

ORIGINAL ARTICLE

No effect of a diet with a reduced glycaemic index on satiety, energy intake and body weight in overweight and obese women

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Objective: To investigate whether a diet with a reduced glycaemic index (GI) has effects on appetite, energy intake, body weight and composition in overweight and obese female subjects.

Design: Randomized crossover intervention study including two consecutive 12-week periods. Lower or higher GI versions of key carbohydrate-rich foods (breads, breakfast cereals, rice and pasta/potatoes) were provided to subjects to be incorporated into habitual diets in *ad libitum* quantities. Foods intended as equivalents to each other were balanced in macronutrient composition, fibre content and energy density.

Subjects: Nineteen overweight and obese women, weight-stable, with moderate hyperinsulinaemia (age: 34–65 years, body mass index: 25–47 kg m⁻², fasting insulin: 49–156 pmol l⁻¹).

Measurements: Dietary intake, body weight and composition after each 12-week intervention. Subjectively rated appetite and short-term *ad libitum* energy intake at a snack and lunch meal following fixed lower and higher GI test breakfasts (GI 52 vs 64) in a laboratory setting.

Results: Free-living diets differed in GI by 8.4 units (55.5 vs 63.9), with key foods providing 48% of carbohydrate intake during both periods. There were no differences in energy intake, body weight or body composition between treatments. On laboratory investigation days, there were no differences in subjective ratings of hunger or fullness, or in energy intake at the snack or lunch meal.

Conclusion: This study provides no evidence to support an effect of a reduced GI diet on satiety, energy intake or body weight in overweight/obese women. Claims that the GI of the diet *per se* may have specific effects on body weight may therefore be misleading.

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Keywords: glycaemic index; carbohydrate; satiety; energy intake; body weight

Introduction

Low glycaemic index (GI) foods have been highlighted as a possible aid to weight control.¹ A number of short-term intervention studies have shown that low GI meals compared with high GI meals increase satiety and delay the return of hunger, and/or reduce energy intake at a later meal.² Other mechanisms for a beneficial effect of low vs high GI diets have also been suggested, including reduced decreases in resting energy expenditure on low vs high GI hypoenergetic diets,³ promotion of nutrient oxidation rather than storage^{4–7} and selective loss of fat rather than lean mass.⁸ Despite these

findings, together with the physiological plausibility of the mechanisms, results of intervention studies have been mixed and others have seen no effects on these outcomes.^{9–11} A number of the studies have been confounded by dietary differences other than GI, and have compared foods or meals with differing energy, macronutrient and/or fibre contents.

Similarly, a number of the longer term intervention studies investigating the effect of GI on the outcome of body weight have not used well-matched diets. In addition, others have used fixed energy prescriptions, which may reduce the likelihood of effects on intake via satiety mechanisms. Two well-controlled longer term studies investigating the effects of *ad libitum* low and high GI diets matched for fibre and macronutrient content did not find a significant effect on body weight.^{8,12}

This study aimed to explore the effects of lower and higher GI foods, independently of changes to other dietary factors, on both appetite and energy intake in the short term, and the impact on body weight and composition over 12 weeks.

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Methods

Subjects

Female subjects with a body mass index $>25 \text{ kg m}^{-2}$ and fasting plasma insulin concentration $>50 \text{ pmol l}^{-1}$ at screening were recruited from the community to participate in a 24-week dietary intervention study at MRC Human Nutrition Research. Subjects were excluded if they were following a weight-reducing diet or had not been weight-stable over the preceding 2 months (weight change of no more than 2 kg). Subjects were also excluded if they suffered from chronic medical conditions (including diabetes, cardiovascular disease, hypertension (BP $>160/100 \text{ mm Hg}$), malignancy, clotting or bleeding disorders, renal, liver or respiratory disease), were anaemic, allergic or intolerant to any of the provided intervention foods, or were pregnant or breastfeeding; or if they were taking regular steroids or non-steroidal anti-inflammatory drugs, lipid-lowering drugs or anti-coagulants. The study was approved by the Cambridge Local Research Ethics Committee and subjects gave written informed consent.

Study design

The study was a crossover dietary intervention including two 12-week periods of incorporation of provided lower or higher GI foods into habitual diets in random order. Subjects were randomized to treatment order using a computer-generated randomization chart, in order of recruitment. Intervention periods were consecutive with no washout period in between. Weight, body mass index (weight (kg)/height (m^2)), waist circumference and body composition (whole-body dual energy X-ray absorptiometry scan; Lunar DPX-IQ, Lunar Corp, Madison, WI, USA) were measured at baseline and at the end of each intervention period.

