

The use of glycaemic index tables to predict glycaemic index of composite breakfast meals

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The applicability of the glycaemic index (GI) in the context of mixed meals and diets is still debatable. The objective of the present study was to investigate the predictability of measured GI in composite breakfast meals when calculated from table values, and to develop prediction equations using meal components. Furthermore, we aimed to study the relationship between GI and insulinaemic index (II). The study was a randomised cross-over meal test including twenty-eight healthy young men. Thirteen breakfast meals and a reference meal were tested. All meals contained 50 g available carbohydrate, but differed considerably in energy and macronutrient composition. Venous blood was sampled for 2 h and analysed for glucose and insulin. Prediction equations were made by regression analysis. No association was found between predicted and measured GI. The meal content of energy and fat was inversely associated with GI (R^2 0.93 and 0.88, respectively; $P < 0.001$). Carbohydrate content (expressed as percentage of energy) was positively related to GI (R^2 0.80; $P < 0.001$). Using multivariate analysis the GI of meals was best predicted by fat and protein contents (R^2 0.93; $P < 0.001$). There was no association between GI and II. In conclusion, the present results show that the GI of mixed meals calculated by table values does not predict the measured GI and furthermore that carbohydrates do not play the most important role for GI in mixed breakfast meals. Our prediction models show that the GI of mixed meals is more strongly correlated either with fat and protein content, or with energy content, than with carbohydrate content alone. Furthermore, GI was not correlated with II.

Glucose: Insulin: Macronutrients: Energy

During the past two decades a large number of studies have described the application of glycaemic index (GI) to different population groups, such as diabetics, the obese and those with CVD. Several epidemiological studies support the suggestion of a connection between GI and type 2 diabetes and CHD (Salmeron *et al.* 1997a,b; Liu *et al.* 2000). In intervention studies glycaemic control has been shown to be improved with low-GI diets in subjects with type 2 diabetes and impaired glucose tolerance (Järvi *et al.* 1999; Wolever & Mehling, 2002, 2003). Based on these results Walter Willet is now advocating a diet with a lower intake of carbohydrates, especially carbohydrates with a high GI, than is currently recommended (Willet, 2002). However, it is generally agreed that there is a need for prospective, long-term clinical trials to clarify the role of GI in relation to the prevention and treatment of diabetes and CHD (Augustin *et al.* 2002; Ludwig

& Eckel, 2002). Furthermore, there is no consensus regarding the use of GI in relation to body-weight regulation and obesity (Pawlak *et al.* 2002; Raben, 2002).

Some concerns regarding the clinical relevance and use of GI have been raised over the years. One of these is the applicability of GI in mixed meals calculated from the weighted GI of the single ingredients as recommended by the Food & Agriculture Organization/World Health Organization (1998). Several tables with lists of the GI of single food items have been published. The latest updated version from 2002 covers more than 750 items (Foster-Powell *et al.* 2002). However, most of the time individuals do not eat single foods but combine them in mixed meals and, furthermore, single foods are consumed as components of complex diets. Therefore, it is important to ensure that the GI concept also applies in the context of mixed meals. Several studies have provided support of the

Abbreviations: E%, % energy; GI, glycaemic index; GI_{meas}, measured glycaemic index of the meal; GI_{pred}, predicted glycaemic index of the meal; GR_{pred}, predicted response of glucose of the test meal relative to the response of the reference meal; iAUC, incremental area under the curve; II, insulinaemic index; II_{meas}, measured insulinaemic index of the meal; IR_{pred}, predicted response of insulin of the test meal relative to the response of the reference meal.

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predictability of the GI in mixed meals (Wolever *et al.* 1985, 1988*b*; Collier *et al.* 1986; Wolever & Jenkins, 1986; Bornet *et al.* 1987; Chew *et al.* 1988). Others argue, however, that the other macronutrients (i.e. protein, fat, dietary fibre, sugar) of a meal interact with the carbohydrates and reduce the predictability of GI (Coulston *et al.* 1984*a,b*, 1987; Laine *et al.* 1987; Hollenbeck *et al.* 1988; Hollenbeck & Coulston, 1991; Pi-Sunyer, 2002).

Another concern about the use of GI is the relationship between glucose and insulin responses. A major rationale for using GI is the assumption that there is a high proportionality between postprandial blood glucose response and insulin response. This relationship has, however, also been questioned in the context of mixed meals, and again the interaction with other macronutrients is the main concern (Collier *et al.* 1984; Coulston *et al.* 1984*a*; Nuttall *et al.* 1984; Hollenbeck *et al.* 1988; Hollenbeck & Coulston, 1991; Brand *et al.* 1990; Östman *et al.* 2001; Pi-Sunyer, 2002). Protein is known to be insulinotropic, giving rise to a higher meal-induced insulin response, despite an unchanged or even lower blood glucose concentration, compared with the carbohydrates alone (Nuttall *et al.* 1984; Elliot *et al.* 1993; Herrmann *et al.* 1995; Pi-Sunyer, 2002). Dietary fat inhibits gastric emptying, which in turn slows down the absorption of carbohydrates (Cooke, 1975; Collier *et al.* 1984; Pi-Sunyer, 2002). This also gives rise to a lower blood glucose response postprandially.

In 1996 Wolever & Bolognesi (1996*a,b*) constructed and tested prediction equations for the glycaemic and insulinaemic responses of a meal, taking both source and amount of carbohydrates into account. These equations have not been validated by other studies, as far as we know.

