The effect of the gel-forming liquid fibre on feeding behaviour in man

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A novel substance called liquid fibre (LF) has been developed which gels in the stomach and dramatically delays gastric emptying. The prolonged stomach distension LF causes would be expected to reduce food intake. The present study tested whether LF affected psychological factors connected with eating behaviour and short-term food intake. Paired studies were carried out on seventeen healthy but overweight volunteers (ten male, seven female) with body mass indices of 24–34 kg/m² who were non-restricted eaters. On one occasion (randomized) they took drinks of LF (300 ml each) at 09.05, 11.55 and 18.00 hours, and on the other they took placebo drinks. Subjective feelings were assessed by visual analogue scales. The amount of food consumed at an appetizing pre-selected meal presented at 12.15 hours was measured covertly. Food diaries were kept until 16.00 hours on the following day. The visual analogue scales indicated that LF reduced hunger and the amount of food desired, and increased fullness, all of which would be expected to cause a reduction in food intake. However, there were no differences in the amount or type of food eaten at the appetizing test-meal (6073 *v.* 5824 kJ, *P* = 0·41). Food eaten later in the day was significantly delayed by LF (7·0 *v.* 5·9 h, *P* = 0·030), and the amount tended to be reduced (4328 *v.* 5439 kJ, *P* = 0·088). The energy consumed on the following day also tended to be lower after LF (3802 *v.* 4737 kJ, *P* = 0·130). This suggests that gastric distension is a relatively unimportant influence on eating behaviour when non-restricted eaters are presented with an appetizing meal and that intestinal factors seem more important for prolonging satiety and reducing subsequent food intake.

Dietary fibre: Eating behaviour: Gastric emptying

Certain types of dietary non-starch polysaccharide (NSP, formerly known as 'dietary fibre') affect food intake. This is particularly true of viscous polysaccharides such as guar gum, which has been shown to suppress energy intake (Evans & Miller, 1975) and reduce hunger ratings (Krotkiewski, 1984). The exact mechanisms by which viscous poly-saccharides affect eating behaviour are unclear. Gastric distension is thought to be an early initiator of satiety signals (Deutsch *et al.* 1978), so by delaying gastric emptying the viscous polysaccharide may prolong or enhance these feelings. Viscous polysaccharides also affect post-gastric events by reducing exposure of the upper small intestine to nutrients, by delaying absorption from the small intestine (Blackburn *et al.* 1984), shifting the site of absorption distally and thus altering gut hormone release (Morgan *et al.* 1979). These effects may also contribute to the prolongation of satiety (the feeling after eating which restricts further consumption for a period of time).

A novel substance called liquid fibre (LF) has been developed which is liquid at room temperature but sets to a firm gel at body temperature. It is made up of the polysaccharide ethyl hydroxy ethyl cellulose with the surfactant sodium dodecyl sulphate in water (Table

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Table 1. *The composition of liquid fibre and placebo drinks*

| | Mass in 1 litre* | |
Component	Liquid fibre	Placebo
Ethyl hydroxy ethyl cellulose†	8·5 g	—
Sodium dodecyl sulphate	870 mg	—
Methyl-*p*-hydroxybenzoate	—	500 mg
Glycerol	26 g	26 g

* Made up to 1 litre with purified water. Manufactured according to Good Manufacturing Practice (GMP) and supplied in sterile 300 ml glass bottles (Kabi Pharma, Solna, Sweden).
† Medical grade EHEC (Berol Nobel AB, Stenungsund, Sweden).

1). It has been shown using γ-scintigraphy that LF stays in the human stomach for much longer than does a placebo drink (half-emptying times, 55·8 and 17·7 min respectively). It also converts the gastric emptying profile from an exponential curve typical of a liquid into a linear form with a lag period which is typical of a solid emptying profile (Tomlin *et al.* 1993). It is postulated that if LF is taken before a meal it should distend the stomach and thus cause a physical signal to reduce hunger, induce early satiation and so reduce food intake. It should also delay the delivery of nutrients to the small intestine and so extend the period for which post-absorptive factors are operative and hence prolong the period of satiety after the meal.

