The Effect of Fat on the Gastric Responses to Foods[1, 2]

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Introduction

THERE has long been prevalent a popular belief that fats incorporated in foods during processes of cooking or baking render them difficult to digest even by the normal human subject. Among the phases of digestion assumed to be impeded by fats in foods are the functions of the stomach. Probably Boas and Ewald, in 1886, were the first to report impairment of gastric function produced by fats. Since that time numerous reports have appeared in clinical and physiological literature which purport to demonstrate that fats retard both gastric secretion and motility. It is not within the scope of this report to present a review of this extensive literature. It will suffice to say that in the large measure these conclusions have been based upon animal experiments in which the technics employed excluded important factors such as palatability and flavors of foods, which are potent stimulants to gastric secretion. In the majority of experiments large amounts of fats have been fed alone or mixed with carbohydrates and proteins in proportions far exceeding the quantities of fat incorporated intimately in foods by cooking or baking. These limitations of the experimental procedures render the conclusions drawn from them inapplicable to foods naturally containing fats or foods prepared with fats by good cooking.

In this laboratory during the past decade comprehensive experimental studies have been directed to determinations of the influences of fats, from different sources, upon the rates of digestion of carbohydrates and proteins with which they have been fed to human subjects. Observations have been made of the effects of fats either added to or intimately incorporated with carbohydrate and protein foods by the best culinary technics. The initial steps in this investigation were concerned with the influence of fats upon gastric secretion in response to the consumption of the foods and upon the rate of evacuation of the food from the stomachs of average normal human subjects. This report has been limited to presentation of studies of the effects of foods containing different fats and varying amounts of fats upon the emptying time of the stomach. Subsequent communications will be devoted to discussions of the influence of these foods upon other phases of digestion and absorption.

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Experimental

Ten adult subjects participated in the several series of experiments described in this report. Seven of these (No. 1-No. 7, inclusive) were men and the remaining three were women.

On the basis of their gastric secretory and motor responses to test meals of dilute ethyl alcohol or of gruel, as determined by the fractional method of gastric analysis, the subjects have been classified as follows: subjects No. 1, No. 2, No. 4, and No. 9 showed normal curves for acidity and emptying times of their stomachs within the normal range. Subjects No. 3 and No. 8 exhibited normal curves for acidity but slowly emptying stomachs. Three subjects, No. 5, No. 6, and No. 7, gave curves for acidity typical of larval hyperacidity with rapidly emptying stomachs. One subject, No. 10, was representative of a persistent achlorhydria with a slowly emptying stomach.

The types of curves for gastric acidity referred to above have been described by Hawk and Bergeim (1). Times required for complete evacuation of test meals from the stomachs of the subjects were determined by the fractional method of gastric analysis as described by Hawk and Bergeim (2). The subjects reported at the laboratory in the morning of the day of the experiment after a fast for 12 to 15 hours. The Rehfuss gastric tube was introduced into the stomach of the subject sitting erect, and the gastric residuum was completely aspirated. The test meal was then fed and thoroughly masticated with the gastric tube in place. The samples of gastric contents not exceeding 15 cc. in volume were withdrawn by means of the gentle suction produced by a syringe at intervals of 15 minutes until the meal had been evacuated completely from the stomach, as determined by the procedure described by Hawk and Bergeim (3).

Experimental Results and Discussion

In any series of experiments undertaken to compare gastric evacuation times for two or more test meals,

TABLE I

Comparative Gastric Evacuation Time for Meals of Pie Crust or Cake in Repeated Experiments on Each of Four Subjects

Subjects	Test Meal	First Experiment	Second Experiment	Third Experiment	Averages	Average Deviations	Averages for Both Test Meals	Average Deviations
		Gastric Evacuation Times in Minutes						
1	Pie Crust	165	135	150	150	±10	148	±13
2	50 gm.	90	105	105	100	± 7	105	± 5
3	containing 16.3	165	135	135	145	±13	145	±10
4	gm. of fat	150	135	150	145	± 7	133	±13
	For All Experiments				135	±18	133	±17
1	Cake	165	135	135	145	±13		
2	50 gm.	105	120	105	110	± 7		
3	containing 7.9	150	135	150	145	± 7		
4	gm. of fat	120	120	120	120	± 0		
	For All Experiments				130	±15		

