

Glycaemic responses to cereal-based Indian food preparations in patients with non-insulin-dependent diabetes mellitus and normal subjects

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The *in vivo* glycaemic responses to six cereal-based foods traditionally consumed in South India were evaluated in patients with non-insulin-dependent diabetes mellitus (NIDDM) and healthy volunteers. All foods contained 50 g carbohydrate and were compared with a 50 g glucose load. Also studied were the *in vitro* starch digestibility and nutrient composition of the foods. The postprandial responses to the foods at 30, 60 and 120 min were significantly ($P < 0.05$) lower than those to the reference glucose, in both groups. The peak glucose responses for three foods, i.e. chapatti, idli and poori, occurred 60 min postprandially in both groups. The glycaemic index (GI) values ranged from 67 to 90 in NIDDM and from 44 to 69 in healthy subjects with no significant differences within the groups. Significant relationships were observed between peak responses and area under the curve for foods in patients with NIDDM and *in vitro* rate of starch hydrolysis ($r = 0.83$, $r = 0.85$, $P < 0.05$). The GI values predicted using *in vitro* data were found to be similar to the GI values observed in patients with NIDDM. The GI concept is useful for identifying foods in the habitual Indian diet with attributes of the desired glycaemic effect such as delayed peak rise and low area under the curve.

Glycaemic response: Carbohydrate: Diabetes: Indian foods

Evidence provided by current research on carbohydrates has revealed that physiological responses are far more complex than was hitherto expected (Jenkins *et al.* 1981, 1983). It has also been established that the rates of digestion of starchy foods differ, and that they relate to the glycaemic responses they produce (Jenkins *et al.* 1980, 1982a). Since the hypothesis that traditional carbohydrate foods which are digested slowly *in vitro* are likely to give low glycaemic responses is largely based on the assumption that small-intestinal digestion is a rate-limiting step, foods which raise the blood glucose level the least for a given carbohydrate content are most suitable for diabetics (O'Dea *et al.* 1981; Jenkins *et al.* 1984).

Since the clinical utility of the glycaemic index (GI) is dependent on the habitual dietary patterns, GI values for conventional food preparations, as eaten by different Indian communities, have to be established. Though there are a few reports on the GI of Indian foods (Raghuram *et al.* 1987; Vishwanath *et al.* 1988; Kurup & Krishnamurthy, 1992; Mani *et al.* 1992), the correlation between *in vivo* glycaemic responses and *in vitro* starch digestibility has not been established in Indian food preparations.

The present study was undertaken to evaluate glycaemic responses to six cereal-based preparations commonly

consumed in South India. In addition, the possibility of obtaining a correlation between *in vivo* and *in vitro* observations was also explored.

Subjects and methods

Test foods

Six conventional cereal-based preparations were selected for the study. They were chapatti, dosai, idli, pongal, poori and upittu with suitable accompaniments. Descriptions of the test foods and the preparation details are given in Table 1. The prepared foods were analysed for nutrient composition (Association of Official Agricultural Chemists, 1984), fibre content (Asp *et al.* 1983), *in vitro* starch digestibility (Jenkins *et al.* 1980) and degree of gelatinization (Wootton *et al.* 1971).

In vitro study

A modification of the method of Jenkins *et al.* (1980) was used. Carbohydrate equivalents (1 g) of each of the six foods (2% of the portion size given to the subjects, prepared in the same way as indicated in Table 1) were homogenized after

Abbreviations: AUC, area under the curve; GI, glycaemic index; NIDDM, non-insulin-dependent diabetes mellitus.

