The effects of pectin and wheat bran on the distribution of a meal in the gastrointestinal tract of the rat

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The effects of wheat bran and pectin on the gastrointestinal distribution of a radiolabelled, homogenized baked-bean meal were investigated in the rat. These fibres were chosen because of their very different physical characteristics; wheat bran is a coarse, particulate, mainly insoluble fibre whilst pectin is a soluble viscous polysaccharide. Sixty male rats were administered orally with control or test meals and five from each group were killed after 50, 100, 200 and 300 min. The gut was removed and the distribution of the meal established scintigraphically. Addition of the fibres altered the distribution of the meal with faster accumulation at the distal and caecal areas. Wheat bran delayed gastric emptying whilst pectin promoted gastric emptying and had a pronounced effect on increasing the distal accumulation of the meal. These alterations in the distribution of a homogenized baked bean meal show that dietary fibres with different physical characteristics may alter gastrointestinal motility in different ways and these differences may have implications for meal absorption and clinical treatments of gastrointestinal disorders.

Dietary fibre: Wheat bran: Pectin: Meal distribution: Rat

The term 'dietary fibre' was introduced to describe the remnants of plant cell walls which are not hydrolysed by digestive enzymes in man (Trowell, 1974). The description covers a wide variety of plant-derived substances with different chemical compositions and different physical properties. As a result of their physical properties, dietary fibres can alter physiological mechanisms and consequently may be used in the treatment of some clinical disorders. Dietary fibres have an important influence on the rate of movement through the gastrointestinal tract. The rate at which the stomach empties controls the release of nutrients to the small intestine and hence the rate of their digestion and absorption into the bloodstream. Gastric emptying may therefore mediate some of the satiety responses necessary to control food intake. Transit through the small intestine affects the rate and amount of nutrient absorption and this in turn affects such factors as blood glucose levels, insulin response, cholesterol and free fatty acid levels. Finally, the rate of entry of nutrients into the caecum may determine the pattern and efficiency of fermentation by the bacteria; rapid fermentation is thought to be inefficient in terms of bacterial proliferation (because substrate is broken down more rapidly than it can be used by the bacteria), and also to produce a lot of gas, which is usually not welcomed by the human host.

We chose to investigate whether dietary fibres with very different physical properties had different effects on gastrointestinal transit and meal distribution in rats.

Coarse wheat bran is sold in the form of flakes or particles with a range of sizes. It is

* For reprints.

derived from part of the outer husk of the wheat grain as well as varying amounts of the endosperm. Its structural components are a mixture of celluloses, hemicelluloses and lignin (Royal College of Physicians, 1980). It is more lignified than any other human food and so is largely insoluble and highly resistant to disruption and enzymic digestion. In the gastrointestinal tract, bran is a bulking agent, probably as a result of its relative indigestibility and its capacity to hold water (Smith *et al.* 1981). It causes a small reduction in the rate of glucose absorption (Jenkins *et al.* 1978) and its speeds whole-gut transit, an effect which is thought to relate to its particulate nature and to be related mostly to movement through the large bowel.

Pectin is a water-soluble, heterogeneous fibre isolated from apple pulp and citrus peel and produced commercially as a powder. It is made up of a polygalacturonic acid backbone with occasional rhamnose links which confer 'kinks' in the three-dimensional structure of the molecule (Rees & Wight, 1971) and help to make it highly soluble in water. It has viscous properties as a result of methoxylated side chains on the polysaccharide backbone (Royal College of Physicians, 1980). Pectin has been shown to delay gastric emptying (Holt *et al.* 1979) and relieve symptoms of dumping syndrome which are thought to arise from too rapid delivery of nutrients into the small intestine (Leeds *et al.* 1981), to increase satiety in obese patients (DiLorenzo *et al.* 1988) and to improve glucose tolerance in diabetic patients (Jenkins *et al.* 1978). The mechanisms for these observations are unclear but are presumably related to the viscosity of pectin and its effects on gastric emptying and subsequent nutrient digestion and absorption.

The aim of this study was to investigate any effect of these different types of dietary fibre on the distribution of a meal along the gastrointestinal tract.

MATERIALS AND METHODS
Test substances

A suspension of coarse wheat bran (J. Sainsbury plc, London) was made in sterile water (10 g/l) by warming to 38° to soften the particles and homogenizing for 10 min. The mean particle size before dispersion was 1·54 mm (extremes were 5% < 0·10 mm and 5% > 2·42 mm), determined by dry-sieving.