Dietary intervention

Subjects were provided with lower or higher GI versions of key 'staple' carbohydrate-rich foods, according to intervention period, to incorporate into their habitual diet. These comprised lower or higher GI breads, breakfast cereals and rice, plus pasta on the lower GI diet and potatoes during the higher GI period. GI values of intervention foods were measured at MRC Human Nutrition Research¹³ and differed significantly for all equivalent 'low' and 'high' GI foods ($P < 0.05$), with a mean difference of 28.5 units (for GI values of intervention foods, see Table 1 and Aston¹⁴).

Data from the UK National Diet and Nutrition Survey reveals that these foods provide around 60% of total dietary carbohydrate.^{15,16} An estimated achievable difference in dietary GI of 12 units was calculated from the GI values and the average daily intakes of the foods in National Diet and Nutrition Survey. Subjects were instructed to maintain their habitual diets for the duration of the study, but to substitute the supplied foods into their diets on at least three

Table 1 GI values of intervention foods

Lower GI foods		Higher GI foods	
Food	GI	Food	GI
Breakfast cereals	55 ^a	Breakfast cereals	77 ^a
Basmati rice	43	Easy-cook basmati rice	68
Penne pasta	43	White potatoes	88 ^b
Bread	55 ^a	Bread	75 ^a

Abbreviation: GI, glycaemic index. ^aMean value for all types provided. ^bMean value for various cooking methods.

occasions per day in the quantity that they would normally consume. No other advice was given regarding quantity, and amounts provided were unlimited. Subjects were given simple advice regarding other foods to choose or avoid, both verbally and in writing, based around the staple carbohydrate choices and excluding reference to pulses, fruits and vegetables to avoid wider dietary changes. Subjects were not informed of the GI difference of study foods. Subjects kept 4-day diet diaries at baseline and during the final week of each intervention period. Data were coded into an in-house database based on McCance and Widdowson's *The Composition of Foods*.¹⁷

Appetite investigation

Appetite investigation days were performed during the final week of each intervention period to determine whether a fixed breakfast, including lower vs higher GI cereal (GI 60 vs 74) and bread (GI 48 vs 71), reduced energy intake of a mid-morning snack 2 h after breakfast, and whether any differences in energy intake were modulated at lunch, 4 h after breakfast. Subjects attended MRC Human Nutrition Research following an overnight fast. Following cannulation and a fasting blood sample, they consumed breakfast including a lower or higher GI cereal and bread according to intervention period. Breakfasts differed in GI by 12 units, provided identical amounts of energy (2.5 MJ) and were closely matched for available carbohydrate, fibre, protein and fat contents. Further blood samples were taken at 15, 30, 45, 60, 90 and 120 min following breakfast for measurement of plasma glucose, insulin and non-esterified fatty acids. Immediately following the final blood sample, subjects were presented with a pre-weighed *ad libitum* snack of crisps, mini savoury biscuits and mini sweet biscuits, with tea or coffee. This was removed after 30 min and remaining food weighed. A pre-weighed *ad libitum* lunch of pizza, undressed green salad, yoghurt and water was served in small discreet cubicles at 4 h following breakfast. The remaining food was weighed once subjects had consumed as much as desired. Subjects completed 10 cm visual analogue scale questionnaires regarding their hunger and fullness at half-hour intervals throughout the investigation, and palatability visual analogue scale questionnaires following meals.

Statistical analysis

Statistical analyses were carried out using Microsoft Excel 2000 (Microsoft Corporation, Redmond, WA, USA) and Stata version 9.1 (StataCorp LP, College Station, TX, USA). Normality of distribution of variables was checked using quantile plots, and data were log-transformed to achieve normality where necessary. End point outcome measures were compared within-person using a fixed-effects linear regression model including subjects as variables, into which period was included to check for period effects. Graphs of end points were examined by randomization group to give an indication of any differing effects by treatment order.

Results

Twenty-six subjects were recruited, of which seven dropped out of the study (one before starting the diet, and six during the first diet treatment; four were on the low GI diet and two on the high GI diet). Of these, three cited time commitments, two were prescribed medications on the exclusion list, one had a bad reaction to initial blood samples and one cited an unspecified health condition. These subjects had a mean body mass index of 32.5 (s.d. 6.3) kg m⁻², and did not differ from completing subjects in any baseline measures. The 19 subjects to complete the study were aged between 34 and 65 years at baseline (mean 51.9 (s.d. 7.6) years). All were overweight or obese, with body mass index ranging from 25.6 to 46.7 kg m⁻² (mean 33.1 (s.d. 4.9) kg m⁻²), and body fat from 38.8 to 52.6% (mean 47.8 (s.d. 3.5) %).

