Gastric emptying of barley–soya-bean diets in the pig: effects of feeding level, supplementary maize oil, sucrose or cellulose, and water intake

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1. A technique for measuring gastric emptying in growing pigs by complete removal of digesta through a gastric cannula is described.

2. Four pigs were fitted with gastric cannulas and each was used in three trials.

3. The effects of level of feeding (trial 1), cellulose (C), maize-oil (MO) or sucrose (SU) supplementation (trial 2) and the level of water intake (trial 3) on gastric emptying of digesta, dry matter (DM) and nitrogen from a barley–weatings–soya-bean (B) diet were measured during 4 h after the morning feed.

4. In trial 1, pigs were given 0·66, 0·83, 1·00 or 1·17 times their standard level of feeding. As the level of feeding rose, so the weight of digesta, DM and N emptied in the first hour after feeding increased. This trend continued to some extent in the second hour, but no effects of level of feeding were seen in the third and fourth hours.

5. In trial 2, maize-oil addition to the diet significantly reduced the gastric-emptying rate of DM in the second hour after feeding, compared with the rates for diet C. The rate of N emptying was significantly slower for diets MO and SU than for diet C.

6. In trial 3 there were no significant effects of water intake level (1·75, 2·50 and 3·25 times the weight of diet) on the rate of DM or N emptying from the stomach. The rate of digesta (and thus of water) emptying in the first hour after feeding increased significantly as the water intake rose.

7. It was concluded that because the pattern of gastric emptying was very similar despite large differences in nutritional inputs, an important property of the process appeared to be resilience.

A major role of the stomach in the pig is to act as a reservoir of food. It provides the small intestine with a relatively continuous supply of nutrients for digestion during periods lasting several hours, between meals which are usually eaten in a few minutes. This process in turn is a determinant of the time-course of absorption and metabolism of nutrients. It is thus of interest to know whether the pattern of gastric emptying can be modified by nutritional means; any effects found could perhaps provide the basis for manipulation of metabolism and growth.

At present little is known about whether changing specific components of the diet modifies the rate of gastric emptying in pigs given meals with a high dry matter (DM) content. The only direct comparisons have been made by Laplace *et al.* (1981) who found that there were minor differences in the patterns of gastric emptying of digesta, DM, starch and nitrogen from semi-purified diets containing maize or wheat starch together with fish meal or wheat gluten. These authors concluded that gastric emptying did not appear to be a major factor limiting the efficiency of nutrient use in the four diets used. There is no information on whether changes in meal size or the proportions of diet and water may affect gastric emptying in pigs. Furthermore, it is not known whether lipids or hyperosmolar amounts of sugars reduce gastric emptying rates, or whether dietary fibre (in the form of cellulose) may increase the rate of gastric emptying in pigs given cereal-based diets. Such effects have been seen in other species, although the nutritional conditions were not the same as those to which pigs are accustomed. The aims of the studies reported here were to examine whether any of these factors could influence gastric emptying of pigs given a practical control diet based on barley and soya-bean meal.

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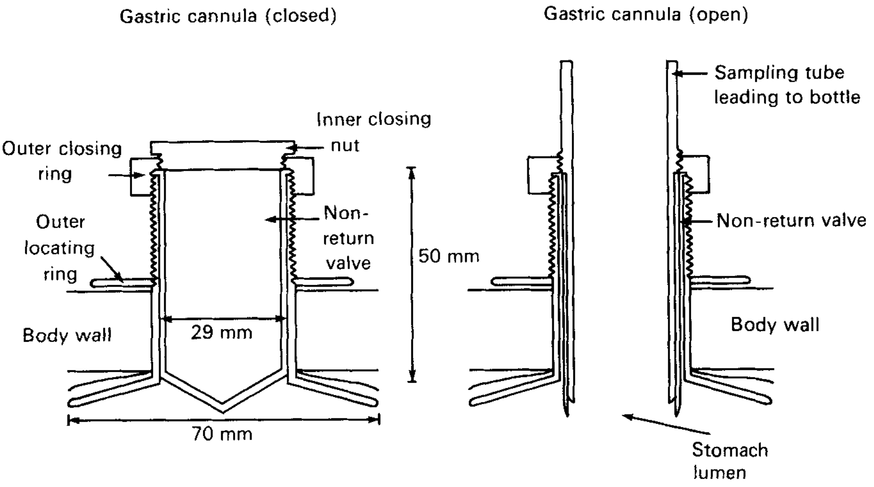