TABLE II

Comparative Gastric Evacuation Times for Meals Containing Varying Amounts of Fat and Protein
Averages for 4 Subjects

Test Meal	Portion Fed	Number of Experiments	Calories Per Portion	Fat	Protein	Gastric Evacuation Times In Minutes	
						Averages	Average Deviations
	gm.			*gm. per portion*	*gm. per portion*		
Bread	50	4	128	0.7	4.6	154	±13
Milk	175	4	120	7.0	5.8	139	± 6
Cake	50	12	214	7.9	2.4	130	±15
Lean Beef	62	4	130	8.2	13.2	180	±15
Egg	88	4	129	9.2	11.8	161	±34
Bread and Hydrogenated Vegetable Fat	35 15	12	225	15.5	3.2	149	±22
Pie Crust	50	12	291	16.2	6.7	135	±18

one or two days intervened between two consecutive tests. A prerequisite for the evaluation of differences in gastric evacuation times for two or more test meals is a knowledge of the day to day variation in the gastric motor responses to the same test meal.

Ryle (4) states that the fractional method of gastric analysis is a valuable test of motility of the stomach and that the rate of emptying is the most constant and accurate of all the findings of gastric function obtained with this method.

Van Liere and Sleeth (5) utilized a radiographic method for determination of the emptying time of the stomach. From 77 tests on nine subjects they concluded that the emptying time of the stomach of any individual remained strikingly uniform from day to day, but great variations existed among different individuals.

Table I presents data for gastric evacuation times found in three consecutive tests on each of four subjects in response to test meals of pie crust or pound cake which were consumed with 150 cc. of water. The maximum deviation between any two consecutive tests was 30 minutes. Average deviations observed in three tests on any one subject varied from ±0 to ±13 minutes.

The average evacuation times for 12 experiments with each test meal agreed within five minutes. In view of this close agreement between the average results for the two meals the results for tests with both meals have been averaged for each subject. The average deviations for each subject in the tests with both meals vary from ±5 to ±13 minutes. For 24 experiments with both test meals the average gastric evacuation time was 133 ±17 minutes.

Since the average deviation in repeated experiments with one test meal may be as great as ±18 minutes, differences in evacuation times between two test meals should be greater than at least ±18 minutes in order to be significant.

During the past 10 years in this laboratory extensive experimental studies have been made of gastric secretory and motor responses to many common foods and combinations of these foods. Results of some of these studies have been reported in Table II which presents data for caloric values and the fat and protein contents of the test meals as well as the gastric evacuation times.

Subjects No. 1 to No. 4 inclusive participated in these experiments. Three experiments with cake, bread and hydrogenated vegetable fat, and pie crust were carried out on each of the four subjects but only one experiment with the other test meals listed in the table. In all cases the meals were fed with 150 cc. of water.

There is evident no relationship between the quantity of fat in the portion of the test meal fed and the gastric evacuation time. Periods required for the evacuation from the stomach of the meals containing the largest quantities of fat, viz., bread and hydrogenated vegetable fat, and pie crust, are not greater than the gastric evacuation times of meals of low fat content, viz., bread and milk. It is of interest to note that the meals of pound cake and of lean beef contain approximately similar quantities of fat, but the evacuation time of the latter meal is significantly greater than that of the former. These findings suggest a closer relationship between the protein content of the meal and the time required for evacuation of the meal from the stomach than between the fat content and the emptying time of the stomach. This topic will be discussed more fully in a later communication.

