

## Human Nutrition and Metabolism

### Reduced Glycemic Index and Glycemic Load Diets Do Not Increase the Effects of Energy Restriction on Weight Loss and Insulin Sensitivity in Obese Men and Women<sup>1,2</sup>

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**ABSTRACT** Reducing the dietary glycemic load and the glycemic index was proposed as a novel approach to weight reduction. A parallel-design, randomized 12-wk controlled feeding trial with a 24-wk follow-up phase was conducted to test the hypothesis that a hypocaloric diet designed to reduce the glycemic load and the glycemic index would result in greater sustained weight loss than other hypocaloric diets. Obese subjects ( $n = 29$ ) were randomly assigned to 1 of 3 diets providing 3138 kJ less than estimated energy needs: high glycemic index (HGI), low glycemic index (LGI), or high fat (HF). For the first 12 wk, all food was provided to subjects (feeding phase). Subjects ( $n = 22$ ) were instructed to follow the assigned diet for 24 additional weeks (free-living phase). Total body weight was obtained and body composition was assessed by skinfold measurements. Insulin sensitivity was assessed by the homeostasis model (HOMA). At 12 wk, weight changes from baseline were significant in all groups but not different among groups ( $-9.3 \pm 1.3$  kg for the HGI diet,  $-9.9 \pm 1.4$  kg for the LGI diet, and  $-8.4 \pm 1.5$  kg for the HF diet). All groups improved in insulin sensitivity at the end of the feeding phase of the study. During the free-living phase, all groups maintained their initial weight loss and their improved insulin sensitivity. Weight loss and improved insulin sensitivity scores were independent of diet composition. In summary, lowering the glycemic load and glycemic index of weight reduction diets does not provide any added benefit to energy restriction in promoting weight loss in obese subjects. *J. Nutr.* 135: 2387–2391, 2005.

**KEY WORDS:** • *glycemic index* • *glycemic load* • *homeostasis model assessment (HOMA)*  
• *insulin sensitivity*

Overweight and obesity are the leading nutrition-related disorders in the United States today. Obesity is a highly prevalent and serious health condition, contributing to a cascade of chronic diseases (1). The 1999–2000 National Health and Nutrition Examination Survey (2) estimated that 64% of the adult population was overweight, and 30.5% were classified as obese according to standards set by the Expert Panel on Obesity (3). Although a variety of educational programs emphasizing dietary restriction and increased physical activity are available, weight loss is characteristically modest and transient (4). This failure may be attributable to the ineffectiveness of lifestyle modification programs; however, it is likely that potent biological homeostatic systems are also a factor. Thus, the

optimal diet(s) for the prevention and treatment of obesity have yet to be determined.

Obesity can be accompanied by a number of metabolic and hormonal abnormalities including insulin resistance, hyperinsulinemia, hypertriglyceridemia, glucose intolerance, and, in some instances, hypertension (5,6). Insulin resistance may be a primary underlying cause of the cardiovascular risk factors associated with the metabolic syndrome (7). Hyperinsulinemia may stimulate hunger, leading to excessive food intake in the insulin-resistant, obese individual (8,9).

Coined by Jenkins and colleagues (10), the “glycemic index” of food describes the responses comparing test foods to the glycemic response from reference foods such as white bread or glucose. A carbohydrate of high glycemic index raises blood glucose more quickly and to a higher level than a carbohydrate of low glycemic index. Many factors affect the glycemic response to a diet such as the food form, the composition of the food (fat, fiber, and protein content; starch characteristics), the method of food processing, and physiologic factors.

Foods of high glycemic index and diets of high glycemic load have been linked to hyperinsulinemia and other alter-

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<sup>2</sup> Supplemental Table 1 is available as Online Supporting Material with the online posting of this paper at [www.nutrition.org](http://www.nutrition.org).

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ations in postprandial metabolism and theoretically are associated with body weight regulation. High glycemic load diets may elicit hormonal changes that limit availability of metabolic fuels in the postprandial state and stimulate increased voluntary food intake (11,12). Accordingly, it was suggested that diets of reduced glycemic load and glycemic index may be effective in promoting weight loss (11,13). However, few controlled studies have evaluated the effects of energy-restricted diets with varied glycemic index and glycemic load.

