Gastric emptying rate of the water and fat phases of a mixed test meal in man¹

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Most reported studies of gastric emptying in humans have been concerned primarily with the regulation of pyloric passage of a single-phase meal. However, Wiggins and Dawson (1961) sampled intestinal contents in man after ingestion of a mixed meal, and found that the proportions of fat and water recovered were different from those of the meal. Harkins, Longenecker, and Sarett (1964) observed in rats that the fat and water phases do not leave the stomach in parallel, fat being retained longer. The present study was conducted in an attempt to elucidate some of the mechanisms involved in this phenomenon and to investigate the effect of fat on the gastric emptying rate of the water phase of a mixed meal.

CLINICAL METHODS

Ten healthy, asymptomatic human volunteers between the ages of 18 and 26 years were studied; three were females and seven were males. They fasted overnight and the experiments were carried out in the morning between 8.45 and 10 the next day. Seven experiments were performed on separate days in each case, five with different test meals and two in different body positions. Three of the test meals (I, II, and III) contained only the water phase but were of different volumes. Two were mixed meals (IV and V) and contained different volumes of fat. Test meal IV was given three times: with the subject sitting, and in the right and left lateral recumbent position.

The five meals administered to each subject were as follows: I, 250 ml water phase only; II, 300 ml water phase only; III, 350 ml water phase only; IV, 250 ml water phase mixed with 50 ml olive oil; and V, 250 ml water phase mixed with 100 ml olive oil. The water

phase was as described by Hunt (1954), using 50 ml of phenol red stock solution as the unabsorbable marker in 950 ml of glucose 10% in distilled water. When this was the only phase the experimental design was as described by him except that the volume varied.

The subjects were intubated and the meal was administered through a Levine tube. Unless otherwise stated, the gastric contents were withdrawn 30 minutes later and the stomach was washed out twice to recover the total residue. It was found that the water phase was recovered easily, but that the fat remained in the stomach. This was difficult to evacuate when washed with water, and fat solvents could not be used *in vivo*. The addition of 2 ml of Decholin to the 250 ml of water used for washing out the stomach was found to result in complete evacuation and, therefore, this method was used in the studies in which fat was administered.

BIOCHEMICAL METHODS

WATER PHASE ONLY The gastric emptying rate, *ie*, the volume passing the pylorus (VPP) in half an hour, was determined according to the original method of Hunt (1954), using the following formula

$$VPP = \frac{VTM \times 100 - (TVGC \times APRGC)}{100 + CPRGC} \times 2$$

where VTM stands for the volume of test meal (in our case, the water phase of the test meal), TVGC for total volume of gastric content after half an hour; APRGC is concentration of phenol red in gastric contents.

$$TVGC = VGC + VGCWO$$

where VGC is the volume of gastric content after 30 minutes, and VGCWO is volume of gastric content in the washout

$$VGCWO = \frac{VWO \times PRWO}{CPRGC}$$

where VWO is volume of wash out, PRWO is concentration of phenol red in wash out.

MIXED MEALS The gastric contents and the washouts were placed into individual separatory funnels and 100 ml of toluene was added to each. The funnels were shaken vigorously for one minute and then were left standing

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for one hour for separation into upper phase (fat, toluene, and mucus) and lower phase (water-soluble substances). It was unnecessary to alter this method since it was shown that the unabsorbable marker (phenol red) stays entirely in the water phase. When the latter had separated it was treated as in experiments with single-phase, water-soluble meals. To estimate the amount of fat recovered, mucus from the upper phase was discarded, the volume of the remaining toluene-fat solution was measured, and the amount of toluene added originally was subtracted. Values obtained with this volumetric method were compared with those obtained by biochemical determinations using the method of

Jover and Gordon (1962): these differed by 1.5%. In contrast to water-phase recovery, where part of the gastric contents may represent secretion, any fat recovered is necessarily part of the administered meal; therefore, further calculations are unnecessary.