Wishnofsky, Kane, and Spitz (6) compared changes in blood sugar and urine sugar after the administration to 11 diabetics of either 60 gm. of glucose or 60 gm. of glucose plus 120 gm. of olive oil. They observed that the concentration of blood sugar was significantly greater 90 minutes after the ingestion of glucose alone than after the ingestion of glucose and fat. This difference between the levels of blood sugar after the two test meals the authors attribute to a slowing of the emptying of the stomach produced by the fat fed with the glucose. Although they made no

TABLE III

Comparative Gastric Evacuation Times for Test Meals of Glucose Alone or of Glucose with Supplements of Fat

Test Meal	Quantities of Ingredients	Gastric Evacuation Times in Minutes					
		Subject 1	Subject 5	Subject 6	Subject 7	Averages	Average Deviations
Glucose	*gm. in 150 cc.* 50	105	165	105	105	120	±23
Glucose and Heavy Craem	50 85	195	165	210	150	180	±23
Glucose and Hydrogenated Vegetable Fat	50 34	180	165	180	195	180	± 8

determinations of the gastric emptying times, a series of experiments was undertaken to check this hypothesis of Wishnofsky, Kane, and Spitz, and the results obtained are presented in Table III. Four subjects participated in these experiments.

Two types of test meals were utilized: (a) glucose alone or (b) glucose and digestible fats. The digestible fats were supplied as heavy cream and hydrogenated vegetable fat. The quantities of fat incorporated in the test meals were equivalent to about two-thirds of the glucose. The volumes of the three test meals were made up to 150 cc. with water.

After ingestion of the meals of glucose supplemented with either heavy cream or hydrogenated vegetable fat, the emptying times of the stomachs of three of the four subjects were significantly longer than the periods for evacuation of the glucose meal. The remaining subject who showed an unusually long gastric evacuation time for the glucose meal exhibited no increases above this level after either of the two meals containing glucose and fat. For both meals of glucose and fat the average gastric evacuation time was 180 minutes. These results indicate that the two forms of fat, as administered in these experiments, retarded the evacuation of the meals from the stomach.

Three series of experiments were undertaken in order to determine the comparative effects of a hydrogenated vegetable fat and of butter upon the rate of evacuation of the stomach.

In the first series (Table IV) gastric evacuation times for meals of French fried and Lyonnaise potatoes were compared with those for boiled potato. Both the French fried and Lyonnaise potatoes were prepared with hydrogenated vegetable fat and with butter according to the best culinary practice. The boiled potatoes were cooked for 30 minutes and then mashed after the removal of their jackets. French fried potatoes were prepared by slicing raw potatoes which were then deep fried either at 385°F. in hydrogenated vegetable fat or in butter at 300-320°F. After frying, the potatoes were drained for one minute on a rack and then for one minute on absorbent paper and finally mashed before feeding. In the preparation of the Lyonnaise potatoes the jackets were removed after boiling for 30 minutes and the potatoes were stored overnight in a refrigerator. On the next morning the potatoes were cut in thin slices and shallow fried in hydrogenated vegetable fat or butter. After draining for one minute on absorbent paper, they were mashed before feeding.

TABLE IV

Comparative Gastric Evacuation Times for Meals Either of 100 Gm. of Properly Cooked Boiled Potato or of 100 Gm. of Potatoes Cooked in Fat According to the Best Culinary Procedure

Subjects	Boiled Potato	Gastric Evacuation Times for Test Meals in Minutes			
		French Fried		Lyonnaise	
		With Hydrogenated Vegetable Fat	With Butter	With Hydrogenated Vegetable Fat	With Butter
1	135	135	150	135	195
4	180	150	150	195	180
5	120	135	120	150	180
6	90	120	135	150	150
Averages	131	137		167	
Average Deviations	±26	±10		±21	
Fat content of test meals—gm. per portion	0.4	18.5	14.0	23.1	14.5

Gastric evacuation times for potatoes French fried either with hydrogenated vegetable fat or with butter differed only within limits of ±15 minutes. This was true also of the Lyonnaise potatoes except for experiments on subjects No. 1 and No. 5. For the eight comparative experiments for both forms of potatoes prepared with either hydrogenated vegetable fat or butter, the average deviation was ±19 minutes. From these results it was concluded that the type of the fat used in cooking potatoes did not influence the rate of evacuation of the meals from the stomach.

