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THE INFLUENCE OF GASTRIC DISTENSION AND THE DUODENAL INFUSATE ON THE PATTERN OF STOMACH (ABOMASAL) EMPTYING IN THE PRERUMINANT CALF

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SUMMARY

1. In the conscious calf it is possible to use duodenal re-entrant cannulae to measure the output of a gastric test meal directly from the proximal cannula placed near to the pylorus. At the same time the duodenum can be isolated from the stomach and maintained under constant stimulus by a continual infusion at regulated pressure, volume and temperature into the distal cannula.

2. Under these experimental conditions the pattern of gastric emptying is exponential in form. Thus direct recording of gastric emptying validates indirect methods, such as the serial test meal, where volume markers are used. It appears likely that the exponential pattern of gastric emptying is common to man, dog, cat and calf.

3. When the isolated duodenum was infused with water, the exponential pattern of gastric emptying was maintained even when the volume of meal instilled was increased substantially from 1 to 4 l.

4. Distension of the stomach by larger test meals did not affect the relative rate of emptying so that the half-time of emptying of all meals was about the same.

5. When the isolated duodenum was infused with 0·06 M-HCl gastric emptying of the smaller meals was almost completely inhibited. The inhibition of gastric evacuation was accompanied by inhibition of the gastric e.m.g.

6. Infusion of the duodenum with acid also produced marked, but not complete, inhibition of emptying the larger test meals but the distension produced by the larger meals appeared to partially overcome the inhibitory effect of the acid duodenal infusate so that a small efflux occurred from the stomach. This small efflux was usually associated with some slight degree of gastric e.m.g. activity.

7. We are still investigating the mechanisms whereby the duodenum affects gastric emptying, but it is clearly demonstrable from our present results that the inhibitory effects of acid duodenal infusate are sufficiently powerful to overcome the forces, both physical and reflex, which normally aid gastric evacuation.

INTRODUCTION

The pattern of gastric emptying was first shown by Marbaix (1898) in the dog to be exponential in form and this has been confirmed many times (see Hunt & Stubbs, 1975). Similar exponential patterns of gastric emptying have been demonstrated in man (Hunt & Spurrell, 1951), dog (Weisbrodt, Wiley, Overholt & Bass, 1969) and the unweaned calf (Bell & Razig, 1973).

In a recent paper Hunt & Stubbs (1975) have examined published and unpublished studies on gastric emptying in man, of meals of varying nutrient density and volume, and have calculated that different volumes of the same nutrient density have different half-times of emptying. They found, however, that the slowing of gastric emptying with a meal of high nutritive density was not sufficient to prevent an increased rate of delivery of energy to the duodenum (nutritive density × volume delivered in unit time).

In earlier papers it has been shown that abomasal (gastric) emptying was similar in the milk-fed calf to that of other mammals (Bell & Razig, 1973) and that gastric emptying was controlled through receptors in the duodenum (Bell & Mostaghni, 1975) which affects the activity of the gastric musculature (Bell & Grivel, 1975). In the majority of investigations of gastric emptying by other workers test meals have been in physiological volumes which did not produce gastric distension (Gianturco, 1934, Stadas, 1975). In some of our experiments we have used test meals of much larger volume than that of the normal abomasum so we were able to examine the possible influences of receptive relaxation and variation in elasticity on gastric emptying. Because of the nature of our preparation the duodenal infusate was not contaminated by the gastric effluent so we were able to stimulate the isolated duodenum sufficiently to maintain either continual activation or inhibition of the stomach (see Bell & Grivel, 1975).

METHODS

Eleven unweaned male Friesian calves, 40–50 kg in weight, were housed individually in pens with slatted floors. They were fed vitamins and mineral reinforced milk substitute but were denied access to roughage. When about 10 days old each calf was prepared surgically with duodenal re-entrant cannulae and an abomasal cannula as described by Bell & Mostaghni (1975). The surgical procedure for the placement of electrodes for electromyographic (e.m.g.) records has been described by Grivel & Ruckebusch (1972) and Bell & Grivel (1975).

