Serum Alanine Aminotransferase Levels Decrease Further With Carbohydrate Than Fat Restriction in Insulin-Resistant Adults

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OBJECTIVE — Although weight loss interventions have been shown to reduce steatosis in nonalcoholic fatty liver disease (NAFLD), the impact of dietary macronutrient composition is unknown. We assessed the effect on serum alanine aminotransferase (ALT) concentrations of two hypocaloric diets varying in amounts of carbohydrate and fat in obese insulin-resistant individuals, a population at high risk for NAFLD.

RESEARCH DESIGN AND METHODS — Post hoc analysis of ALT concentrations was performed in 52 obese subjects with normal baseline values and insulin resistance, as quantified by the steady-state plasma glucose (SSPG) test, who were randomized to hypocaloric diets containing either 60% carbohydrate/25% fat or 40% carbohydrate/45% fat (15% protein) for 16 weeks. The primary end point was change in ALT, which was evaluated according to diet, weight loss, SSPG, and daylong insulin concentrations.

RESULTS — Although both diets resulted in significant decreases in weight and SSPG, daylong insulin, and serum ALT concentrations, the 40% carbohydrate diet resulted in greater decreases in SSPG ($P < 0.04$), circulating insulin ($P < 0.01$), and ALT (9.5 ± 9.4 vs. 4.2 ± 8.3 units/l; $P < 0.04$) concentrations. ALT changes correlated with improvement in insulin sensitivity ($P = 0.04$) and daylong insulin ($P < 0.01$). Individuals with ALT concentrations above the proposed upper limits experienced significant declines in ALT, unlike those with lower ALT levels.

CONCLUSIONS — In a population at high risk for NAFLD, a hypocaloric diet moderately lower in carbohydrate decreased serum ALT concentrations to a greater degree than a higher-carbohydrate/low-fat diet, despite equal weight loss. This may result from a relatively greater decline in daylong insulin concentrations. Further research with histological end points is needed to further explore this finding.

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Nonalcoholic fatty liver disease (NAFLD) is a clinicopathologic syndrome that encompasses a spectrum of conditions ranging from simple hepatic fat (steatosis) to nonalcoholic steatohepatitis (NASH), fibrosis, and end-stage liver disease (1–3). NAFLD affects up to 74% of obese individuals (4,5) and is almost always associated with both hepatic and peripheral insulin resistance (6–9).

There has been recent interest in the optimal diet to reduce the cardiometabolic complications of obesity-associated insulin resistance. As the same population also is at risk of NAFLD, it is of interest to identify the optimal dietary approach to prevent steatosis, the initial lesion, in this group. Furthermore, the development of steatosis per se, even in the absence of fibrosis, may stimulate inflammatory pathways that adversely affect metabolism (10–12), possibly contributing to systemic insulin resistance and risk for cardiovascular disease and diabetes.

Current therapeutic guidelines for NAFLD advocate weight loss as a first-line treatment (13). Although a number of studies (14–17) have demonstrated a reduction in steatosis with weight loss, there are no published studies comparing the relative benefits for NAFLD of a hypocaloric diet that is restricted in fat versus carbohydrate. In this regard, it seems intuitive that a low-fat diet would be preferable to a high-fat diet in preventing or reversing established steatosis. Indeed, the American Heart Association, the American Diabetes Association, and the National Heart, Lung, and Blood Institute all recommend for weight loss a diet with <30% of total calories derived from fat. However, we and others have previously shown that diets enriched in carbohydrate lead to increased circulating insulin concentrations (18,19), which contribute to elevated fasting and daylong triacylglycerol concentrations and lower HDL cholesterol concentrations under isocaloric conditions. Even under weight loss conditions, diets that are lower in carbohydrate and higher in fat have relatively greater benefits on insulin, triacylglycerol, and HDL cholesterol concentrations than similarly hypocaloric, low-fat diets (20–22). We hypothesized that a lower-carbohydrate diet, via greater reductions in daylong insulin concentrations, also may be relatively more effective in reducing intrahepatic fat in the insulin-resistant obese population. This hypothesis is based on the observation that de novo lipogenesis in the liver is increased fourfold in insulin-resistant individuals (23), possibly as a result of insulin stimulation of the transcription factor sterol regulatory binding protein-1c, which regulates expression of lipogenic genes in the liver (24). Thus, we sought to determine, in an obese insulin-resistant population without established liver disease, whether restriction in dietary carbohydrate or fat

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Abbreviations: ALT, alanine aminotransferase; AUC, area under the curve; NAFLD, nonalcoholic fatty liver disease; SSPG, steady-state plasma glucose.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

would yield relatively greater reduction in serum alanine aminotransferase (ALT) concentrations during dietary weight loss.