The primary aim of the present study was therefore to evaluate the predictability of the GI in composite breakfast meals as predicted from table values, and second, to develop prediction equations using meal descriptors (for example, energy content, energy density, macronutrients). Furthermore, we investigated the relationship between GI and insulinaemic index (II), and tested the validity of the prediction equations for glycaemic and insulinaemic responses for mixed meals proposed by Wolever & Bolognesi (1996*a*).

Subjects and methods

Subjects

Twenty-eight healthy men were included in the present study. They were young (aged 24.7 (SEM 0.2) years), of normal weight (BMI 22.6 (SEM 0.1) kg/m²), were non-smokers, were not elite athletes, and they had no history of metabolic diseases. The subjects were recruited through the posting of flyers at several locations. The subjects gave informed written consent after the study was explained to them verbally and in writing. The study was approved by the municipal ethical committee of Copenhagen and Frederiksberg (J.nr. (KF) 01–213/00).

Protocol

The study was a randomised, cross-over, test-meal study carried out at the Department of Human Nutrition, Centre

for Advanced Food Studies, The Royal Veterinary and Agricultural University, Frederiksberg, Denmark. Each subject tested nine of thirteen meals, plus a reference meal, on a total of ten different occasions, each separated by at least 7 d. The selection of test meals was randomised by using a computerised randomisation matrix. The order of meals was further randomised to a subject. This randomisation matrix resulted in each breakfast meal being tested eighteen to twenty-one times, whereas the reference meal was tested twenty-eight times. The subjects were asked to refrain from physical activity and from drinking alcohol for 2 d before the test day. The subjects consumed a standardised dinner meal before 21.00 hours on the evening before a test day. They were allowed to drink water until midnight. After an overnight fast the subjects arrived at 08.00 hours at the department using the least strenuous means of transportation. After voiding they were weighed (Lindell Tronic 8000, precision 0.01 kg; Copenhagen, Denmark) wearing only underwear. On the first test day the height of the subjects without shoes was measured. Body composition was measured by bioelectrical impedance using an Animeter (Unitech, Humble, Denmark). The subjects rested in a supine position for at least 10 min after which a venflon catheter (BOC Ohmeda AB, Helsingborg, Sweden) was inserted in an antecubital vein. Venous blood samples were drawn before (0 min) and after (15, 30, 45, 60, 90 and 120 min) the test meal was given. The participants had to lie down for at least 10 min before each blood sample, but otherwise they were allowed to read, watch videos, and walk slowly around during the test day. The test meal was given at 08.30 hours and was to be eaten within 15 min.

Test meals

The thirteen different test meals were designed to resemble typical European breakfast meals (representing countries such as Finland, Sweden, Denmark, Germany, France, Italy and Great Britain) and therefore included different types of bread meals, cereal products and other typical European breakfasts. All meals contained 50 g available carbohydrate measured as the sum of free glucose and glucose released from starch after 120 min of *in vitro* digestion (Englyst *et al.* 1992). The total amount served of each breakfast meal was adjusted to reach this level of carbohydrate. The meals therefore differed in contents of energy (1134–2990 kJ), carbohydrate (30–75 % energy (E %)), protein (5–28 g; 6–22 E %), fat (3–42 g; 11–55 E %) and dietary fibre (1–24 g) (Table 1). The quantities of butter (22 g/100 g bread), cheese (65 g/100 g bread) and jam (50 g/100 g bread) were means of the standard amounts for different European countries. The cheese was a Danish Danbo-type (45 % fat). The amount of milk (semi-skimmed milk; 1.5 % fat) given with the meals corresponded to the amounts recommended by the manufacturers on the packages. The reference meal was white wheat bread baked at the Department of Human Nutrition. Water (250 ml) was served with each test meal. The content of fat, protein, dietary fibre and digestible energy was calculated from the Danish food composition tables (Møller & Saxholt, 1996) and from the information given

Table 1. Composition of breakfast meals containing 50 g available carbohydrates*

Meal name	Components and weight (g)	Breakfast (g)	Energy content (kJ)	Dietary fibre † (g)	Protein (g)	Fat (g)	Carbohydrate (E%)	Protein (E%)	Fat (E%)	Predicted GI
Ref	Reference bread (105)	105	1338	5	12	7	66	15	19	100
Ref-B	Reference bread (105) Butter (23)	128	2050	5	12	25	43	10	47	100
Ref-B-C	Reference bread (104) Butter (23) Cheese (67)	194	2990	5	28	42	30	16	54	99
Fin-B-C	Finnish bread (106) Butter (23)	198	2882	10	25	39	33	15	52	91
Ger-B-C	Cheese (69) German bread (116) Butter (25)	216	2843	5	25	41	30	15	55	91
Ref-B-J	Cheese (75) Reference bread (73) Butter (16)	125	1695	3	8	18	52	8	40	96
Fre-B-J	Jam (36) French bread (66) Butter (15)	114	1456	2	5	13	60	6	34	94
AB-M	Jam (33) All-bran (62)	318	1376	9	15	5	68	18	14	86
ABplus-M	Milk (256) All-bran plus (81)	419	1732	24	22	8	60	22	18	55
Corn-M	Milk (338) Cornflakes (49)	252	1168	1	10	3	74	15	11	97
Fros-M	Milk (203) Frosties (47)	244	1134	1	9	3	75	14	11	77
Ita-Cof-M	Milk (197) Italian biscuits (59) Coffee (96)	381	1569	1	12	14	54	13	33	74
Oat-Sug-M	Milk (226) Rolled oats (55) Sugar (10)	230	1352	6	13	6	66	16	18	74
Por-App	Milk (165) Porridge: rolled oats (59) Water (320) Apple sauce (117)	496	1213	6	8	5	74	11	15	76
Range		105–496	1134–2990	1–24	5–28	3–42	30–75	6–22	11–55	55–100

E%, % energy; GI, glycaemic index.