Investigations were started a week later. The experiments were performed at 9 a.m. each day with the calves standing quietly on a recording platform under minimal restraint. The evening meal of the previous day had usually passed to the intestine and the abomasum was washed clear with 500 ml. distilled water immediately before the experiment.

The test meal was always distilled water and was instilled by gravity at 39° C into the abomasum via a cannula at 1·0 l min^{-1}. The duodenal infusion of water or 0·06 M-HCl at 10 ml. min^{-1} at 39° C was commenced 5 min before the test meal was instilled into the abomasum and continued for a standard period of 45 min to allow passage of the test meal. The abomasal effluent was collected directly from the proximal cannula and the volume evacuated during each 5 min period noted. A series of e.m.g. from various sites in the abomasum was recorded continuously during the 5 min before instillation of the test meal and for the subsequent 45 min. Any volume remaining after 45 min was aspirated from the abomasum, the duodenal and abomasal cannulae closed and the calf given its normal milk meal.

RESULTS

The individual calves responded in a consistent fashion when similar volumes of test meal were instilled into the abomasum. The gastric effluent of instilled meal was such that a similar percentage volume of each test meal remained in the viscus. This was the case whether larger volumes were emptied during the stimulatory water infusion of the duodenum or when very small volumes were emptied during the inhibitory infusion of acid. In Fig. 3 the mean percentage volumes (± S.E. of mean) remaining after 45 min are illustrated for the whole series of experiments.

The pattern of emptying of the abomasum for the different experimental situations showed the usual three phases of gastric emptying (Hunt & Spurrell, 1951; Hunt & McDonald, 1954; Bell & Razig, 1973). The first 10 min of the test meal period showed an initial phase where emptying was faster or slower than the longer middle exponential phase while the third and last 10 min phase again showed a variable pattern. Because of the irregularity of emptying during the first and last phase only the data between 10 and 35 min were used to assess the individual reactions to the duodenal infusate. In Figs. 1 and 2 because of the semilogarithm display the S.E. of mean have not been added but they were comparable or less than those shown in Fig. 3 and the tables.

Abomasal emptying during duodenal infusion with water

There was no difference between the pattern of gastric emptying of the physiological volumes of test meal 1–1·5 l, and the larger volumes of 2–4 l. The pattern of emptying was exponential, irrespective of the volume of the test meal (Fig. 1). At the end of 45 min between 64–70% of the meal had been expelled (Fig. 3).

To allow comparisons of the emptying of different volumes of test meal from the abomasum the percentage of the original volumes remaining in the abomasum at each 5 min period (10–35 min) for each experiment has been aggregated and the mean value (±S.E. of mean) calculated. Using ln of the mean percentage volume remaining, the linear regression of