Fig. 1. Diagram of the gastric cannula, closed and open.

Until recently most information on the flow of digesta and of its components from the stomach of pigs has been obtained using pigs with re-entrant cannulas in the duodenum, always caudal to the bile duct, and usually caudal to the pancreatic duct, which are both important routes of entry of endogenous secretions (for example, Kvasnitskii, 1951; Auffray *et al.* 1967; Laplace & Tomassone, 1970; Horszczaruk, 1971; Zebrowska & Buraczewska, 1972; Braude *et al.* 1976). Such preparations have the potential disadvantage that nutrient absorption might occur in the duodenum cranial to the cannula, thus giving an underestimate of the amount emptied from the stomach. In addition, neuromuscular continuity is broken, leading to possibly disturbed patterns of emptying (Laplace, 1980). Furthermore, problems may exist with methods of collecting digesta from duodenal re-entrant cannulas (Low & Zebrowska, 1977). These problems led to the development of a simple and reliable method of measuring gastric emptying directly by evacuation of gastric residues at different times after the meal. A brief communication of preliminary findings was given to the European Association of Animal Production (Low & Pittman, 1979) and in detail in the present paper. A similar method was described by Cuber *et al.* (1980).

EXPERIMENTAL METHODS

Animals and surgery

Five large white boar pigs initially of approximately 30 kg were used. Each pig was given an antibiotic powder in the diet for 3 d before surgery (Terramycin; Pfizer, Sandwich, Kent). The pigs were starved for 24 h before surgery but water was continuously available.

Anaesthesia was induced with a 1:12·5 (v/v) mixture of halothane (Fluothane; ICI Ltd, Macclesfield, Cheshire) and oxygen. The animal was placed in dorsal recumbancy and the abdominal cavity was opened through the linea alba. A 70 mm incision was made in the fundic region of the stomach at right angles to the long axis of the greater curvature. The acetal co-polymer (Kemetal; ICI Ltd, London) cannula (Fig. 1) was inserted and held in position by a purse-string suture. An area of skin overlying the right flank adjacent to the stomach was resected with a cork-borer of 25 mm diameter, and the hole extended into the abdominal cavity by blunt dissection to form a fistula. The cannula barrel was pulled through the fistula until the gastric wall and the parietal peritoneum were in contact. The cannula was held in place by the outer retaining ring and the abdominal cavity was closed by successively suturing the peritoneum, the muscle layers and the skin.

A one-piece moulded, flexible PVC non-return valve (with walls 2·0 mm thick) was fitted inside the barrel of the cannula (Fig. 1). Three flaps were formed by cutting three lines from the tip of the valve towards the side of the barrel. These flaps remained closed except when the threaded sampling tube was pushed through them. This prevented the loss of digesta when the inner closing nut was opened.

One of the five pigs was also fitted with a re-entrant cannula in the duodenum about 150 mm caudal to the pylorus and caudal to the opening of the bile and pancreatic ducts following the procedure described by Braude *et al.* (1976). This pig was only used in the preliminary study.

The pigs were given water containing soluble nutrients (Leoglycin Plus; Leo Laboratories, Princes Risborough, Bucks.) and antibiotic powder, for the first 24 h after surgery. The normal diet was then gradually re-introduced and full intake was achieved 4–5 d after surgery. Collections of gastric and duodenal digesta began 14 d after surgery. During digesta collections, pigs were housed in metabolism cages.