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Table 1. Ingredients of and preparation details for the Indian foods used in the present study

Food	Ingredients	Raw wt (g)	Cooked wt (g)	Cooking procedure
Chapatti and dhal*	Wheat flour	60	200	Flour kneaded into dough, rolled into thin chapatti, baked both sides on a griddle
	Oil	8		
	Green gram (<i>Phaseolus aureus</i>) dhal	16		
Dosai and chutney†	Rice, raw	35	190	Soaked (5 h), wet ground to a paste, mixed, fermented overnight, ladleful of batter cooked on griddle with oil
	parboiled	15		
	Oil	8		
Idli and chutney†	Rice, raw	60	240	Soaked (5 h), wet ground rice (coarse) and dhal (fine), mixed, fermented overnight and steam cooked
	parboiled	15		
	Black gram (<i>Phaseolus mungo</i>) dhal	12		
	Oil	8		
Pongal	Rice	50	240	Dhal was lightly roasted, pressure cooked with rice, and seasoned
	Green gram dhal	25		
	Oil	10		
Poori and potato palya‡	Wheat flour	60	185	Flour kneaded into dough, rolled into small discs, deep fried in oil
	Potato	45		
	Onion	20		
Upittu	Semolina	65	180	Semolina was roasted (2 min), seasoned with onions and cooked in water (125 ml) until done
	Onion	20		
	Oil	8		

* Dhal cooked in water (150 ml), seasoned in oil (5 ml), with mustard and curry leaves.

† Coconut (fresh) 20 g, Bengal gram (*Cicer arietinum*) dhal 10 g, green chilli, salt and coriander leaves were ground to a paste.

‡ Boiled and mashed potato, seasoned in oil with mustard, curry leaves, green chillies, onion and salt.

cooking to simulate mastication and mixed separately with 2 ml fresh human saliva and 50 mg porcine pancreatin (BDH Chemicals, Poole, Dorset, UK). The volume of each mixture was made up to 15 ml with distilled water. The resulting slurries were dispensed into dialysis bags made from 130 mm strips of dialysis tubing (width 45 mm, molecular mass cut-off 18 000 Da; Chicago, IL, USA). Each bag was placed in a separate stirred water bath, containing 400 ml distilled water at 37°. After 3 h, 10 ml portions of dialysate were taken for sugar analysis. Maltose and oligosaccharides were analysed together as glucose after hydrolysis of a 2 ml sample with 2 ml 8.8 M HCl for 1 h at 75°, and neutralization with NaOH. Glucose was analysed by the standard glucose oxidase–peroxidase method using a semi-auto-analyser (POLI-MAK, F4, Rome, Italy). White bread was digested as a standard during each run. A control was also prepared in a similar manner but with enzymes inactivated by boiling to make allowances for free sugars already present in the food. The sugars enzymically released from the foods gave an index of starch digestibility.

In vivo study

Fifty-seven patients with confirmed non-insulin-dependent diabetes mellitus (NIDDM) (thirty-four men and twenty-three women) aged 42–59 years with BMI in the range 21–26 kg/m² who had been routinely visiting the outpatient diabetes clinic at the Railway Hospital and the Vikram clinic were randomly selected for the study. All subjects were in good general health except for having diabetes. Thirteen subjects were being treated by diet alone, forty-four by oral hypoglycaemic agents. The clinical characteristics of the NIDDM subjects are given in Table 2. Fifty-nine healthy

individuals (thirty men, twenty-nine women) aged 22–40 years with normal glucose tolerance (as tested by oral glucose tolerance test) and within the desirable range of BMI participated in this study. Informed consent was obtained from all subjects and approval for the study was given by the respective hospital authorities.

On the first visit, an oral glucose tolerance test was carried out for all the subjects, using 50 g glucose. All the subjects remained on their usual diets, but fasted overnight before the study. The subjects were then randomly divided into six groups (*n* 8–10). They received 50 g carbohydrate portions of one of the six test foods allotted to them on separate mornings within 1 week of the oral glucose tolerance test. They consumed the test food over a 10 min period. Any oral hypoglycaemic agents had been withheld for a period of 24 h before the tests in NIDDM subjects. All the foods were prepared on the morning of the test.