Citrus pectin (methoxy content 7·7%, sucrose (and other sugars) content nil; Sigma, St. Louis, MO, USA) was dissolved in saline (9 g NaCl/l) to give 10 g/l. The solution was stirred continuously overnight.

Meal preparation

Baked beans (HP Foods Limited, Market Harborough, Leics.) were stained free of tomato sauce and rinsed with water. Water (control) or test solution (35 ml) was added to 35 g washed beans and the mixture was homogenized until it could pass through a 5 ml syringe bore (1 mm). Care was taken to ensure that the particles of wheat bran were in suspension before addition to the beans. The final concentration of wheat bran and pectin was 5 g/l. Each 'meal' was 3 ml, therefore the amount of test substance given was 0·015 g; this resulted in only minor alterations in nutrient composition and water content of each meal compared with the control (Table 1). Lactose (100 g/l; BDH Chemicals Ltd., Poole, Dorset) was thoroughly incorporated into the meal to allow data to be compared with that from previous experiments which used the breath hydrogen technique.

The physical properties of the control and test meals were very similar at the time of oral administration. The viscosity of the bean meal is such that it is possible to deliver an accurate volume of 3 ml from a syringe via the tube directly into the stomach; any significant increase in viscosity would make this method of administration unfeasible.

Table 1. *The nutrient composition* of meals containing homogenized baked beans (control) supplemented with coarse wheat bran (bran) or pectin, expressed as g/kg and also as the amount provided by a 3 ml 'meal'*

	Control		Bran		Pectin	
	g/kg	mg/meal	g/kg	mg/meal	g/kg	mg/meal
Protein	33	99	34	101	33	99
Fat	3	8	3	9	3	8
Carbohydrate	86	258	87	262	86	258
Water	848	2544	843	2530	848	2529
Dietary fibre†	34	101	36	107	39	116
Cellulose	8	23	8	24	8	23
Soluble NSP	14	41	14	41	19	56
Insoluble NSP	10	29	11	33	10	29
Lignin	3	8	3	9	3	8

NSP, non-starch polysaccharides.
* Calculated from food composition tables.
† Measured by the Southgate method.

The homogenates were radioactively labelled by mixing the appropriate volume of Technetium[99m]-tin colloid (Amersham, Bucks) into the meals to deliver approximately 1 MBq to each rat. Since the meals were homogeneous it is likely that the marker provided an index of the movement of the combined liquids and solids through the stomach and small intestine (Hinder & Kelly, 1977; Malagelada *et al.* 1979).

Protocol

Sixty male albino Wistar rats weighing approximately 240 g each were starved for 18 h before the experiment but were allowed free access to water before and during the procedure.

The rats were divided into three groups of twenty rats. A tube was inserted into the stomach of the unanaesthetized rats and 3 ml of the appropriate bean meal was administered into the stomach. Five animals from each group were killed at 50, 100, 200 and 300 min after the meal. Death was by exposure to chloroform (FSA Laboratory Supplies, Loughborough, Leics.) in a closed chamber. Death occurred within 30 s with minimum trauma to the internal organs.

After death the gut was immediately ligated *in situ* at the lower oesophageal sphincter, pylorus, ileocaecal valve and caeco–colon junction. The gut was removed into a petri dish containing saline (9 g/l) and transferred to a longitudinal perspex trough (1060 × 18 mm). Care was taken not to stretch the gut or displace the lumen contents. The total, stomach and caecal lengths were measured. The trough was pulled at a constant rate of 0·1 m/min under a scintillation detector (type DMI-2 Nuclear Enterprises Limited, Edinburgh) which had a 6 mm collimator slit. The detector was connected to a ratemeter (Scaler Ratemeter SR3; Nuclear Enterprises Ltd, Reading, Berks) and the display was recorded on-line by a chart recorder (Vitatron) running synchronous to the trough and also logged into a computer (BBC Datalogger program) for later analysis (Brown *et al.* 1988).