Average results indicated no significant difference between gastric evacuation times for meals of either boiled or French fried potatoes. The average emptying time of the stomach after meals of Lyonnaise potatoes, i.e., 167 minutes, was greater than either that for the boiled (131 minutes) or that for the French fried potatoes (137 minutes). However, it is questionable whether these two differences are significant.

In the next series of experiments an attempt was made to add to the potatoes more fat, either as hydrogenated vegetable fat or as butter, than it was possible to incorporate in them by the methods of preparation of either French fried or Lyonnaise potatoes which were utilized in the preceding series. This result was accomplished by pan-frying 100 gm. of slices of boiled potatoes in an excess of fat and pouring the excess fat over the mashed potatoes immediately before consumption. These fried potatoes were "greasy." Gastric evacuation times shown by four subjects for meals of the fried potatoes were compared with emptying times of the subjects' stomachs after ingestion of 140 gm. of the potatoes which had been boiled but not fried.

Results of this series of experiments are reported in Table V. Each of the meals of fried potatoes contained 34 gm. of fat. With the exception of the experiment on subject No. 7 with potatoes fried with hydrogenated vegetable fat, gastric evacuation times for all meals with the "greasy" fried potatoes were significantly greater than the periods for gastric emptying of boiled potaties. The average emptying times of the stomach for potatoes fried in hydrogenated vegetable fat and for potatoes fried in butter were 59 and 88% greater than the average gastric evacuation time for the boiled potatoes. With the exception of the experiments on subject No. 7 no significant difference was observed between hydrogenated vegetable

TABLE V

Comparative Gastric Evacuation Times for Meals Either of 140 Gm. of Boiled Potato or of 140 Gm. of Potatoes Fried and Consumed with Excess Fat

Subjects	Gastric Evacuation Times for Test Meals in Minutes		
	Boiled Potato	Potatoes Pan-Fried with Excess Fat	
		Hydrogenated Vegetable Fat	Butter
1	90	180	180
5	75	120	150
6	105	165	180
7	90	105	165
Averages	90	143	169
Average deviations	±8	±30	±11
Fat Content of test meals—gm. per portion	0.6	34	34

fat and butter, as used in this method of frying potatoes, in respect to their effects upon the emptying of the stomach.

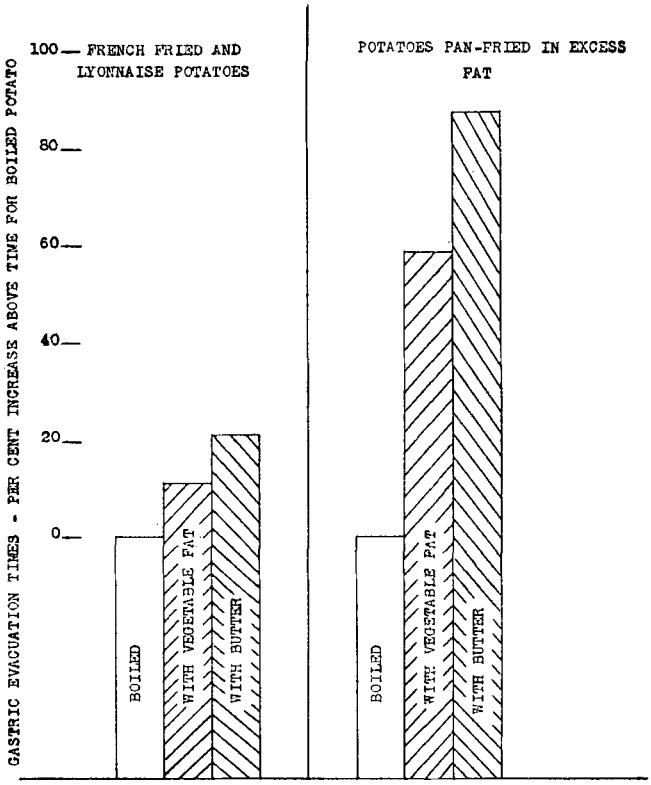

FIG. 1. Comparative gastric evacuation times for meals of boiled potatoes and of potatoes prepared with fats.