LF may therefore act as a food-intake depressant and be useful in the treatment of obesity. The present experiment used healthy volunteers to test whether LF altered psychological factors associated with eating through the use of visual analogue scales, quantified the amount eaten at an appetizing test meal and assessed the free-feeding behaviour for the subsequent 26 h. Eating behaviour is sometimes consciously modified by psychological influences, so the volunteers were not told that their eating behaviour was being studied until the end of the experiment. In addition a psychometric questionnaire (Stunkard & Messick, 1985) was used to exclude restricted eaters.

MATERIALS AND METHODS

Volunteers

Ten male and seven female volunteers aged between 21 and 31 years were selected. They were overweight (body mass indices of 24–34 kg/m²) but otherwise healthy. They were not restricted eaters, scoring less than 10 on scale I (conscious restraint) of the eating behaviour questionnaire of Stunkard & Messick (1985).

Protocol

The study was presented to the volunteers as an investigation of the effect of LF on fluid balance so that they would be less conscious of their eating behaviour. The study was approved by the Research Ethics Committee of the Northern General Hospital, Sheffield.

Paired studies were carried out with the LF and placebo given in a random order. The two studies were at least a week apart for male volunteers and 1 month apart for the female volunteers, between days 7 and 10 of the menstrual cycle when hormonal influences on feeding behaviour are thought to be least variable (Abraham *et al.* 1981).

An appetizing midday meal was selected from a menu at the initial recruitment visit. Volunteers were encouraged to select a main course (e.g. pizza, lasagne, roast beef and

Table 2. *Visual analogue questionnaires used in the study included the following extremes at the ends of 100 mm bars on which the volunteers were asked to mark according to their feelings*

Factor	Rating 0	Rating 100
Hunger	Not at all hungry	As hungry as I've ever felt
Desire to eat	I'd not like to eat at all	I'd very much like to eat
Amount of food desired	I'd not like to eat anything at all	I'd like to eat as much as I've ever eaten
Fullness	Not at all full	As full as I've ever felt

gravy), plus vegetables (e.g. crumbed mushrooms, chips, peas), a drink (e.g. cola, fruit juice) and a dessert (e.g. cheesecake, apple pie and cream).

Food intake was recorded in a diary, using approximate portion sizes, from 16.00 hours on the day before the first study. The volunteers were asked to repeat this intake exactly on the day before the second study. No food was taken from 22.00 hours on the days before studies.

The volunteers came to the laboratory at 09.00 hours. They were given a visual analogue questionnaire to complete (Table 2) and then the first drink (300 ml) at 09.05 hours. Questionnaires were repeated every 30 min until 14.00 hours.

Another drink (300 ml) was given at 11.55 hours, just before the questionnaire at 12.00 hours. The appetizing pre-selected meal began at 12.15 hours. Volunteers were presented with two to three times the normal size of a portion of each of the chosen foods and they were allowed to help themselves. The amount of food eaten at this meal was covertly measured by weighing the different types of food individually before meal presentation and after meal consumption. The time taken to complete the meal was also recorded.

Volunteers left the laboratory at 14.00 hours. They were allowed to eat freely after this time and recorded their food intake in a diary using approximate portion sizes. They took a third drink (300 ml) at 18.00 hours. The following day they recorded food intake until 16.00 hours.

The diaries were analysed to find the length of time between the appetizing lunch and the next spontaneous meal (for this analysis a meal was defined as more than 1464 kJ (350 kcal) ingested in 30 min, in order to exclude snacks or small drinks). The energy consumed during the remainder of the test day and on the following day to 16.00 hours was derived from food tables (Paul & Southgate, 1991).

Statistical analysis

Statistical analysis was parametric; results are expressed as means with their standard errors. The questionnaire results between 09.00 hours and 14.00 hours were analysed using repeated measures ANOVA with time of day and treatment as factors. The changes in rating (post-drink compared with pre-drink) caused by the two drinks were compared by two-tailed Student's paired *t* tests. Differences in the amount of food consumed at the test-meal and recorded in the food diaries between the two drinks were tested using two-tailed Student's paired *t* tests.