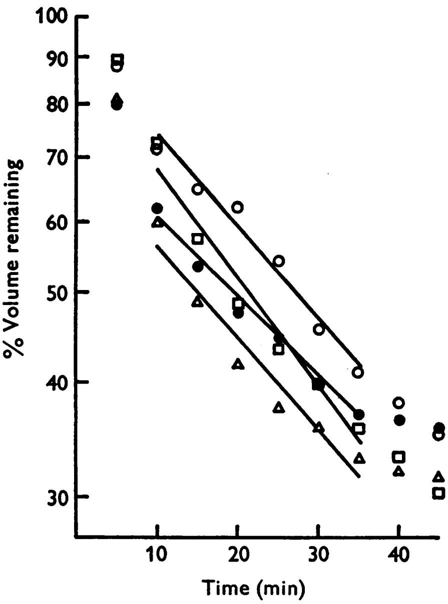

Fig. 1

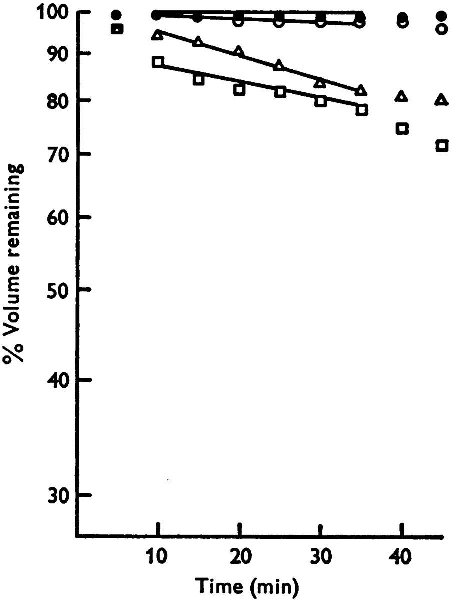

Fig. 2

Fig. 1. The emptying of water test meals from the stomach (abomasum) of preruminant calves. The duodenum was under constant infusion with water at 10 ml min^{-1} at 39° C. The gastric output was collected directly from a proximal duodenal cannula for each 5 min period after instillation of test meal into the abomasum. The volume of meal instilled is shown: ●, 1·0–1·5 l. ($n = 22$); ○, 2 l. ($n = 4$); △, 3 l. ($n = 8$); □, 4 l ($n = 4$); n being the number of experiments used to compile the average data. The linear regressions drawn in for each volume of meal were calculated from ln of the mean of the percentage volume of test meal remaining in the abomasum at each 5 min period; data from the exponential phase of emptying (10–35 min) was used.

Fig. 2. The inhibition of emptying water test meals from the stomach (abomasum) of preruminant calves. The conditions were the same as those of Fig. 1 except that 0·06 M-HCl was used as duodenal infusate. The volume of meal instilled is shown: ●, 1·0–1·5 l. ($n = 19$); ○, 2 l. ($n = 4$); △, 3 l. ($n = 7$), □, 4 l. ($n = 4$); n being the number of experiments used to compile the average data.

percentage remaining against time was calculated and then used to draw in the lines of Fig. 1. These calculated regression coefficients (*r*) ranged from −0·973 to −0·992 and had slopes from −0·020 to −0·027 (Table 1).

In Fig. 1 the abscissae corresponding to the 50% level of each line have

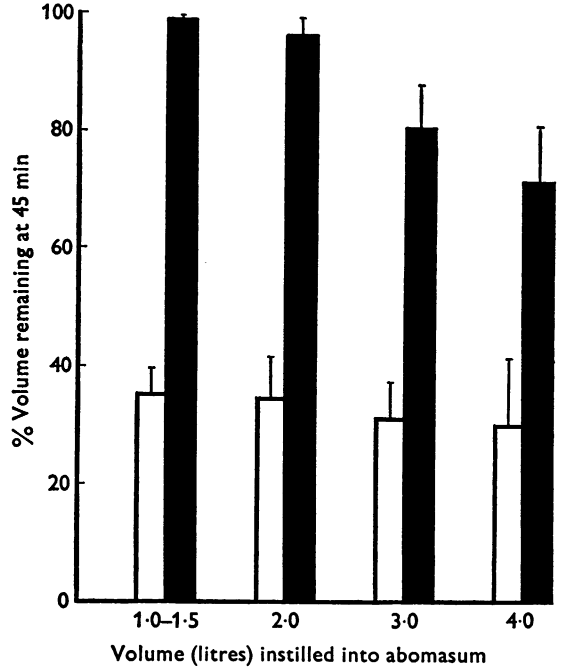

Fig. 3. The fraction (%) of water test meal remaining in the abomasum at 45 min when the duodenum is perfused with water (open columns) and the inhibition of efflux brought about when the duodenum is perfused with 0·06 M-HCl (filled columns). The *n* for each test meal is given in the tables, and the mean ± S.E. of mean of the volume remaining for the data is reflected in the column for each abomasal test meal.