It has been suggested that the upper limits of normal for serum ALT concentrations set in the 1980s may have been falsely elevated by undiagnosed NAFLD in the reference population (25). A secondary goal of this study was to determine whether ALT values within the current normal limits decrease with weight loss, presumably to truly "normal" concentrations. Insulin-sensitizing thiazolidenedione treatment has been demonstrated to cause a decrease in ALT concentrations in the normal range (26), and we hypothesized that a similar decrease would be seen with weight loss. Thus, we compared change in ALT in those above and below the newly proposed upper limit for the normal range (30 units/l for men and 19 units/l for women) (25).

RESEARCH DESIGN AND METHODS

The study population consisted of 52 apparently healthy, obese, and insulin-resistant individuals, selected on the basis of baseline ALT concentrations in the normal range at our institution (<60 units/l), from a larger group of subjects ($n = 57$) who participated in a weight loss study (20). All participants gave written informed consent, and the protocol was approved by the Stanford University Human Subjects Committee. To determine eligibility, blood frozen at −80°C was sent to the clinical laboratory at Stanford Medical Center for measurement of baseline serum ALT.

Inclusion criteria included BMI 30.0–36.0 kg/m^2, fasting plasma glucose <126 mg/dl, stable body weight, and no preexisting heart disease, anemia, or kidney disease. Subjects with positive viral serology, previously abnormal serum hepatic transaminases, or alcohol use of more than two standard alcoholic drinks per day were excluded.

Insulin-mediated glucose uptake was quantified by a modification (27) of the insulin suppression test, as originally described and validated (28,29). This approach to the quantification of insulin-mediated glucose uptake has been used for >30 years, and the results are highly correlated with the euglycemic-hyperinsulinemic clamp technique (29). Briefly, after a 12-h overnight fast, an intravenous catheter is placed into each of the patient's arms. A 180-min infusion of somatostatin (0.27 μg/m^2 per min), insulin (32 mU/m^2 per min), and glucose (267 mg/m^2 per min) is administered into one arm. Blood is drawn from the other arm at 30-min intervals, increasing to 10-min intervals for the last 30 min of the study, to determine steady-state plasma glucose (SSPG) and insulin concentrations. As steady-state insulin concentrations are similar for all subjects, the SSPG directly measures the subject's ability to dispose of the glucose load. All subjects entering the dietary intervention phase were required to be insulin resistant on the basis of an SSPG concentration ≥180 mg/dl. This level corresponds to the most insulin-resistant third of 490 apparently healthy individuals (30), a cut point that predicts the development of a variety of adverse clinical outcomes (31,32).

Daylong plasma glucose and insulin concentrations were determined, as described previously (33), at hourly intervals before and after two standardized meals given at 8:00 A.M. and noon. Both meals contained (as percentages of total calories) 15% protein, 43% carbohydrate, and 42% fat (<10% saturated fat), with breakfast comprising 20% and lunch comprising 40% of estimated daily caloric requirements. Insulin was measured in a stepwise sandwich enzyme-linked immunosorbent assay procedure on an ES 300 (Boehringer Mannheim Diagnostics). Glucose was measured using the hexokinase method on the Hitachi 747 (Boehringer Mannheim Diagnostics).

Following baseline testing, subjects were randomized to follow a hypocaloric diet containing either 60% carbohydrate/25% fat or 40% carbohydrate/45% fat. Both diets contained 15% protein and 7% saturated fat. American Diabetes Association–modified diabetes exchange lists were used. Choices included complex carbohydrates with high fiber content, lean protein, and low saturated fat. All subjects were encouraged to attempt to consume 25 g of fiber. No glycemic index targets were set. Following 2 h of individualized dietary instruction, meals were prepared at home according to weekly diet plans from the study dietitians. Calorie deficit for both diets was −750 kcal/day, as estimated by the Harris Benedict equation (34) and an activity factor for each subject. Subjects were required to keep a daily food diary, which was reviewed weekly with study dietitians to monitor weight and enhance compliance. Actual macronutrient intake was estimated by FOOD PROCESSOR software (version 8.0; ESHA, Salem, OR) analysis of food diaries. Adjustments in intake were recommended as needed to enhance compliance with assigned diets. Sixteen weeks of a hypocaloric diet was followed

Table 1—*Baseline characteristics and reported macronutrient composition consumed by subjects assigned to a 60 vs. 40% carbohydrate diet*