RESULTS

The ANOVA test revealed that time of day significantly affected all ratings. Treatment by time of day was significant for feelings of fullness ($P = 0.014$) and tended towards significance for hunger ($P = 0.059$) and amount of food desired ($P = 0.130$). Treatment
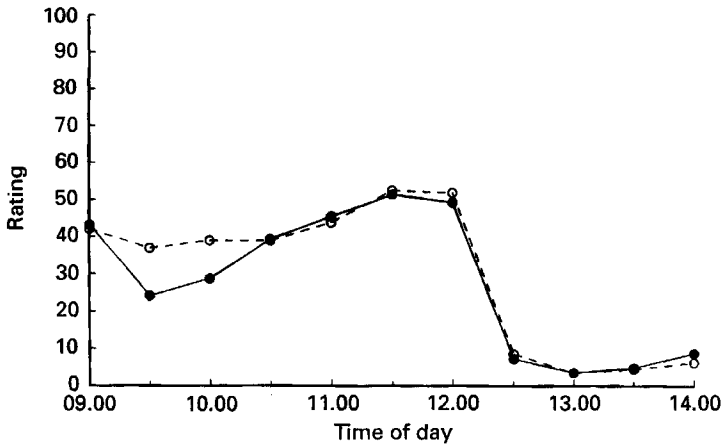
Fig. 1. Mean hunger ratings for seventeen volunteers during 5 h following consumption of gel-forming liquid fibre (–●–) and placebo (--○--) drinks. Drinks were given at just after 09.00 hours and just before 12.00 hours. For details of drinks and procedures, see Table 1 and pp. 428–429.

Fig. 2. Mean fullness ratings for seventeen volunteers during 5 h following consumption of gel-forming liquid fibre (–●–) and placebo (--○--) drinks. Drinks were given at just after 09.00 hours and just before 12.00 hours. For details of drinks and procedures, see Table 1 and pp. 428–429.
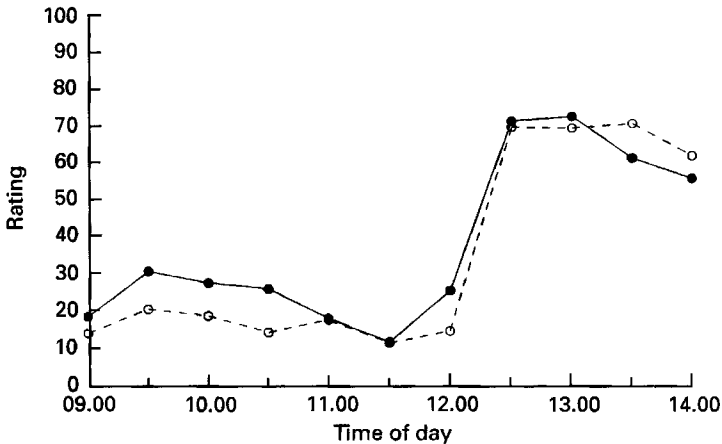
alone as a factor had no significant effect on any of the ratings but came closest to significance with its effect on ratings of hunger ($P = 0.107$). However, this analysis was confounded by the fact that on four occasions (three during LF and one during placebo) the meal was served slightly late so the volunteers were not all in the same state for the 12.30 hours questionnaire. For this reason paired analysis of the change in ratings caused by the drinks was also examined.

Drink 1

LF significantly reduced hunger ratings between 09.05 and 09.30 hours (Fig. 1; $P = 0.011$). The ratings were not significantly different between the two drinks for any of the other factors but people were generally more full, thought they could eat less (amount) and wanted to eat less (desire) after LF than other placebo (Figs. 2–4; all $P > 0.10$).
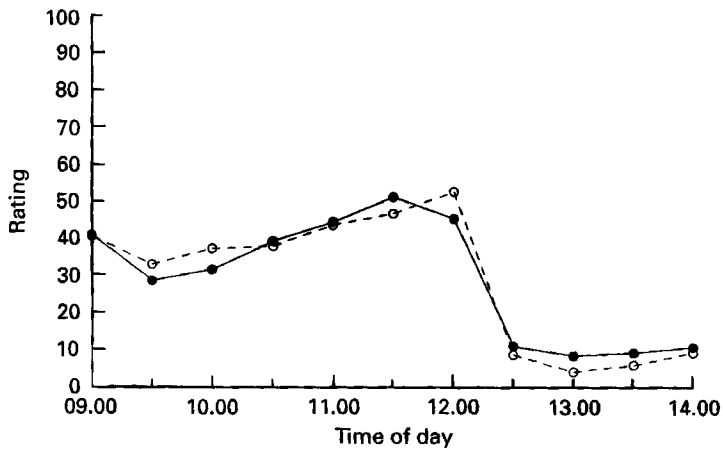
Fig. 3. Mean 'amount to eat' ratings for seventeen volunteers during 5 h following consumption of gel-forming liquid fibre (-●-) and placebo (--○--) drinks. Drinks were given at just after 09.00 hours and just before 12.00 hours. For details of drinks and procedures, see Table 1 and pp. 428–429.