TABLE 1. Data of water test meal remaining in abomasum of calves while the duodenum was infused with water at 10 ml. min^{-1} at 39° C for 5 min before and for 45 min after instillation of the meal directly into the stomach. In the pattern of emptying (linear regression) the slopes of the lines and the correlation coefficients were calculated from the ln of the mean % data at 5 min intervals from 10 to 35 min

Calves		Test meal		Pattern of emptying Linear regression	
No. of animals	No. of experiments	Volume instilled (l.)	Volume remaining after 45 min of mean (% ± S.E. of mean)	*r*	Slope
10	22	1·0–1·5	35·6 ± 3·95	−0·992	−0·020
4	4	2·0	35·0 ± 6·98	−0·987	−0·023
7	8	3·0	31·5 ± 5·76	−0·973	−0·023
4	4	4·0	30·3 ± 11·62	−0·983	−0·027

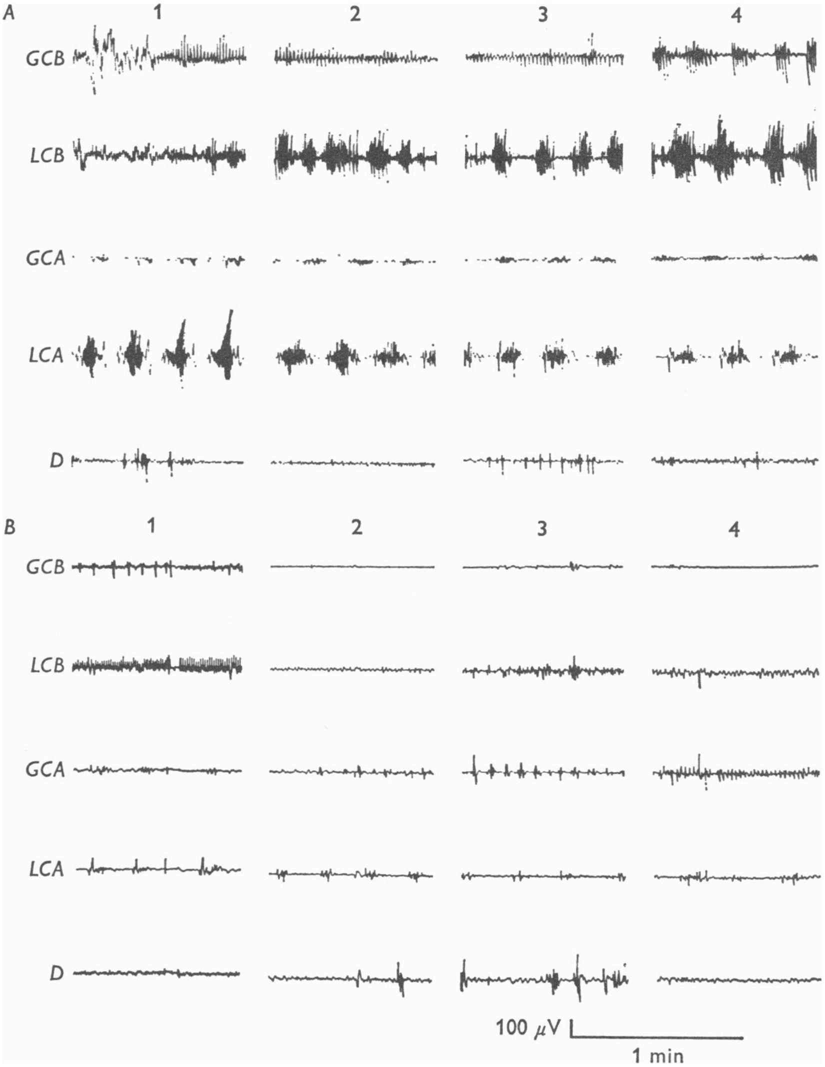

Fig. 4. Montage of gastric e.m.g. recorded during the first 5–10 min of a test meal period to indicate that gastric emptying is associated with motility of the viscus and inhibition of emptying is associated with an inactive viscus. All the e.m.g. records are from the same animal: in *A*, during perfusion of the duodenum with water; and in *B*, when the perfusate was 0·06 M-HCl; the volume of the test meal (litres) instilled is shown at the top of each trace. The electrode positions are: *GCB*, body, greater curvative; *LCB*, body, lesser curvative; *GCA*, antrum, greater curvative; *LCA*, antrum, lesser curvative; *D*, duodenum.