Diets and feeding

The composition of the basal diet (diet B) was (g/kg air-dry diet): ground barley 606·2, fine wheat offal 250·0, solvent-extracted soya-bean meal 120·0, limestone flour 4·5, $CaHPO_4.2H_2O$ 6·0, mineral and vitamin mixture 12·5, $CuSO_4.5H_2O$ 0·8. In trial 2 diet B was mixed with wood cellulose (Solkafloc; Brown & Co., Berlin, New Hampshire, USA) in the proportion 9:1 (w/w) (diet C), maize oil, in the proportion 9:1 (w/w) (diet MO), or sucrose, in the proportion 4:1 (w/w) (diet SU).

The diets were fed to the pigs in two equal feeds at 09.00 and 17.00 hours daily. The diets were mixed with water (1:2·5, w/v) immediately before feeding. The pigs were weighed weekly and fed on a standard scale based on live weight (Barber *et al.* 1972), except during trial 1 when the pigs were fed at 0·66, 0·83, 1·00 or 1·17 times the standard scale.

Collection procedures

Gastric digesta collection. Water at approximately 40° was added to a flexible 5 litre PVC bottle (the volume of water used was 50% of the volume used at the preceding meal, or 250 ml in the case of a pre-feed sample). The bottle was linked via a 1·0 m PVC tube to a threaded tube. The inner closing nut was removed from the cannula and the threaded tube pushed past the non-return valve and screwed into place. The bottle of water was then placed above the level of the pig and the water squeezed into the stomach. Immediately afterwards the bottle was placed on the ground below the pig and the digesta and added water allowed to drain out. The digesta and water were then rapidly returned to the stomach and again allowed to drain out into a beaker. This evacuation procedure was rapidly repeated twice more with two further portions of water (each was 25% of the volume used at the preceding meal). The complete evacuation procedure lasted for up to 1 min. The entire contents including the added water (the total volume of which was the same as given at the preceding meal) were weighed, sampled and the remainder returned to the pig. The stomach was evacuated once daily.

Duodenal digesta collection. The procedure used was as described by Braude *et al.* (1976).

Analytical procedures

DM was estimated by heating samples, initially of approximately 100 g, at 100° for 18 h. N was measured by Kjeldahl digestion followed by automatic analysis (AutoAnalyzer; Technicon Instruments Ltd, Basingstoke, Hants). Chromic oxide was measured by the method of Christian & Coup (1954).

Experimental design

Preliminary study. The purpose of the present study (using the pig with a gastric and a duodenal cannula) was to check that all the diet eaten could be recovered through the gastric cannula, and through the duodenal cannula 1, 2, 3 or 4 h after the morning feed. The stomach was rinsed free of any residual digesta before the morning feed and the diet was given with a supplement of 5 g Cr_2O_3/kg diet as a non-absorbed marker of the insoluble phase of digesta. Two duodenal digesta collections were made during each of the four time-periods and immediately after the end of each duodenal digesta collection the gastric digesta were evacuated. Samples of the digesta were analysed for their Cr_2O_3 content. On the final day of collection, digesta were collected for 2 h from the duodenum. Then, immediately, the gastric digesta were evacuated and the pig was killed using a captive-bolt pistol. The stomach was rapidly removed for examination of its contents.

Trial 1. Each of the four pigs (average weight 35 kg during the trial) received diet B at either 0·66, 0·83, 1·00 or 1·17 times the standard feeding level. Each feeding level was given to each pig for 1 week, in a Latin-square design. Gastric digesta were evacuated once on each of the last 4 d of each week, 1, 2, 3 or 4 h after feeding. The timing of sampling on a particular day for each pig was randomized.

Trial 2. Each of the four pigs (average weight 55 kg during the trial) received diets B, C, MO or SU at the standard level of feeding, in a Latin-square design. Each diet was given to each pig for 1 week and digesta were collected as in trial 1.