Reported dietary intakes

Dietary data were collected from 4-day diet diaries at baseline (before intervention) and during the final week of each intervention period. Dietary data are presented in Table 2 (intervention data for 18 subjects only, as one diary was lost in the post). Subjects reported similar intakes to the nationally representative National Diet and Nutrition Survey sample of the UK female population for all macronutrients

expressed as a percentage of energy intake, with reported intakes of energy and non-starch polysaccharide similar to, although slightly higher than, that in National Diet and Nutrition Survey.^{15,16} Foods for which GI values had been specifically measured contributed 25% total carbohydrate intake. Fifty-five percent of the total carbohydrate intake was from foods for which there were published values for identical or closely equivalent foods. A further 10% was provided by foods for which a nominal low/medium/high GI value had been ascribed (45/63/85), and the final 10% was provided by foods for which there were no data available (GI value of 70 assigned).

All subjects reduced dietary GI on the lower GI diet compared with the higher GI diet, with a mean difference of 8.4 units ($P < 0.001$; range 2.8–18.4). Glycaemic load was not significantly reduced on the lower GI diet due to a small but statistically significant increase in carbohydrate intake (51 vs 48% of total energy; $P = 0.01$). There was also a small but significant increase in the intake of non-starch polysaccharide on the lower GI diet compared with the higher GI diet (18.4 vs 15.6 g; $P = 0.04$). There were no other differences between diets. GI was lower at all main meals during the lower GI period compared with the higher GI period, but there were no differences in the GI of foods eaten between meals. The weighted average GI difference from the main meals only was calculated to be 10.0 units (65.8 vs 55.8; $P < 0.001$).

Body weight and composition

There were no differences in body weight, waist circumference or fatness between intervention periods (Table 3). Weight increased during both intervention periods, although weight gain did not differ between treatments (1.1 (s.d. 1.5) kg on the low GI diet vs 1.4 (s.d. 1.7) kg on the higher GI diet; $P = 0.7$).

Short-term appetite investigation

Energy intakes of the *ad libitum* snack and lunch meals are presented in Figure 1. There were no differences at either

Table 2 Baseline ($n = 19$) and intervention ($n = 18$) diets

	Baseline diet		High GI diet		Low GI diet		Difference between high & low GI diets			
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.e.	95% CI	P
Glycaemic index	62.2	3.8	63.9	3.0	55.5	3.8	-8.4	1.0	-10.4, -6.3	<0.001
Glycaemic load	138.9	35.0	138.8	30.5	133.8	22.9	-5.0	5.0	-14.5, 4.6	0.3
Energy (kJ)	7784	1810	7844	1629	8071	1523	+227	175	-143, 597	0.2
Energy density (kJ g ⁻¹)	2.8	0.8	2.9	0.7	3.0	0.7	+0.1	0.1	-0.1, 0.3	0.4
Available carbohydrate (%E)	48.8	5.5	47.6	6.1	51.4	6.0	+3.8	1.3	1.1, 6.5	0.01
Starch (%E)	27.1	6.1	26.8	4.9	29.4	6.1	+2.7	1.4	-0.3, 5.6	0.07
Sugars (%E)	21.5	5.4	20.9	5.7	21.5	5.1	+0.6	0.8	-1.2, 2.4	0.5
Non-starch polysaccharide (g)	15.4	4.4	15.6	4.5	18.4	5.0	+2.7	1.2	0.2, 5.3	0.04
Protein (%E)	16.7	2.9	17.6	3.3	17.0	2.4	-0.6	0.6	-1.8, 0.6	0.3
Fat (%E)	34.4	6.1	34.1	5.7	32.2	5.1	-1.9	1.4	-4.8, 0.9	0.2

Abbreviation: GI, glycaemic index; %E, % total energy intake.