EVALUATION OF THE METHOD In order to evaluate the accuracy of fat recovery, test meal IV (250 ml water phase and 50 ml olive oil) was recovered immediately after its ingestion in one subject on five consecutive days. The recovery rate of fat was 84, 86, 88, 86, and 88% (mean, 86.4 ± 0.751 SE). In another five subjects a single similar experiment resulted in the recovery of 80, 80, 84,

TABLE I

REPRODUCIBILITY OF EXPERIMENT WITH TEST MEAL IV IN TWO SUBJECTS ON FIVE OCCASIONS IN THE SITTING POSITION FOR 30 MINUTES

Subject	Experiment No.	Volume of Water Phase Passing Pylorus (ml)	Loss of Oil (ml)
B.L.	1	160 (64%)	7 (14%)
B.L.	2	144 (58%)	6 (12%)
B.L.	3	166 (66%)	8 (16%)
B.L.	4	149 (60%)	7 (14%)
B.L.	5	180 (72%)	7 (14%)
P.L.	1	213 (85%)	4 (8%)
P.L.	2	251 (100%)	10 (20%)
P.L.	3	277 (>100%)	11 (22%)
P.L.	4	309 (>100%)	9 (18%)
P.L.	5	315 (>100%)	3 (6%)

TABLE II

RESULTS OBTAINED WITH FIVE TEST MEALS IN 10 SUBJECTS

Subject	Volume of Water Phase Passing Pylorus (ml)	Loss of Oil within the Stomach (ml)	Volume of Water Phase Passing Pylorus (ml)	Loss of Oil within the Stomach (ml)	Volume of Water Phase Passing Pylorus (ml)
<i>Test Meal I</i>			<i>Test Meal II</i>		
P.L.	176 (70%)	—	138 (46%)	—	234 (67%)
J.S.	131 (52%)	—	162 (54%)	—	175 (50%)
R.G.	249 (100%)	—	273 (91%)	—	267 (76%)
J.D.	143 (57%)	—	153 (51%)	—	206 (59%)
B.L.	126 (50%)	—	121 (40%)	—	112 (32%)
C.C.	180 (72%)	—	209 (70%)	—	233 (67%)
B.T.	165 (66%)	—	204 (68%)	—	178 (51%)
P.W.	106 (42%)	—	142 (47%)	—	131 (37%)
J.R.	255 (102%)	—	241 (80%)	—	248 (71%)
D.C.	138 (55%)	—	172 (57%)	—	177 (51%)
Mean	167 (67%)	—	182 (60%)	—	196 (56%)
SD±	50 (20%)	—	49 (16%)	—	51 (15%)
SE±	15.9 (6.3%)	—	15.5 (5.2%)	—	16.1 (4.7%)
<i>Test Meal IV</i>			<i>Test Meal V</i>		
P.L.	213 (85%)	4 (8%)	235 (94%)	10 (10%)	
J.S.	171 (68%)	4 (8%)	258 (100+%)	20 (20%)	
R.G.	162 (65%)	9 (18%)	244 (98%)	20 (20%)	
J.D.	130 (52%)	4 (8%)	224 (90%)	8 (8%)	
B.L.	160 (64%)	7 (14%)	147 (59%)	6 (6%)	
C.C.	226 (90%)	14 (28%)	159 (64%)	8 (8%)	
B.T.	151 (60%)	9 (18%)	227 (91%)	7 (7%)	
P.W.	115 (46%)	25 (50%)	144 (58%)	10 (10%)	
J.R.	134 (54%)	3 (6%)	391 (100+%)	7 (7%)	
D.C.	153 (61%)	4 (8%)	130 (52%)	9 (9%)	
Mean	162 (65%)	8.4 (17%)	216 (87%)	11 (11%)	
SD±	35 (14%)	6.6 (14%)	78 (31%)	5 (5%)	
SE±	11.1 (4.4%)	2.1 (4.4%)	24.7 (9.8%)	1.6 (1.6%)	

90, and 86% (mean, $8410 \pm \text{SE } 1.9\%$). The mean loss of fat in the stomach during these 10 experiments with immediate recovery was 7.4 ± 0.5 ml, therefore, any lesser loss cannot be due to pyloric emptying of fat.

