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THE EFFECT OF GRAVITY ON GASTRIC EMPTYING WITH VARIOUS TEST MEALS

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The rates at which the gastric contents are usually passed into the duodenum are much less than the maximal rate which the stomach can achieve. The rates are submaximal because the propulsive mechanism of the stomach is usually partly inhibited through the excitation of duodenal receptors responding to the duodenal contents, recently transferred from the stomach. This being so, mechanical hindrance to the gastric propulsive mechanism might be expected to have little influence on the usual rate of gastric emptying, since the reduced rate of transfer of gastric contents resulting from the hindrance would be offset by the reduced inhibitory action of the duodenal receptors. On the other hand, if a test meal were specially selected to have minimal action on the duodenal receptors, mechanical hindrance of the stomach should significantly slow gastric emptying because there would in this instance be no possibility of reducing the inhibition playing on the stomach.

In the experiments described below the stomach was mechanically hindered by tipping supine subjects feet up, head down. The results with test meals which emptied at different rates were consistent with gastric emptying being controlled by duodenal receptors as outlined above.

METHODS

The subjects were eight healthy adults of whom seven were medical students. They came to the laboratory without breakfast at about 8 a.m. Their stomachs were washed out through a rubber tube with a 3 mm bore with 250 ml. of tap water at room temperature. After the subjects had taken up their experimental position for the day the meals were instilled into the stomach. The positions were either sitting, or lying supine and horizontal, or lying supine with the whole body tipped to 45° head down on a tilted table. When the meal had been given the tube was occluded until it was used for withdrawing the gastric contents after varying periods on different days. The experimental position was maintained until the gastric contents had been withdrawn and the stomach washed out with 250 ml. of tap water.

Three types of meal were used: (*a*) 750 ml. of 50 mN trisodium citrate; (*b*) 750 ml. of 35 mN hydrochloric acid; (*c*) 750 ml. of 560 mM glucose (100 g./l.). These solutions were chosen in the expectation that they would leave the stomach at different rates, the trisodium citrate solution the most rapidly, (Hunt & Knox 1962), and the glucose solution the most slowly

(Hunt, Macdonald & Spurrell 1951; Hunt & Pathak 1960). All meals contained about 60 mg phenol red/l. The volume of the original meal recovered from the stomach was calculated as the product of the volume of the gastric contents and the ratio of the concentration of phenol red in the gastric residue to that in the original meal.

The methods have been discussed critically by Hunt (1959).

Subjects received different numbers of tests with the three types of meal, the times of the recovery of the gastric contents varying from 5 to 30 min. It was found that the volume of the original meal recovered, plotted on a logarithmic scale, against time on a linear scale, gave a straight line, thus confirming the exponential emptying of the stomach which has been many times reported (Marbaix, 1898; Hunt, 1959). Such lines were fitted by the method of least squares to the results for each type of meal for each subject. As the meal of sodium citrate solution left the stomach rapidly, 20 min after instillation was the latest time at which it was possible to make comparisons of the volumes of all three types of meal remaining in all subjects. Accordingly, the volume of each of the three meals remaining in each subject at 20 min was calculated from the relevant regression equations. Twenty-one out of seventy-two volumes depend upon a single withdrawal made 20 min after giving the meal.

RESULTS

The calculated volumes of each of the three test meals remaining in the stomach 20 min after instillation for the eight subjects, based on 279 test meals, are shown in Table 1. The mean volumes remaining in the stomach in the three positions and with the three types of meal are shown in Table 2. The standard errors of the mean differences between the volumes of the various meals remaining were calculated from within subject comparisons. Reading across Table 2 it may be seen that for any position, the volume remaining in the stomach after 20 min is least for the meal of 50 mN sodium

TABLE 1. The effect of gravity on the volume of meal remaining in the stomach at 20 min with three types of meal (ml.)

	WS	HT	FL	LN	GE	VZ	CE	JN
50 mN sodium citrate								
Sitting	15	123	56	234	151	120	348	274
	(8)	(6)	(7)	(8)	(5)	(10)	(4)	(4)
Lying	155	79	101	191	102	126	274	399
	(4)	(7)	(3)	(4)	(4)	(4)	(2)	(2)
45° head down	135	155	371	240	182	371	365	340
	(8)	(10)	(10)	(7)	(3)	(10)	(4)	(4)
35 mN hydrochloric acid								
Sitting	331	437	182	429	389	484	516	467
	(4)	(4)	(5)	(1)	(1)	(3)	(1)	(1)
Lying	398	427	389	423	369	537	532	494
	(5)	(6)	(3)	(3)	(1)	(1)	(1)	(1)
45° head down	479	427	525	431	499	566	543	499
	(5)	(3)	(4)	(2)	(2)	(3)	(2)	(1)
560 mM glucose								
Sitting	472	637	460	634	630	621	563	623
	(10)	(4)	(13)	(1)	(1)	(1)	(1)	(1)
Lying	562	603	513	583	648	599	585	593
	(5)	(4)	(4)	(1)	(1)	(2)	(1)	(1)
45° head down	556	600	594	592	584	642	530	573
	(8)	(4)	(8)	(1)	(1)	(2)	(2)	(1)