	60% carbohydrate diet	40% carbohydrate diet	*P*
n	26	26	
Age (years)	54 ± 10	49 ± 11	0.08
Sex (male/female)	14/12	12/14	0.48
Postmenopausal women [*n* (%)]	9 (35)	7 (27)	0.56
Ethnicity (% Caucasian)	92	93	0.89
BMI (kg/m^2)	33.0 ± 2.4	32.3 ± 1.8	0.20
Weight (kg)	95.1 ± 13.0	94.2 ± 12.3	0.80
SSPG (mg/dl)*	227 ± 26	247 ± 47	0.77
AUC glucose (mg · dl^{-1} · 8 h^{-1})*	869 ± 88	852 ± 98	0.53
AUC insulin (μU · ml^{-1} · 8 h^{-1})*	435 ± 439	459 ± 256	0.82
Serum ALT (units/l)	27.0 ± 10.4	29.0 ± 9.5	0.49
Carbohydrate (%)	58 ± 4	42 ± 5	**<0.01**
Protein (%)	18 ± 2	18 ± 2	0.69
Total fat (%)	23 ± 4	39 ± 5	**<0.01**
Saturated fat (%)	8 ± 2	9 ± 2	0.14
Monounsaturated fat (%)	8 ± 2	13 ± 2	**<0.01**
Polyunsaturated fat (%)	4 ± 1	7 ± 2	**0.01**
Fiber (g)	26 ± 6	23 ± 8	0.27
kcal/day	1,699 ± 334	1,595 ± 262	0.24

Data are means ± SD unless otherwise indicated. *P* values were calculated using Student's unpaired *t* tests. Two women in each dietary group were taking hormone replacement therapy. **P* values for variables that are not normally distributed refer to analyses performed with logarithmically transformed data. Data in bold face are statistically significant.

by 2 weeks of weight maintenance, with calorie requirements for each subject recalculated according to their current weight. Following the weight maintenance phase, baseline measurements were repeated.

To test our theory that the current normal range of serum ALT included undiagnosed NAFLD, a secondary analysis was performed. Subjects were divided into two groups, regardless of diet, based on whether their baseline ALT was above ("abnormal") or below ("normal") the cut points suggested by Prati et al. (25). We then compared the decline in ALT in the two groups, with the hypothesis that those with the abnormal ALT at baseline, suggestive of NAFLD, would have a greater decline in serum ALT with the hypocaloric diet.

Results are expressed as means ± SD, unless otherwise stated. Between-group differences in experimental variables were assessed with Student's unpaired *t* tests, whereas within-group changes resulting from the diets were assessed with Student's paired *t* tests. Differences in categorical variables were tested with χ^2 analysis. SSPG, glucose, and insulin area under the curve (AUC) values were log transformed for normality. All other variables were normally distributed. For clarity of presentation, actual values of variables are presented. *P* values were done with log-transformed values as per above. Because of the relatively great number of potential confounders for our sample size, stepwise multiple linear regression models were used for the magnitude of change in each dependent variable (weight and ALT, insulin, glucose, and SSPG concentrations) to assess the independent effect of the dietary group (between-group difference). Potential confounders entered into each model included age, sex, baseline concentration of the dependent variable, and amount of weight lost. In all cases, *P* values <0.05 were considered statistically significant. Analyses were performed using SAS 9.2 and SPPS (version 12).

RESULTS — Twenty-six subjects from each dietary group were eligible for the current analysis. As shown in Table 1, demographic characteristics did not differ significantly between the two groups. Among women, postmenopausal status was not significantly different, and only two women in each group used hormone replacement therapy. There also were no significant differences between the baseline metabolic variables of weight; BMI; and SSPG, plasma insulin, glucose, and ALT concentrations for the two diet groups. Table 1 also details the estimated actual macronutrient composition of meals consumed. Amounts of carbohydrate and total, mono-, and polyunsaturated fats differ significantly between groups.

Both groups experienced a significant decrease in weight (7.0 ± 3.8 kg [$P < 0.001$] vs. 5.7 ± 4.1 kg [$P < 0.001$]) as a result of the dietary intervention (Table 2), but the amount of weight loss did not differ significantly between the two groups. Serum ALT concentrations decreased twice as much in the group assigned to the 40% carbohydrate compared with the 60% carbohydrate diet group (−9.5 ± 9.4 vs. −4.2 ± 8.3; $P < 0.01$). This difference remained statistically significant ($P < 0.02$) after adjusting for baseline ALT concentration, sex, age, and weight loss.

Insulin resistance, as quantified by SSPG, declined significantly in both groups (Table 2). The magnitude of decline was greater in the 40% carbohydrate group, but after adjustment for age, sex, baseline SSPG, and weight loss this difference was not statistically significant. Daylong insulin concentrations declined significantly only in the 40% carbohydrate diet group, and this decline was significantly greater than the decline in the 60% carbohydrate group, even after adjustment for baseline insulin concentration, age, sex, and weight loss. Daylong glucose concentrations did not change significantly in either group.