Table 3 Effect of dietary intervention on body weight and composition ($n=19$)

	Baseline		High GI diet		Low GI diet		Difference			P
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.e.	95% CI	
Weight (kg)	87.5	15.0	89.2	16.1	89.1	15.6	-0.1	0.5	-1.1, 0.9	0.8
Waist ^a (cm)	103	0.12	106	0.13	105	0.12	+0.99	1.01	0.96, 1.02	0.4
Fat mass (kg)	42.3	8.4	42.9	8.9	44.54	9.2	+0.22	0.34	-0.50, 0.94	0.9
Lean mass (kg)	43.8	5.2	44.6	5.7	43.13	5.6	-0.02	0.03	-0.61, 0.57	0.5
Body fat (%)	47.8	3.5	47.6	3.6	47.72	3.8	+0.07	0.32	0.60, 0.74	0.8

Abbreviation: GI, glycaemic index. ^aLog_e transformed for statistical analysis; geometric mean and s.d. of logged data, ratio of geometric means and confidence interval around ratio of geometric means presented.

meal, or in the total energy intake over the day. Neither were there any differences in subjective ratings of appetite at any time point between investigation days. There were no differences in glucose, insulin and non-esterified fatty acids responses to the lower vs higher GI breakfasts, with no differences in either total area under the curve or single measurements at any time point (Figure 2).

Discussion

This study found no effect of reduction in the GI of the diet on short- or longer term energy intake, or on body weight or composition in a group of 19 overweight but weight-stable, hyperinsulinaemic female subjects. This intervention was longer than many previous studies, the diets were well matched for energy, macronutrient and fibre intakes, and the crossover design minimized any effects of differences in background diet. Although subjects in this study were selected on a criterion of being overweight/obese, this was not a weight-loss study. Subjects were not attempting to lose weight and were not given advice about quantities to consume, being instructed to maintain habitual intakes. Simple *ad libitum* (in terms of quantity) substitution of reduced GI versions of key 'staple' carbohydrate foods did not reduce energy intake in this study, indeed there was a modest weight gain during both periods, possibly as a function of receiving 'free' food.

The difference in GI of 8.4 units was lower than the planned difference of 12 units, due to a lower than expected intake of the key 'staple' foods. These provided <50% of total available carbohydrate intake compared with around 60% estimated from a national survey.^{15,16} Although this difference was smaller than achieved in some previous studies, the intervention diets were representative of habitual diets, and so perhaps more achievable and sustainable long-term than more extreme dietary manipulations. The aim of the intervention was to be non-prescriptive, with no advice given regarding portion sizes and foods consumed *ad libitum*. Commercially available lower and higher GI versions of key staple foods were provided to aid compliance, and advice on foods such as pulses, whole-grains and fruit and

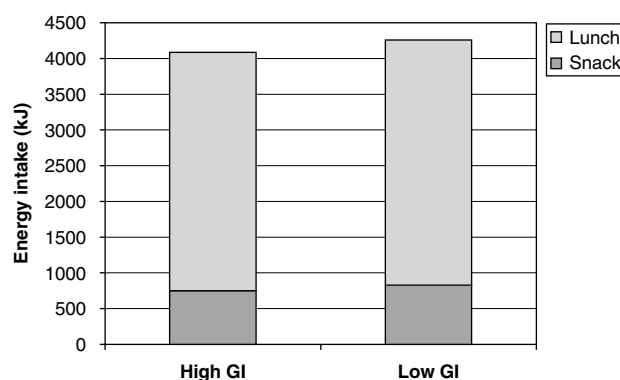


Figure 1 Energy intakes of *ad libitum* snack and lunch following a higher/lower GI meal.

vegetables was avoided to prevent broader changes to diet. The intention was that intakes of macronutrients and fibre would remain constant between intervention periods. There were statistically significant increases in both carbohydrate and fibre intakes on the lower GI diet compared with the higher GI diet, although absolute differences were small. An increase in fibre intake is commonly seen on low GI diets, with differences of up to 15 g per day in some previous studies.^{18,19}

Few previous longer term intervention studies have been designed to compare *ad libitum* macronutrient-matched low and high GI diets without accompanying weight-loss advice. Of those which have, no significant differences have been seen in weight or energy intake, although a trend towards a reduction on low GI diets have been observed.^{8,12} Several studies have compared low GI diets with standard low-fat hypoenergetic diets, and have seen greater weight loss on the low GI diet; however, these are confounded by other broader differences between intervention diets.^{20,21} Other interventions investigating low vs high GI dietary advice for weight loss have seen no added beneficial effect on weight loss.^{22,23} Many, but by no means all, short-term studies have observed reduced hunger and/or energy intake following low GI meals compared with high GI meals,^{2,24} although it is unclear whether short-term effects of low GI meals on energy intake are maintained at later meals.