The numbers of experiments are given in parentheses.

citrate, and most for the meal containing 560 mM glucose. Reading down Table 2 it may be seen that with the meals of 50 mN trisodium citrate and 35 mN-HCl, the volume of the meal remaining increased as the position changed from sitting to head down. For the meal of 560 mM-glucose, which left the stomach much more slowly than the other two meals, position made no difference to the volume of meal recovered.

TABLE 2. The effect of gravity on the mean volumes of meal remaining in the stomach 20 min after instillation (ml.)

Composition of meal	50 mN Na citrate	35 mN HCl	550 mM glucose
Sitting (A)	165	404	580
Lying	178	446	586
45° head down (B)	270	496	584
$B-A$	105 S.E. ± 42	92 S.E. ± 4	4 S.E. ± 25

DISCUSSION

The significance of the composition of the test meals

Trisodium citrate meals. Other things being equal, in a single subject a maximal rate of transfer of a test meal from the stomach to the duodenum is taken as evidence that the composition of such a meal offers a minimal stimulus to the duodenal receptors which inhibit gastric emptying. Previous experiments with a variety of test meals have shown that the most rapid gastric emptying is found with solutions containing 125 mN sodium ion with chloride, bicarbonate or citrate as the anion (Hunt & Pathak, 1960; Hunt & Knox, 1962).

To make comparisons of the volumes of meal remaining in the present experiments, it was desirable that a period of not less than 20 min should be occupied with emptying. This precluded the use of 125 mN trisodium citrate solution as in some subjects none of this meal remained in the stomach 20 min after its ingestion. The use of 50 mN trisodium citrate overcame this difficulty at the cost of mildly stimulating the duodenal receptors.

Hydrochloric acid meals. The stimulation of duodenal receptors whose adequate stimulus is hydrogen ions slows gastric emptying to an extent dependent upon the concentration (Hunt & Pathak, 1960). The concentration of hydrochloric acid chosen for these experiments, 35 mN, lies at the lower end of the range of concentrations studied previously, and it is known to be a relatively weak stimulus to the duodenal receptors.

Glucose meals. Glucose is believed to act on duodenal receptors responding to the osmotic pressure of the luminal contents (Hunt & Pathak, 1960; Hunt, 1963). The concentration chosen, 100 g/l., is as high as can be given to a series of subjects with little chance of producing nausea, and usually produces very marked slowing of gastric emptying.

Relative magnitude of stimuli to duodenal receptors

The relation between the magnitude of the stimuli offered by the three types of meals to the duodenal receptors can be appreciated from the mean volumes of the meals remaining in the sitting position at 20 min, 50 mM trisodium citrate, 165 ml.; 35 mN hydrochloric acid, 404 ml.; and 560 mM glucose, 580 ml.

The composition of the meal and the effect of the head-down position

This section deals only with effects on the mean volumes of meal remaining at 20 min. With meals containing trisodium citrate or hydrochloric acid the head-down position reduced the rate of gastric emptying, a reduction which may possibly be ascribed to a gravitational hindrance to the gastric propulsive mechanism; yet the same gravitational hindrance with the meal containing a high concentration of glucose did not produce a change in gastric emptying.

In explanation, it can be suggested that in the head-down position the gravitational hindrance to emptying reduced the amount of meal transferred to the duodenum during a short interval after the meal was instilled. As a result there was less excitation of the duodenal receptors and so less inhibitory braking of the expulsive activity of the stomach. This allowed a corresponding increase in the activity of the gastric antral pump which offset the disadvantage imposed by the head-down position.

It might be anticipated that the head-down position would slow gastric emptying proportionately more for the meal which was the least effective stimulus to the duodenal receptors. This was so, for the head-down position increased the volume of meal remaining from 165 to 270 ml., that is 64 % for the meal containing trisodium citrate, but only from 404 to 496 ml., that is 23 % for the meal containing hydrochloric acid whereas the emptying of the glucose meal was unaffected. This line of thought suggests an examination of the results for individual subjects shown in Table 1.