Table 2. Clinical characteristics of the patients with non-insulin-dependent diabetes mellitus (NIDDM) and healthy subjects used in the present study

	NIDDM (n 57)		Normal (n 59)	
	Mean	SD	Mean	SD
Age (years)	50	2.5	28	2.5
BMI (kg/m ²)	23	4.1	22	1.9
Duration of the disease (years)	4.7	2.0	–	–
Fasting blood glucose (mmol/l)	8.7	1.7	4.0	0.6
Plasma cholesterol (mmol/l)	5.1	0.5	4.8	0.6
Haemoglobin (g/l)	116	25	120	13

Blood samples were drawn just before and at intervals of 30, 60 and 120 min after consumption of the test food or glucose. Plasma was removed after centrifugation for 20 min at 800 g and glucose was determined by the glucose oxidase method using a diagnostic kit (Accurex Biomedical, Bombay, India).

Statistical analysis

The incremental areas under the blood glucose curves (AUC) after the food and glucose were calculated geometrically and GI was calculated for each subject as described by Wolever *et al.* (1991), using the following formula:

$$GI = \frac{\text{incremental area of the test food}}{\text{incremental area of the glucose}} \times 100.$$

The difference between the highest postprandial glucose value, minus fasting blood glucose is referred to as 'peak above fasting blood glucose'.

Results are expressed as means and standard deviations. The mean GI values and blood glucose values at each time interval, for each food, were separately analysed in the two subject groups by one-way ANOVA followed by Duncan's multiple range test for comparison of foods (Harter, 1960). Also, the GI values for each food in the two groups were compared by the *t* test. Simple linear correlation coefficients were calculated between GI and nutrient composition, GI and AUC, rate of starch digestion and AUC, peak glucose rise and AUC, using the mean data for each variable. The predicted GI was calculated by multiple linear regression analysis using the nutrient composition and *in vitro* analysis data (degree of gelatinization, digestibility index, starch digested (%) and 3 h sugar value). The multiple linear regression equations used were:

$$GI = -66.04 - 6.91 x_1 + 5.23 x_2 + 0.60 x_3 - 7.39 x_4 - 0.06 x_5, R 0.87,$$

where x_1 is protein, x_2 is fat, x_3 is energy, x_4 is fibre and x_5 is starch.

$$GI = 139.47 - 0.60 x_1 + 0.51 x_2 + 0.74 x_3 - 2.40 x_4, R 0.90,$$

where x_1 is percentage starch digested, x_2 is the 3 h sugar value, x_3 is degree of gelatinization and x_4 is digestibility index.

Results

The nutrient compositions of the test foods are shown in Table 3. The composition varied depending on the ingredients used in the preparation.

In vitro study

The percentage starch digested *in vitro* ranged from 13 in poori to 19 in dosai (Table 3). Poori (13%) and upittu (19%) were digested more slowly than other foods. The starch in the bread control after 3 h was 28% digested, which was significantly higher than that for other foods. This observation is similar to reported data (Jenkins *et al.* 1980). Significant differences ($P < 0.05$) existed in 3 h sugar concentrations between the foods ranging from 300 mg/l liberated from dosai to 225 mg/l from chapatti.

In vivo study

The mean blood glucose data for each food tested in NIDDM subjects are given in Table 4. The overall glycaemic response at each time interval was significantly lower for poori compared with other foods ($P < 0.05$). The mean peak rises for the six foods ranged from 3.4 mmol/l for poori to 5.3 mmol/l for idli. The peak rises were comparable in chapatti and dosai, and in pongal and upittu respectively. The GI in NIDDM subjects ranged from 67 to 90. The GI of upittu was lowest and those for dosai and idli, chapatti and poori were similar. Although the GI values for dosai, idli and upittu appeared to be lower than that of pongal, the differences were not significant.

The integrated AUC in NIDDM are shown in Fig. 1. All foods produced lower incremental areas than glucose ($P < 0.05$). Upittu and poori had significantly lower areas than the other foods ($P < 0.05$).