Trial 3. Each of the four pigs (average weight 75 kg during the trial) received diet B at the standard level of feeding, with water added in the proportions 1:1·75, 1:2·50 or 1:3·25 (diet–water, w/v). One level of water was given to each pig for 1 week and digesta were collected as in trial 1. The order of feeding was designed as a 4 × 3 randomized block.

RESULTS

Preliminary study. The pig used in the present study remained in good health. No problems were experienced with the cannulas or the digesta collection procedures.

The sum of the recovered Cr_2O_3 from the gastric and duodenal cannulas varied between 98 and 102% of the amount ingested. As the analytical error in Cr_2O_3 measurement is at least 2% these results were taken to indicate that the method used resulted in complete recovery of marker, and thus of gastric contents. There was no visible sign of Cr_2O_3 or of dietary residues in the stomach of this pig after slaughter, thus confirming the reliability of the technique. The complete recovery of marker indicates that the evacuation procedure did not cause digesta to empty into the duodenum (and thereby lead to an overestimate of gastric emptying).

Trial 1. The effects of varying the level of feeding on gastric emptying of digesta, DM and N are shown in Table 1 (expressed as the percentage of the diet intake recovered from the stomach through the cannula) and in Table 2 (expressed on the basis of the weight which emptied from the stomach into the duodenum).

When the results were analysed on an output:intake basis, the only significant effects of level of feeding at a given time were found for N (0·66 times the standard level *v.* other levels in hour 1 and 0·66 *v.* 1·17 times the standard level in hour 2). The patterns of emptying with time were on average quadratic for digesta and N, and linear for DM ($P < 0·05$).

When the results were analysed on a weight basis, there were significant linear increases in the rates of emptying, at a given time, of digesta, DM and N as the level of feeding increased. The patterns of emptying with time were quadratic for digesta and N, and linear for DM ($P < 0·05$).

Table 1. *Trial 1. Effect of level of feeding on gastric emptying of digesta, dry matter (DM) and nitrogen in pigs (percentage of intake recovered from the stomach 1, 2, 3 or 4 h after feeding)*

	Level of feeding*	Period after feeding (h) 1	2	3	4
Digesta	0·66	66	47	41	30
	0·83	55	32	31	37
	1·00	58	49	41	36
	1·17	54	33	36	30
	SED (1)	8·1		(5% LSD 18)	
	SED (2)	7·5		(5% LSD 15)	
DM	0·66	69	48	37	34
	0·83	66	54	40	48
	1·00	60	51	46	43
	1·17	50	49	48	41
	SED (1)	9·8		(5% LSD 22)	
	SED (2)	7·6		(5% LSD 15)	
N	0·66	85	62	41	30
	0·83	66	51	35	39
	1·00	68	52	42	38
	1·17	64	43	44	34
	SED (1)	7·7		(5% LSD 17)	
	SED (2)	7·3		(5% LSD 15)	

SED, standard error of difference; SED (1), for comparison of two levels of feeding at a given time based on a pool of the main plot Latin-square error (6 df) and the interaction between pigs and times within levels of feeding (36 df); SED (2), for comparison of two times at a given level of feeding based on the interaction between pigs and times within levels of feeding (36 df); LSD, least significant difference.

* For details, see p. 440.

Trial 2. The effects of varying the composition of the diet on gastric emptying of digesta, DM and N are shown in Table 3 (expressed as the percentage of the diet intake recovered from the stomach, through the cannula).

There were no significant differences between diets in the rates of emptying of digesta at a given time. The only significant differences between diets were seen in hour 2, when the DM from diet MO had emptied significantly more slowly than from diet C, and the rate of N emptying was significantly slower for diets MO and SU than for diet C.

The patterns of emptying with time were on average quadratic for digesta and linear for DM and N ($P < 0{\cdot}01$).

Trial 3. The effects of varying the amount of water given with the diet on gastric emptying of digesta, DM and N are shown in Table 4 (expressed as the percentage of the diet intake recovered through the gastric cannula).