Analysis of radioactivity profiles

The area under the resulting profile was taken to be the total radiation administered. The profile was divided into thirteen sections: stomach, ten equal length sections for the small
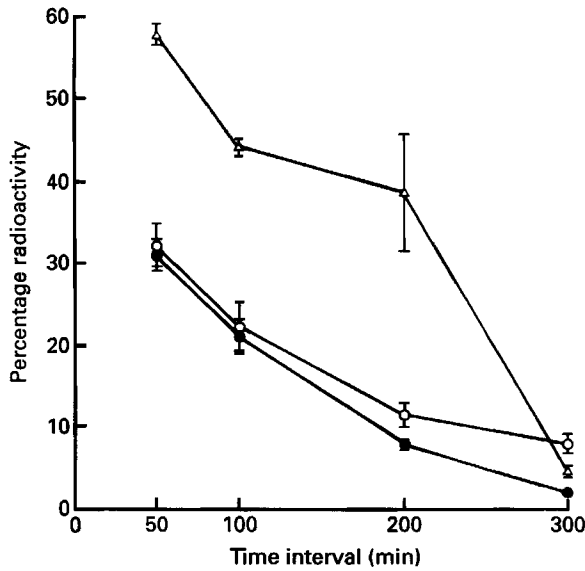
Fig. 1. Percentage radioactivity present in the stomach of rats at various time intervals after oral administration of meals containing homogenized baked beans (control, ○) supplemented with pectin (●) or wheat bran (△). Values are means with their standard errors shown by vertical bars.

intestine, the caecum and the colon. Section 1 of the small intestine represents the duodenum, sections 2–4 the proximal, 5–7 the middle and 8–10 the distal sections of the small intestine. The area under the radioactivity profile of each section was expressed as a percentage of the total radiation.

The geometric centre of the labelled meal was found using the following equation:

$$\text{Geometric centre} = \Sigma(\text{fraction of radioactivity} \times \text{section no}).$$

(Miller *et al.* 1981).

Statistical analysis

The results are expressed as means with their standard errors. Statistical significance was established using Student's *t* test for unpaired data and the Mann–Whitney U test for non-parametric data.

RESULTS
Wheat bran

Initially the presence of wheat bran retarded gastric emptying of the radiolabelled meal; significantly more label was present in the stomach at 50 and 100 min compared with controls ($P < 0.05$; Fig. 1), but at 200 and 300 min there was no significant difference ($P > 0.05$). The standard error value at 200 min was quite large because in some rats there was still a large amount of the labelled meal containing bran present in the stomach whilst only a small amount was present in other rats.

The initial retention of the bran meal in the stomach is supported by the observation of significantly less radioactivity at the mid-small intestine at 50 min (Fig. 2(*a*)).