* Data are based on information from the Danish food composition tables (Møller & Saxholt, 1996).

† The energy contribution from dietary fibre used is 8 kJ/g.

by the producers. The composition of the breakfast meals is shown in Table 1.

Standardisation meal

The meal consumed by all participants on the evening before each test meal consisted of a goulash with parboiled rice and a honey cake. The macronutrient content was 50 E% carbohydrate, 37 E% fat and 13 E% protein, which is comparable with the energy composition of the average Danish diet. The energy content of the evening meal amounted to 35% of the daily energy needs of each individual.

Laboratory analysis

Blood samples were kept on ice and centrifuged at 2800 g for 10 min at 4°C. They were then separated into plasma and serum and kept at -20°C until analysed. The blood samples were analysed for plasma glucose and insulin.

Plasma glucose concentration was analysed using a COBAS®MIRAplus (Roche Diagnostic Systems, L. Hoffmann-La Roche LTP, Basel, Switzerland) and an ABX Diagnostics Glucose HK 125 kit (Deeg *et al.* 1980). The intra- and interassay variations (CV) were 1.6 and 2.8%, respectively. Serum insulin concentration was measured using the principle of radioimmunoassay described by Albano *et al.* (1972) against a standard of human insulin. The tracer was human insulin moniodinated in position A14 (NOVO-Nordic A/S, Bagsvaerd, Denmark). The guinea-pig antibody (code 2004) used cross-reacted with pro-insulin and split insulin. The intra-assay variation (CV) was <5%, and the sensitivity was <5 pmol/l.

Data analysis

The predicted GI of the meal (GI_{pred}) was calculated as recommended by the Food and Agriculture Organization/World Health Organization (1998), by weighting the GI of each component in the test meals:

$$GI_{\text{pred}} = GI_A \times g_A/g + GI_B \times g_B/g \dots,$$

where GI_A is the GI of component A, g_A is the amount of available carbohydrate in component A (g), and g is the total amount of available carbohydrate in grams in the meal (50 g). The GI of single components was either provided by Kelloggs Europe (All-bran regular (GI 102) and Frosties (GI 87); personal communication), or found in the table of Foster-Powell & Brand-Miller (1995). When possible the table values of tests with normal subjects were chosen. The GI were found to be (the entry-numbers refer to the entries in the international table): All-bran plus, 64 (entries 89, 91); cornflakes, 112 (entries 99, 100); Finnish bread, 92 (entries 45–54); French bread, 99 (entry 56); German bread, 92 (entries 45–54); Italian biscuits, 84 (entry 231); oatmeal, 78 (entry 116, 117); oatmeal porridge, 70 (entry 119). Other estimates of GI were: jam, 89 (entries 485, 488); milk, 37 (entries 266, 268, 270); sugar, 89 (entries 485, 488); apple sauce, 89 (entries 485,

488). Butter and cheese were ignored due to their low carbohydrate content. The predicted value of each meal is shown in the last column of Table 1.

The measured GI (GI_{meas}) and II (II_{meas}) were calculated as recommended by the Food and Agriculture Organization/World Health Organization (1998):

$$GI \text{ and } II = 100 \times iAUC (\text{test meal})/iAUC (\text{reference meal}),$$

where iAUC is incremental area under the curve. iAUC under the response curve and over the fasting level was calculated using the trapezoid rule leaving out the negative values (Food and Agriculture Organization/World Health Organization, 1998).

The predicted responses of glucose and insulin of the test meals relative to the responses of the reference meal (GR_{pred} and IR_{pred}) were calculated by the equations of Wolever & Bolognesi (1996a):

$$GR_{\text{pred}} = 1.5 \times GI_{\text{pred}} \times (1 - e^{-0.018D}) + 13,$$

$$IR_{\text{pred}} = 2.9 \times (0.6 \times GI + 0.003 \times GI^2) \times (1 - e^{-0.0078D}) + 5,$$

where D is the amount of available carbohydrate (g) (50 g in the present study). GI_{meas} and II_{meas} were calculated as the incremental areas under the 2 h postprandial glucose and insulin response curves after the test meal related to the same area after intake of the reference meal for the same individual.

Statistical analysis

All results are given as means and standard errors of the mean. Data were transformed using Cox-Box transformation where this was necessary in order to meet the assumptions of the analysis. The following transformations have been used (where x is data): $\log_{10}(x)$, $(x)^{-1}$, $(x)^{0.5}$.

The effects of the meals on glucose and insulin responses were analysed using ANOVA for summary measures (GI_{meas} , II_{meas} , and iAUC for plasma glucose and insulin), with subject and meal as class variables and fasting value, body weight and body-fat percentage of the subjects as covariates. Tukey-Kramer-adjusted least-square means were used in the *post hoc* test.

Linear regression analysis was used to investigate relationships between all parameters. Adjusted R^2 as opposed to the unadjusted R^2 compensates for the number of parameters in the equation and the number of data observations, and is therefore used to describe the goodness of fit of the multiple linear regression models. Means of GI_{meas} and II_{meas} were adjusted for variation between subjects. The relationships between GI_{meas} and GI_{pred} and between GI_{meas} and II_{meas} were investigated by simple linear regression analysis on means. Simple and multiple linear regression analyses were used to predict GI_{meas} and II_{meas} by the meal variables. The meal variables included were content of energy (kJ), energy

density (kJ/g), amount of breakfast (g), protein (g and E%), fat (g and E%), carbohydrate (E%) and dietary fibre (g and g/MJ).