An interpretation of variations between individuals

Each point in Fig. 1 relates the volume of a meal recovered 20 min after instillation in the sitting position, to the increase in volume recovered produced by the head-down position. There are three points for each subject, representing the results for the three types of meal. For all three types of meal the distribution of the points indicates that the head-down position produced the least slowing of gastric emptying in those subjects in whom emptying in the sitting position was slowest, that is in those supposedly showing the most duodenal inhibition of gastric emptying in the sitting position.

Scrutiny of the values in Table 1 will show that not all subjects show slowing of emptying in the head-down position, and that the lack of effect with the glucose meals of the head-down position in the mean results for the eight subjects hides considerable intersubject variation. However, where the head-down position produces considerable slowing of emptying of the citrate meal, relative either to the emptying in the sitting or horizontal position, the slowing of emptying so produced is much less with the glucose meal.

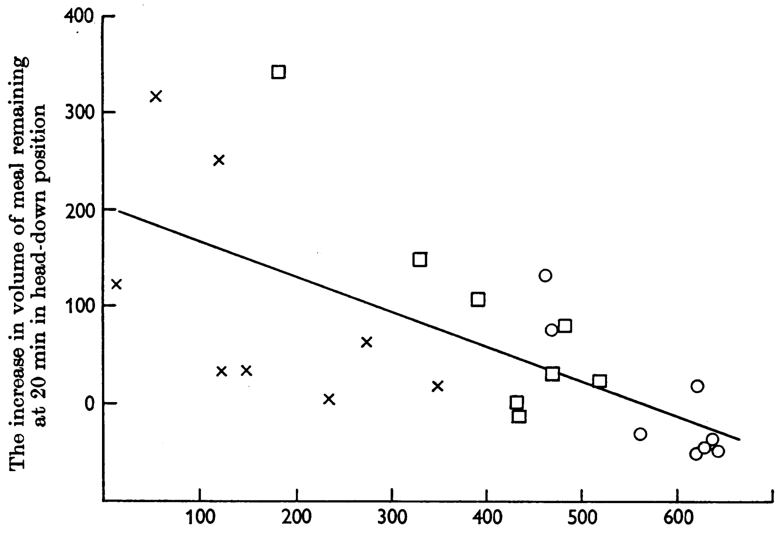

Fig. 1. Relation between volume of meal remaining in the stomach in sitting position and slowing of gastric emptying by head-down position. Open circles, 560 mM-glucose; open squares, 35 mN-HCl; crosses, 50 mN-trisodium citrate.

It may be supposed where the head-down position does not slow the emptying of the citrate meal either that the head-down position does not hinder, or that the 50 mN trisodium citrate was an effective stimulus to the duodenal receptors involved in the regulation of gastric emptying.

Relevance to ordinary food

It seems reasonable to conclude that under the conditions of these experiments, with the solution of glucose (560 mM) any mechanical hindrance caused by the head-down position was offset by a withdrawal of inhibition. However, which of the three types of meal studied most closely mimics the conditions with ordinary food? There is insufficient experience with the gastric emptying of ordinary food mixtures to make a firm statement on this point but the rate of emptying of the meal containing glucose resembles that for a dietary mixture of sugar, fat and protein (Hunt, 1963). There are, therefore, grounds for thinking that the mechanism envisaged above would limit the effect of ordinary changes of posture on the gastric emptying of ordinary food.

The example of stabilized delivery to the duodenum discussed above is the second so far encountered, for it has previously been reported that the gastric emptying of citric acid and its sodium salts occurs in such a way as to transfer titratable acid to the duodenum at a more or less constant rate independent of the intragastric pH (Hunt & Knox, 1962).

SUMMARY

1. Eight subjects were given test meals containing 50 mN trisodium citrate, 35 mN hydrochloric acid or 560 mM glucose.

2. During the tests subjects sat, lay supine and horizontal, or lay supine with the body tilted to 45° feet up, head down.

3. The head-down position slowed the gastric emptying of the meals containing trisodium citrate and hydrochloric acid but had no systematic effect on the gastric emptying of the meals containing glucose.

4. These results are explained on the grounds that the head-down position mechanically interferred with the effectiveness of the stomach as a pump. With the meal containing glucose, which was a powerful stimulus to the duodenal receptors, withdrawal of duodenal inhibition of gastric activity balanced the gravitational disadvantage under which the stomach was working.

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