In two subjects, test meal IV (250 ml water phase and 50 ml olive oil) was administered on five different occasions in the sitting position. Gastric contents were withdrawn 30 minutes later. As shown in Table I, there was good reproducibility from day to day.

RESULTS

EFFECT ON GASTRIC EMPTYING OF DIFFERENT COMPOSITION OF TEST MEALS Variance calculation revealed no statistically significant difference ($P = 0.05$) in the volume of the water phase passing the pylorus, irrespective of the presence or absence of oil in the test meal (Table II), with the subjects sitting. The apparently significantly greater amounts of water passing the pylorus with the meal containing 250 ml water phase and 100 ml oil (total volume 350 ml) than with the meal containing 250 ml water phase and 50 ml oil (total volume 300 ml) are in fact nullified by the greater volume of the former; comparison of results obtained with meal V (250 ml water phase and 100 ml olive oil) with those obtained with a meal of equal volume but without fat (meal III, 350 ml water phase only) shows no difference. It appears, therefore, that the presence of fat in the

stomach does not influence passage of the water phase through the pylorus.

DIFFERENCES IN EMPTYING OF FAT AND WATER The amount of oil lost during experiments with test meals containing 50 or 100 ml oil, as seen in Table II, is not significantly different from the mean 7.4 ml that was obtained in the immediate recovery experiments. It appears, therefore, that under the conditions of our experiments the fat phase does not pass the pylorus in the first 30 minutes after ingestion. On the other hand, 65% of the water phase of meal IV (250 ml water phase and 50 ml oil) and 87% of the water phase of meal V (250 ml water phase and 100 ml oil) pass through the pylorus at this time. Thus, it is apparent that the two phases separate in the stomach.

EFFECT OF BODY POSITION ON GASTRIC EMPTYING Figure 1 demonstrates that body position has an important effect on the passage through the pylorus of both phases of the test meal. Compared with the sitting position, when the subjects lay in the left lateral position the amount of fat passing the pylorus was significantly increased and the water phase was reduced; in the right lateral recumbent position, the amount of fat passing the pylorus was unchanged and the water phase passing the pylorus was increased ($P > 0.05$).

FIG. 1. Various parameters correlated with body position. A Position of the stomach. Sitting: the pylorus points to the right, the fat floats, and the water phase reaches the pylorus. Right lateral decubitus: the pylorus points downward, fat floats, and water reaches the pylorus easily. Left lateral decubitus: the pylorus points upward, so that fat floats to it. B Passage of the fat phase. Left ordinate: fat lost during experiment. Right ordinate: the amount of fat passing the pylorus, as calculated on the basis of immediate-recovery experiments. C Passage of the water phase.

TABLE III

TEST MEAL IV AND RIGHT LATERAL RECUMBENT POSITION

Subject	Volume of Water Phase Passing Pylorus (ml)	Loss of Oil within the Stomach (ml)
P.L.	272 (100%)	6 (12%)
J.S.	239 (96%)	11 (22%)
R.G.	363 (100%)	21 (42%)
J.D.	332 (100%)	7 (14%)
B.L.	90 (36%)	12 (24%)
C.C.	352 (100%)	27 (54%)
B.T.	190 (76%)	9 (18%)
P.W.	160 (64%)	9 (18%)
J.R.	346 (100%)	3 (6%)
D.C.	220 (88%)	6 (12%)
Mean	256.4 86.0	11.1 22.2
SE $\pm$	44.4 6.78	7.4 4.69

TABLE IV

TEST MEAL IV AND LEFT LATERAL RECUMBENT POSITION

Subject	Volume of Water Phase Passing Pylorus (ml)	Loss of Oil within the Stomach (ml)
P.L.	37 (14.8%)	15 (30%)
J.S.	35 (14.0%)	26 (52%)
R.G.	38 (15.2%)	26 (52%)
J.D.	88 (35.2%)	30 (60%)
B.L.	23 (9.2%)	23 (46%)
C.C.	59 (23.6%)	28 (56%)
B.T.	64 (25.6%)	27 (54%)
P.W.	87 (34.8%)	28 (56%)
J.R.	71 (28.4%)	21 (42%)
D.C.	50 (20.0%)	23 (46%)
Mean	55.2 22.1	24.7 49.4
SE $\pm$	7.1 2.83	1.39 2.76