All statistical analyses were done using SAS version 8, 1999 (SAS Institute Inc., Cary, NC, USA), and the level of significance was $P < 0.05$.

Results

Predicted and measured glycaemic indices

The GI_{pred} and the GI_{meas} for the fourteen different meals are shown in Fig. 1. GI_{pred} ranged from 55 to 100 and GI_{meas} from 26 to 116. Bread meals with butter and cheese had the lowest GI_{meas} (26 (SEM 3), 27 (SEM 4), 30 (SEM 7)) while white bread and oat porridge with apple sauce had the highest GI_{meas} (100 (SEM 0), 116 (SEM 16)). Significant differences of GI_{meas} between meals were found ($P < 0.001$), but there was no single meal that differed significantly from all the others.

There was no significant relationship between GI_{pred} and GI_{meas} using linear regression on means of the meals (R^2 0.002; $P = 0.88$) (Fig. 2). Restricting the linear regression analysis to meals with a carbohydrate content of more than 50 E% (n 10), or 55 E% (n 8), did not change this (R^2 0.08 and 0.25, respectively; $P > 0.15$) (Fig. 2).

Relationships between measured glycaemic index and meal variables

In univariate analyses energy content (kJ) and amount of fat (g) of the breakfasts were inversely related to GI_{meas} and explained most of the variation in GI (GI_{meas} R^2 0.93 and 0.88; $P < 0.001$) (Fig. 3). There was a positive

relationship between GI_{meas} and %E of carbohydrate (R^2 0.80; $P < 0.001$) (Fig. 3). GI_{meas} was inversely related to the amount of protein (g) and %E of fat (R^2 0.65 and 0.66, respectively; $P < 0.001$).

Multiple linear regression analysis on GI_{meas} with the meal variables as explanatory variables resulted in the following best fitted model:

$$GI_{meas} = 1/(0.0057 + 0.0005 \times \text{fat (g)} + 0.0006 \times \text{protein (g)}); \text{ adjusted } R^2 \text{ 0.93, } P < 0.001.$$

Simple linear regression analysis on meals with a carbohydrate E% larger than 50 E% or 55 E% showed no associations between any of the meal variables and GI_{meas} .

Insulinaemic index

The II_{meas} are shown in Fig. 4 together with GI. The II of the fourteen meals ranged from 76 (SEM 8) for French bread with butter and jam to 120 (SEM 6) for All-bran with milk. Significant differences in II were found between meals ($P < 0.001$), but there was no single meal that differed significantly from all of the other meals. No significant model could predict the II from the meal components in either univariate or multivariate analyses. There was no significant relationship between GI_{meas} and II using simple linear regression (R^2 0.06; $P = 0.40$). Neither did we find any relationship between GI_{meas} and II when using only meals with a carbohydrate content of more than 50 E% or 55 E% (R^2 0.15, R^2 0.07; $P > 0.2$). This was also the case when meals with milk were excluded (n 8, R^2 0.09; $P = 0.47$).

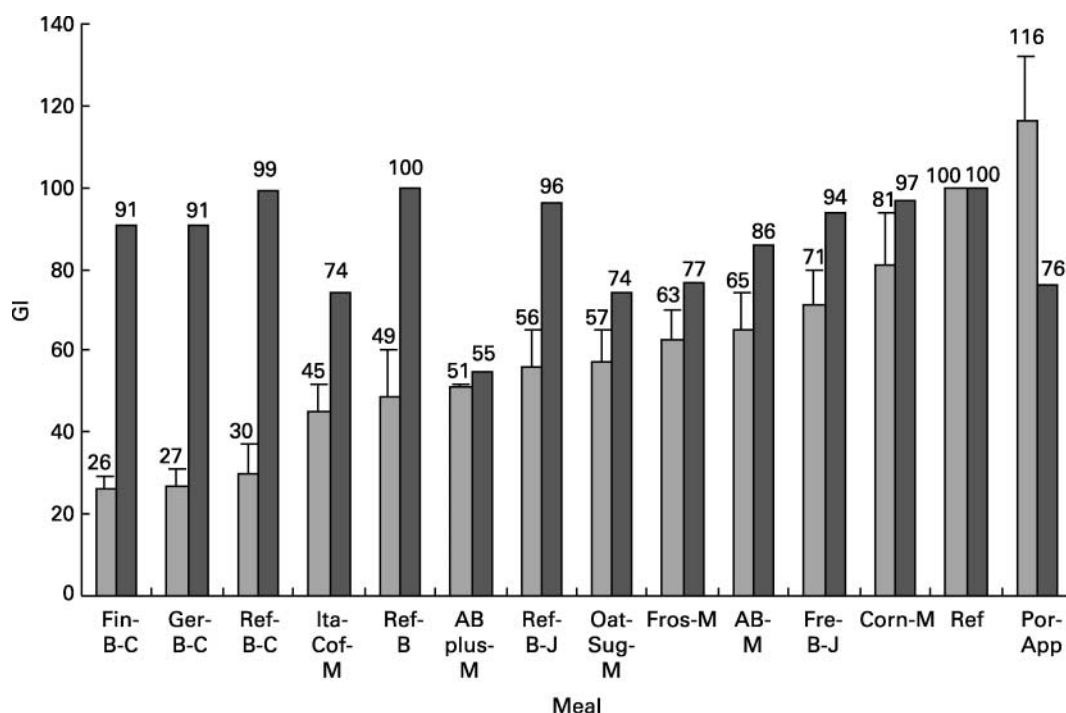


Fig. 1. Predicted (■) and measured (■) glycaemic indices (GI) for fourteen different breakfasts (see Table 1) containing 50 g available carbohydrate. Values are means, with standard errors of the mean represented by vertical bars.