Epidemiologic studies suggest an increased risk for weight gain, diabetes, and heart disease with the consumption of a high glycemic index, high glycemic load diet (12,14–16). Ludwig and colleagues (12) demonstrated that obese teenage boys responded to low glycemic index test meals by consuming substantially less energy in a 5-h postprandial period compared with medium or high glycemic index test meals. That study concluded that high glycemic index foods induce hormonal and metabolic changes that limit the availability of metabolic fuels and lead to overeating in obese subjects. Studies of short duration suggested that diets with reduced glycemic index and glycemic load have beneficial effects on body composition. Bouche et al. (17) demonstrated a significant reduction of body fat mass in subjects consuming low glycemic index diets compared with conventional diets. Obese adolescents who were taught to select diets with a reduced glycemic load had significant reductions in BMI compared with subjects consuming conventional diets for weight reduction (18). Obese, hyperinsulinemic women lost significantly more weight while consuming energy-restricted low glycemic index diets compared with control diets (19).

As the epidemic of obesity continues to rise, identifying effective dietary regimens for weight management is increasingly important. Given the magnitude of this problem and the paucity of clinical evidence, we designed a study to compare 3 hypocaloric diets of varying glycemic index and glycemic load. The primary outcome was change in body weight. The secondary outcomes included plasma glucose and serum insulin levels, a calculated insulin sensitivity score [homeostatic assessment model (HOMA),<sup>4</sup>] and body composition. We hypothesized that a hypocaloric diet with reduced glycemic load and glycemic index would result in greater sustained weight loss and metabolic improvements in obese men and women.

## SUBJECTS AND METHODS

Approval for this study was obtained from the University of Minnesota Committee for the Use of Human Subjects in Research.

**Study design.** The study was designed as a 36-wk prospective, 3-arm, parallel group trial. At baseline, subjects were randomly assigned to 1 of 3 hypocaloric test diets: high glycemic index (HGI), low glycemic index (LGI), or high fat (HF) with varying macronutrient composition, glycemic index, and glycemic load (Table 1). The study was conducted in 2 continuous phases, a 12-wk feeding phase, followed immediately by a 24-wk “free-living” phase. For wk 1–12 (feeding phase), subjects consumed individualized energy-restricted diets. All meals were prepared in the Metabolic Kitchen of the General Clinical Research Center (GCRC) at the University of Minnesota. Subjects were required to consume all foods provided and eat no foods other than those provided. Anthropometric and biochemical measurements were obtained at baseline and wk 4, 8, and 12.

For wk 13–36 (free-living phase), diet assignment was maintained but participants prepared their own meals. All subjects received

TABLE 1

Composition of the controlled HGI, LGI, and HF diets consumed by obese men and women during the 12-wk feeding phase

|                             | HGI diet | LGI diet | HF diet |
|-----------------------------|----------|----------|---------|
| Carbohydrate, %             | 60       | 60       | 45      |
| Protein, %                  | 15       | 15       | 15      |
| Fat, %                      | 25       | 25       | 40      |
| Glycemic index <sup>1</sup> | 63       | 33       | 59      |
| Glycemic load <sup>2</sup>  | 272      | 178      | 182     |
| Fiber, g/4184 kJ            | 9.1      | 16.7     | 8.6     |

<sup>1</sup> Glycemic index is the proportional effect of a carbohydrate food on the area under the curve compared with a standard. The meal glycemic index is calculated as the food glycemic index × proportional carbohydrate content.

<sup>2</sup> Glycemic load = glycemic index × carbohydrate amount.

intensive dietary instruction regarding their assigned dietary regimen. Participants returned to the GCRC every 2 wk for ongoing nutrition counseling; 5-d food records, and anthropometric and biochemical measurements were obtained at wk 24 and 36.

**Study participants.** Subjects were recruited from the University of Minnesota and Minneapolis/Saint Paul metropolitan communities. Healthy men and women, ages 18–70 y with a BMI of 30–40 kg/m<sup>2</sup>, who habitually consumed a regular diet with no food restrictions were recruited. Individuals were excluded if they were taking prescription medication, had an existing medical condition, or were pregnant. Eligible subjects underwent screening at the GCRC.

