Absorption of iron from Western-type lunch and dinner meals[1, 2]

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ABSTRACT The absorption of nonheme iron was measured from 20 lunch and dinner meals, in 187 subjects with varying iron status. The meals comprised both vegetarian meals and meals containing meat and fish. The extrinsic tag method was used to label the nonheme iron. All absorption figures were related to the absorption of a 3-mg reference dose of inorganic iron and all absorption figures were normalized to a 40% absorption from the reference dose, corresponding to subjects who are borderline iron deficient. Despite only a 3-fold variation in content of nonheme iron in the meals there was a 7-fold difference in absorption of nonheme iron (0.13 to 0.98 mg) and a 20-fold variation in percentage absorption (2.2 to 45%). The highest absorption (0.98 mg) was seen from a vegetarian meal with a high content of ascorbic acid. The relative role of meat/fish and ascorbic acid in stimulating the absorption of nonheme iron was studied by adding or subtracting single food components. *Am J Clin Nutr* 1982; 35:502–509.

KEY WORDS Iron absorption, meals, man

Introduction

The extrinsic tag technic has made it possible to measure the absorption of iron from composite meals (1, 2). Recent studies on food iron absorption have shown that several dietary factors can markedly affect the iron absorption and especially the absorption of the nonheme iron. In a previous paper on the absorption of iron from different breakfast meals it was reported that the absorption could vary almost 6-fold as an effect of various factors enhancing or inhibiting the absorption of nonheme iron (3). The present paper reports studies on the nonheme iron absorption from Western-type lunch and dinner meals. Some studies are also included which were made to assess the relative role of different food items in explaining observed differences in absorption between different meals.

Materials and methods

Material

One hundred eighty-seven subjects, 69 women and 118 men, between 19 and 60 yr of age volunteered for the present studies. Forty-four of the men and 16 of the women were regular blood donors. Hematological and other data are given in **Table 1**.

Experimental design

Absorption of nonheme iron from 20 lunch and dinner meals was studied. Each subject was served two different meals, A and B. After fasting overnight the two meals were served on four consecutive mornings in the sequence ABBA or BAAB. "A" and "B" were labeled with two different radioiron isotopes, ^{55}Fe and ^{59}Fe. A blood sample was drawn 2 to 4 wk after the last test, to measure the relative iron absorption of the two tracers. At the same time a whole body counting was performed to measure the absolute retention of ^{59}Fe. A solution of ^{59}Fe labeled ferrous sulphate containing 3 mg of elemental iron and 30 mg of ascorbic acid (reference dose R) was then given after an overnight fast on 2 consecutive mornings. Two weeks later a new whole body counting was performed.

In series 11, 12, 14, and 17, iron absorption from a lunch or dinner meal ("A") labeled with one radioiron isotope, was compared with the absorption of a reference dose of ferrous ascorbic ("R"), labeled with the other isotope. The meals and reference dose were given on 4 consecutive mornings in the order ARRA or RAAR. Two weeks later blood was drawn to determine radioiron absorption.

In series 1 to 6, six common Swedish meals were served. They were selected from a food habit survey carried out in 1968 and repeated in 1980. The meals that were chosen are among the most popular lunch/dinner meals and reflect an average choice of lunch/dinner

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TABLE 1
The material (mean values ± SEM)

Series	No. and sex of subjects	Age	Ht	Wt	Hb	Hematocrit
		yr	*cm*	*kg*	*g/l*	*%*
1, 2	4 M	22 ± 1	186.5 ± 4.5	77.8 ± 3.2	152 ± 3	45.3 ± 0.8
	5 F	23 ± 2	168.4 ± 1.4	57.8 ± 1.7	139 ± 3	42.1 ± 1.0
3, 4	4 M	24 ± 1	183.8 ± 4.4	72.8 ± 3.5	152 ± 4	44.5 ± 1.2
	4 F	22 ± 1	167.0 ± 0.7	58.5 ± 2.6	131 ± 3	39.8 ± 0.9
5, 6	4 M	25 ± 2	174.5 ± 3.1	70.5 ± 1.7	155 ± 4	46.8 ± 1.9
	4 F	25 ± 1	165.3 ± 4.7	55.5 ± 1.2	137 ± 6	42.0 ± 2.2
7, 8	2 M	23	181	66	146	45
	8 F	32 ± 2	165.8 ± 1.3	59.5 ± 2.9	132 ± 2	40.5 ± 0.6
9, 10	3 M	28 ± 2	176.3 ± 3.3	65.3 ± 4.4	154 ± 6	44.3 ± 2.0
	7 F	22 ± 1	168.4 ± 1.7	62.1 ± 2.2	136 ± 3	41.3 ± 0.8
11	47 M	40 ± 2	177.9 ± 0.8	75.4 ± 1.7	148 ± 2	44.3 ± 0.4
	12 F	23 ± 1	165.3 ± 1.5	56.8 ± 1.0	133 ± 3	40.8 ± 1.1
12	9 M	24 ± 2	179.7 ± 1.6	71.2 ± 1.9	141 ± 3	44.4 ± 0.9
	2 F	23	166	53	134	42
13	7 M	24 ± 1	182.1 ± 1.8	71.1 ± 1.8	152 ± 3	44.6 ± 0.6
	3 F	23 ± 4	167.3 ± 4.7	59.7 ± 3.0	129 ± 4	39.0 ± 1.2
14	7 M	25 ± 1	181.4 ± 2.2	74.4 ± 1.5	145 ± 3	44.9 ± 1.1
	3 F	21 ± 1	168.3 ± 2.2	60.3 ± 1.9	126 ± 7	41.3 ± 1.5
15	5 M	24 ± 2	179.8 ± 3.1	70.0 ± 3.1	143 ± 4	44.0 ± 0.8
	5 F	24 ± 1	167.0 ± 2.1	56.0 ± 2.8	136 ± 4	41.2 ± 1.3
16	5 M	29 ± 2	182.4 ± 3.1	79.8 ± 5.5	143 ± 2	44.4 ± 0.8
	5 F	29 ± 3	167.2 ± 1.2	59.4 ± 2.2	130 ± 3	40.4 ± 0.7
17	8 M	27 ± 2	177.1 ± 2.4	68.4 ± 3.2	144 ± 3	45.0 ± 1.0
	4 F	25 ± 2	167.3 ± 1.6	55.5 ± 1.2	130 ± 3	42.0 ± 0.8
18, 19	7 M	23 ± 1	183.6 ± 2.4	77.0 ± 2.1	151 ± 2	47.1 ± 0.8
	3 F	23 ± 1	170.3 ± 4.8	61.0 ± 1.0	137 ± 1	42.0 ± 1.2
20	6 M	29 ± 3	181.8 ± 2.3	74.7 ± 3.0	156 ± 4	47.3 ± 1.1
	4 F	32 ± 3	169.5 ± 0.6	61.3 ± 2.4	131 ± 3	41.3 ± 0.5