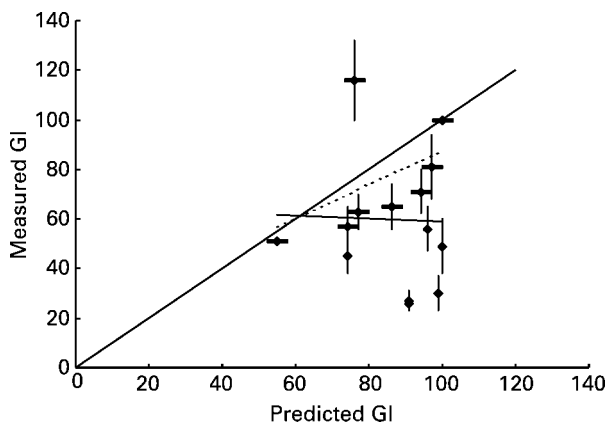


Fig. 2. Relationships between means of measured glycaemic indices (GI) *v.* predicted GI for fourteen different breakfasts (see Table 1) containing 50 g available carbohydrate by simple linear regression. Regressions were made for all test meals (\blacklozenge and $-$; R^2 0.002, $P=0.88$) and for eight meals that had over 55% energy as carbohydrate ($-$, \cdots ; R^2 0.25, $P=0.16$). Values are means, with standard errors of the mean represented by vertical bars.

Predictions of the relative glycaemic and insulinaemic responses

The predicted and measured responses of glucose and insulin to the test meals relative to the responses to the reference meal (measured glucose response, GR_{pred} , measured insulin response and IR_{pred}) are shown in Fig. 5.

Using simple linear regression analyses, we found no associations between the measured glucose response and GR_{pred} (R^2 0.0005; $P=0.94$) or between the measured insulin response and IR_{pred} (R^2 0.02; $P=0.62$). Nor did we find any relationship between them when using only meals with a carbohydrate content of more than 50 E% (glucose response R^2 0.20, $P=0.19$; insulin response R^2 0.04, $P=0.58$) or 55 E%, (glucose response R^2 0.30, $P=0.16$; insulin response R^2 0.05, $P=0.60$).

Discussion

In the present study we found no association between GI_{pred} and GI_{meas} in a wide range of different European breakfast meals. Furthermore, GI did not correlate significantly with II. Finally, neither the glycaemic nor insulinaemic response predicted by earlier proposed prediction equations (Wolever & Bolognesi, 1996a) were correlated with the glycaemic and insulinaemic responses measured in the present study. The best prediction model of GI included the fat and protein content of the test meal, explaining 93% of the variation. It was not possible to predict II from the components of the test meals.

Prediction of glycaemic index based on table values

The applicability of GI in mixed meals has been discussed for decades, but has never been assessed by as large a study as the present. Each of the thirteen test meals was tested by eighteen to twenty-one subjects and the reference meal was tested by all twenty-eight subjects. This number of subjects is two to five times the number recommended and typically