Figure I presents, in graphic form, the comparative gastric evacuation times of potatoes cooked with fats by the best culinary methods and of potatoes fried in and consumed with an excess of fat. Results are presented as percentage increases above the emptying times of the stomach in experiments with boiled potatoes included in the same series. On the left-hand side of the chart columns marked "with hydrogenated vegetable fat" and "with butter" represent averages for both French fried and Lyonnaise potatoes prepared with these fats.

For potatoes cooked properly with either hydrogenated vegetable fat or butter, the average gastric evacuations are 11 and 21%, respectively, above the average for boiled potatoes. This increase for potatoes prepared with hydrogenated vegetable fat amounts to only 14 minutes and is not significant. Since the greater increase for potatoes prepared with butter, amounting to 27 minutes, is attributable to unusually high values in two of the experiments, it possesses only doubtful significance.

On the other hand, the average gastric evacuation times for potatoes fried in and consumed with excess fat are significantly greater than the average gastric emptying times for boiled potatoes in the same series of experiments. The increases are 59% for potatoes pan-fried in hydrogenated vegetable fat and 88% for potatoes cooked in a similar manner with butter.

Table VI presents results of two series of experiments undertaken to determine the comparative rates of evacuation from the stomach of meals of doughnuts and of meals of bread and butter. Doughnuts were selected as test meals because they are representative of foods of a high content of fat, incorporated by deep-frying, and frequently are considered difficult to digest whereas bread and butter are regarded generally as easily digestible.

TABLE VI

Comparative Gastric Evacuation Times for Meals of Either Bread and Butter or Doughnuts Fed in Portions of 100 Gm.

Series	Fat Content of Test Meals	Subjects	Gastric Evacuation Times in Minutes	
			Bread and Butter	Doughnuts
	gm. per portion			
I	29.9	1	225	165
		4	210	180
		5	195	165
		6	180	180
II	37.8	8	180	240
		9	180	180
			195	
			210	165
			210	165
		10	180	180
			165	210
Averages			194	183
Average deviations			±15	±17

Both meals supplied equivalent amounts of fat. In the first series the amount of fat contained in a 100 gm. portion of either meal was 29.9 gm., but in the second series this was increased to 37.8 gm. The doughnuts were prepared in the laboratory kitchen. In the first series of experiments, 35 gm. of butter were spread over 65 gm. of white bread. For the second series the butter was increased to 44.3 gm. and the bread decreased to 55.7 gm.

Four subjects participated in the first and three subjects in the second series of experiments. Three of the four subjects employed in the first series showed gastric evacuations for the meal of bread and butter which were from 30 to 60 minutes greater than their gastric emptying times after meals of doughnuts. Both meals were evacuated from the stomach of the fourth subject 180 minutes after ingestion.

Of the six comparative tests with the two meals containing greater amounts of fat two gave longer gastric evacuation times for the meal of bread and butter than for the meal of doughnuts, but two showed greater gastric emptying times after meals of doughnuts than following meals of bread and butter. These differences varied from 45 to 60 minutes. For the 11 comparative experiments the average gastric evacuation time for bread and butter was 194 minutes and 183 minutes for doughnuts. Between these two averages there appears no significant difference. Results of these two series indicate that, under the conditions of the experiments reported, meals of doughnuts leave the stomach as rapidly as do meals of bread and butter supplying equivalent amounts of fat.

Fats may influence gastric function both through direct contact with the stomach and by a humoral mechanism, initiated by the entrance of fats into the small intestines. Farrell (7) has shown that olive oil, applied to the stomach for a period of 30 minutes, caused an inhibition of gastric secretion for 60 minutes. The experimental method used by Farrell did not permit observations of gastric emptying time. Kosaka and Lim (8) and Greengard, Gray, and Ivy (9) have reported experimental evidence from which these authors conclude that the presence of fat in the small intestines activates a hormone, enterogastrone, which, carried by the blood to the stomach, depresses

gastric motility and retards the evacuation of the food remaining in the stomach.

