end of a two-week period on the high-fat diet as compared to the well-balanced diet. There were trends ($P=0.07$) for a higher B-hydroxybutyrate and a lower insulin resistance following the high-fat diet.

DISCUSSION

We investigated if lipolytic rate is higher in subcutaneous adipose tissue of sedentary males when they consume a high-fat diet as compared to a well-balanced diet. The present data suggest that interstitial glycerol concentrations are indeed higher in the absence of any difference in adipose tissue blood flow in sedentary overweight males on the high-fat diet as compared to the well-balanced diet. This is the first report of a higher in-vivo lipolytic rate

in subcutaneous adipose tissue in response to a higher fat, low carbohydrate diet as compared to a balanced diet over the course of a day.

The primary measure in the present study was lipolysis as determined using microdialysis measures of interstitial glycerol and local adipose tissue nutritive blood flow. The average interstitial glycerol concentration over the course of the day from probes perfused at 0.3 $\mu\text{l}/\text{min}$ was higher when participants were on the high-fat diet as compared to when they were on the well-balanced diet. Furthermore, during the portions of the day when participants were sedentary, instead of ambulatory, interstitial glycerol concentrations from probes perfused at 0.3 $\mu\text{l}/\text{min}$ were also higher during the high-fat diet than during the balanced diet. Although dialysate glycerol concentration from probes perfused at 2.0 $\mu\text{l}/\text{min}$ (Table 3) were not significantly different, the 0.3 $\mu\text{l}/\text{min}$ flow rate provides nearly 100% recovery (Table 3 and Fig. 1), and is therefore a better indicator of actual interstitial glycerol concentration than dialysate from 2.0 $\mu\text{l}/\text{min}$ perfusates flow that we have found to yield approximately 40% recovery. Local adipose tissue blood flow, as monitored by the ethanol clearance from the probe, was not different between the diets. Differences in average interstitial glycerol between the two diet plans were therefore not the result of differences in blood flow that may influence interstitial metabolite concentrations, microdialysis probe recovery, or adipose tissue metabolism. The higher interstitial glycerol concentration with an absence of detectable difference in blood flow indicates that lipolytic rate was higher when the participants were on the high-fat diet plan than when they were on the balanced diet plan. These data do not agree with a previous study (Suljkovicova H et al, 2002), in which it was reported that there was no difference in interstitial glycerol concentration in the fasted or fed resting state in participants ingesting a low carbohydrate as compared to a high carbohydrate diet. The discrepancies in results may be attributable to the durations of the studies. The previous study by Suljkovicova et al. allowed for only 5 days on each diet, whereas in the present study participants consumed each diet for 14 days.

The dialysate glycerol data presented in Figure 1 demonstrate the time course of differences in mean changes over the day. It should be noted that interstitial glycerol may not only reflect the overall rate of lipolysis, but may instead be the net result of triglyceride and glycerol metabolism and thus reflect net glycerol turnover. However, there are interesting trends in glycerol (Fig. 1) that warrant discussion. It can be seen that there are reductions in lipolysis with the well-balanced diet during and following first meal and the evening meal. This suppression of lipolysis, likely due to the insulin response to the ingested (high carbohydrate) meal, was not apparent in the high-fat diet condition. The higher total daily lipolysis with the high-fat diet is therefore not due to an increased lipolysis, but due to a reduced suppression of lipolysis following meals. There is therefore likely an insulin resistance with respect to suppression of lipolysis following 14 days of a high-fat diet. We have previously reported a reduced suppression of lipolysis in obese as compared to lean women (Hickner et al. 1999). However, there does not appear to be insulin resistance with respect to glucoregulation in the high-fat diet condition in the current study: the HOMA-calculated insulin resistance tends to be lower in the high-fat than in the well-balanced diet condition.

Caloric Content of the diets

There was no significant difference in caloric intake when comparing the high-fat and well-balanced diets; however, the participants consumed fewer calories during the diet period than was needed to maintain weight stability. This factor likely contributed to the weight loss seen in both groups. Differences in weight loss between the two diets were not due to differences in caloric intake, as caloric intake during both diets was similar. It is likely that the larger weight loss on the high-fat than the well-balanced diet was due to a greater water loss on the high-fat diet, as has been previously demonstrated (Seshadri P & Iqbal, 2006).