The only significant differences between treatments were found for digesta (diet:water value 1:1·75 slower than 1:3·25) 3 and 4 h after feeding.

The patterns of emptying with time were on average quadratic ($P < 0{\cdot}01$) for all variates.

Table 2. *Trial 1. Effect of level of feeding on gastric emptying of digesta, dry matter (DM) and nitrogen in pigs: weights (g) in diet and in digesta, DM and N emptied from the stomach into the duodenum 1, 2, 3 or 4 h after feeding*

	Level of feeding*	Amount in feed	Period after feeding (h)			
			1	2	3	4
Digesta	0·66	1875	617	996	1099	1317
	0·83	2271	1022	1516	1571	1423
	1·00	2614	1129	1363	1568	1675
	1·17	3249	1494	2146	2084	2277
	SED (1)		262·9		(5% LSD 599)	
	SED (2)		193·3		(5% LSD 393)	
DM	0·66	479	144	247	299	314
	0·83	561	191	257	338	291
	1·00	732	296	356	392	417
	1·17	822	406	415	433	490
	SED (1)		66·4		(5% LSD 150)	
	SED (2)		51·0		(5% LSD 104)	
N	0·66	13·8	2·0	5·2	8·2	9·6
	0·83	16·2	5·5	8·0	10·6	9·8
	1·00	21·1	6·8	10·1	12·2	13·0
	1·17	23·9	8·6	13·5	13·5	15·8
	SED (1)		1·56		(5% LSD 3·3)	
	SED (2)		1·54		(5% LSD 3·1)	

SED, standard error of difference; SED (1), for comparison of two levels of feeding at a given time based on a pool of the main plot Latin-square error (6 df) and the interaction between pigs and times within levels of feeding (36 df); SED (2), for comparison of two times at a given level of feeding based on the interaction between pigs and times within levels of feeding (36 df); LSD, least significant difference.

* For details, see p. 440.

DISCUSSION

Methodology

The pigs used in the present study grew normally throughout. There were no problems with digesta leakage or with sampling procedures.

The choice of technique used for measuring the rate of gastric emptying in pigs appears to be very important because marked differences are apparent between the results of the present study and that of Cuber & Laplace (1979*a*) who used pigs with re-entrant cannulas in the duodenum caudal to the bile duct and cranial to the pancreatic duct. In the present study, 52–70% of the ingested DM and N had emptied from the stomach after 4 h, while Cuber & Laplace (1979*a*, *b*) found 41–45% had emptied, as measured in duodenal digesta. In view of the fact that Cuber & Laplace (1979*a*, *b*) used a semi-purified diet this is difficult to explain, because semi-purified diets typically leave the stomach faster than those based on cereals (Zebrowska *et al.* 1975; Braude *et al.* 1976; Low *et al.* 1978). Cuber *et al.* (1980) used a similar technique to that used in the present study and compared the results obtained with those of Cuber & Laplace (1979*a*, *b*), using the duodenal re-entrant technique; these authors found that the latter method led to estimates of more rapid gastric emptying of DM, N and starch in the first 2 h after feeding. However, 4 and 7 h after feeding, the rate was faster using the gastric cannulation method for DM and starch but not for N (which was affected by endogenous N additions cranial to the re-entrant cannula). Cuber *et al.*

Table 3. *Trial 2. Effect of cellulose, maize oil or sucrose on gastric emptying of digesta, dry matter (DM) and nitrogen in pigs (percentage of intake recovered from the stomach 1, 2, 3 or 4 h after feeding)*

	Diet code*	Period after feeding (h)			
		1	2	3	4
Digesta	B	63	42	36	29
	C	70	46	31	39
	MO	63	57	35	36
	SU	61	43	28	26
	SED (1)	8·7		(5% LSD 19)	
	SED (2)	8·0		(5% LSD 16)	
DM	B	66	51	48	40
	C	66	49	46	41
	MO	67	67	43	43
	SU	55	52	32	30
	SED (1)	8·2		(5% LSD 18)	
	SED (2)	8·1		(5% LSD 17)	
N	B	70	52	44	37
	C	68	49	44	37
	MO	73	66	44	41
	SU	69	65	36	35
	SED (1)	7·7		(5% LSD 16)	
	SED (2)	8·0		(5% LSD 16)	