Fig. 4. Mean 'desire to eat' ratings for seventeen volunteers during 5 h following consumption of gel-forming liquid fibre (-●-) and placebo (--○--) drinks. Drinks were given at just after 09.00 hours and just before 12.00 hours. For details of drinks and procedures, see Table 1 and pp. 428–429.
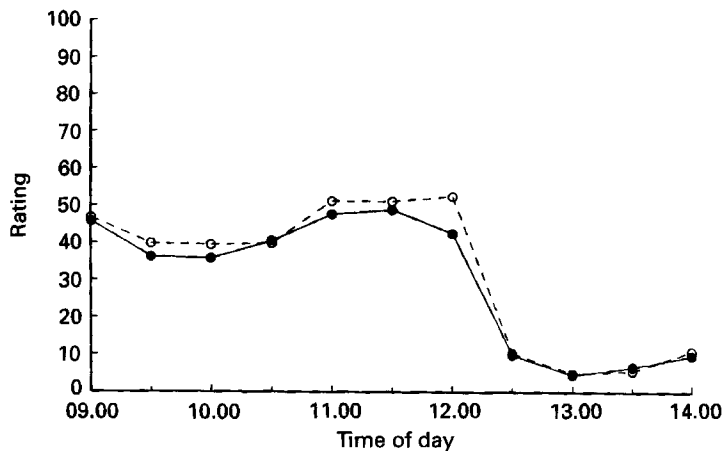
Drink 2

Fullness was significantly increased by LF (Fig. 2; $P = 0.048$) and the amount people thought they could eat was significantly decreased (Fig. 3; $P = 0.014$) compared with the effect of the placebo. Neither drink significantly affected hunger or desire to eat (Figs. 1 and 4; $P > 0.10$). The amount people thought they could eat and their desire to eat increased after the placebo drink (Figs. 3 and 4), presumably reflecting the previous 14 h without food; however both of these ratings fell after LF.

Appetizing meal

There were no significant differences in the mass of food and drink consumed, nor in the energy, protein, fat or carbohydrate contents of the appetizing test meals after LF and

Table 3. *Amount and type of food eaten at an appetizing meal presented 15 min after a liquid fibre or placebo drink, the time taken to eat the meal and the rate of eating**

(Mean values with their standard errors for seventeen subjects)

| | Liquid fibre | | Placebo | |
Measurement	Mean	SE	Mean	SE
Total energy intake				
(kJ)	6073	596	5824	641
(kcal)	1452	143	1393	153
Total intake (g)	1157	94	1157	104
Solid intake (g)	759	78	750	96
Liquid intake (g)	399	38	407	33
Protein intake (g)	50	5	49	5
Fat intake (g)	61	7	58	7
Carbohydrate intake (g)	176	20	178	21
Duration of meal (min)	18	1	18	1
Rate of eating				
(kJ/min)	343	23	331	29
(g/min)	69	5	67	5

* For details of drinks and procedures, see Table 1 and pp. 428–429.

Table 4. *Effect of consumption of liquid fibre or a placebo before an appetizing lunch meal on time to the next spontaneous meal, energy consumed during the remainder of the test day (14.00 hours to midnight), energy consumed on the subsequent day (midnight to 16.00 hours) and total 26 h energy intake (including the test meal)**

(Mean values with their standard errors for seventeen subjects)

| | Liquid fibre | | Placebo | | |
Measurement	Mean	SE	Mean	SE	*P* value
Time to next meal (h)	7·0	0·4	5·9	0·3	0·030
Test day energy intake					
(kJ)	4328	519	5439	412	0·088
(kcal)	1035	124	1300	99	
Next day energy intake					
(kJ)	3802	463	4737	525	0·130
(kcal)	909	111	1133	125	
Total 26 h energy intake					
(kJ)	14203	1151	16000	1193	0·098
(kcal)	3396	275	3826	285	

* For details of drinks and procedures, see Table 1 and pp. 428–429.

placebo (Table 3; $P > 0.05$). There was also no difference in the time taken to eat the test meal and hence in the rate of eating (Table 3; $P > 0.05$).