Based on the proposal that the upper limits of normal for ALT concentrations should be adjusted to be 30 units/l for men and 19 units/l for women (25), we divided our study subjects into those who had baseline ALT concentrations above (abnormal) or below (normal) these proposed alternative cut points. There were no significant differences between the abnormal versus normal ALT groups in terms of age (51 ± 11 vs. 52 ± 10; $P = 0.83$), number of women (64 vs. 42%; $P = 0.14$), postmenopausal status (27 vs. 37%; $P = 0.56$), BMI (32.5 ± 2.6 vs. 32.5 ± 1.9; $P = 0.97$), SSPG (237 ± 38 vs. 234 ± 41; $P = 0.83$), glucose AUC (859 ± 90 vs. 864 ± 98; $P = 0.85$), or insulin AUC (391 ± 164 vs. 534 ± 539; $P = 0.18$), and the mean baseline ALT concentrations for two groups were significantly different (19.5 ± 5.5 vs. 32.9 ± 8.6 units/l; $P < 0.01$). Comparison of the

Table 2—*Change in metabolic variables as a result of hypocaloric dietary intervention in individuals assigned to the 40 vs. 60% carbohydrate diet*

	60% carbohydrate diet (n = 26)				40% carbohydrate diet (n = 26)					
	Prediet	Postdiet	Δ	*P**	Prediet	Postdiet	Δ	*P**	*P*†	*P*‡
Weight (kg)	95.1 ± 13.0	89.4 ± 13.0	−5.7 ± 4.1	<0.01	94.2 ± 12.3	87.1 ± 11.3	−7.0 ± 3.8	0.20	0.20	0.23
ALT units/l	27.0 ± 10.4	22.9 ± 7.7	−4.2 ± 8.3	0.02	29.0 ± 9.5	19.5 ± 4.7	−9.5 ± 9.4	<0.01	<0.01	0.02
SSPG (mg/dl)	226.5 ± 26.4	194.1 ± 42.9	−32.4 ± 40.7	<0.01	246.6 ± 47.2	185.4 ± 67.9	−61.3 ± 52.3	<0.02	<0.02	0.06
AUC insulin ($\mu U \cdot ml^{-1} \cdot 8\ h^{-1}$)	435 ± 439	400 ± 383	−35 ± 115	0.14	459 ± 256	295 ± 180	−164 ± 151	0.03	0.03	0.04
AUC glucose ($mg \cdot dl^{-1} \cdot 8\ h^{-1}$)	869 ± 88	873 ± 87	−4 ± 68	0.75	852 ± 98	826 ± 92	26 ± 76	0.12	0.16	0.74

Data are means ± SD unless otherwise indicated. *Within-group comparison for each diet (paired Student's *t* test). †Unadjusted between-group comparison (unpaired Student's *t* test) of the change in dependent variable. ‡Adjusted for age, sex, baseline concentration of variable, and weight loss (stepwise multiple linear regression analysis).

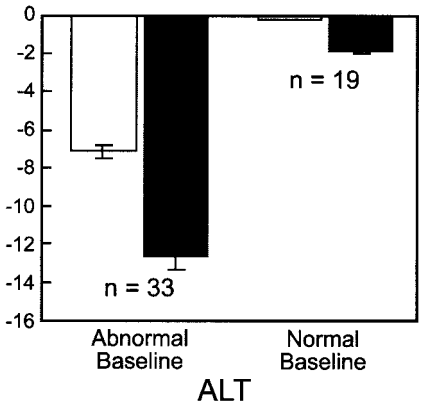

Figure 1—*The change in ALT is shown in the two diet groups divided into those with an abnormal and a normal baseline ALT based on proposed upper limits of 19 units/l for women and 30 units/l for men (24).* $P < 0.01$ *for the decrease in ALT in those with abnormal versus normal ALT at baseline (both dietary groups combined,* n = *52). In the abnormal ALT group* (n = *33),* $P < 0.01$ *for the between-diet comparison of the decrease in ALT after adjustment for age, sex, baseline ALT, and weight loss by stepwise multiple linear regression.* $P = 0.97$ *for the between-diet comparison of the decrease in ALT in the normal baseline group* (n = *19). Carbohydrate diet:* □*, 60%;* ■*, 40%.*