The glycaemic responses following ingestion of the six foods in normal subjects are given in Table 5. The differences in the fasting glucose values were not significant among the subjects. All six foods elicited low glycaemic responses at each time interval. The mean peak rises for the foods ranged from 1.6 mmol/l for upittu to 2.6 mmol/l for pongal. The values for chapatti and pongal, dosai and poori were similar. There were no significant differences among the GI of any of the foods in this group either.

The mean total AUC for five of the six foods were significantly lower than the AUC after glucose ($P < 0.05$) (Fig. 1). However, only the AUC for poori was similar to

Table 3. Nutrient composition and digestibility characteristics of the Indian foods tested in the present study*

Food	Protein (g)	Fat (g)	Dietary fibre (g)	Energy (kJ)†	Starch digested <i>in vitro</i> (%)	Degree of gelatinization (%)	Digestibility index (%)
Chapatti and dhal	10.8	16.0	14.2	1590	22	45	53
Dosai and chutney	9.2	18.0	14.0	1640	19	69	70
Idli and chutney	11.0	9.6	10.8	1640	24	64	61
Pongal	7.4	13.4	8.8	1390	23	90	66
Poori and palya	8.4	20.0	15.0	1680	13	52	57
Upittu	8.3	14.0	9.0	1350	19	64	70

* For details of foods, see Table 1.

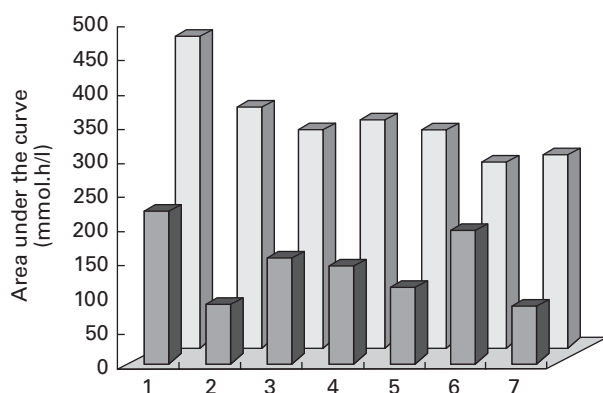
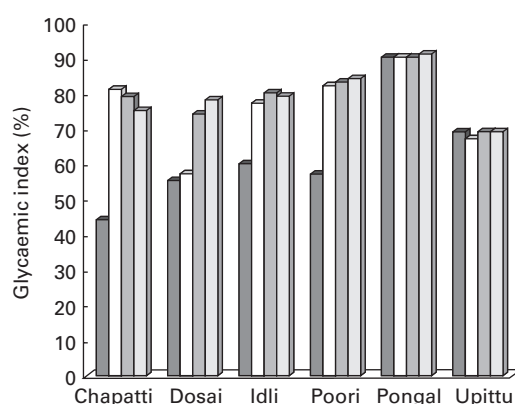
† Calculated value.

Table 4. Glycaemic responses at 0, 30, 60 and 120 min, peak blood glucose rises and glycaemic index (GI) values for six Indian foods in patients with non-insulin-dependent diabetes mellitus*

(Mean values and standard deviations for eight to twelve subjects)

Food	n	Mean blood glucose concentration (mmol/l)								Peak rise (mmol/l)		GI	
		0 min		30 min		60 min		120 min		Mean	SD	Mean	SD
		Mean	SD	Mean	SD	Mean	SD	Mean	SD				
Chapatti	8	8.8	1.4	11.3	0.7	13.6	1.8	11.1	1.0	4.6	0.8	81	12
Dosai	9	7.9	1.7	13.7	1.5	12.0	1.2	10.2	2.1	4.6	1.3	77	10
Idli	10	8.6	2.2	10.6	2.0	13.2	1.4	12.0	1.2	5.3	1.1	77	7
Pongal	10	8.4	2.0	13.3	1.0	11.9	0.6	10.7	1.6	4.9	1.2	90	9
Poori	8	7.2	1.3	8.3	1.1	10.6	0.9	10.4	1.4	3.4	1.0	82	7
Upittu	12	8.5	1.3	12.0	0.8	13.7	1.4	12.4	1.6	4.8	1.3	67	11

* For details of foods and subjects, see Tables 1–3.