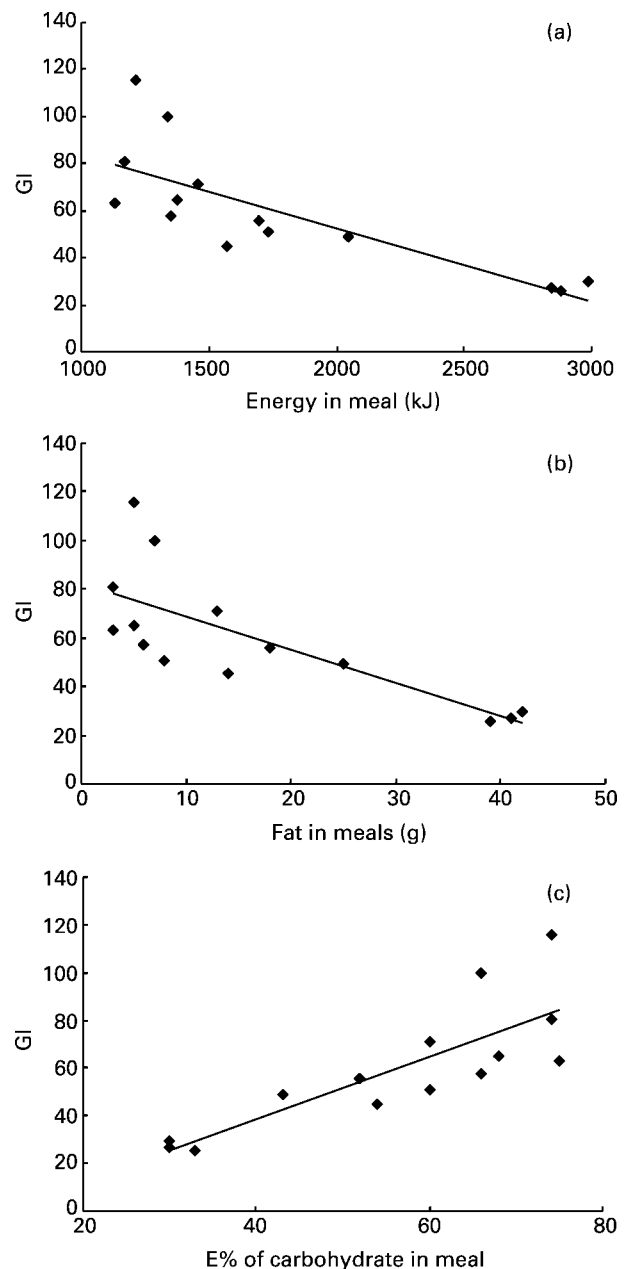


Fig. 3. Relationships between amount of energy (a), fat (b) and carbohydrate (% energy (E%); c) in the fourteen different breakfast meals (see Table 1) containing 50 g available carbohydrate and the means of measured glycaemic indices (GI) of the meals. For energy the relationship was $GI = 1/(-0.0076 + 173e^{-7} \times \text{energy in meal})$; R^2 0.93, $P < 0.001$. For fat the relationship was $GI = 1/(0.0105 + 0.0008 \times \text{fat in meal})$; R^2 0.88, $P < 0.001$. For carbohydrate the relationship was $GI = 10 \times (1.037 + 0.0116 \times \text{E \% of carbohydrate})$; R^2 0.80, $P < 0.0001$.

used to measure GI (Bornet *et al.* 1997; Food and Agriculture Organization/World Health Organization 1998; Foster-Powell *et al.* 2002). In this setting it was not possible to predict the GI of mixed meals based on GI values from the international tables (Foster-Powell & Brand-Miller, 1995). However, the GI concept has been claimed to be useful in the context of high-carbohydrate meals but not for high-fat or high-protein meals. We fully recognise that some of the meals in the present study were not

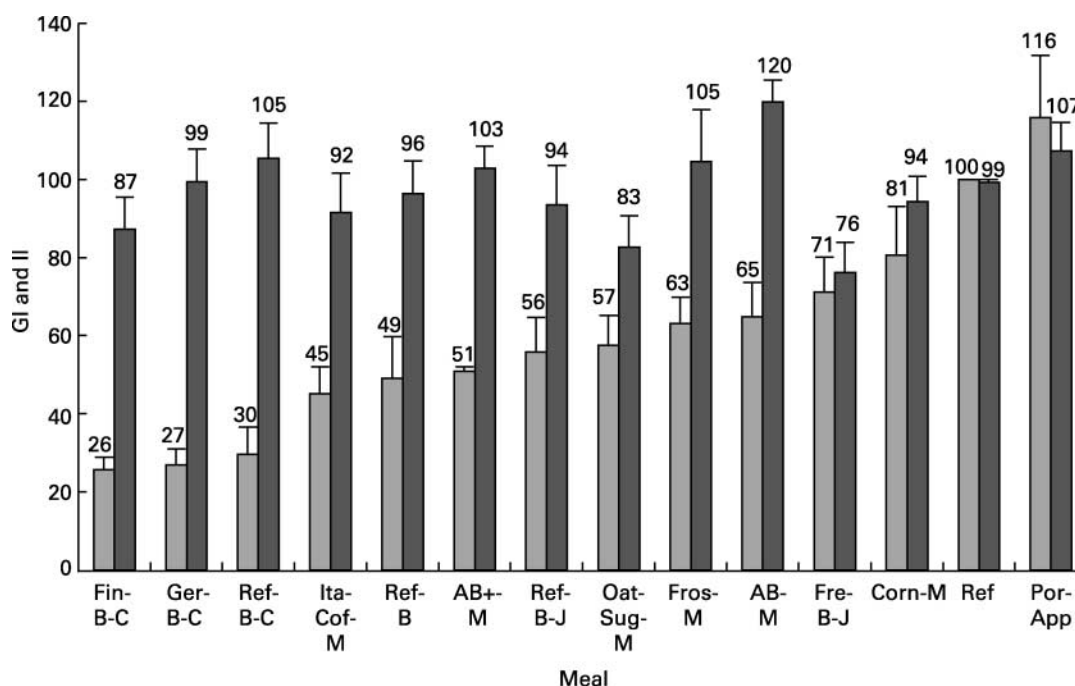


Fig. 4. Measured glycaemic indices (GI; ■) and insulinaemic indices (II; ■) for fourteen different breakfast meals (see Table 1) containing 50 g available carbohydrate. Values are means, with standard errors of the mean represented by vertical bars.

high-carbohydrate meals, but limiting the analysis to meals with an E% from carbohydrates of more than 50 (ten meals) or 55 (eight meals) did not change the results, although the correlation coefficients increased and the *P* values decreased.

The present results are in accordance with some studies (Coulston *et al.* 1984a,b, 1987; Laine *et al.* 1987; Hollenbeck *et al.* 1988), while in contrast with others (Wolever *et al.* 1985, 1988b; Collier *et al.* 1986; Wolever & Jenkins, 1986; Bornet *et al.* 1987; Chew *et al.* 1988). Most of the studies that report good predictability of GI compare mixed meals in which a single component of the whole meal has been changed, for example, potatoes as a substitute for pasta or rice (Wolever *et al.* 1985, Collier *et al.* 1986; Wolever & Jenkins, 1986; Bornet *et al.* 1987), or have a fixed content of macronutrients across test meals (Chew *et al.* 1988). In the present study the meals represented typical breakfasts from across Europe. The carbohydrate content was fixed, and in order to keep the meal composition typical, we also fixed the relative amounts of food components in the meal (for example, bread:butter:jam). This resulted in some variation in other aspects of the meals, for example, energy content and weight of the meal, none of which caused problems during eating for the subjects. In order to investigate the relationship between GI_{pred} and GI_{meas} , the GI range should be wide. The present study covered a range from 55 to 100 in GI_{pred} , and a range from 26 to 116 in GI_{meas} , which is comparable with other studies (Wolever *et al.* 1985, 1988b; Collier *et al.* 1986; Wolever & Jenkins, 1986; Bornet *et al.* 1987; Chew *et al.* 1988). Limiting the analysis to carbohydrate-rich meals did not reduce this range.