ALT responses of those with abnormal or normal baseline ALT concentrations to the 40 and 60% carbohydrate diets is shown in Fig. 1. Irrespective of dietary macronutrient content, the decline (mean ± SD) in ALT concentrations with weight loss in the 33 subjects with baseline abnormal ALT concentrations was 10-fold greater than in the 19 with normal baseline values (−10.2 ± 9.3 vs. −1.0 ± 5.4 units/l; $P < 0.01$). In addition, in the abnormal baseline ALT group, concentrations fell to a greater degree in those assigned to the 40% carbohydrate diet (n = 18) compared with those on the 60% carbohydrate diet (n = 15) (−12.8 ± 8.8 vs. −7.2 ± 9.1 unit/l; $P < 0.01$ after adjustment for age, sex, baseline ALT, and weight loss). Among those with normal baseline ALT concentrations (n = 19), ALT decreases were −2.0 ± 1.4 vs. −0.8 ± 0.6 units/l ($P = 0.97$) on the 40 and 60% carbohydrate diets, respectively.

CONCLUSIONS — The main finding of this study is that among obese, otherwise-healthy, insulin-resistant individuals, a hypocaloric diet moderately restricted in carbohydrate (40%) and enriched in fat (45%), compared with a traditional low-fat hypocaloric diet (25% fat and 60% carbohydrate), lowers serum ALT concentrations to a significantly greater degree, even after adjustment for amount of weight loss and other potential confounders, including baseline concentration of ALT. Of note, the subjects in our study were selected to have no prior diagnosis of liver disease and baseline ALT concentrations that did not exceed the current upper limit of the normal range. Thus, it is important to consider that even in apparently healthy obese, insulin-resistant individuals, weight loss can reduce ALT concentrations, suggesting that steatosis was present. Furthermore, our study adds to the accumulating data suggesting that among this population at particularly high risk for obesity-related morbidities, hypocaloric diets that differ in macronutrient composition yield different weight loss–related benefits. For example, we and others (20–22,35,36) have previously shown that hypocaloric diets lower in carbohydrate are more effective in reducing triglyceride and increasing HDL cholesterol concentrations, which may be related to relatively greater reductions in insulin concentrations (18,20,21,35,36) as a result of lower dietary carbohydrate intake. Indeed, it is plausible that relatively greater reductions in ambient insulin concentrations in the current study also contributed to the lowering of serum ALT, given that significantly greater reductions were seen on the 40% compared with the 60% carbohydrate diet.

There are several lines of evidence supporting a biological link between insulin concentrations and hepatic steatosis. First, strong correlations have been observed between the degree of hyperinsulinemia and the extent of hepatic steatosis (9,37). Also, in NAFLD, the area of the lobule containing the highest number of steatotic hepatocytes is zone 3, the area closest to portal drainage with the highest concentration of insulin (38). The more insulin resistant an individual, and the higher the daylong insulin and free fatty acid concentrations, the greater is hepatic VLDL-triacylglycerol synthesis and secretion (39–42). Furthermore, ex vivo hepatic perfusion studies have shown that the higher the ambient in vivo insulin concentration, the greater the stimulatory effect of a given increment in perfusate free fatty acid concentrations on hepatic triglyceride synthesis and secretion (43). In regard to ALT, links between glucose-mediated insulin sensitivity and serum ALT have been demonstrated previously (37,44,45). On a molecular level, sterol regulatory binding protein 1, the peroxisome proliferator–activated receptor system, and Fas genes are key transcriptional factors regulated by insulin. In situations of insulin and free fatty acid abundance, such as obesity, insulin binding increases the expression of sterol regulatory binding protein-1c, leading to increased expression of lipogenic genes and a consequent increase in de novo lipogenesis (46). All of these observations support the biologic plausibility of our observation that those assigned to the 40% carbohydrate diet experienced a greater decline in ALT concentrations as a result of greater reductions in ambient insulin concentrations.

Alternatively, there is a growing body of evidence that intrahepatic fat accumulation potentiates insulin resistance via stimulation of inflammatory pathways regulated by nuclear factor-κB (10–12). In this regard, prevention/reduction of early intrahepatic fat accumulation may not only prevent the development of NASH and subsequent cirrhosis in a minority of affected patients but may potentiate improvement in insulin sensitivity and other metabolic parameters.

Baseline ALT concentrations for our subjects did not exceed the upper limit of the normal range (60 units/l), but 63% of subjects had a baseline ALT above that of new, more conservative limits (<19 units/l for women and <30 units/l for men) (25). Our results further support these limits, as individuals with ALT levels above these limits decreased with dietary weight loss, while those below the new upper limits did not. Furthermore, even in this smaller subgroup, the impact of dietary macronutrient composition was statistically significant, with greater reductions in ALT observed in the 40% carbohydrate diet group. Although ALT is not a precise marker of NAFLD, these results suggest that the majority of our subjects did indeed have some degree of steatosis.

