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The Effect of Food Consistency on Iron Absorption

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Iron absorption and the half-time of gastric emptying were measured concurrently in 13 normal volunteer subjects. Each subject ate two test meals of identical composition; one meal was prepared and served in the usual manner while the second was homogenized before serving. No correlation was found between the half-time of gastric emptying and the absorption of either heme or nonheme iron among subjects eating the conventional meal. Homogenization of the meal led to a 31% fall in the mean half-time of gastric emptying and an increase in iron absorption of 22% for nonheme and 42% for heme. These findings indicate that the physical form of a meal has a modest effect on iron absorption.

INTRODUCTION

One of the most puzzling aspects of the measurement of iron absorption is the range of values that may be obtained even in apparently healthy volunteers (1). While differences in iron stores may be a major factor contributing to this phenomenon (2, 3), percentage absorption of iron from the same meal eaten by the same individual on 2 successive days may differ by as much as 100%. The exact cause of day-to-day variation has not been identified although it has been suggested that it may be related to physiological differences in gastric secretion, gastrointestinal motility, or possibly biliary or pancreatic secretions. Recent studies using pentagastrin and cimetidine, an H2 receptor blocker of hydrochloric acid secretion in the stomach, suggests that physiological variation in gastric acid secretions is unlikely to have a major effect on iron absorption from a mixed meal containing meat (4, 5). However, since solubilization is a time-dependent process, one might expect the physical form of the food and the time it is retained in the stomach to influence absorption. We therefore examined the relationship between gastric emptying time and iron absorption and the effect on these of altering the physical nature of the meal.

METHODS

Food iron absorption was measured in 13 normal volunteer subjects, eight male and five female, whose ages ranged from 22–44 years. All were in good health and denied a history of gastrointestinal or hematological disorders. Measurements of hematocrit and serum ferritin (6) performed at the outset of the study indicated that none of them were anemic although several had borderline iron reserves. Each subject gave written informed consent before the study and all procedures were carried out with the approval of the Human Subjects Committee at the University of Kansas Medical Center.

Two iron absorption tests were performed in each subject, the second after a 2-wk interval to allow complete red cell incorporation of radioiron absorbed from the first test. The test meals were fed between 7:00 and 11:00 AM after an overnight fast and no further food or liquid was allowed for 4 h. The composition of all meals was identical and consisted of ground beef (113 g), a bun (53 g), french fries (68 g), and a milkshake (145 g). This meal furnished a total of 820 kcal and contained 4.8 mg iron of which 1.4 mg was heme iron. For one of the absorption tests this meal was prepared and served in the conventional manner. In the other test the hamburger and french fries were thoroughly homogenized with 100 ml water in a blender; the meal was then eaten with the milkshake. Half the subjects ate the conventional meal first.

The heme and nonheme iron pools of both the standard and ground test meals were tagged extrinsically (1, 7, 8) as follows. Immediately prior to serving the meal, the heme iron fraction was labeled by adding 0.18 mg ^{55}Fe heme (5 μCi) isolated from a pathogen-free rabbit (9) to the hamburger while the nonheme fraction was labeled by adding 0.1 mg iron as $^{59}FeCl_3$ (2 μCi) to the milkshake. The validity of extrinsic radioiron tagging for determining composite absorption from a complete meal has been established (8, 10). Retention of absorbed radioiron was based on measurements of incorporated red cell radioactivity 14 days later (11–13).

Statistical analysis of absorption data was performed after log transformation because of the skewed distribution of the measurements (14). Paired t tests were used to determine whether mean log absorption values differed significantly from 0, which is equivalent to testing whether the mean ratio in percentage absorption differs from 1. Multiple linear regression analysis was

performed after log transformation of both ferritin and absorption, to evaluate the relationship of these variables to iron absorption (15).