SED, standard error of difference; SED (1), for comparison of two diets at a given time based on a pool of the main plot Latin-square error (6 df) and the interaction between pigs and times within diets (36 df); SED (2), for comparison of two times for a given diet based on the interaction between pigs and times within diets (36 df); LSD, least significant difference.

* B, basal diet; C, diet B mixed with wood cellulose; MO, diet B mixed with maize oil; SU, diet B mixed with sucrose (for further details, see p. 439).

(1980) suggested that the different results might be explained in part by the considerably greater amount of gastric content found before the morning meal in pigs with duodenal re-entrant cannulas than in those with gastric cannulas. This digesta would be a component of the first digesta to reach the duodenum and would thus increase the apparent rate of emptying of the meal.

Measurements by Cuber *et al.* (1980) have shown that cannulation and collection methods similar to those used in the present study do not disturb the electromyographic activity of the gastric antrum seen in pigs without gastric cannulas. On the other hand, disturbed gastric emptying patterns have been noted when re-entrant cannulas have been placed in the proximal duodenum of pigs (Laplace, 1980).

There are two qualifications to make about measurement of gastric emptying by collection of the residual gastric contents. Firstly, it is assumed that no absorption occurs in the stomach and secondly, measurements can only be made at one point in time and once daily, rather than continuously, as in a re-entrant preparation of the duodenum. However, there was no evidence of N or glucose absorption by the stomach of 3-d-old or 5-month-old pigs (A. G. Low, unpublished results). Digesta collected from the duodenum contains bile, and usually pancreatic juice as well. There is also some evidence that N and glucose may be absorbed cranial to re-entrant cannulas in the duodenum (caudal to the

Table 4. *Trial 3. Effect of changing diet: water value on gastric emptying of digesta, dry matter (DM) and nitrogen in pigs (percentage of the intake recovered from the stomach 1, 2, 3 or 4 h after feeding)*

	Diet: water (w/v)	Period after feeding (h) 1	2	3	4
Digesta	1:1·75	59	46	44	41
	1:2·50	59	40	32	34
	1:3·25	51	38	27	26
	SED (1)	6·4		(5% LSD 14)	
	SED (2)	6·4		(5% LSD 13)	
DM	1:1·75	57	42	42	37
	1:2·50	64	44	43	43
	1:3·25	56	52	47	39
	SED (1)	7·8		(5% LSD 18)	
	SED (2)	6·2		(5% LSD 13)	
N	1:1·75	56	41	38	30
	1:2·50	62	49	38	41
	1:3·25	64	50	41	35
	SED (1)	7·8		(5% LSD 18)	
	SED (2)	6·3		(5% LSD 13)	

SED, standard error of the difference; SED (1), for comparison of two diet: water values at a given time based on a pool of the interaction between pigs and diets (6 df) and the interaction between pigs and times within diets (27 df); SED (2), for the comparison of two times for a given diet: water value based on the interaction between pigs and times within diets (27 df); LSD, least significant difference.

bile and pancreatic ducts) of pigs (Zebrowska *et al.* 1982, 1983). Furthermore, our experience with more than thirty pigs with re-entrant cannula preparations in the duodenum has shown that their reliable working life was about 6 weeks, whereas all the pigs in the present study (and a further sixteen pigs used in other studies) remained in a good condition until slaughter 3 or more months later. Thus, on balance, the technique used in the present study was considered to be preferable to the method of re-entrant cannulation of the duodenum.

