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Rate of digestion of foods and postprandial glycaemia in normal and diabetic subjects

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Summary and conclusions

Carbohydrate portions (2 g) of lentils, soya beans, and wholemeal bread were incubated for three hours with human digestive juices and the effect of digestibility on blood glucose examined. Lentils and soya beans released only 39% and 8% respectively of the sugars and oligosaccharides liberated from bread. In healthy volunteers 50 g carbohydrate portions of cooked lentils and soya beans raised blood glucose concentrations by only 42% ($p<0{\cdot}001$) and 14% ($p<0{\cdot}001$) of the bread value. There was a similar response in diabetics.

These results suggest that rate of digestion might be an important factor determining the rise in blood glucose concentration after a meal and that supplementing chemical analysis with in-vitro and in-vivo food testing might permit identification of especially useful foods for diabetics.

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Introduction

Studies suggest that the postprandial rise in blood glucose concentration may be influenced by the rate of carbohydrate absorption.[1] Work with various dietary fibres[1] and food starches[2] emphasised that great differences in rates of digestion and absorption may exist between foods. Hence foods that liberate their carbohydrate slowly might be of use to diabetics by reducing the rise in blood glucose values after a meal.

We have examined digestibility and the effect on blood glucose of two different types of foods—namely, bread, a cereal product and traditionally a staple food in the West; and two leguminous seeds, lentils and soya beans, representing foods much more commonly eaten in those parts of the world where diabetes is less common.

Methods

IN-VITRO STUDIES

Carbohydrate portions (2 g) of cooked soya beans and lentils, ground to a smooth paste, and finely crumbed wholemeal bread (see table I) were mixed separately with 2·5 ml fresh pooled human saliva and 7·5 ml human postprandial jejunal juice (Lundh test-juice pooled from samples of mean tryptic activity exceeding 15 IU/l and stored at −20°C). Distilled water was added to the bread and lentils to make the final volume of all foods up to 30 ml. Food and digestive juices were then mixed well and placed in dialysis bags made of 13 cm strips of dialysis tubing (Visking size 9-36/32″, Medicell International, London). Each bag was suspended in separate stirred water baths containing 800 ml distilled water at 37°C. Other experiments with isotonic phosphate buffer pH 7·25 gave similar results. Aliquots of dialysates were taken at 0, 1, 2, and 3 hours for analysis of glucose, maltose, and oligosaccharides. Glucose was analysed by a standard enzymatic technique.[3] Maltose and oligosaccharides were analysed together as glucose[3] after acid hydrolysis with an equal volume of 10M HCl for one hour at 75°C and neutralisation with NaOH. We find that with this method a solution of maltose 10 mmol/l is completely hydrolysed to glucose.

Further tests were undertaken with saliva and jejunal juice inactivated by boiling so that allowances could be made for free glucose already in the foods or Lundh juice. Also 3 mmol of either glucose or maltose was substituted for the enzyme solutions in the dialysis bags to allow the potential trapping of sugars by the three foods to be measured. The proportion trapped together with the value for the carbohydrate liberated into the dialysate by enzymatic digestion allowed the total amount of starch digested to be calculated.

TABLE I—*Weights of foods (g) used in dialysis experiments to give 2 g carbohydrate portions*

Food	50 g Carbohydrate portion		2 g Carbohydrate portion,* cooked
	Uncooked	Cooked	
Wholemeal bread	—	120	4·8
Red lentils	94	361	14·4
Soya beans	250	510	20·4†

*Made up to 30 ml with digestive enzymes (10 ml) and distilled water.
†Only digestive enzymes added owing to volume.

TABLE II—*Test meals taken by normal volunteers and diabetics**

Constituents	Weight (excluding tea) (g)	CH_2O (g)	Fat (g)	Protein (g)	Dietary fibre (g)	Energy (kcal†)
		Normal volunteers				
Wholemeal bread, tea (400 ml)	120	53·4	5·1	12·5	11·3	297
Red lentils, tea (300 ml)	94	53·4	2·9	24·0	12·1	324
Soya beans,‡ tea (250 ml)	250	53·4	46·9	90·0	12·4	993
		Diabetics				
Wholemeal bread	88±13	43·9±5·7	16·3±1·2	35·5±2·5	9·3±1·1	486±43
Edam cheese	51±4					
Cottage cheese	92±4					
Tea§ (500±40 ml)						
Soya beans‡	75±7	42·5±5·6	15·8±1·2	38·8±4·1	10·0±1·2	461±48
Red lentils	41±8					
Tea§ (500±40 ml)						

*Calculated by method of Paul and Southgate.[6]
†1000 kcal≈4·2 MJ.
‡Calculated by method of Platt.[7]
§One patient took tea without milk.