Subjects who met the inclusion criteria ( $n = 42$ ) were randomly assigned to diet groups. Of these, 13 withdrew before completing 12 wk and were excluded from analysis. Of the 29 subjects who completed 12 wk, 9 were assigned to the HGI diet, 10 to the LGI diet, and 10 to the HF diet; 22 subjects completed the full 36-wk trial. During the free-living phase, 7 subjects withdrew (4 from the LGI diet, 1 from the HGI diet, and 2 from the HF diet). No participant withdrew due to side effects or health complications. No adverse events were reported.

**Diets.** The energy-controlled HGI, LGI, and HF diets were designed to provide varying levels of glycemic load and glycemic index (Table 1). Compared with the other diets, the HGI diet provided a high glycemic load and index, the LGI diet provided a low glycemic load and index, and the HF diet provided a low glycemic load and high glycemic index. The 3 experimental diets were formulated with commonly available food items. The nutrient composition was calculated using the Nutritionist V nutrient analysis software (20). The glycemic index and glycemic load of the diets were calculated according to FAO/WHO guidelines (21) for estimating the glycemic index of meals; the calculations used glycemic index with glucose as the reference food (22).

The fatty acid distribution of the diets was 1:1:1 for the ratio of polyunsaturated to monounsaturated to saturated fatty acids. The cholesterol content of the diets was constant at 100 g/4184 kJ. Modifications in glycemic index were achieved by utilizing carbohydrate foods with a lower glycemic index for the LGI diet and by increasing the total fat content of the HF diet. Sample menus for the feeding phase are provided in Supplemental Table 1.

An energy level designed to promote a weight loss of 0.70 kg/wk was estimated for each subject. The energy intake level required for weight maintenance was determined by measuring resting energy expenditure with a DeltaTrac II Metabolic Monitor (Sensormedics) and adjusting by an estimated activity factor. Activity factors, which ranged from 1.6 to 1.75, were estimated on the basis of each subject's reported physical activity level. Once total daily weight maintenance energy needs were established, 3138 kJ were deducted to determine the energy prescription for weight loss. The daily energy level provided during the 12-wk feeding phase was (mean ± SEM) 7883 ± 57.8 kJ, with individual levels ranging from 5021 to 11297 kJ.

<sup>4</sup> Abbreviations used: GCRC, General Clinical Research Center; HGI, high glycemic index diet; HF, high-fat diet; HOMA, homeostatic assessment model; LGI, low glycemic index diet; TG, triglyceride.

Daily weights were obtained to track weight change. The prescribed energy levels did not require modification.

During the free-living phase, all subjects were advised to continue their assigned hypocaloric diet. A registered dietitian provided nutritional counseling using standard exchange list instructional materials available from the American Dietetic Association (23). Subjects were given sample menus and recipes to provide dietary adherence guidance. For compliance with the low glycemic index diet, instructional materials were modified to indicate appropriate food choices and recipes were provided.

Subjects completed 5-d food records at wk 24 and 36 during the free-living phase of the trial. Records were analyzed for macronutrient content using the Nutritionist V nutrient analysis software (20). The glycemic index and glycemic load of the reported diets were calculated as described above for the feeding phase.

**Dietary compliance.** Dietary compliance was evaluated by questionnaires. Subjects were asked to complete daily questionnaires throughout the feeding phase to report any dietary treatment deviations by recording any foods consumed in addition to or omitted from the prescribed diet.

**Laboratory data.** A whole blood sample was collected from fasting participants by venipuncture at screening, baseline, 4, 8, 12, 24, and 36 wk. All samples were sent immediately to the Biochemistry Laboratory of the Fairview University Medical Center for analysis. Plasma glucose and triglyceride (TG) levels were measured by colorimetric reflectance spectrophotometry (Vitros 950, Ortho Clinical Diagnostics; CV = 0.013 and 0.012 for glucose and TG, respectively), and serum insulin was determined by chemiluminescent immunoassay (Diagnostic Products Corporation; CV = 0.033).

**Mixed meal tolerance test.** At the conclusion of the feeding period (wk 12) a mixed meal tolerance test was performed. After an overnight fast, a time zero blood sample was drawn and subjects consumed 360 mL of Ensure (Ross Laboratories). Additional blood samples were taken at 15, 30, 60, 90, 120 min. Samples were analyzed for glucose, insulin and TG concentrations.