**Fig. 1.** Areas under the total plasma glucose curves for healthy subjects (⊗) and patients with non-insulin-dependent diabetes mellitus (⊠) after consumption of six Indian foods and a glucose standard. (1), Glucose; (2), chapatti; (3), dosai; (4), idli; (5), pongal; (6) poori; (7), upittu. For details of foods and subjects, see Tables 1–3. Values are means for the numbers of subjects shown in Tables 4 and 5.**Fig. 2.** Observed glycaemic index (GI) values in healthy subjects (⊗) and patients with non-insulin-dependent diabetes mellitus (⊠), and GI values predicted from *in vitro* indices (⊞) and nutrient composition (⊠) for six Indian foods. For details of foods and subjects, see Tables 1–3. Observed values are means for the numbers of subjects shown in Tables 4 and 5.

that of glucose. The AUC after upittu was the lowest in both groups of subjects.

The GI of the six test foods in NIDDM and normal subjects are presented in Fig. 2. The GI after test foods in NIDDM were significantly higher than those of normal subjects with the exception of upittu. The observed GI of upittu were similar in both groups of subjects. The predicted GI is also shown in Fig. 2. The GI of the foods predicted

from both nutrient composition and *in vitro* indices were found to be similar to the GI observed in NIDDM subjects. The *in vitro* indices proved to be better predictors of GI as the magnitude of deviation between observed and predicted GI was smaller (0–4 %).

There were significant positive correlations between peak responses, AUC for foods in NIDDM and *in vitro* rate of starch hydrolysis (r 0.83, 0.85, $P < 0.05$). The nutrient

Table 5. Glycaemic responses at 0, 30, 60 and 120 min, peak blood glucose rises and glycaemic index (GI) values for six Indian foods in healthy human subjects*

(Mean values and standard deviations for six to eleven subjects)

Food	n	Mean blood glucose concentration (mmol/l)								Peak rise (mmol/l)		GI	
		0 min		30 min		60 min		120 min		Mean	SD	Mean	SD
		Mean	SD	Mean	SD	Mean	SD	Mean	SD				
Chapatti	11	4.2	0.6	5.4	0.7	5.9	1.0	4.3	0.8	1.9	0.4	44	11
Dosai	6	4.0	0.6	6.6	0.5	5.2	0.7	4.5	0.5	2.5	0.5	55	4
Idli	11	3.8	0.5	4.9	0.8	5.7	1.0	4.5	0.7	2.4	1.1	60	7
Pongal	8	4.0	0.7	6.2	1.0	5.4	0.4	4.6	0.6	2.6	0.9	45	7
Poori	8	4.1	0.3	5.4	0.5	6.0	0.9	3.8	0.4	2.3	0.6	57	4
Upittu	11	3.8	0.7	4.9	0.6	4.2	0.4	4.1	0.6	1.6	0.3	69	13

* For details of foods and subjects, see Tables 1–3.

composition and *in vitro* starch digestibility of the foods did not relate to the GI observed in the two groups of subjects.

Discussion

The results show that glycaemic responses to conventional Indian foods are modulated by an array of factors. The GI approach was used to allow comparison of results between different individuals. This was possible since each subject was standardized with a reference food, in this case glucose. The blood glucose area of each test food was then expressed as a percentage of that for the reference food for a given individual. In this way allowances could be made for differences in glucose tolerance status. It is reported that there is less variability between the GI values of different subjects than there is within the same subjects (Jenkins *et al.* 1981, 1983). Therefore, the mean GI values of foods are independent of the glucose tolerance status of the subjects being tested, which implies that it is valid to apply the GI values for foods determined in one group of subjects to different individuals.