values of 20 min (1·0–1·5 l.), 27 min (2·0 l.), 16 min (3·0 l.) and 21 min (4·0 l.). The distension of the stomach did not affect the relative rate of emptying, the time course of emptying being proportional to the size of the meal, so that the half-times of emptying of the abomasum for the meals were approximately the same.

In Fig. 4*A* a montage of a short run of e.m.g. taken from the same animal on different days but always during the 5–10 min after the instillation of different volumes of test meal shows the degree of activity of the gastric musculature. The e.m.g. from the various electrodes' sites indicate similar activity when different volumes of test meal are instilled into the abomasum. The e.m.g. activity does not vary significantly even when the viscus is markedly distended and there is a relative increase in the volume being emptied.

Abomasal emptying during duodenal infusion with 0·06 M-HCl

The emptying time of the same volumes of test meal were re-examined when 0·06 M-HCl was used as duodenal infusate. The other conditions of the experiment were exactly the same as when water was used as duodenal infusate; the experimental data were treated similarly.

TABLE 2. Data of water test meal remaining in abomasum of calves while the duodenum was infused with 0·06 M-HCl at 10 ml. min^{-1} at 39° C for 5 min before and for 45 min after instillation of meal directly into the stomach

Calves		Test meal		Pattern of emptying Linear regression	
No. of animals	No. of experiments	Volume instilled (l.)	Volume remaining after 45 min (% ± S.E. of mean)	*r*	Slope
11	19	1·0–1·5	99·0 ± 0·49	−0·986	−0·0001
4	4	2·0	96·3 ± 3·09	−0·939	−0·0005
7	7	3·0	80·4 ± 7·53	−0·983	−0·0060
4	4	4·0	71·6 ± 9·36	−0·970	−0·0040

Infusion of the duodenum with HCl reduced gastric emptying significantly whatever the volume of the test meal (Fig. 2). The lower volumes of meal were almost wholly retained for the 45 min test meal period, but some of the 3 and 4 l. meals were expelled (Table 2). The data are shown in Fig. 3 and it is clear that the inhibitory action of 0·06 M-HCl on duodenal receptors only partially overcomes the effects produced by marked distension of the abomasum. During the inhibition of gastric emptying by the acid duodenal infusion the gastric e.m.g. was also inhibited (Fig. 4*B*). During the expulsion of small volumes of the larger test meals from the abomasum the gastric e.m.g. showed slight recurrence of e.m.g. activity.

The data from the emptying of the different test meals are shown in Fig. 2 together with the calculated linear regressions of the 1–4 l. water test meals. The calculated regression coefficients ranged from −0·939 to −0·986 but the slopes varied from −0·0001 for 1·0−1·5 l. meals to −0·006 for the 3·0 l. meals (Table 2). The inhibitory effect of HCl infusion of the duodenum showed a small but definite progressive reduction in effectiveness as the volume of the test meal was increased (Fig. 3). Nevertheless the inhibition produced by duodenal acid infusion was profound compared to the water perfusion.

Instillation of 4 l. into an abomasum which has been estimated to have a normal capacity of 1·5 l. produced little if any evidence of abdominal discomfort. Movement of the animal was, however, sometimes associated with evacuation of very small amounts of test meal from the abomasum accounting for some of the small efflux when large volume meals were instilled. The greater output, and this was a small volume, occurred when the animal vocalized (mooed), in response to other calves, when presumably the increased thoracic pressure was transferred to the abdomen and thence to the abomasum. Defaecation and urination were not normally associated with abomasal emptying.