Our findings are limited to the obese, insulin-resistant population who *1*) have compensatory hyperinsulinemia and may be more sensitive to variations in dietary macronutrient composition with regard to insulin concentrations and *2*) have a high likelihood of steatosis (5,6,9). Furthermore, our subjects were engaged in dietary weight loss, and, thus, we cannot extrapolate the results of our study to eucaloric diets. We also did not quantify variability in micronutrients consumed, including relative proportions of refined and unrefined carbohydrates, types of carbohydrate, or n-6/n-3 polyunsaturated fats and thus cannot rule out the

possibility that these factors and/or glycemic index or differences in fiber intake in our two study diets had an impact on our results. Finally, we did not quantify hepatic steatosis radiologically or histologically, but given the current findings, it would be reasonable to use more costly and/or invasive studies in this subject pool as well as in those with established steatohepatitis to evaluate the potential benefits of moderate reductions in dietary carbohydrate.

In summary, it appears that a hypocaloric diet moderately restricted in carbohydrate may be beneficial in reducing hepatic steatosis in obese, insulin-resistant adults. Given the ongoing debate as to which macronutrient composition is optimal for reducing health risks associated with obesity, our results demonstrate yet another benefit of a carbohydrate-restricted diet moderately enriched in fat compared with the currently recommended higher carbohydrate diets typically prescribed for weight loss in this population (47–49). Further research is needed to identify the mechanism by which lowering carbohydrate lowers ALT concentrations in patients with steatosis and the relative benefit to those with more advanced NASH.