**Insulin sensitivity.** Each subject's insulin sensitivity was calculated using the HOMA according to the method described by Matthews (24) and Duncan (25). The HOMA, or insulin sensitivity score, was computed as follows: [fasting plasma glucose (mmol/L) × fasting serum insulin (mU/L)/25]. A calculated HOMA value ≤ 1.0 indicated normal insulin sensitivity, whereas a value > 1.0 indicated insulin resistance (22). The HOMA score was calculated at screening, baseline, 4, 8, 12, 24, and 36 wk.

**Anthropometric measurements.** Anthropometric assessments were obtained at screening, baseline, 4, 8, 12, 24, and 36 wk. Body weight was measured to the nearest 0.1 kg and height to the nearest 0.5 cm using a digital scale with a stadiometer (Scaletronix). BMI was calculated (kg/m<sup>2</sup>). Body composition was estimated from the sum of 4 skinfold measurements, triceps, biceps, subscapular, and suprailliac, as described by Durnin and Womersley (26).

TABLE 2

Baseline characteristics of subjects by diet group<sup>1</sup>

|                        | HGI Diet                | HF Diet                 | LGI Diet                |
|------------------------|-------------------------|-------------------------|-------------------------|
| <i>n</i>               | 9                       | 10                      | 10                      |
| Men                    | 2                       | 0                       | 3                       |
| Women                  | 7                       | 10                      | 7                       |
| Weight, kg             | 102 ± 4.7               | 105 ± 4.9               | 99.6 ± 5.9              |
| BMI, kg/m <sup>2</sup> | 34.6 ± 1.4              | 37.7 ± 1.8              | 36.5 ± 1.8              |
| Body fat, %            | 39.3 ± 2.9              | 44 ± 1.0                | 41.4 ± 1.8              |
| Fat, kg                | 40.2 ± 3.6              | 46.5 ± 2.6              | 41.5 ± 3.1              |
| Lean body mass, kg     | 62.0 ± 3.9              | 58.9 ± 2.7              | 58.1 ± 3.8              |
| Serum insulin, pmol/L  | 54.9 ± 9                | 56.3 ± 9.7              | 67.4 ± 11.8             |
| Plasma glucose, mmol/L | 4.9 ± 0.2               | 4.7 ± 0.1               | 4.8 ± 0.1               |
| Plasma TG, mmol/L      | 2.04 ± 0.3 <sup>a</sup> | 1.04 ± 0.1 <sup>b</sup> | 1.79 ± 0.3 <sup>a</sup> |
| HOMA score             | 1.61 ± 0.3              | 1.56 ± 0.3              | 1.90 ± 0.3              |

<sup>1</sup> Values are means ± SEM. Means in a row with superscripts without a common letter differ, *P* < 0.05.

TABLE 3

Change in endpoint measurements in obese men and women fed HGI, LGI, and HF diets from baseline to wk 12 of the feeding phase<sup>1</sup>

|                                     | HGI diet    | HF diet    | LGI diet    |
|-------------------------------------|-------------|------------|-------------|
| <i>n</i>                            | 9           | 10         | 10          |
| Weight, kg                          | -9.3 ± 1.3  | -8.4 ± 1.5 | -9.95 ± 1.4 |
| BMI                                 | -3.0 ± 0.4  | -3.0 ± 0.5 | -3.91 ± 0.5 |
| Body fat, %                         | -2.8 ± 0.7  | -2.5 ± 0.8 | -2.9 ± 0.4  |
| Fat, kg                             | -4.5 ± 1.9  | -5.8 ± 1.0 | -6.9 ± 0.9  |
| Lean body mass, kg                  | -4.8 ± 2.2  | -2.6 ± 1.0 | -3.04 ± 0.6 |
| Serum insulin, <sup>2</sup> pmol/L  | -20.1 ± 6.9 | -6.3 ± 4.8 | -28.5 ± 6.3 |
| Plasma glucose, <sup>2</sup> mmol/L | -0.3 ± 0.1  | -0.2 ± 0.1 | -0.2 ± 0.1  |
| Plasma TG, <sup>2</sup> mmol/L      | -0.5 ± 0.2  | 0 ± 0.1    | -0.4 ± 0.3  |

<sup>1</sup> Values are means ± SEM.

<sup>2</sup> Blood samples were drawn from fasting subjects.