Macronutrient Diet Composition

Participants on the high-fat diet consumed a higher quantity of total fat than participants on the well-balanced diet, although saturated fat intake was not significantly different between the two diets. Protein consumption was higher on the high-fat diet. It has been proposed that higher levels of protein and fats in a low carbohydrate diet (LCD) contribute to a greater “satiety” effect than a traditional balanced diet; resulting in a lower caloric intake in dieters consuming a LCD as compare to a balanced diet (Seshadri P & Iqbal, 2006). In the present study, however, total caloric intakes on the two diets were not different from one another (Table 2). The limitation of the present study in this respect is that the nutrient intakes were self-reported, although the data indicate that percentage of fat and protein in the diet did not have a large effect on caloric intake in the present study. The timing of the morning meal did appear to be diet dependent, as the first meal of the day was consumed on the high-fat diet 30-120 minutes later than when participants were on the well-balanced diet. Dinner, however, was consistently consumed at a similar time of day regardless of the diet type.

Blood Metabolite Data

Our plasma data demonstrated that there were no difference in fasting plasma insulin, glucose, and lactate on the high-fat diet as compared to the well-balanced diets in our participants. This was contrary to previous research that showed individuals on a LCD exhibited lowered plasma insulin and glucose (Noble & Kushner, 2006) (Yancy et al, 2004). The previous studies were conducted over a much longer timeframe than our study and on a greater number of participants. The insulin resistance results from our study, though not statistically significant, demonstrate that a LCD may induce higher insulin sensitivity, as suggested in previous studies (Mavropoulos et al, 2005). A limitation of the present study is that plasma catecholamines were not measured. Local catecholamine concentration in the adipose tissue could alter lipolytic rate, but if the higher lipolytic rate in the high-fat diet condition was due to a higher catecholamine concentration, the higher catecholamine concentration in the high-fat diet condition would be expected to reduce, not enhance, insulin sensitivity.

There was no difference between the two diets with respect to fasting serum triglycerides, HDL, and total cholesterol levels. We were not able to verify the lipid profile improvements shown in other studies with longer-term dietary intervention, likely due to the relatively short duration of our study (Rosenfeld, 2007). It appears that there is a rapid alteration in lipid metabolism with respect to lipolysis, and fat oxidation, but a diet duration longer than two weeks is needed for alterations in fasting HDL and total cholesterol.

Conclusion

It can be concluded from this study that over a two-week period, the high-fat diet induces a higher rate of lipolysis than a well-balanced diet in subcutaneous abdominal adipose tissue of sedentary overweight adult males. The higher rate of lipolysis over a one-day cycle is most evident during the post-prandial, fasting and sedentary conditions. There is a greater suppression of lipolysis after mealtime in the well-balanced than high-fat diet condition. The effect of diet composition on lipolysis in women, and in depots other than subcutaneous abdominal adipose tissue depots remains to be determined.

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Figure 1.

Comparison between participants' dialysate (nearly equal to interstitial) glycerol concentrations when on the high-fat or Well-Balanced diets. Data are presented as a 24-hour average (overall average), during eating (eating average), and during sedentary periods (sedentary average). Microdialysis probes were placed in the abdominal subcutaneous adipose tissue and perfused at 0.3 µl/min. N= 6,6,6 (* P <0.05; different from well-balanced).

Figure 2.

Comparison between participants' dialysate glycerol concentrations when on the High-fat or Well-Balanced diets. Data are presented as a 24-hour average (overall average), during eating (eating average), and during sedentary periods (sedentary average). Microdialysis probes were placed in the abdominal subcutaneous adipose tissue and perfused at 2.0 µl/min. N= 6,6,6 (* P <0.05; different from well-balanced).

Figure 3.