Movement of the meal along the small intestine seemed to be more rapid despite the retention in the stomach; significantly more of the labelled meal containing bran was at the caecum at 200 and 300 min compared with control, and significantly less in the proximal and mid-small intestine and more in the colon at 300 min (Fig. 3).
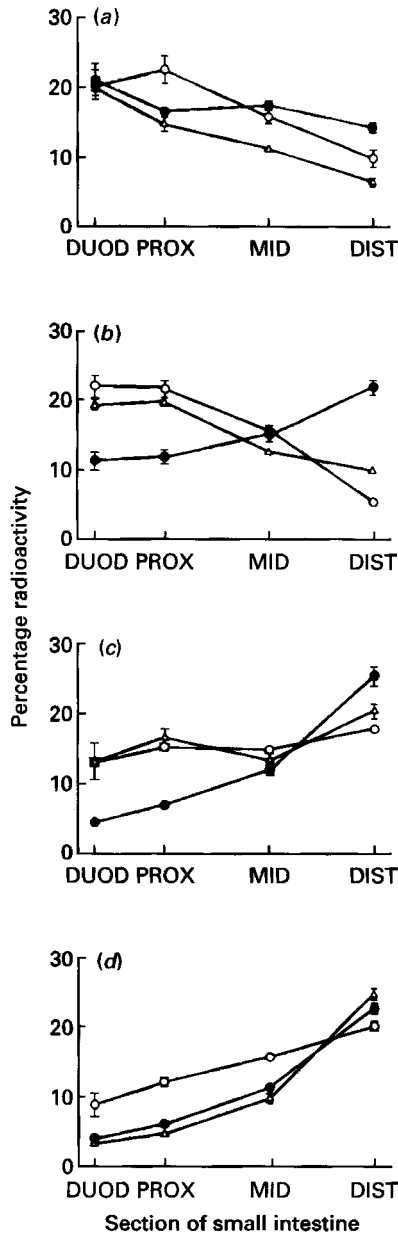
Fig. 2. Percentage radioactivity in different parts of the rat small intestine (a) 50 min (b) 100 min (c) 200 min and (d) 300 min after oral administration with meals containing homogenized baked beans (control, ○) supplemented with pectin (●) or wheat bran (△). Values are means, with standard errors over 0·5 indicated by vertical bars. The various sections of the small intestine were: DUOD, duodenum; PROX, proximal small intestine; MID, mid-small intestine; DIST, distal small intestine.
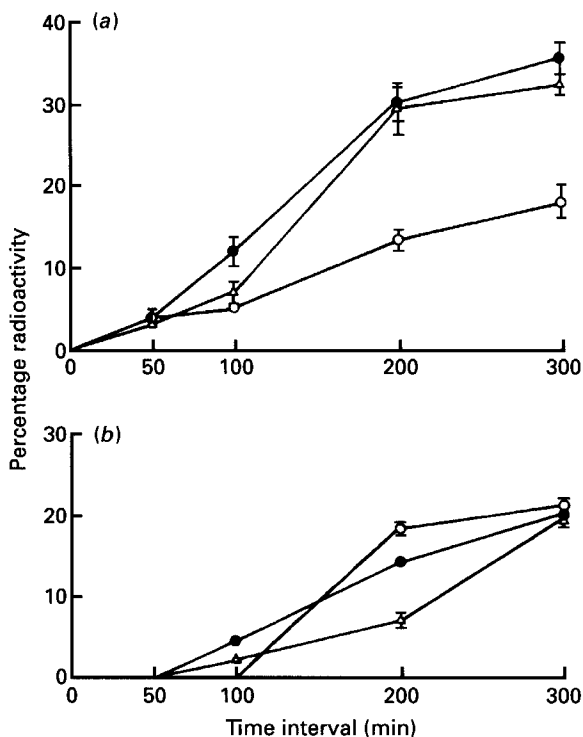
Fig. 3. Percentage radioactivity in (*a*) caecum and (*b*) colon of rats at various time intervals after oral administration of meals containing homogenized baked beans (control, ○) supplemented with pectin (●) or wheat bran (△). Values are means, with standard errors over 0·5 indicated by vertical bars.

Table 2. *Geometric centres,*† *within the rat gastrointestinal tract, of meals containing homogenized baked beans (control) supplemented with coarse wheat bran (bran) or pectin, measured at various time intervals*‡

(Mean values with their standard errors for five rats)

	Control		Bran		Pectin	
	Mean	SE	Mean	SE	Mean	SE
50 min	5·1	0·3	4·3	0·2	5·5	0·1
100 min	5·1	0·3	4·7	0·1	6·8**	0·5
200 min	7·2	0·3	7·8	1·1	8·7**	0·3
300 min	8·1	0·3	9·8	0·3	9·5	0·3

** Mean value was significantly different from that of the control ($P < 0.01$).
† A larger value indicates further progression down the gut.
‡ For details of diets and procedures, see Table 1 and pp. 290–292.

The geometric centre of the wheat bran meal was not significantly different from that of the control (Table 2).

Pectin

Gastric emptying rate was similar to control (Fig. 1). There was significantly less of the labelled meal containing pectin present in the stomach at 300 min ($P < 0.05$).

Movement through the small intestine was faster when pectin was included in the radiolabelled bean meal; there was significantly more radioactivity in the distal section at 100 min, whilst there was significantly less in the duodenal and proximal sections at 100 and 200 min and less in the proximal and middle sections at 300 min (Fig. 2).

More radioactivity was present in the caecum and colon at 200 and 300 min than in controls (Fig. 3).

The geometric centre of the pectin meal was significantly more distal at 100 and 200 min than that of the control (Table 2).

DISCUSSION

The results show that the dietary fibres wheat bran and pectin do alter the transit time of a homogenized baked-bean meal. Wheat bran initially delayed gastric emptying whereas pectin had little effect. Both wheat bran and pectin seemed to accelerate transit through the small intestine resulting in both fibre-supplemented meals accumulating in the caecal region more quickly than the control meal.