The experimental findings cited above suggest an explanation for the prolongation of gastric emptying time effected by addition of large quantities of digestible fats to glucose solutions and by the excess fats in "greasy" fried potatoes. Fats are easily separable from both of these meals on contact with gastric juice. Thus, large amounts of free fats may contact the gastric mucosa, or they may be delivered into the small intestines in quantities adequate to inhibit gastric secretory or motor functions.

On the other hand, fat taken in moderate amounts, particularly if it has been incorporated intimately into the food by the proper methods of cooking, may during gastric digestion be separated slowly from the food. Hence, amounts of free fat in the gastric contents or the quantities delivered into the small intestines during the early stages of digestion of these foods may be inadequate to influence gastric function either by direct contact with the stomach or by activation of enterogastrone.

Summary

1. In eight series of triplicate tests on persons in good health and with normal secretory responses who were fed test meals of foods cooked with fat, the day to day variations in gastric evacuation times ranged from 0 to 30 minutes with an average deviation from the mean of ± 17 minutes.

2. Experiments with meals of foods in which moderate quantities of fats were incorporated intimately by either baking or frying according to good culinary procedure revealed no relationship between the fat contents of the foods and the times required for complete evacuation of the foods from the subjects' stomachs.

3. The experiments indicated a parallelism between the protein contents of the test meals and the gastric evacuation times.

4. No significant differences were observed between the influences of a hydrogenated vegetable fat and of butter upon the rates of evacuation from the subjects' stomachs of meals of potatoes in which these fats had been incorporated intimately by good culinary technic. Within the limits of error of the experimental procedure, French fried and Lyonnaise potatoes containing moderate amounts of fat were evacuated from the stomachs as rapidly as boiled potatoes.

5. Gastric emptying times for meals of doughnuts did not differ significantly from gastric evacuation times for meals of bread and butter supplying equivalent amounts of fat.

6. The addition to a test meal of glucose in water of either hydrogenated vegetable fat or butter fat in amounts equivalent to two-thirds the weight of the glucose retarded the evacuation of the glucose meal from the stomach.

7. Excess fat, added to potatoes by pan-frying in hydrogenated vegetable fat or butter to the extent of making the potatoes "greasy," such as may occur in poor culinary practice, prolonged the emptying time of the stomach beyond the period for boiled potatoes.

8. An explanation has been suggested for this retardation of the emptying of the stomach effected both by digestible fats added to glucose solutions and by foods containing fats in excess of that which is incorporated intimately in these foods by good culinary methods.

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Stability Test End-Points by Refractive Index

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RECENT runs on the Swift Stability Tester (1) in this laboratory have indicated that highly satisfactory end-points can be established by butyro or refractive index measurements. Thus far the work has been limited to soybean oil (hydrogenated and unhydrogenated), but the method is believed to be generally applicable to the Swift Test.

Advantages

In a modification of King, Roschen, and Irwin's (1) original method Riemenschneider et al. (2) reduced the number of tubes for each stability test from 3 to 1 by using only 0.2 gms. of oil for each peroxide value (P.V.) determination. This increased the capacity of the standard Swift box from six to 18 determinations. This advantage is retained in the proposed method with the further advantage that sampling can be done in approximately 60 seconds. Rapid sampling results in a minimum of interference with equilibrium conditions in the individual sample and in the box as a whole.

Without sacrificing accuracy, the method proposed here substitutes the relatively simple reading of refractive indices on a Zeiss refractometer for P.V. determinations, thus eliminating the preparation of solutions, weighing, and titrating.

It is evident that a great many tests can be made on one sample without materially reducing its size, enabling more completely defined plots to be drawn.

Procedure

The refractive index of the original oils and any other desired characteristics are measured and recorded immediately before the start of the test. Duplicate samples (when possible) of the oils to be tested are measured into the aeration test tubes (20 cc.) and