**Statistical methods.** Only data from the 29 subjects who completed the full 12-wk feeding phase of the study were analyzed. ANOVA with *t* tests among group means was used for anthropometric and metabolic measurements. Changes from baseline within treatment groups were compared by paired *t* tests. These were planned comparisons; thus no adjustment was made for multiple comparisons. Statistical significance was assigned if *P* < 0.05 and a *P* = 0.10 denoted a trend. All analyses were carried out in SAS Version 8.0 (SAS Institute).

## RESULTS

The 29 subjects who completed the feeding phase of the study had similar baseline characteristics other than significantly lower fasting TGs in the HF diet group than in the other 2 groups (Table 2).

**Feeding phase (wk 1–12).** Each diet group lost body weight during the 12-wk feeding phase of the study (*P* < 0.001) but the amount lost did not differ among the groups (Table 3). The HF and LGI groups tended to maintain their LBM (*P* = 0.1). The calculated HOMA scores were significantly improved at 12 wk compared with baseline in all 3 groups (*P* = 0.03) (Fig. 1). The improvement in the LGI group was significantly greater than the improvement in the HF group at wk 12 (Fig. 1). The HGI diet group had normalized insulin sensitivity with a postintervention (wk 12)

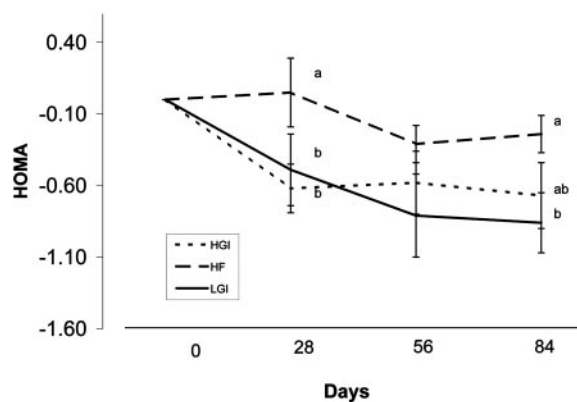


FIGURE 1 Change in HOMA score by diet assignment for obese subjects fed HGI, LGI, and HF diets from baseline to wk 12 of the feeding phase. Values are means ± SEM, *n* = 9 (HGI) or 10 (HF and LGI). Means at a time without a common letter differ. *P* < 0.05.

HOMA value of 0.94, whereas the HOMA values of 1.04 and 1.32 for the LGI and HF diet groups indicated residual insulin resistance. Plasma glucose ( $P = 0.18$ ) or serum insulin ( $P = 0.33$ ) responses to the mixed meal tolerance test did not differ among the groups. The plasma TG concentration was lower ( $P = 0.02$ ) in the HF group than in the HGI and LGI groups (data not shown). Subjects reported a high level of compliance with the diets with no difference among the groups.

**Free living phase (wk 13–36).** A total of 22 participants completed 36 wk of study. Weight loss and improvements in HOMA scores achieved in the feeding-phase of the study were maintained in all 3 groups. Weight changes between wk 12 and 36 did not differ among the groups and were  $-1.8 \pm 1.9$  kg ( $n = 6$ ),  $-1.6 \pm 1.9$  kg ( $n = 8$ ), and  $1.1 \pm 1.5$  kg ( $n = 8$ ) for the LGI, HGI, and HF groups, respectively. HOMA score changes during this time also did not differ and were  $0.09 \pm 0.33$ ,  $-0.06 \pm 0.16$ , and  $0.22 \pm 0.22$  for the LGI, HGI, and HF diet groups, respectively.

Eighteen subjects provided complete 5-d food records at 24 and 36 wk. These records were analyzed for energy and macronutrient content; the dietary glycemic index and glycemic load were calculated. All 3 groups, despite receiving dietary instruction for their specific assignment, consumed diets of relatively low glycemic index and low glycemic load when making their own food selections. The glycemic indices of the diets at 24 wk differed ( $P = 0.014$ ), with subjects in the LGI group initially consuming a lower glycemic index diet than the other 2 groups; however, at 36 wk, diet glycemic indices did not differ among the 3 groups ( $P = 0.14$ ). The 5-d food record review showed that subjects in the LGI group tended to choose lower glycemic index foods but members of the other 2 groups simply increased dietary fat.