In a recently published paper the GI of five identical centrally distributed products was determined by seven

different experienced GI laboratories (Wolever *et al.* 2003), and a difference between centres of more than 30 GI units was seen for rice and spaghetti. This is quite a substantial inter-laboratory difference for a standardised procedure, showing some methodological difficulties in the measurement of GI, and in turn in the use of table values. We also found large variations in GI for the same food item in the tables when trying to find the most correct value for prediction. We chose to use the mean values of the most relevant studies for the various different food items, but for some items we had to rely on personal communication or estimates of other similar items.

It has been suggested that in order for GI to be predictable in mixed meals, each single meal component should ideally be tested in advance in the same group of individuals (Jenkins *et al.* 1988). If this is true then the efforts to create international tables of GI for different food items would seem to have been wasted. Furthermore, the workload of creating GI values of single food items would be tremendous if the demands of meal and diet planning are to be met. Thus, testing of local foods, different brands within the same food and seasonal variations of food items is necessary. This reduces the practical and clinical usefulness of the GI concept.

Other factors that may complicate the predictability of GI are the physical form of the food, the processing, the preparation, the ripeness of fruits and the content of anti-nutrients (O'Dea *et al.* 1980; Brand *et al.* 1985; Englyst & Cummings, 1986; Jenkins *et al.* 1988; Truswell, 1992; Pi-Sunyer, 2002). The second-meal effect, i.e. the fact that the glycaemic response is influenced by the preceding meal (Wolever *et al.* 1988a; Liljeberg *et al.* 1999), also contributes to the difficulties of using GI outside the laboratory during non-standardised conditions.