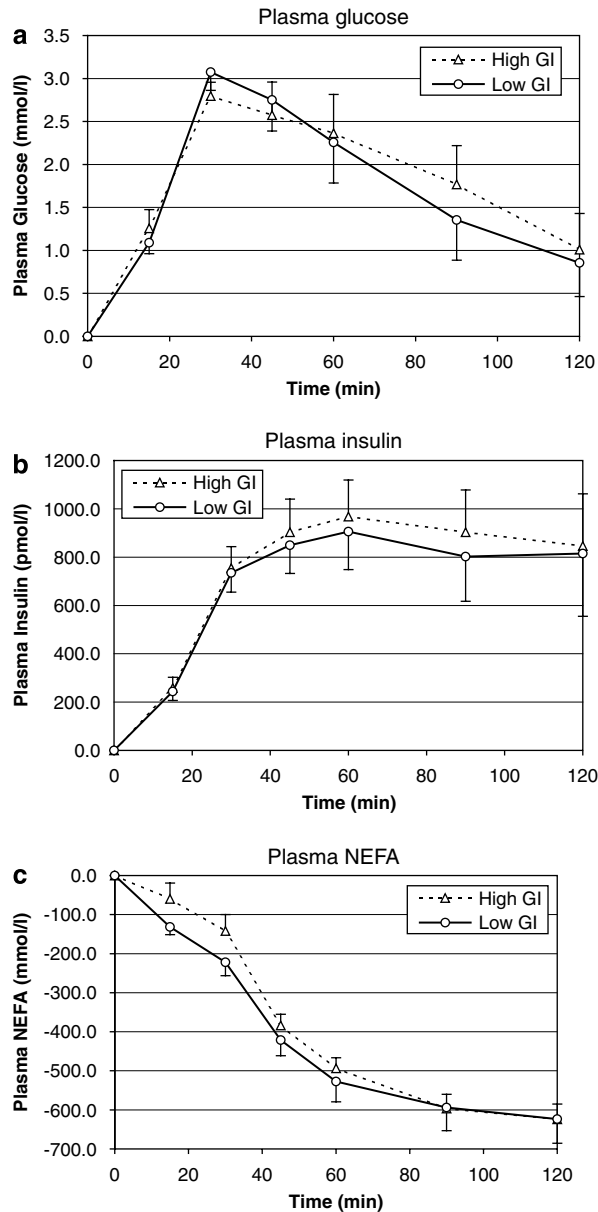


Figure 2 Plasma glucose, insulin and non-esterified fatty acids responses to higher and lower GI mixed breakfast meals (mean \pm s.e.m.). (a) Plasma glucose; (b) Plasma insulin; (c) Plasma NEFA.

This study found no effect on satiety or energy intake in the short-term, with a GI difference at breakfast of 12 units. Some previous studies that did observe an effect have used test meals with larger GI differences, but these have often also had differences in macronutrient and fibre contents. It was notable that the fixed breakfasts incorporating lower and higher GI foods did not result in differing postprandial glucose responses. This was particularly surprising as the breakfast cereals and breads had differing GI values from each other when tested separately (cereals

59 vs 74, breads 48 vs 71). While a number of studies show that the glycaemic response to a mixed meal can be predicted reasonably accurately from the GI values of the constituent foods,^{25–27} this finding is not universal and a recent study found no association between predicted and measured GI, with GI being best predicted by fat and protein contents of the meals.²⁸ The GI of cereals had been measured with milk and breads with butter, so the only additions as part of this breakfast were jam/marmalade and tea/coffee. It is possible that the greater overall quantity of food being consumed here, relative to the GI testing methodology, resulted in a larger amount of glucose entering the circulation which masked differences in the glucose response attributable to GI. A previous study has found no significant differences in the glycaemic and insulinaemic responses to low or high GI foods consumed in isolation *ad libitum*, despite no differences in energy or macronutrient intake.⁹ Neither were there any differences in hunger or fullness. The weights of the foods consumed *ad libitum* in this previous study were around one-third higher than the loads provided for the prior determination of the GI values.

An additional alternative explanation for the lack of a difference in the glucose responses to the higher and lower GI breakfasts in the present study could be the use of venous plasma for the measurement of glucose. Capillary whole blood was previously used in the GI testing and is recommended by FAO/WHO as it results in lower within-subject variation than venous blood.^{29,30} It should also be noted that as the appetite tests were performed at the end of each intervention period, the possibility that there were chronic effects of adaptation in the acute responses to lower or higher GI meals cannot be ruled out.

In conclusion, this controlled laboratory investigation and free-living dietary intervention study has found no evidence to support a beneficial effect of a reduction in GI of the diet on satiety, energy intake, body weight or fatness through simple substitution of staple carbohydrate foods. It does not preclude an impact on weight from a greater reduction in dietary GI, but this is likely to involve wider dietary changes. Claims that the GI of the diet *per se* may have specific effects on body weight may therefore be misleading.

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