The method of returning the digesta and washings to the stomach once they had been sampled differed from that of Cuber *et al.* (1980) who re-fed the animals after sampling, at a level equal to the amount of DM which was removed from the stomach before it was sampled and discarded. We considered that it was important to return the entire gastric contents (less the 2–5% removed as a sample) so that losses of endogenous components of the gastric digesta were minimal. The non-return valve was particularly useful in preventing digesta loss as the sampling tube was removed from the cannula.

The amounts of DM recovered in the prefeeding gastric contents of the pig in the preliminary study represented about 5% of that eaten in the feed on the previous afternoon. It was clear from visual inspection of the prefeeding digesta that it included bile and strands of mucous material, as well as grain residues. In view of the small amounts of DM recovered and the fact that some was of endogenous origin, the prefeeding gastric contents were not removed daily in trials 1, 2 and 3. Removal of this digesta could have led to depletion of gastric enzymes and cations which could influence gastric digestion and emptying.

Trial 1

The volume of digesta and the amounts of DM and N which left the stomach during the first hour after feeding increased in approximate proportion to the increases in level of feeding, but this relation was not clearly seen subsequently. Hunt & Macdonald (1954) observed that the larger the initial volume of liquid test meals (containing 20 and 35 g/l sucrose), the greater was the initial rate of emptying in man. However, these authors found that the larger the original meal volume, the smaller was the proportion of the meal which emptied per min. This was not found in the present study for digesta, DM or N, perhaps because of the very much higher DM content of the meals used than those of Hunt & Macdonald (1954). More recently, Hunt & Stubbs (1975) concluded from a survey of thirty-three published and unpublished reports of gastric emptying that the original volume of a meal did not necessarily define its emptying rate; the authors also noted that in many of the studies included in their survey there were changes not only in nutrient composition of the meals but also of mean volume which made it difficult to identify effects which were due entirely to volume.

During studies in 60-kg pigs with re-entrant cannulas in the duodenum, Cuber & Laplace (1979*a*) concluded that the amounts of DM from a semi-purified diet collected in the first 2 h after a meal were proportional to the amounts eaten (880, 1320 or 1650 g). Thereafter the overall emptying rate in relation to the amount eaten decreased as intake rose: it was suggested that the proportionality found in the first 2 h after feeding was due to the massive initial phase of gastric emptying, resulting from the high intragastric pressure found in the stomach after a large meal.

In the present study there were no significant effects of feeding level on digesta and DM emptying expressed either in terms of output: intake or of weight, in relation to intake, except in the first hour after feeding. This suggests that wide variations in the level of intake were handled by altering the emptying rate in the first hour, with the result that the emptying rates in subsequent hours gradually declined in patterns and amounts which were similar and independent of the intake level.

Trial 2

The results of this trial indicated that the effects of cellulose, maize oil and sucrose substitution in the basal diet on gastric emptying were minor.

Maize oil. It has been established for many years that gastric emptying can be slowed by triglycerides (Roberts, 1931) and fatty acids (Quigley & Meschan, 1941); the latter authors recognized that free fatty acids were more effective in delaying emptying than triglycerides. These and many more recent studies on this theme have been made with simple test meals containing stable emulsions, in contrast to the high-solid meal used in the present study. The reasons for the absence of a delaying effect of maize oil in this trial are not clear. There is no detailed physiological information on how gastric emptying may be affected by lipids in the pig, and nothing is known about lipid receptors in the small intestine of the pig. In the second hour after feeding, maize oil did significantly delay gastric emptying of DM and N compared with diet C; there was some indication of a difference compared with diet B ($P < 0{\cdot}10$). This is consistent with studies in humans given normal solid meals by Bernier & Jian (1981) who found that the lipid phase of gastric contents emptied at the same rate as the rest of the solids in the first hour after the meal, but rather more slowly during the second and subsequent hours. However, in human subjects no effects on gastric emptying were seen when butterfat or hydrogenated vegetable oil replaced 63% of a basic oatmeal test meal on an isoenergetic basis (Henschel *et al.* 1947). More recent studies indicate that the greater the energy concentration of a meal (and thus of the initial gastric contents) the slower is the rate of gastric emptying. This effect appears to be the result of the combined sensitivities of the small intestinal osmoreceptors and fatty acid receptors which are so tuned that equal rates of emptying are observed for meals of equal energy density irrespective of the proportions of fat, carbohydrate or protein in the meal (Hunt, 1980). This observation, based on results from a wide range of studies (though not in pigs), is consistent with the results of the present study in which the energy density of diet MO was about 15% higher than that of diet B (based on energy values from tables of feedstuffs composition).