NORMAL AND DIABETIC VOLUNTEERS

Groups of six healthy volunteers drawn from a pool of eight (three women, five men; mean age 28±2 years; 100±3% ideal body weight[4]) were given 50 g carbohydrate portions of soya beans or lentils, which were compared with a 50 g portion of wholemeal bread. For palatability all meals also contained 120 g skinned and pipped tomatoes and a sufficient volume of tea (minimum 250 ml) with 50 ml milk to bring the meal water content to at least 600 ml. Bread and bean breakfasts were eaten over 10 or 15 minutes in random order after an overnight fast. Finger-prick blood samples were taken for glucose analysis[5] at 0, 15, 30, 45, 60, 90, and 120 minutes (see fig 3).

Six diabetics (four women, two men; mean age 43±5 years; 99±3% ideal body weight, five on insulin 30±4 U/day, one on diet alone) took a mixed meal of soya beans and lentils to compare with wholemeal bread. Lentils, being richer in carbohydrate, were taken with the soya beans to reduce the volume of this meal. The carbohydrate content of the meals was adjusted to the patient's normal intake at breakfast, and the protein and fat content of the beans was balanced as closely as possible by adding Edam and cottage cheese to the bread meal. The volume of tea, containing 50 ml milk, was given according to individual preference and was the same for both bread and bean meals.

Morning insulin doses were given at the same time before each breakfast, which was eaten over 15 to 20 minutes. Finger-prick blood samples were taken for glucose analysis[5] at 0, 30, 60, 90, 120, and 180 minutes (see fig 4).

The compositions of the foods for both dialysis (table I) and test meals (table II) were calculated from food tables.[6 7] In the case of both soya beans and lentils the lowest percentage figures for carbohydrate content were used to ensure that the results were weighted as much as possible against finding a difference between bread and the legumes. Results were expressed as means±SEM and the significance of differences calculated with Student's *t* test for paired data.

The study was approved by the ethical committee of the Brent Area Health Authority.

Results

IN-VITRO STUDIES

Figure 1 shows the appearance of the products of carbohydrate digestion measured as glucose in the dialysate over three hours for the three foods tested. By three hours the values for lentils and soya beans were lower than for bread by 61% and 92% respectively. For bread 10% of the digested carbohydrate was glucose, and for lentils and soya the figures were 0% and 77% respectively, the remainder being maltose and oligosaccharides.

In the sugar-trapping experiments soya beans reduced the mean output of maltose and glucose at three hours by 60% of the control and lentils by 35%, while wholemeal bread was without effect.

From the data on both the enzymatic liberation of sugars and oligosaccharides and the trapping effect of foods, the proportion of each 2 g carbohydrate portion digested at three hours was 27% for bread, 15% for lentils, and 6% for soya (fig 2).

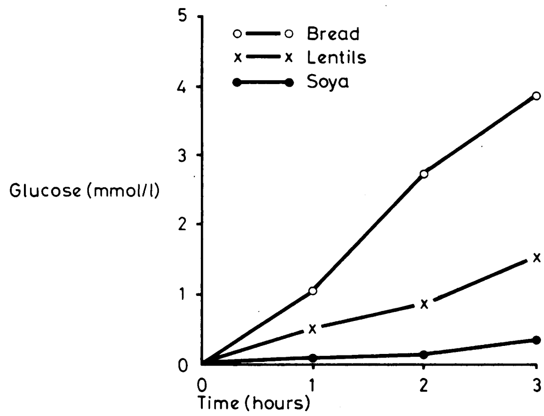

FIG 1—Concentration of total sugars and oligosaccharides (measured as glucose) in dialysate during in-vitro digestion of bread, lentils, and soya beans.
Conversion: SI to traditional units—Glucose: 1 mmol/l≈18 mg/100 ml.

TEST MEALS

The meals were well received. Normal subjects finished the bread and lentils comfortably within 10-15 minutes. Two subjects did not take the full amount of soya beans in the allotted time and, for comparison, subsequently took bread meals of equivalent carbohydrate content. The diabetics, who took the same amount of carbohydrate as contained in their normal breakfasts, had no difficulty in eating the composite meals in the prescribed time. The mean fasting blood glucose concentration for the normal volunteers ranged from 4·1 to 4·3 mmol/l (73·9 to 77·5 mg/100 ml) for the four sets of tests, and the means for the two diabetic meals were 11·4 and 11·8 mmol/l (205·4 and 212·6 mg/100 ml). In both the normal and diabetic subjects the rise in blood glucose concentrations after legumes was much less than after bread. Figures 3 and 4 show the significance of differences at each time. In normal subjects the area under the glucose curve for lentils was only 42% ($p < 0·001$) and for soya 14% ($p < 0·001$) compared with the bread meal (fig 3). Similarly in the diabetics the glucose area of the composite soya and lentil meal was reduced to 28% ($p < 0·002$) (fig 4).