The gastric emptying rate of the radioiron-labeled test meals was measured by adding 100 μCi Indium-113m chloride to the milkshake just before ingestion. While the meal was being eaten measurement of ^{113}mIn activity was initiated using a γ camera positioned over the stomach with the patient in a semirecumbent position (16). Indium-113m activity was followed for 2 h and plotted semilogarithmically after correction for radioactive decay. Gastric emptying was expressed as the time in minutes required for disappearance of one-half of the radioactivity.

Since separate components of a complete meal may leave the stomach at varying rates, *in vitro* studies were performed to examine the distribution of radioiron and ^{113m}In in the meal at different pH's. Indium-113m, $^{59}FeCl_3$, and ^{55}Fe heme were added to separate 100 ml samples of the homogenized meal and incubated for 20 min at 37°C in a rotating water bath. Five milliliters of each homogenate was then placed in individual flasks and the pH adjusted with either 0.1 N HCl or 0.1 N NaOH to obtain a pH range of 1–8. The samples were incubated a further 20 min at 37°C and the pH adjusted if necessary. Specimens were then centrifuged at 2200 rpm for 20 min to determine the distribution of ^{113m}In and radioiron between the supernatant and precipitate fractions (solid phase). Indium-113m was measured in a γ counter while the samples for iron determination were digested according to the method of Eakins and Brown (17) and counted by liquid scintillation.

RESULTS

In vitro studies

The distribution of ^{113m}In and both radioiron tags in the soluble phase was similar except at the extremes of pH (Fig. 1). At a pH above 5 more of the heme and nonheme iron fractions tended to remain in the soluble phase as compared with ^{113m}In. In contrast, at pH 1, more than 50% of ^{113m}In remained in the liquid phase of the meal in comparison with 44% of the nonheme iron and 30% of the heme iron. In the intermediate pH range 2–5, a range that would be expected for gastric pH after the ingestion of this type of meal (18), the distribution of the three isotopic labels was very similar. This preliminary study indicated that emptying times as determined with the ^{113m}In would provide a reliable guide to the rate at which iron-containing foods left the stomach.

Iron absorption

The results of the simultaneous measurements of gastric emptying and iron absorption are shown in Table 1. Five subjects were given 6 μg/kg pentagastrin

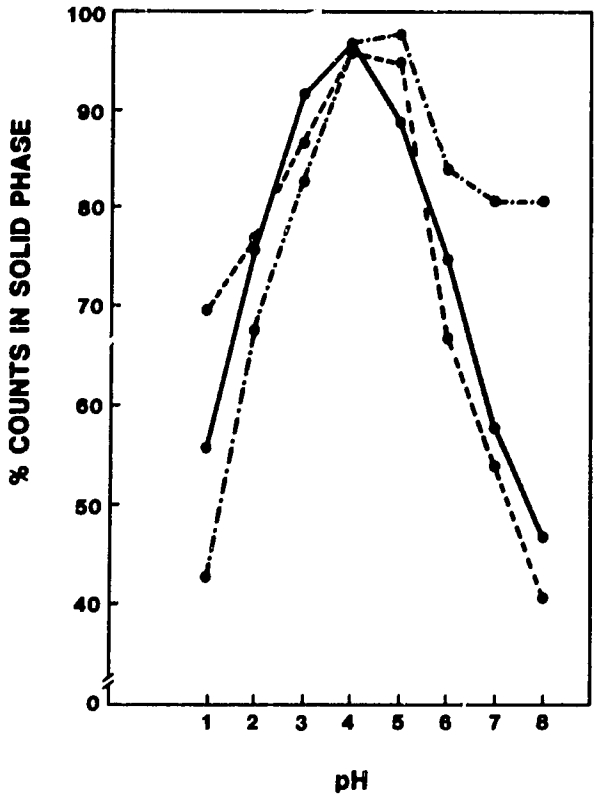

FIG. 1. The segregation of ^{113m}In (·—·—), ^{59}Fe (·——·), and ^{55}Fe-heme (—) in the solid phase of the meal at different pH levels.