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References

1. Ludwig J, Viggiano TR, McGill DB, Ott BJ: Nonalcoholic steatohepatitis: Mayo Clinic experience with a hitherto unnamed disease. *Mayo Clin Proc* 55:434–438, 1980
2. Angulo P, Lindor KD: Nonalcoholic liver disease. *N Engl J Med* 346:1221–1231, 2002
3. Clark JM: The epidemiology of nonalcoholic fatty liver disease in adults. *J Clin Gastroenterol* 40 (Suppl. 1):S5–S10, 2006
4. Luyckx FH, Desaive C, Thiry A, Dewe W, Scheen AJ, Gielen JE, Lefebvre PJ: Liver abnormalities in severely obese subjects: effect of drastic weight loss after gastroplasty. *Int J Obes Relat Metab Disord* 22: 222–226, 1998
5. Wanless IR, Lentz JS: Fatty liver hepatitis and obesity: an autopsy study with analysis of risk factors. *Hepatology* 12:1106–1110, 1990
6. Chalasani N, Deeg MA, Persohn S, Crabb DW: Metabolic and anthropometric evaluation of insulin resistance in nondiabetic patients with nonalcoholic steatohepatitis. *Am J Gastroenterol* 98:1849–1855, 2003
7. Seppala-Lindroos A, Vehkavaara S, Hakkinen AM, Goto T, Westerbacka J, Sovijarvi A, Halavaara J, Yki-Jarvinen H: Fat accumulation in the liver is associated with defects in insulin suppression of glucose production and serum free fatty acids independent of obesity in normal men. *J Clin Endocrinol Metab* 87:3023–3028, 2002
8. Tiikkainen M, Tamminen M, Hakkinen AM, Bergholm R, Vehkavaara S, Halavaara J, Teramo K, Rissanen A, Yki-Jarvinen H: Liver-fat accumulation and insulin resistance in obese women with previous gestational diabetes. *Obes Res Sep* 10: 859–867, 2002
9. Bugianesi E, Gastaldelli A, Vanni E, Gambino R, Cassader M, Baldi S, Ponti V, Pagano G, Ferrannini E, Rizzetto M: Insulin resistance in non-diabetic patients with non-alcoholic fatty liver disease: sites and mechanisms. *Diabetologia* 48:634–642, 2005
10. Shoelson SE, Lee J, Goldfine AB: Inflammation and insulin resistance. *J Clin Invest* 116:1793–1801, 2006
11. Arkan MC, Havener AL, Greten FR, Maeda S, Li ZW, Long JM, Wynshaw-Boris A, Poli G, Olefsky J, Karin M: IKK-beta links inflammation to obesity-induced insulin resistance. *Nat Med* 11:191–198, 2005
12. Boden G, She P, Mozzoli M, Cheung P, Gumireddy K, Reddy P, Xiang X, Luo Z, Ruderman N: Free fatty acids produce insulin resistance and activate the proinflammatory nuclear factor-kB pathway in rat liver. *Diabetes* 54:3458–3465, 2005
13. American Gastroenterological Association: Medical position statement: nonalcoholic fatty liver disease. *Gastroenterology* 123:1702–1704, 2002
14. Park HS, Kim MW, Shin ES: Effect of weight control on hepatic abnormalities in obese patients with fatty liver. *J Korean Med Sci* 10:414–421, 1995
15. Palmer M, Schaffner F: Effect of weight reduction on hepatic abnormalities in overweight patients. *Gastroenterology* 99: 1408–1413, 1990
16. Huang MA, Greenson JK, Chao C, Anderson L, Peterman D, Jacobson J, Emick D, Lok AS, Conjeevaram HS: One-year intense nutritional counseling results in histological improvement in patients with non-alcoholic steatohepatitis: a pilot study. *Am J Gastroenterol* 100:1072–1081, 2005
17. Ueno T, Sugawara H, Sujaku K, Hashimoto O, Tsuji R, Tamaki S, Torimura T, Inuzuka S, Sata M, Tanikawa K: Therapeutic effects of restricted diet and exercise in obese patients with fatty liver. *J Hepatol* 27:103–107, 1997
18. Garg A, Bantle JP, Henry RR, Coulston AM, Griver KA, Raatz SK, Brinkley L, Chen YD, Grundy SM, Huet BA, Reaven GM: Effects of varying carbohydrate content of diet in patients with non-insulin-dependent diabetes mellitus. *JAMA* 271: 1421–1428, 1994
19. McLaughlin T, Abbasi F, Lamendola C, Yeni-Komshian H, Reaven GM: Carbohydrate-induced hypertriglyceridemia: an insight into the link between plasma insulin and triglyceride concentrations. *J Clin Endocrinol Metab* 85:3085–3088, 2000
20. McLaughlin TL, Carter S, Lamendola C, Abbasi F, Yee G, Schaaf P, Basina M, Reaven GM: Effects of moderate variations in macronutrient composition on weight loss and cardiovascular risk reduction in obese, insulin resistant adults. *Am J Clin Nutr* 84:813–821, 2006
21. Foster GD, Wyatt HR, Hill JO, McGuckin BG, Brill C, Mohammed BS, Szapary PO, Rader DJ, Edman JS, Klein SA: randomized trial of a low-carbohydrate diet for obesity. *N Engl J Med* 348:2082–2090, 2003
22. Cornier MA, Donahoo WT, Pereira R, Gurevich I, Westergren R, Enerback S, Eckel PJ, Goalstone ML, Hill JO, Eckel RH, Draznin B: Insulin sensitivity determines the effectiveness of dietary macronutrient composition on weight loss in obese women. *Obes Res* 13:703–709, 2005
23. Diraison F, Dusserre E, Vidal H, Sothier M, Beylot M: Increased hepatic lipogenesis but decreased expression of lipogenic gene in adipose tissue in human obesity. *Am J Physiol Endocrinol Metab* 282:E46–E51, 2002
24. Girard J, Perdereau D, Foufelle F, Prip-Buus C, Ferre P: Regulation of lipogenic enzyme gene expression by nutrients and hormones. *FASEB J* 8:36–42, 1994
25. Prati D, Taioli E, Zanella A, Della Torre E, Butelli S, Del Vecchio E, Vianello L, Zanuso F, Mozzi F, Milani S, Conte D, Colombo M, Sirchia G: Updated definitions of healthy ranges for serum alanine aminotransferase levels. *Ann Intern Med* 137:1–10, 2002
26. Cataldo NA, Abbasi F, McLaughlin TL, Basina M, Fechner PY, Giudice LC, Reaven GM: Metabolic and ovarian effects of rosiglitazone treatment for 12 weeks in insulin-resistant women with polycystic ovary syndrome. *Hum Reprod* 21:109–120, 2006
27. Pei D, Jones CN, Bhargava R, Chen YD, Reaven GM: Evaluation of octreotide to assess insulin-mediated glucose disposal by the insulin suppression test. *Diabetologia* 37:843–845, 1994
28. Shen SW, Reaven GM, Farquhar JW: Comparison of impedance to insulin-mediated glucose uptake in normal subjects and in subjects with latent diabetes. *J Clin Invest* 49:2151–2160, 1970
29. Greenfield MS, Doberne L, Kraemer F,