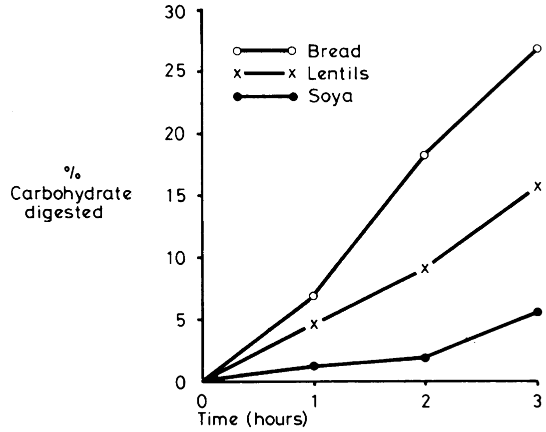

FIG 2—Estimated percentage of bread, lentil, and soya bean carbohydrate digested over three hours.

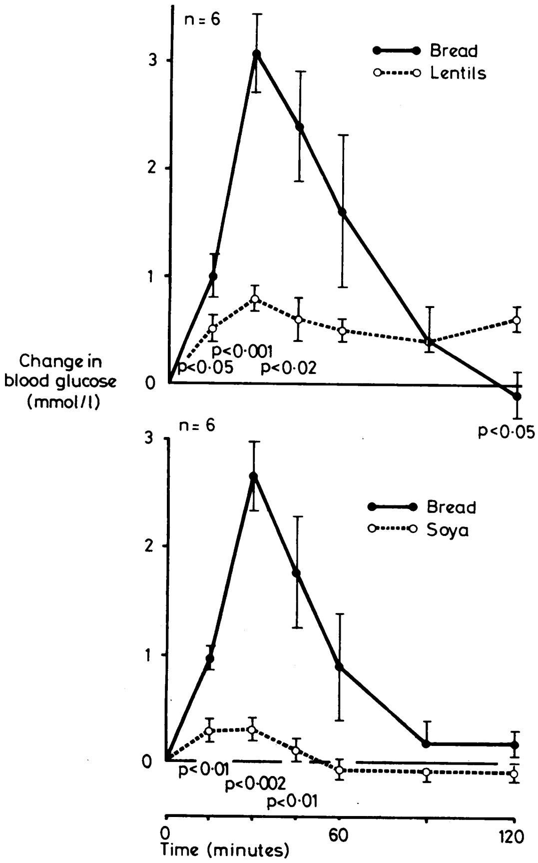

FIG 3—Rise in blood glucose concentrations in six healthy volunteers after meals containing 50 g carbohydrate as wholemeal bread or lentils (top) or wholemeal bread and soya beans (bottom).

Conversion: SI to traditional units—Glucose: 1 mmol/l ≈ 18 mg/100 ml.

Discussion

Our results support the concept that the rate of digestion of foods may be important in determining the extent to which they raise the blood glucose concentration in normal and diabetic people.[1]

The use of the dialysis system was an attempt to simulate human luminal digestion. In man salivary and pancreatic amylase cleaves α-1,4-glucose linkages in starch, liberating maltose, maltotriose, α-limit dextrins (glucose polymers with terminal α-1,6 linkages), and a relatively small amount of glucose. Maltose, maltotriose, and α-limit dextrins are then hydrolysed at the brush border during absorption in a process that is not rate-limiting.[8] Measuring these products of digestion gave dramatic evidence of a difference between legumes and bread and suggested that in-vivo leguminous carbohydrate would be digested much more slowly than bread. Great variation in the glycaemic response to carbohydrates from potato and various cereal sources has already been described,[2] but until now there have been no reports on the effect of their digestion in vitro.

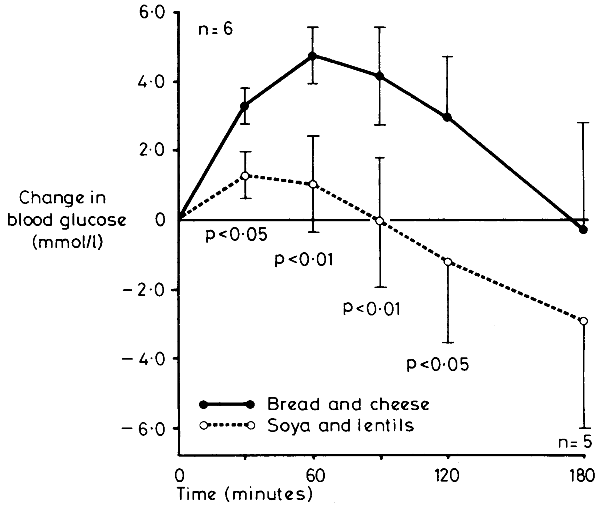

FIG 4—Rise in blood glucose concentrations in six diabetics after meals containing identical amounts of carbohydrate as wholemeal bread or lentils and soya beans.