(Peptavlon, Ayerst, NY) 20 min before each test meal to achieve maximal acid secretion and thereby eliminate differences in gastric acid output as a factor altering absorption. However, since the observations were made we have demonstrated that pentagastrin does not alter iron absorption from this type of meal (4). Statistical analysis of the present data showed no effect of pentagastrin on iron absorption or gastric emptying time and analysis was therefore performed on the combined group of 13 subjects.

When the test meal was prepared and consumed in the conventional manner, the percentage absorption of nonheme iron showed a typically wide range of 0.6–25.5% with a geometric mean of 3.3% (Table 1). Characteristically, the highest absorption values were observed in those individuals with the lowest serum ferritin levels. The absorption of heme iron was much higher, averaging 21.2% with a range from 9.4–40.9%. This 7-fold difference in the percentage absorption of heme and nonheme iron is in keeping with prior studies (7). The half time of gastric emptying with the standard meal varied markedly, from 76–423 min, with a mean of 189 min. No significant correlation was observed between gastric emptying time and absorption of either nonheme ($r = 0.263$, $p > 0.5$) or heme ($r = 0.086$, $p > 0.5$) iron.

The geometric mean half time of gastric emptying was reduced from 189 to 130 min with the homogenized meal; 11 of the 13 subjects had a faster gastric

TABLE 1
Iron Absorption and Gastric Emptying Time from Conventional and Homogenized Meals

Sex/Age	Hematocrit	Ferritin	Iron Absorption				Gastric Emptying	
			Standard meal		Ground meal			
			Nonheme	Heme	Nonheme	Heme	Standard	Ground
	%	μg/l	% of dose				t½ min	
F/24	42	21	6.29	20.01	14.28	51.03	335	144
M/30	39	42	1.83	18.08	3.53	20.34	200	128
M/38	42	14	13.85	40.93	17.56	30.68	135	59
M/24	46	373	3.98	20.35	3.53	33.33	175	113
M/26	48	83	1.91	28.59	3.11	49.89	111	96
F/26	43	6	25.45	28.76	20.02	34.16	76	98
M/28	47	52	1.72	38.05	1.52	29.14	123	70
F/28	43	68	7.24	15.21	6.30	17.34	287	94
*M/26	44	67	2.26	9.39	3.25	25.73	145	82
*M/24	46	45	3.25	10.55	5.13	24.60	174	130
*M/22	42	64	0.60	10.00	1.04	14.28	139	106
*F/22	40	66	1.70	33.23	1.29	39.06	423	468
*F/44	44	40	2.13	36.06	2.26	53.01	134	107
Mean 28	43	46†	3.32†	21.15†	4.09†	30.15†	189	130
−1SE		34.91	2.52	18.29	3.12	26.83		
+1SE		60.24	4.39	24.46	5.35	33.79		

* Pentagastrin.
† Geometric means.