DISCUSSION

Our results corroborate our previous findings, that the abomasum of the calf behaves physiologically like the simple stomach and empties in a similar exponential pattern (Bell & Razig, 1973). Furthermore, they validate the serial test meal technique as a means of assessing evacuation of the stomach, for in the experiments reported here the actual output of the abomasum collected and measured per unit time showed good agreement with results obtained by calculation using phenol red as a volume marker (F. R. Bell, unpublished).

Earlier results in the milk-fed calf have shown unequivocally that it is the duodenal infusate which controls gastric emptying (Bell & Mostaghni, 1975; Bell & Grivel, 1975) and we have confirmed this in the current series of experiments. When the stomach is isolated from the duodenum, gastric emptying can be manipulated from the duodenum whatever the stomach contents might be. Our method of maintaining a constant duodenal perfusion via the distal member of the duodenal re-entrant cannulae permits optimal activation (either stimulatory or inhibitory) of abomasal motility and the use of the proximal member of the duodenal re-entrant cannulae to collect gastric effluent provides the same 'sink' pressure for each experiment and avoids varying pressure gradients between stomach and duodenum. This standardization of method has permitted the comparison of evacuation of different gastric volumes under the same conditions of duodenal infusion. Our results show that during stimulatory infusion of the duodenum all volumes of test meal are emptied from the abomasum at the same rate and gastric muscle activity, as judged by e.m.g., does not appear to vary. This may be due to the fact that the electrodes only sample a small number of smooth muscle elements which become active whenever the duodenal receptors are stimulated. On the other hand when the duodenum is inhibited by acid infusate, gastric contents, including volumes which distend the viscus, are almost wholly retained for the test meal period and the gastric e.m.g. is quiescent. During the test meal period, however, when there was some active evacuation of stomach contents the e.m.g. often recurred. We have no explanation for this phenomenon but it could possibly be some form of accommodation in the duodenal receptor or the gastric receptor or the 'exhaustion' of some precursor at either of these sites.

The duodenal perfusate of 10 ml min^{-1} which we used is much less than the volume evacuated by the abomasum to the duodenum in the intact preparation (Bell & Razig, 1973) and from e.m.g. evidence this perfusion did not normally activate the duodenal musculature. The report of Weisbrodt *et al.* (1969) that duodenal receptors augmented motor activity of the proximal duodenum and inhibited the gastric antrum in the dog was not demonstrable in the calf from our e.m.g. records. It was noted, however, that occasionally during duodenal perfusion the anterior duodenal e.m.g. showed short bursts of activity (1·5 min) which coincided with complete abolition of e.m.g. activity in the gastric body while in the antrum only the rhythmic slow waves persisted (F. R. Bell and D. J. Watson, unpublished). In these latter circumstances, however, the effect occurred with a wide variety of duodenal perfusates including both stimulatory and inhibitory substances.

Hunt & McDonald (1954), using the serial test meal technique in man, showed a series of curves of different slope when test meals of different volume were introduced into the stomach; larger meals discharged at a slower rate than the smaller meals. This was not so in the calf, where large meals were expelled at a much faster rate than small meals, and when the patterns of emptying expressed semilogarithmically for all meals, large and small, were compared they showed remarkably similar slopes. The calculated slopes for the emptying of each volume from all the calves were almost parallel and the evacuation time was similar. In consequence the half-life of any test meal of the same composition in our experimental situation was similar irrespective of the initial volume. Marbaix (1898) has already shown that in the dog a small range of test meals of varying volumes emptied at the same rate. It is difficult, therefore, to reconcile animal experiments with the marked differences in rate of emptying of test meals of different volumes in man, especially the very rapid evacuation of small meals (Hunt & McDonald, 1954). The latter authors did, however, remark on this variation of emptying time and suggested emotional circumstances as a cause of difference between individuals. In our animals the variation between calves, and in the same calf from experiment to experiment, is small as can be seen from Table 1 and Fig. 1.