The different effects on gastric emptying would suggest that the physical properties of the fibres do influence the motility of the stomach. The initial delay and subsequent rapid emptying of the wheat bran meal contrasted with the steady emptying of the pectin meal. In a human study, gastric emptying of wheat bran added to a wheatmeal porridge was not significantly different from the control (Rydning et al. 1985) but in another study radiolabelled bran emptied steadily and slowly from the stomach when given with a mixed meal (Malagelada et al. 1979). Solid food is retained in the stomach longer than liquids and the bran particles may have been retained until they could be ground to a smaller size by the antrum. Gastric emptying of 'indigestible' solids is thought to be dependent on the motility caused by the gastric burst activity occurring after the postprandial inhibition of migrating motor complexes (Kelly, 1981). However, emptying also depends on the size of the particles (probably relative to the size of pylorus in different species; Russell & Bass, 1985) and also the density of particles (Meyer et al. 1985). Wheat bran is not very dense and so may have been retained by the stomach for this reason.

The significantly smaller amount of bran present in the stomach at 300 min suggests that the meal which included bran left very rapidly once emptying was initiated, perhaps in a single large bolus when the pylorus dilated sufficiently to let the ground particles through. This may explain the large scatter of results with the wheat-bran-containing meal, particularly at 200 min, when it seemed that in some rats the bran had completely moved out of the stomach whilst in others it still remained.

Pectin has been shown to delay gastric emptying of both liquid and solid test meals in normal human volunteers (Sandhu et al. 1987) but the present study showed a slight acceleration, or to be more exact a more complete emptying than control, which was also seen by Andersen et al. (1989) in patients with dumping syndrome.

Small bowel transit measured in man using the breath hydrogen technique showed that wheat bran caused either a small delay (Jenkins et al. 1978) or had no effect on transit (Bond & Levitt, 1978). However, bran is a relatively poor substrate for hydrogen production so in these studies there may have been a delay between the arrival of bran at the caecum and the breath hydrogen increase. The timing of our measurements does not allow direct comparisons, but the profile for meal distribution at 100 min shows similarly low amounts of bran and control meal at the caecum (3·4% and 2·8%), whilst at 200 min the amount of bran has increased substantially (14·7% and 6·6%) suggesting that it had been there for a longer time and thus that small bowel transit time had been more rapid than the control.

Pectin was the fibre which accumulated first in the distal small intestine and caecal areas

and had the fastest moving geometric centre. Pectin had no effect on mouth-to-caecal transit time in man (Jenkins *et al.* 1978).

The lumen contents of the gut appeared very yellow after the pectin-containing meal. Pectin has been shown to induce bile secretion in the rat (Ide & Horii, 1989). Bile acids may increase gut motility (Penagini *et al.* 1988) and so may contribute to the rapid passage of the pectin meal.

Both fibres and control showed similar amounts of radioactive meal in the mid-gut at 100 and 200 min. This may be because the mid-gut at these times was full to capacity with the meal evenly distributed along the length of the gastrointestinal tract.

The caecum seemed to retain the fibre-containing meals for a longer time than the control meal. This may be because the fibres would be fermented there by the colonic bacteria and the additional endproducts of fermentation released could affect caecal motility. Short-chain fatty acids which are produced during fibre fermentation have been shown to inhibit contractions and fluid flow in the rat caecum and colon (Squires *et al.* 1992).

Although the homogenized baked-bean test meals differ slightly from the usual diet of these rats (rat cake), we do not feel that this would alter significantly the physiological transit of a meal. In terms of composition the baked-bean meals have a lower protein concentration (35 compared with 175 g/kg) and higher water content than rat cake (850 compared with 150 g/kg in rat cake, although normal fluid intake on a rat cake diet brings the total water concentration up to 650 g/kg). However, we have previously shown that rats administered orally with 0·5 g ground rat cake suspended in water (5 ml) have a stomach-to-caecum transit time of 116 (SD 6) min (Brown, 1988), which is similar to that of the homogenized baked-bean meal, 113 (SD 3) min, measured using the breath hydrogen technique (Brown *et al.* 1990), suggesting that differences in nutrient content do not affect the transit time. Beans were chosen as the basis of the test meal in these studies because they contain sufficient unabsorbable carbohydrate and fibre to maintain the bulk of the lumen contents, they are easily homogenized and an accurate volume can be administered orally to the rats. The size of the meals (3 ml) was chosen to be within the range of what a rat would normally eat at one meal; food intake studies in the rat have revealed that the average meal size is 2·3 g (Richardson *et al.* 1990). Thus we would not expect a significant difference in transit between the baked-bean meals used in the present study and that of a 'normal' rat meal of rat-cake and the results can be considered valid.

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