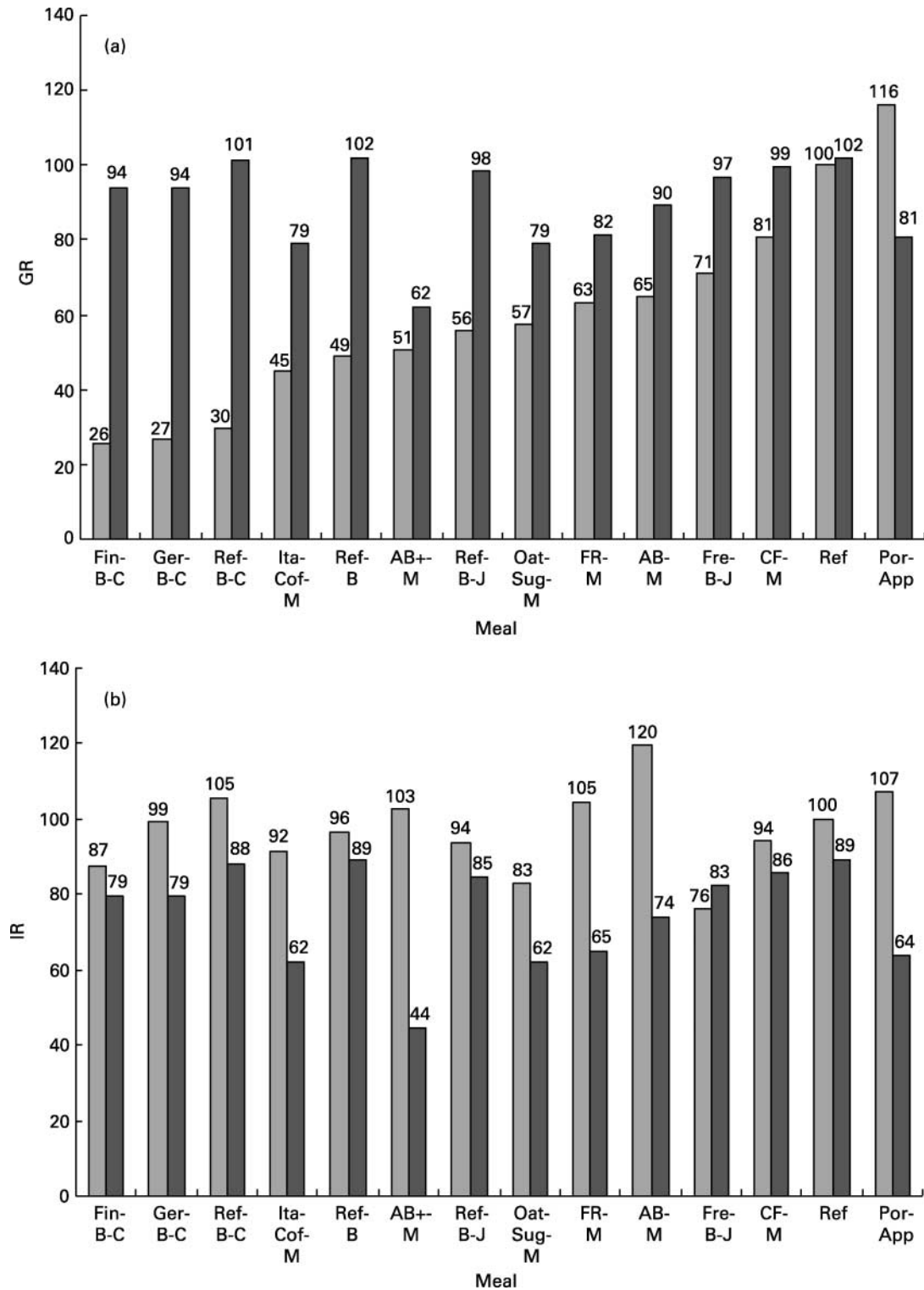


Fig. 5. Measured (■) and predicted (■) glycaemic response (GR) (a) and insulinaemic response (IR) (b) for fourteen different breakfasts (see Table 1) containing 50 g available carbohydrate. GR_{meas} , GR_{pred} , IR_{meas} and IR_{pred} are the measured and predicted responses of glucose and insulin of the test meals relative to the responses of a reference meal (white wheat bread). The measured responses are calculated as the incremental areas under the curves 2 h postprandial to a breakfast meal related to the same area after intake of the reference meal. GR_{pred} and IR_{pred} are calculated by the equations by Wolever & Bolognesi (1996a). $GR_{pred} = 1.5 \times GI \times (1 - e^{-0.018D}) + 13$; $IR_{pred} = 2.9 \times (0.6 \times GI + 0.003 \times GI^2) \times (1 - e^{-0.0078D}) + 5$, where GI is the predicted GI of the meal, and D is amount of carbohydrate (g).

Prediction of glycaemic index based on meal components

In a recent comprehensive study of GI and II, twenty-three breakfast products including cereals, bakery products, crackers and biscuits were characterised by their macronutrient content and type of carbohydrates (Englyst *et al.* 2003). It was found that rapidly available carbohydrates were positively related to GI, whereas slowly available carbohydrates and fat were inversely related to GI. Slowly available carbohydrates and fat together accounted for 73% of the variation of GI, with slowly available carbohydrates as the dominant variable. However, in the present study the fat content was equivalent to less than 27% of the carbohydrate content (Englyst *et al.* 2003). So if a low fat content is this powerful in predicting GI it would seem reasonable to assume that fat becomes more dominant in predicting GI in mixed meals that contain more fat. This seems to be the case in the present study, in which we found the combined content of fat and protein, as well as total energy, to be stronger predictors than the carbohydrate content alone. Thus, our prediction models showed that the energy content of the test meal was the single best predictor of GI. Due to the fixed amount of available carbohydrates in the present study, increased energy is reflected by an increased amount of fat and/or protein content as well. It is therefore not surprising that the best prediction model using multivariate analysis included both the fat and protein content of the test meals, each explaining equal amounts of the variation in GI. Dietary fat is known to slow down the rate of gastric emptying and absorption of nutrients from the gut (Cooke 1975), which in turn slows the release of glucose to the blood. Increased amounts of fat and protein in the gut also induce a larger secretion of the incretin hormones, glucose-dependent insulinotropic polypeptide and glucagon-like peptide-1 (Elliot *et al.* 1993; Herrmann *et al.* 1995). This increases the meal-induced insulin response, which in turn results in a faster clearance of blood glucose. Both mechanisms give rise to a lower GI.

Prediction of glycaemic and insulinaemic responses

It has been debated whether the amount or source of the carbohydrates is the most important factor in relation to blood glucose response. Wolever & Bolognesi (1996a) created prediction equations of both glycaemic and insulinaemic responses to individual foods taking both factors into account. They tested four carbohydrate-rich foods, each in three to four energy levels. The source and amount of carbohydrate were found to explain similar amounts of the variability in glucose and insulin responses, and together they accounted for 85–94% of the variability. Subsequently, these equations were evaluated in five mixed meals differing in energy, fat, protein and carbohydrate content, and with GI_{pred} ranging from 43 to 99 (Wolever & Bolognesi, 1996b). The amount and source of carbohydrates accounted for approximately 90% of the observed glucose and insulin responses.

Using the same prediction equations on our data material, we found no associations, and restricting the analysis to cover meals with a carbohydrate content of

more than 50 or 55 E% did not change this finding. However, it should be noted that in the present study, although representing typical meals, the amount of carbohydrate was fixed and the variation of energy, fat and protein was larger than in the studies by Wolever & Bolognesi (1996a,b). All in all, it seems that predictions constructed solely on aspects of carbohydrate content are insufficient, and that it is important to take other meal factors into account when trying to predict the glycaemic response to mixed meals.

Relationship between glucose and insulin responses

GI did not correlate with II. In fact, II was consistently larger compared with GI in all meals except one. This probably reflects the effect of fat and protein on the secretion of the primary incretin hormones, glucose-dependent insulinotropic polypeptide and glucagon-like peptide-1 (Elliot *et al.* 1993; Herrmann *et al.* 1995). It has been shown that milk products are insulinotropic, inducing a large insulin response independently of blood glucose (Östman *et al.* 2001), but investigation of the correlations between GI and II leaving out the meals with a milk component (eight meals) produced the same result. Other studies have shown the same inconsistency in glucose and insulin responses (Coulston *et al.* 1984a; Brand *et al.* 1990; Östman *et al.* 2001; Englyst *et al.* 2003; Schenk *et al.* 2003), thereby suggesting the need for information on both GI and II in relation to dietary recommendations. Furthermore, it has recently been shown that the cause of a lower GI of bran cereal compared with cornflakes was an earlier hyperinsulinaemia and an earlier increase in glucose disappearance (Schenk *et al.* 2003).

Conclusion

In the present study it was not possible to predict GI in composite breakfast meals using values from international GI tables. Nor was it possible to predict glycaemic or insulinaemic response from earlier equations. Based on the present results, it seems crucial to incorporate the total energy, fat and protein content of a meal in order to predict its GI. Furthermore, GI_{meas} and II_{meas} were not correlated. To conclude from the present results we question the practical usefulness of GI in the context of mixed meals and diet planning.

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