Drink 3

None of the scales showed any significant differences ($P > 0.10$). Hunger and the amount people thought they could eat tended to decrease after LF and increase after placebo (changes in rating for LF and placebo respectively were -1 and $+7$ for hunger and -4 and $+5$ for amount to eat).

Subsequent feeding behaviour

The food diaries revealed that the time to the next meal was prolonged by LF by a mean of 1·12 h (Table 4; $P = 0·030$). LF also tended to decrease the energy value of food eaten during the remainder of the day by a mean of 1111 kJ (about 270 kcal) ($P = 0·088$). There was a tendency towards a decrease in the energy taken the following day by a mean of 935 kJ (225 kcal) ($P = 0·130$). Total energy intakes over the 26 h of the tests when eating was allowed (from 12.00 hours on the day the drinks were administered to 16.00 hours on the following day), were 14203 kJ during LF and 16000 kJ during placebo (about 3400 *v.* 3825 kcal), a difference of 1797 kJ ($P = 0·098$).

DISCUSSION

The study showed that LF did alter psychological factors associated with eating behaviour. This was only true of the first and second drinks, probably because these were taken before any other food was consumed. The visual analogue scales revealed that LF tended to decrease hunger, increase fullness, and reduce the amount of food people wanted to eat, but had a much lesser effect on the desire to eat. These results are presumably due to the delayed gastric emptying and thus prolonged gastric distension.

A relationship between gastric fullness and satiation has been proposed for many years; Hertz (1911) established that inflation of a balloon in the stomach could elicit feelings of fullness although there was no measurement of subsequent food intake. Other workers have proposed that isolated NSP increase satiation by slowing gastric emptying and so prolonging gastric distension (Holt *et al.* 1979; Di Lorenzo *et al.* 1988; Bergmann *et al.* 1992). The theory that gastric distension may affect eating behaviour is supported by the observation that the time at which hunger begins to increase is linearly correlated with the time taken for 90% of a meal to empty from the stomach (Sepple & Read, 1989).

However, it is interesting that despite the differences in motivation to eat which were apparent after the LF and placebo drinks at 12.00 hours, there was no significant difference in the amount of food eaten at the appetizing pre-selected test meal taken at 12.15 hours. There was also no significant difference in the rate at which the volunteers ate, nor in the balance of fat, protein and carbohydrate supplied by the food consumed at this meal.

The volunteers were selected as 'non-restricted eaters'; hence it is possible that the availability of the appetizing meal overruled any psychological intent about eating behaviour as assessed by the visual analogue scales completed before the meal. Similar discrepancies have been observed by other workers; Burley *et al.* (1987) found that a high-fibre breakfast (8·7 g NSP from guar-gum bread and wheat-bran cereal) increased fullness but had no effect on the amount of food consumed at lunch-time. Similarly, Porikos & Hagamen (1986) found that a pre-load of 6·2 g guar gum reduced hunger but did not affect the size of meal taken 30–45 min later by normal volunteers. However, obese subjects may be more sensitive to distension as a control mechanism, or alternatively their food intake may reflect more accurately their hunger/satiety sensations because Porikos & Hagamen (1986) found that the same pre-load (6·2 g guar gum) did reduce food intake in a group of obese volunteers. LF may therefore prove effective at reducing food intake directly in obese people in contrast to the lack of direct effect in the volunteers we studied.

A physiological explanation for the discrepancy between sensations recorded before the test-meal and the actual food consumed is that by delaying gastric emptying, LF stopped nutrients entering the intestine and hence the inhibitory effects on food ingestion due to intestinal factors were absent. This fits with previous results which suggest that gastric distension is a relatively unimportant factor regulating food intake compared with the results of interactions of nutrients with intestinal receptors (Sepple & Read, 1989).