DISCUSSION

Cannon (1904) found radiological evidence of a different rate of gastric emptying for carbohydrate (fastest), fat (slowest), and protein. Carnot and Chassevant (1905) and Hunt (1956, 1961) have shown that the osmolarity and pH of a watery solution affect the gastric emptying rate, and the latter author suggested that these factors are regulated by receptors in the duodenum and upper small intestine. Hunt, Knox, and Oginski (1965) have shown that body position may influence emptying, on the basis of mechanical hindrance. Mixing of the gastric contents is effected by movement of the gastric wall (Code, Hightower, and Morlock, 1952; Cummins, 1963; Fenton and Cowgill, 1955), and some have assumed that '... triglyceride is emulsified in the stomach . . . , a physiological emulsification process similar to that commonly used in industrial emulsification practices' (Hofmann, 1966). This concept, however, is open to question. Harkins *et al* (1964), who administered mixed meals in rats, observed that carbohydrate and protein leave the stomach independently of fat and that the amount of fat does not influence the rate of emptying of the stomach. Similar studies in humans

have been reported only by Wiggins and Dawson (1961), who found a significant disproportion of fat and water in the upper intestinal tract.

Since in our experiments a mean of 7.4 ml of oil could not be recovered, even when the meal was withdrawn immediately after administration, and since this value is of the same order as was found after 30 minutes in the sitting position, it is apparent that no fat passed the pylorus in the first half-hour and that this amount was taken up in the gastric folds. This being the case, the fat did not enter the gastric emptying regulatory mechanism located in the duodenum, which explains why the emptying of the water phase was not affected by the presence of fat. Had the fat entered the duodenum during this time, it is presumed that the gastric emptying rate would have been inhibited (Gershon-Cohen and Shay, 1937). It appears that fat in the stomach, if it does not enter the duodenum, exerts no influence on gastric emptying of the water phase. On the other hand, when fat enters the duodenum, as it does when the subject ingests meal IV (250 ml water phase and 50 ml oil) and adopts the left lateral position, emptying of the water phase is diminished.

Our studies further indicate that the gastric emptying rate of fat and of glucose 10% solution differs with body position (Fig. 1A). When the subjects lay in the right lateral position, the volume of water phase passing the pylorus was significantly higher than when they sat or assumed the left lateral recumbent position. On the other hand, the volume of fat passing the pylorus was significantly higher when the subjects lay in the left lateral than in the right lateral or sitting position.

It is assumed that fat and water separate in the stomach and that fat floats on the water phase because of its lesser specific gravity. In the right lateral recumbent position, fat floats near the fundus and water is near the pyloric region, so that the latter passes through the pylorus first. Conversely, in the left lateral, recumbent position, fat floats towards the pyloric region, water stays in the fundus, and fat passes through the pylorus first, in large amounts. It is likely that the presence of fat in the duodenum inhibits gastric emptying of the water phase.

SUMMARY

The passage through the pylorus of fat and water-soluble components of mixed meals was studied during 70 experiments in 10 normal subjects. Pyloric passage of the fat component was determined by the recovery of fat from the stomach. The passage of water-soluble substances was measured by Hunt's technique (1954).

With the subjects sitting, pyloric passage of the water phase in 30 minutes was unchanged by the addition of fat to the water phase of the meal: the water phase passed freely through the pylorus, but the stomach retained the entire fat phase for 30 minutes. When the subjects lay in the left lateral position, the pyloric passage of fat was significantly increased and that of water was reduced. In the right lateral recumbent position, fat did not pass the pylorus but greater amounts of water phase passed, compared with results obtained in the sitting position.

It appears that water and fat separate in the stomach and that, because of their different specific gravity, body position has an important effect on their differential passage through the pylorus.

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