The GI of the foods tested here were similar to those in earlier reports (Raghuram *et al.* 1987; Vishwanath *et al.* 1988). The results indicate that most Indian foods may be similar in their glycaemic effect, as there were no significant differences among the GI within the normal or diabetic group. However, the GI did differ significantly between the two groups. This is in conformity with the observation that consumption of different carbohydrate foods is found to elicit different glycaemic responses in normal subjects and diabetic subjects (Crapo *et al.* 1977; Jenkins *et al.* 1981, 1983).

All the foods tested here were consumed on an equicarbohydrate basis and thus differences in their responses could arise due to the composition of the food, and to other food-related variables such as added ingredients (Collier & O'Dea, 1983; Sahi *et al.* 1985) and accompaniments. The latter factors in turn may largely influence the ultimate nutrient composition of the prepared foods. The cooking method and cooking time also determine the extent of starch gelatinization and affect the glycaemic response (Collings *et al.* 1981).

The slow-release nature of traditional foods is attributed to the presence of pulses contributing the viscous type fibre (Jenkins *et al.* 1982*b*, 1983). However, in the present study foods prepared with a combination of pulses and cereals, e.g. dosai, idli and pongal, or even a cereal food like chapatti which is normally eaten with a pulse, had no greater hypoglycaemic effect than foods based on a single cereal, e.g. poori and upittu, as the GI in the groups were not significantly different. Perhaps the quantity of pulses was too low to produce their known viscous effect. In addition, processing treatments are also known to alter the starch-fibre relationship, increase the accessibility of starch and thus abolish the effect on glycaemia (Jenkins *et al.* 1982*b*; Trianedes & O'Dea, 1986).

There is increasing evidence to suggest that the immediate glycaemic response to a food may be a predictor of its effect in the longer term (Jenkins *et al.* 1978*a,b*). In the present study, glycaemic responses to dosai and pongal at 30 min after consumption were higher than the responses to

other foods in both groups of subjects. The finer particle size of dosai and the higher degree of gelatinization attained in pongal probably contributed to increased digestion and absorption of glucose from these foods.

One goal of assessing *in vitro* starch digestion was to screen foods and thus establish a realistic digestibility index ranking with a view to predict GI. Good correlations between the starch digestion rates measured *in vitro* and the GI have been established for foods being used by Western societies (Jenkins *et al.* 1980, 1982*a*, 1984). In the present study, the correlation did not reach statistical significance. This is the first study reporting both *in vitro* and *in vivo* observations in Indian foods. Although the correlation was not conclusive the emerging relationship of GI with all the food-related variables indicates that *in vitro* measurements are helpful in screening food preparations particularly regarding the choice of basic ingredients, pre-processing, cooking method and accompaniment.

A close correlation between the peak responses of NIDDM subjects and rate of starch hydrolysis *in vitro* suggests that intraluminal digestion rates of foods are more important for the subjects with diabetes. Also, the magnitude of the AUC for a food assumes greater significance in diabetic than normal subjects as the AUC for foods in NIDDM subjects correlated positively with the *in vitro* rate of starch hydrolysis.

The macronutrient composition and *in vitro* indices of the foods did not correlate well with the GI when tested individually, but they could be related by the application of multiple linear regression. By this analysis, it was possible to predict GI, the values of which were similar to the observed GI. This indicates that factors governing the glycaemic responses to mixed preparations are far more complex than those determining the responses to single foods where carbohydrate is derived from a single source.

We conclude that it is possible to identify food preparations in the habitual Indian diet having attributes of desired glycaemic effect, i.e. delayed peak rise, low glucose response curves. Three of the foods studied, chapatti, idli and poori, showed the desired attributes. The GI concept is useful in classifying foods; however, the importance of choice of carbohydrate and cooking method should be specified and appropriate dietary guidelines have to be formulated for diabetics.

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