The major factor contributing to satiation (i.e. the process which terminates an eating episode) is probably the energy content of the food eaten, and it is possible that the gastric distension caused by LF was a relatively weak effect and was masked by the energy value of the meal itself (Blundell & Burley, 1987). In support of this theory, the meals eaten were very large, the mean energy consumption being about 6000 kJ (1450 kcal).

A recent study (French & Read, 1994) showed that although addition of 30 g/l guar gum to a low-fat soup significantly delayed gastric emptying there was only a small delay in the time for hunger to return. However, satiety was prolonged when guar gum was added to a high-fat meal although it had little effect on the rate of gastric emptying. Thus in the absence of nutrients, gastric distension appears to be a factor influencing fullness and the return of hunger. This is equivalent to the situation when drink 1 was given; compared with the placebo, LF made people significantly less hungry. The satiating effect of guar in a high-fat meal appears to be related to delayed absorption and increased intestinal exposure and not to any effect on gastric emptying. This may explain why the effect of LF in drink 2 was not seen at the appetizing test meal but became apparent after nutrients had been ingested in the meal, and it was the delayed absorption of these nutrients which caused the longer time to subsequent food ingestion and a tendency towards a lower energy consumption later in the day.

The most likely mechanism for the effect of LF on food ingestion is that the LF delays nutrient absorption and so delays nutrient–receptor interactions thought to be involved in food intake regulation (Sepple & Read, 1990). A previous study in the rat showed that LF dramatically slowed movement down the small intestine (Tomlin et al. 1993).

Some evidence for a distal shift in the site of absorption of nutrients after viscous NSP comes from another rat study in which guar gum led to an increased percentage of fat absorbed from the ileum rather than the more proximal small intestine (Imaizumi et al. 1982), and an ileostomy study in which feeding guar gum increased the amount of fat excreted from the stoma (Higham & Read, 1992).

The time to the next meal was a mean of 67 min later with LF compared with the placebo, showing that LF prolongs satiety. This is a promising effect because one strategy for decreasing food intake is to reduce the frequency of food consumption and prolong intervals between meals. The tendency towards lower energy intake later in the day and on the following day is also obviously highly important if LF is to be considered in the treatment of obesity.

A delayed effect on the lowering of food intake was also observed by Burley & Blundell (1990) who saw that high-NSP lunches had no effect on food intake from an afternoon meal 2·5 h later but reduced food intake during the remainder of the day compared with low-NSP lunches (30 v. 3 g NSP).

Other possible mechanisms for the late effect of LF may involve intestinal distension by the gel, or the effect of the NSP in the colon. The latter is presumably responsible for the tendency towards decreased food intake on the day following the test day.

The maximum amount of non-absorbed polysaccharide provided by LF was 7·65 g/d (3 × 2·55 g) which is quite a substantial amount given that the normal daily intake of NSP in the UK is about 11·8 g/d (Bingham et al. 1990). Stevens et al. (1987) found that a supplement of 19 g psyllium gum/d in crackers taken before a meal significantly reduced intake of digestible energy by 640 kJ/d (153 kcal/d). The reduction we observed was 1797 kJ over 26 h or about 1660 kJ/d (400 kcal/d). Thus, for a smaller NSP content, LF is a much more effective food-intake depressant than psyllium-gum crackers.

Fermentation of NSP in the colon releases short-chain fatty acids (acetate, butyrate and propionate), some of which are absorbed into the bloodstream, metabolized in the liver and possibly other tissues, releasing energy. The metabolizable energy value of fermentable

NSP has been estimated to be about 3 kJ/g (Wisker & Feldheim, 1990). The maximum energy supplied by LF in the present study would therefore only be about 23 kJ (5 kcal), obviously not sufficient to compensate for the apparent energy deficit of nearly 1800 kJ. *In vitro* incubations of LF with faecal bacteria for 24 h showed that LF resisted fermentation (J. Tomlin, unpublished results), suggesting that the 'next day' effect on eating may be due to large-intestinal distension.

In conclusion, LF appears promising as a food-intake depressant both through subjective effects on feelings of e.g. hunger and fullness, and through post-ingestive changes which naturally reduce food consumption. Both of these mechanisms are presumably mediated via the physiological actions of LF. It remains to be seen whether this effect would be apparent in obese subjects and sustained in long-term studies or whether adaptation would occur.

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