Hopkins (1966*a*) reconsidered the results published by Hunt & McDonald (1954) and showed that the square root of the volume emptied related better to time than did the logarithm of the volume. This is not so in the calf where gastric emptying is clearly exponential in form. George (1968) also reconsidered the results of gastric evacuation in man published by Hunt & Spurrell (1951) and showed that of seventy-nine tests, seventy-four were exponential in form similar to his own results obtained from a fractional test meal technique. It is now clear from studies on man, cat, dog and calf that despite the somewhat different techniques used, the emptying of the gastric viscus has a basic exponential pattern, no matter what the volume of gastric contents might be. This was suggested long ago by Marbaix (1898).

Hunt & Stubbs (1975) have recently examined data which suggest that in man test meals of different volume but of the same nutrient density are transferred to the duodenum at a constant rate. These data are contrary to our findings in the calf, for when the duodenum is subjected to a constant activating stimulus, comparable to the constant stimulus of material of the same nutrient density, the transfer volume always increases proportionately with the volume of the meal. Hunt & Stubbs (1975) go further and calculate that in man under constant duodenal stimulation the half-time of emptying of larger volumes is longer than for smaller volumes. Our results in the calf do not conform to this suggestion: for the half-time of emptying is similar for all gastric volumes. It is noteworthy that the rate of efflux from the abomasum of the calf per unit time, 5–25 ml min^{-1}, is very similar to that of the stomach of man calculated by Hunt & McDonald (1954), 6·3–24 ml. min^{-1}, and by Hunt & Stubbs (1975), *ca.* 5·0 ml. min^{-1}. According to the calculations of Hunt & Stubbs (1975), however, the volume emptied per unit time is almost constant, whereas in the calf the *actual* volume collected is greatest at the beginning of the meal whatever the volume of the meal. It should be noted, however, that in our experiments test meals, of water only, were instilled directly into the stomach and the duodenum was maintained at optimal stimulation. Our findings are in agreement with those of Hunt & Spurrell (1951) on the episodal evacuation of serial test meals in man.

As far as we know, this is the first report of a study of the evacuation of test meals of different volume when the stomach is inhibited by constant perfusion of the duodenum with acid or any other inhibitory stimulus, made possible by our particular surgical preparation of the calf. The results show that the constant inhibition of abomasal efflux (or emptying) induced by perfusion of the duodenum (Bell & Mostaghni, 1975) occurs even when the viscus is distended well above its normal volume. Suppression of the gastric e.m.g., under duodenal inhibition which Bell & Grivel (1975) showed to be correlated directly with gastric motility, is maintained even with the larger volumes. Furthermore, the duodenal inhibitory stimulus dominates the intragastric reflexes which in the distended viscus aid emptying when the gastric muscle is under positive stimulus. We have no evidence to date to account for the mechanism of this gastric inhibition but it is obviously very powerful, being sufficient to block the normal forces, generated in accordance with the Law of Laplace, which affect the elastic modulus controlled by intragastric reflexes (Hopkins, 1966*b*). Under the conditions of maximal distension created in our experiments, the duodenal inhibitory stimulus may be opposed by that of abdominal pressure generated by vocalization and general movement.

Our results show that the gastric evacuation varies only with the nature of the duodenal infusate and that the volume of the contents of the duodenum does not directly affect gastric emptying since we maintained the duodenum at a constant volume in our experiments. These present results in the calf augment our earlier findings that duodenal receptors control gastric muscle activity (Bell & Grivel, 1975). The mechanism of this indirect control is being investigated and we have preliminary evidence that the stimulatory effect is curtailed by bilateral transthoracic vagotomy (Bell & Watson, 1976) and also that an i.v. infusion of physiological amounts of pentagastrin causes the simultaneous inhibition of gastric emptying and the gastric e.m.g. (Bell, Titchen & Watson, 1975).

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