Conversion: SI to traditional units—Glucose: 1 mmol/l ≈ 18 mg/100 ml.

Also other food components such as dietary fibre may protect starch from enzymatic attack, while both fibre and starch may trap the products of digestion, so slowing their liberation and absorption. With cooked foods our dialysis studies showed the ability of lentils and soya beans to trap glucose and maltose, while wholemeal bread had no effect.

Similar conclusions on the ability of certain forms of fibre to trap sugars have come from studies in which volunteers took glucose and xylose mixed with viscous types of dietary fibre—namely, guar and tragacanth—obtained from leguminous plants.[1] These fibre preparations flattened the rise in blood glucose concentrations and delayed urinary xylose excretion.

Flatter blood glucose responses also raise the question of malabsorption. Detailed studies of guar using xylose[1] and paracetamol[9] as markers, however, showed that guar did not reduce the amount of these substances absorbed but merely prolonged the time course of absorption. Furthermore, if malabsorption was responsible for the low blood glucose values seen here then over 25 g carbohydrate would have to be lost to the colon after each bean meal, which would be likely to result in severe abdominal symptoms. The lack of symptoms in our normal and diabetic volunteers during the 24 hours after their bean meals therefore argues against malabsorption. On the other hand, the mild flatulence sometimes noticed after eating leguminous seeds is more likely to result from colonic fermentation of such unabsorbable sugars as raffinose and stachyose. These are not included in food tables under available carbohydrate and so did not form part of the calculated carbohydrate used in our studies.

In parts of the world where diabetes is less common a substantial proportion of the daily carbohydrate and protein intake may come from leguminous seeds. In India lentils are eaten regularly as dahl together with other leguminous seeds—for example, chick peas—while the soya bean has been cultivated and used for millennia in south-east Asia, China, and Japan. In contrast, in contemporary Western diets wheat as bread, breakfast cereals, pasta, biscuits, pastry, cakes, etc provides the major proportion of the daily starch intake. Nevertheless, this has not always been so, and in the past legumes may have played a much more important part in the European diet, at one time being eaten regularly in Lent, and still being important dietary constituents in southern Italy[10] and parts of Spain.

A change of diet making use of more leguminous "lente-carbohydrate" sources would allow higher carbohydrate diets to be eaten with relative exclusion of fat. Such changes would probably result in lower fasting serum cholesterol concentrations and smaller rises in postprandial blood glucose values. These changes might help to reduce morbidity and mortality from both diabetes and arterial disease towards levels seen in communities where more slow-release carbohydrates are eaten.

Our results therefore suggested that "slow release" or "lente carbohydrate" in leguminous seeds resulted in flatter blood glucose responses than would otherwise be predicted for a given carbohydrate intake. Further in-vitro studies of digestibility of foods, especially those eaten by communities where diabetes is rare, may provide useful information not only for constructing diabetic diets but to help shape dietary advice in general.

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Smoking habits of men and women

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Summary and conclusions

The smoking habits of 1501 cigarette smokers attending 28 general practitioners in five group practices in London were assessed. Prevalence of smoking, daily cigarette consumption, and the use of cigars, untipped cigarettes, and hand-rolled cigarettes were lower in the women. After controlling for consumption the proportions of men and women who smoked every day were similar. Women who smoked 20 or more a day were similar to men in their self-reported inhaling habits and use of low-nicotine cigarettes.

The results suggest that women differ from men in those aspects of smoking that are determined predominantly by social factors but that their smoking habits become similar when pharmacological motivation takes over. This apparently occurs when consumption reaches about 20 cigarettes a day, when smoking almost inevitably becomes a regular event and the sex differences disappear.

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Introduction

For several years there has been a steady decline in the prevalence of cigarette smoking in men, but not in women.[1] Among women smokers there has been a steady increase in daily cigarette consumption, and women have also tended to start smoking at an increasingly early age. Recently there has been concern that they may be less successful than men in giving up smoking.[2] Our understanding of the differences in smoking habits between men and women is incomplete. This is partly because some of the major surveys—for example, that of McKennell and Thomas[3]—have not focused sufficiently on the sex differences.

During a study of a representative sample of general practitioners' patients[4] we found the prevalence of cigarette smoking to be 43% in the men and 34% in the women (Russell *et al*[4] and unpublished observations). We now describe the smoking habits of 1501 cigarette smokers in this sample and analyse the similarities and differences between men and women.

Subjects, methods, and results

All current cigarette smokers aged 16 or more attending the surgeries of 28 general practitioners in five group practices in London during the three weeks from 29 April to 19 May 1974 were asked to complete a questionnaire on smoking. Of the 1666 eligible subjects,