Cellulose. Effects of dietary fibre on digestive function are seen throughout the gut. Among the earliest reported effects on the stomach was more rapid emptying of wholemeal than of white bread in man (McCance *et al.* 1953). While these authors did not specifically ascribe the effect to the higher dietary fibre content of brown bread, this was the main chemical difference between the two breads. However, in the present study cellulose did not affect the rate of gastric emptying (compared with diet B). This is consistent with studies in rats by Shurpalekar *et al.* (1969). It is thus likely that the increased rate of gastric emptying observed by McCance *et al.* (1953) as a result of eating wholemeal bread was the result of other components of dietary fibre, or of some other constituent of the bread, or perhaps of cellulose in a more coarsely ground form than was used in the present study.

Sucrose. While inclusion of sucrose in the diet would have led to gastric contents of higher osmolarity than those of the control diet, it had no effect on gastric emptying. This is consistent with the results of Henschel *et al.* (1947) who partially substituted sucrose for oatmeal and found that the gastric emptying rate of such a meal was not different from the rate for an all-oatmeal control meal. When simple liquid test meals containing pectin were given to human subjects, the addition of 200 g sucrose/l significantly increased the gastric emptying time from 15·3 to 81·5 min (time for 50% emptying of the test meal) as a result, it was suggested, of osmoreceptors in the duodenum which inhibited the gastric emptying rate (Hunt *et al.* 1951). However, in the present study the gastric contents from diets B and SU were approximately isoenergetic: under these circumstances, if the digesta leaving the stomach were also isoenergetic, then according to Hunt & Stubbs (1975) and Hunt (1980) the same rate of gastric emptying would be expected, energetic factors overriding those of osmolarity.

The only studies on the gastric-emptying rate in pigs of liquid meals containing monosaccharides showed that as their concentration rose, so the rate of emptying fell (Reed & Kidder, 1972).

Trial 3

No significant effects on gastric-emptying rates of DM or N were seen as a result of altering the amount of water given in the meal. However, there were significant effects on digesta-emptying rates and therefore of water (i.e. digesta less DM) emptying in the first hour after feeding. The mean amounts of digesta emptied in the first hour were 1508, 1966 and 2910 g for the three diet:water values. It is thus apparent that the stomach quickly regulated the DM content of the digesta to about 299 g/kg (mean values for all treatments in hours 1–4 after feeding) from the mean values of 318, 250 and 206 g/kg for the meals containing water at 1·75, 2·50 and 2·35 times the weight of air-dry diet. This is consistent with the view of Laplace (1982) that the liquid fraction of digesta leaves the stomach first, especially when high intragastric pressures are found immediately after feeding.

Trials 1–3

The results of these three trials indicate that the emptying of nutrients (as represented by DM and N) from the stomach was little affected by changes in the level of feeding, inclusion of cellulose, maize oil or sucrose in the diet or by variation in the amount of water given.

It thus seems that gastric emptying of large meals based on grains is little affected by input changes. The possibility of changing the pattern in a way which might significantly modify the time course of digestion, absorption and metabolism therefore appears to be rather remote. Similar conclusions about the importance of gastric emptying of pigs, under different nutritional conditions, were drawn by Laplace *et al.* (1981), Rérat *et al.* (1984) and A. L. Rainbird and A. G. Low (unpublished results). It appears that an important property of the stomach is resilience and that this cannot be disturbed easily by variations in the amount or nature of the diet.

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