## DISCUSSION

Weight loss and insulin sensitivity improved with weight reduction similarly in all 3 groups. Although insulin sensitivity differed between the LGI and HF diets at wk 12, none of the groups differed at wk 36. The amount of weight loss predicted by energy restriction was achieved under controlled dietary conditions. However, the reduced glycemic index and glycemic load did not demonstrably enhance weight reduction in obese men and women.

Upon completion of the feeding phase, subjects in the LGI and HF diet groups tended to have a reduction in body fat and maintenance of lean body mass loss. Our results are consistent with those of Boucher and colleagues (15) who demonstrated lower fat mass by densitometry in subjects following a low glycemic index diet. However, at the conclusion of the free-living phase, body composition did not differ among the groups. It is noteworthy that participants successfully maintained weight loss in a free-living environment when provided with intensive education, consistent nutritional support, and regular follow-up.

The results of this dietary trial demonstrate that energy restriction over a 36-wk period promotes weight loss and improves insulin sensitivity in obese individuals, irrespective of dietary substrate. The hypothesis that a low glycemic load diet would enhance weight loss, relative to other diets, was not supported in either study phase. However, the LGI diet did improve insulin sensitivity at 12 wk compared with the HF diet.

Surprisingly, the calculated glycemic index and glycemic load of diets consumed during the free-living phase were similar among the groups. The glycemic index and glycemic

load were lowered electively and despite dietary advice in the HGI and HF diet groups. We speculate that subjects in a glycemic index study chose low glycemic index foods regardless of diet assignment, and chose less processed and more whole-grain foods that lowered dietary glycemic index and glycemic load. However, when evaluating the food records, it was apparent that subjects lowered their dietary glycemic index and glycemic load by reduced portion sizes of carbohydrate-containing foods and increased dietary fat. Total fat intake at 24 and 36 wk increased in all groups and reverted back to screening levels (data not shown).

Clinical feeding trials and free-living studies in which energy intake is reduced over a long period of time are challenging due to high drop-out rates and nonadherence to the prescribed dietary program. A limitation of our study is the loss of subjects during the study follow-up phase. These subjects simply did not return for clinic visits. We thus have no knowledge of why they dropped out. We speculate that these subjects did not return due to a lack of weight loss, weight regain, or boredom with the assigned diet.

In summary, our findings suggest that hypocaloric diets will promote weight reduction at predicted rates, irrespective of dietary composition. The carbohydrate and fat content, glycemic load, and glycemic index of the energy-controlled diets had no distinguishable effect above that provided by energy restriction. Energy reduction resulted in the loss of  $\sim 10$  kg of body weight, leading to improved insulin sensitivity. An independent effect of substrate modification on insulin sensitivity was only transiently discernible. This study, albeit preliminary due to the small sample size, does not support an added benefit of low glycemic load or low glycemic index diets in the treatment of obese men and women. Until more information becomes available, it seems reasonable to suggest that energy intake, not dietary composition, determines weight loss, and intervention efforts should focus on total energy restriction to promote weight reduction.

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## LITERATURE CITED

- Pi-Sunyer, F. X. (2002) The obesity epidemic: pathophysiology and consequences of obesity. *Obes. Res.* 10 (suppl. 2): 97S–104S.
- (1998) Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults—the evidence report. National Institutes of Health. *Obes. Res.* 6 (suppl. 2): 51S–209S.
- Flegal, K. M., Carroll, M. D., Ogden, C. L. & Johnson, C. L. (2002) Prevalence and trends in obesity among US adults, 1999–2000. *J. Am. Med. Assoc.* 288: 1723–1727.
- Jeffery, R. W. & Utter, J. (2003) The changing environment and population obesity in the United States. *Obes. Res.* 11 (suppl.): 12S–22S.
- Grundey, S. M., Brewer, H. B., Jr., Cleeman, J. I., Smith, S. C., Jr. & Lenfant, C. (2004) Definition of metabolic syndrome: report of the National Heart, Lung, and Blood Institute/American Heart Association conference on scientific issues related to definition. *Circulation* 109: 433–438.
- Reaven, G. M. (1992) The role of insulin resistance and hyperinsulinemia in coronary heart disease. *Metabolism* 41: 16–19.
- Haffner, S. & Taegtmeier, H. (2003) Epidemic obesity and the metabolic syndrome. *Circulation* 108: 1541–1545.
- Brand-Miller, J. C., Holt, S. H., Pawlak, D. B. & McMillan, J. (2002) Glycemic index and obesity. *Am. J. Clin. Nutr.* 76: 281S–285S.
- Ludwig, D. S. (2000) Dietary glycemic index and obesity. *J. Nutr.* 130: 280S–283S.
- Jenkins, D. J., Wolever, T. M., Taylor, R. H., Barker, H., Fielden, H.,