Tobey T, Reaven G: Assessment of insulin resistance with the insulin suppression test and the euglycaemic clamp. *Diabetes* 30:387–392, 1981
30. Yeni-Komshian H, Carantoni M, Abbasi F, Reaven GM: Relationship between several surrogate estimates of insulin resistance and quantification of insulin-mediated glucose disposal in 490 healthy nondiabetic volunteers. *Diabetes Care* 23: 171–175, 2000
31. Yip J, Facchini FS, Reaven GM: Resistance to insulin-mediated glucose disposal as a predictor of cardiovascular disease. *J Clin Endocrinol Metab* 83:2773–2776, 1998
32. McLaughlin T, Abbasi F, Cheal K, Chu J, Lamendola C, Reaven G: Use of metabolic markers to identify overweight individuals who are insulin resistant. *Ann Intern Med* 139:802–809, 2003
33. McLaughlin T, Stuhlinger M, Lamendola C, Abbasi F, Bialek J, Reaven GM, Tsao P: Plasma asymmetric dimethylarginine concentrations are elevated in obese, insulin-resistant women and fall with weight loss. *J Clin Endocrin Metab* 91: 1896–1900, 2006
34. Harris JA, Benedict FG: *A Biometric Study of Basal Metabolism in Man*. Washington DC, Carnegie Institute of Washington, 1919 (publ. no. 279)
35. Boden G, Sargrad K, Homko C, Mozzoli M, Stein P: Effect of a low carbohydrate diet on appetite, blood glucose levels and insulin resistance in obese patients with type 2 diabetes. *Ann Intern Med* 142:403–411, 2005
36. Pelkman CL, Fishell VK, Maddox DH, Pearson TA, Mauger DT, Kris-Etherton PM: Effects of moderate-fat (from monounsaturated fat) and low-fat weight-loss diets on the serum lipid profile in overweight and obese men and women. *Am J Clin Nutr* 79:204–212, 2004
37. Ardigo D, Numeroso F, Valtuena S, Franzini L, Piatti PM, Monti L, Delsignore R, Reaven GM, Zavaroni I: Hyperinsulinemia predicts hepatic fat content in healthy individuals with normal transaminase concentrations. *Metabolism* 54:1566–1570, 2005
38. MacDonald GA, Bridle KR, Ward PJ, Walker NI, Houglum K, George DK, Smith JL, Powell LW, Crawford DH, Ramm GA: Lipid peroxidation in hepatic steatosis in humans is associated with hepatic fibrosis and occurs predominately in acinar zone 3. *J Gastroenterol Hepatol* 16: 599–606, 2001
39. Reaven GM: Compensatory hyperinsulinemia and the development of an atherogenic lipoprotein profile: the price paid to maintain glucose homeostasis in insulin-resistant individuals. *Endocrinol Metab Clin North Am* 34:49–62, 2005
40. Reaven GM, Lerner RL, Stern MP, Farquhar JW: Role of insulin in endogenous hypertriglyceridemia. *J Clin Invest* 46: 1756–1767, 1967
41. Olefsky JM, Farquhar JW, Reaven GM: Reappraisal of the role of insulin in hypertriglyceridemia. *Am J Med* 57:551–560, 1974
42. Jeng C-Y, Fuh MM-T, Sheu WH-H, Chen Y-DI, Reaven GM: Hormone and substrate modulation of plasma triglyceride concentration in primary hypertriglyceridemia. *Endocrinol Metab* 1:15–21, 1994
43. Reaven GM, Mondon CE: Effect of in vivo plasma insulin levels on the relationship between perfusate free fatty acid concentration and triglyceride secretion by perfused rat livers. *Horm Metabol Res* 16: 230–232, 1984
44. Wang CH, Leung CH, Liu SC, Chung CH: Safety and effectiveness of rosiglitazone in type 2 diabetes patients with nonalcoholic fatty liver disease. *J Formos Med Assoc* 105: 743–752, 2006
45. Burgert TS, Taksali SE, Dziura J, Goodman TR, Yeckel CW, Papademetris X, Constable RT, Weiss R, Tamborlane WV, Savoye M, Seyal AA, Caprio S: Alanine aminotransferase levels and fatty liver in childhood obesity: associations with insulin resistance, adiponectin and visceral fat. *J Clin Endocrinol Metab* 91:4287–4294, 2006
46. Foufelle F, Ferre P: New perspectives in the regulation of hepatic glycolytic and lipogenic genes by insulin and glucose: a role for the transcription factor sterol regulatory element binding protein-1c 4. *Biochem J* 366:377–391, 2002
47. American Diabetes Association: Nutrition principles and recommendations in diabetes. *Diabetes Care* 27 (Suppl. 1):S36–S46, 2004
48. American Heart Association: Dietary guidelines, revision 2000. *Circulation* 102: 2284–2299, 2000
49. National Institutes of Health, National Heart, Lung, and Blood Institute: Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: the evidence report. *Obes Res* 6 (Suppl. 2):51S–209S, 1998