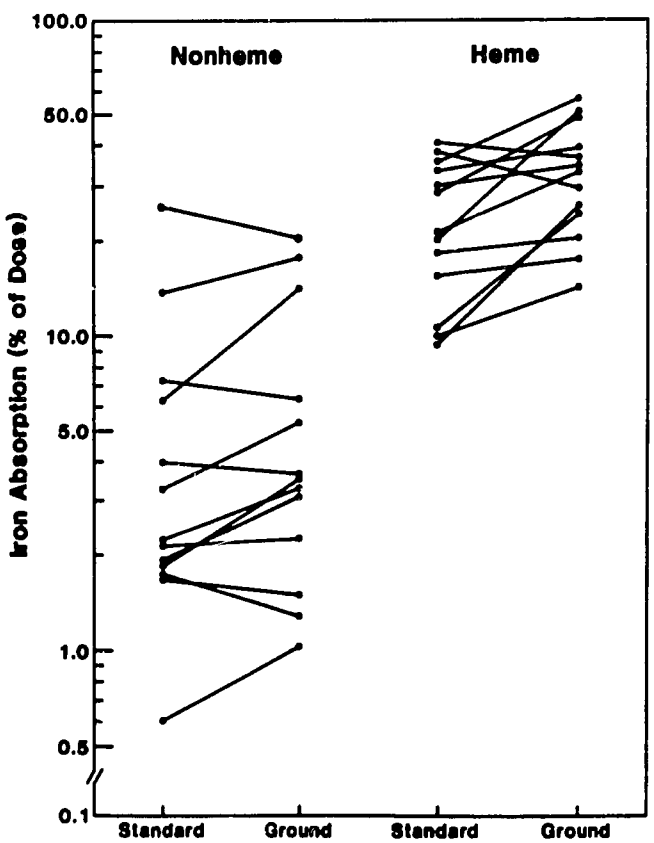

FIG. 2. Absorption of nonheme and heme iron from the conventional and ground meals.

emptying time with the ground meal (Table 1). This 31% decrease was statistically significant ($t = 3.906$, $p < 0.01$). Once again there was no correlation between the half-time of gastric emptying and iron absorption, although both forms of iron were better absorbed from the homogenized meal (Fig. 2). Nonheme iron assimilation rose from 3.32–4.09% ($t = 2.033$, $p < 0.05$) and that of heme iron from 21.15–30.15% ($t = 3.096$, $p < 0.005$).

DISCUSSION

The well-known variability of measurement of iron absorption using single meals in apparently normal human beings was demonstrated again in this study with percentage values for heme and nonheme iron ranging from 9–53% and less than 1–25%, respectively. Diminished gastrointestinal motility has previously been shown to increase iron absorption in experimental animals (19). However, in this group of randomly selected subjects no correlation could be demonstrated between the half-time of gastric emptying and the absorption of either heme or nonheme iron with the standard and homogenized meals. While an effect of gastric emptying could not be excluded, the current observations indicate that if present it is small when compared with other factors modifying absorption.

One of the most powerful determinants of iron absorption is the iron status of the individual. Serum ferritin concentrations predict the size of iron stores in health and uncomplicated iron deficiency or iron overload accurately (20, 21). The subjects we studied demonstrated considerable variation in serum ferritin values, two falling in the range considered to be indicative of reduced storage iron and one having a value indicat-

ing absent iron stores. A highly significant correlation between serum ferritin concentration and iron absorption ($p < 0.005$) was present for both heme and nonheme iron in the standard as well as the homogenized meal. Multiple linear regression analysis was performed on the results obtained with each of the meals since it seemed possible that a small effect resulting from changes in the rate of gastric emptying could have been obscured by the powerful influence of iron stores. It was not possible to demonstrate any significant effect of the rate of gastric emptying on the absorption of either form of iron.

Absorption from the second test meal was studied in each volunteer in an attempt to manipulate the rate of gastric emptying and eliminate variation in absorption due to subject-to-subject differences in the body's avidity for iron. This meal contained components identical to those used in the first but was administered after the solid component had been homogenized in water so that it could be eaten as a gruel. A change in emptying rate was anticipated because only relatively small particulate matter is able to pass through the pylorus (22). The 30% decrease in gastric emptying time induced by using the ground meal was paralled by a 42% increase in heme and a 23% increase in nonheme iron absorption. Although this result indicates that the physical form of the meal affects both gastric emptying and the assimilation of food iron, it was not possible to determine whether the alteration in absorption was due to changes in gastric emptying time or whether the effects on iron absorption and gastric emptying were independent consequences of a change in the physical form of the meal.

Considered together these studies demonstrate that the physical form of a meal may have a modest effect on the efficiency of iron absorption. Unfortunately, we were not able to determine whether this was a consequence of changes in the rapidity with which food passes into the duodenum. Nevertheless, it is apparent that changes in gastric emptying do not play a major role in producing the day-to-day variability in iron absorption.

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