- Baldwin, J. M., Bowling, A. C., Newman, H. C., Jenkins, A. L. & Goff, D. V. (1981) Glycemic index of foods: a physiological basis for carbohydrate exchange. *Am. J. Clin. Nutr.* 34: 362–366.
11. Ludwig, D. S. (2002) The glycemic index: physiological mechanisms relating to obesity, diabetes, and cardiovascular disease. *J. Am. Med. Assoc.* 287: 2414–2423.
12. Ludwig, D. S., Majzoub, J. A., Al-Zahrani, A., Dallal, G. E., Blanco, I. & Roberts, S. B. (1999) High glycemic index foods, overeating, and obesity. *Pediatrics* 103: E26.
13. Pawlak, D. B., Ebbeling, C. B. & Ludwig, D. S. (2002) Should obese patients be counselled to follow a low-glycaemic index diet? *Yes. Obes. Rev.* 3: 235–243.
14. Ludwig, D. S., Pereira, M. A., Kroenke, C. H., Hilner, J. E., Van Horn, L., Slattery, M. L. & Jacobs, D. R., Jr. (1999) Dietary fiber, weight gain, and cardiovascular disease risk factors in young adults. *J. Am. Med. Assoc.* 282: 1539–1546.
15. Liu, S., Willett, W. C., Stampfer, M. J., Hu, F. B., Franz, M., Sampson, L., Hennekens, C. H. & Manson, J. E. (2000) A prospective study of dietary glycemic load, carbohydrate intake, and risk of coronary heart disease in US women. *Am. J. Clin. Nutr.* 71: 1455–1461.
16. Salmeron, J., Manson, J. E., Stampfer, M. J., Colditz, G. A., Wing, A. L. & Willett, W. C. (1997) Dietary fiber, glycemic load, and risk of non-insulin-dependent diabetes mellitus in women. *J. Am. Med. Assoc.* 277: 472–477.
17. Bouche, C., Rizkalla, S. W., Luo, J., Vidal, H., Veronese, A., Pacher, N., Fouquet, C., Lang, V. & Slama, G. (2002) Five-week, low-glycemic index diet decreases total fat mass and improves plasma lipid profile in moderately overweight nondiabetic men. *Diabetes Care* 25: 822–828.
18. Ebbeling, C. B., Leidig, M. M., Sinclair, K. B., Hangen, J. P. & Ludwig, D. S. (2003) A reduced-glycemic load diet in the treatment of adolescent obesity. *Arch. Pediatr. Adolesc. Med.* 157: 773–779.
19. Slabber, M., Barnard, H. C., Kuyl, J. M., Dannhauser, A. & Schall, R. (1994) Effects of a low-insulin-response, energy-restricted diet on weight loss and plasma insulin concentrations in hyperinsulinemic obese females. *Am. J. Clin. Nutr.* 60: 48–53.
20. Nutritionist V. (1999) First Data Bank Division, The Hearst Corporation, San Bruno, CA.
21. FAO/WHO (1998) Carbohydrates in Human Nutrition. Report of a Joint FAO/WHO Expert Consultation, 14–18 April 1997, Rome. FAO Food and Nutrition Paper No. 66. Rome, Italy.
22. Foster-Powell, K. & Miller, J. B. (1995) International tables of glycemic index. *Am. J. Clin. Nutr.* 62: 871S–890S.
23. American Dietetic Association (1995) Exchange Lists for Weight Management. ADA, Chicago, IL.
24. Matthews, D. R., Hosker, J. P., Rudenski, A. S., Naylor, B. A., Treacher, D. F. & Turner, R. C. (1985) Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia* 28: 412–419.
25. Duncan, M. H., Singh, B. M., Wise, P. H., Carter, G. & Alaghband-Zadeh, J. (1995) A simple measure of insulin resistance. *Lancet* 346: 120–121.
26. Durnin, J. V. & Womersley, J. (1974) Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *Br. J. Nutr.* 32: 77–97.