Comparison between participants' overall interstitial glycerol concentrations over time when on the high-fat and well-Balanced diets. Dialysate samples were collected every hour from microdialysis probes perfused at 0.3 μ l/min and placed in subcutaneous abdominal adipose tissue in non-lean adult males. The first sample was collected the first morning in a fasted state. The second-to-last sample was collected during the overnight period. The final sample was collected the following morning in a fasted state. $P = 0.026$. $N=6,6$

Table 1

Summary of Weight, BMI, and Percent Fat of six non-lean adult males before and after the high-fat (HF) and well-balanced (BAL) diets

	Diet	Before	After	P	CHANGE	P
Weight	HF	93.2 ± 5.8 kg	91.1 ± 5.4 kg *	0.02	2.1 kg	0.47
	BAL	94.1 ± 5.7 kg	92.8 ± 5.8 kg	0.08	1.4 kg	
BMI	HF	29.2 ± 1.6 kg/m ²	30.2 ± 2.1 kg/m ²	0.64	0.94 ± 1.80 kg/m ²	0.60
	BAL	29.2 ± 1.5 kg/m ²	29.1 ± 1.6 kg/m ²	0.32	0.18 ± 0.16 kg/m ²	
% FAT	HF	22.4% ± 2.7%	20.59% ± 2.67%	0.08	1.78% ± 0.82%	0.24
	BAL	21.1% ± 2.4%	21.08% ± 2.75%	0.95	0.05% ± 0.66%	

* Different from before

Table 2

Summary of Plasma Data (insulin, glucose, β -Hydroxybutrate) from six non-lean adult males at the end of a two-week period on either a high-fat diet (HF) or a balanced diet (BAL).

Plasma	Diet	Measurement	P
Insulin	HF	6.72 ± 2.1 uU/ml	0.11
	BAL	15.46 ± 5.6 uU/ml	
Glucose	HF	93.0 ± 4.3 mg/dl	0.31
	BAL	104.7 ± 14.7 mg/dl	
Insulin Sensitivity	HF	$156.03 \pm 38\%$	0.12
	BAL	$129.13 \pm 43\%$	
Insulin Resistance	HF	0.93 ± 0.25	0.07
	BAL	1.72 ± 0.58	
β -Hydroxybutrate	HF	0.901 ± 0.45 mmol/L	0.07
	BAL	0.247 ± 0.05 mmol/L	

Table 3

Summary of Serum (blood lipid) Data from six non-lean adult males at the end of a two-week period on either a high-fat diet (HF) or a well-balanced diet (BAL).

Serum	Diet	Measurement	P
triglyceride	HF	95.67 $\pm$ 13.9 mg/dl	0.35
	BAL	105.00 $\pm$ 18.5 mg/dl	
HDL	HF	42.83 $\pm$ 4.6 mg/dl	0.46
	BAL	41.83 $\pm$ 3.7 mg/dl	
Total Cholesterol	HF	169.00 $\pm$ 11 mg/dl	0.56
	BAL	172.83 $\pm$ 14.9 mg/dl	

Table 4

Summary of Plasma Data Insulin, glucose, β -Hydroxybutrate, and blood lipids from six non-lean adult males at the end of a two-week period on either a high-fat diet (HF) or a balanced diet (BAL).

Plasma	Diet	Measurement	P
Insulin (uU/ml)	HF	6.72 $\pm$ 2.1	0.11
	BAL	15.46 $\pm$ 5.6	
Glucose (mg/dl)	HF	93.0 $\pm$ 4.3	0.31
	BAL	104.7 $\pm$ 14.7	
HOMA-%B (%)	HF	156.03 $\pm$ 38	0.12
	BAL	129.13 $\pm$ 43	
HOMA Insulin Resistance	HF	0.93 $\pm$ 0.25	0.07
	BAL	1.72 $\pm$ 0.58	
β -Hydroxybutrate (mM)	HF	0.901 $\pm$ 0.45	0.07
	BAL	0.247 $\pm$ 0.05	
Triglyceride (mg/dl)	HF	95.67 $\pm$ 13.9	0.35
	BAL	105.00 $\pm$ 18.5	
HDL (mg/dl)	HF	42.83 $\pm$ 4.6	0.46
	BAL	41.83 $\pm$ 3.7	
Total Cholesterol (mg/dl)	HF	169.00 $\pm$ 11	0.56
	BAL	172.83 $\pm$ 14.9	