meals over a weeks time. The two vegetarian meals (nos. 14 and 17) were examples from a recent paper in which a new model to calculate the bioavailability of iron in a meal was described, based on the amounts of heme and nonheme iron, the content of meat and/or ascorbic acid influencing the bioavailability of nonheme iron (4).

Preparation of meals

The *meatball meal* (no. 1) consisted of meatballs (100 g), mashed potatoes (200 g), and lingonberry jam (30 g). The meatballs served was a commercial product containing 60 g of minced meat. Each meal was labeled with 4 μCi ^{55}Fe. the radioiron solution was added dropwise to the mashed potatoes.

The *pea soup meal* (no. 2) was a commercial product containing 250 g of pea soup, made from dry yellow peas, and 10 g of lean boiled pork. The soup was served with 5 g of mustard. The radioiron solution, 2 μCi ^{59}Fe, was added to each portion of soup.

The *brown beans meal* (no. 3), was a commercial product made from dry brown beans, which were boiled in water, seasoned, and canned. The beans, 250 g, were served with lean fried pork weighing 100 g initially and 50 g after frying. Each meal was labeled with 2 μCi ^{59}Fe. The radioiron was added dropwise to the brown beans.

The *pancake meal* (no. 4) was made from eggs (30 g) mixed with milk (200 ml), wheat flour (60 g), and margarine to a smooth batter. Each portion was poured into an aluminum pan. The pancake was baked at 225°C for 20 min and served with lingonberry jam (30 g). The radioiron, 4 μCi ^{55}Fe, was added to the batter before baking.

The *roast beef meal* (no. 5) consisted of 65 g of beef, weight before cooking 125 g, green beans (70 g), and mashed potatoes (200 g). The radioiron, 4 μCi ^{55}Fe, was added dropwise to the mashed potatoes.

The *sandwich meal* (no. 6) consisted of three slices of bread, 90 g, made from 65 g of unfortified wheat flour and ryeflour. The bread had a total iron content of 3.9 mg of which 3.1 mg was added as ferrous sulphate as fortification iron. Each slice of bread was covered with margarine (5 g), and either cheese (20 g), sausage (15 g), or Swedish caviar (5 g). The radioiron, 2 μCi ^{59}Fe, was added dropwise to the three slices of bread, before spreading the margarine. All these six meals were served with 200 ml of milk (3% fat).

The *spaghetti meal* (no. 7) was prepared from unfortified spaghetti (75 g) made from durum wheat which was boiled for 8 min and served with ragu Bolognese. This was prepared from minced, smoked ham (25 g) which was fried in oil (3 g) together with finely chopped onion (40 g), carrot (35 g), celery root (15 g), and thin slices of garlic. Minced beef (60 g), tomato purée (5 g), and beef bouillon (75 ml) was then added. The ragu was allowed to simmer for 2 h. The radioiron 1.5 μCi was mixed into each portion of the meat sauce.

The *sauerkraut meal* (no. 8) was prepared from 150 g of salted, fermented white cabbage which was boiled with peeled and sliced potatoes (70 g), water, and Debrezin polish sausage (90 g) for 30 min. The radioiron, 1.5 μCi ^{55}Fe, was injected into the sausage with a Mantoux syringe.

The *Borscht-beetroot soup meal* (no. 9) was prepared from beetroots (60 g), celery root (celeriac) (20 g), leek (15 g), white cabbage (35 g), potatoes (15 g), and tomato (20 g). The vegetables were washed, peeled, scraped, and cut into thin slices. Meat bouillon (250 ml) was added together with lean beef (80 g). The soup was allowed to simmer until the meat was tender. The soup was flavored with vinegar (8 ml) and served with fermented cream (20 g). The radioiron, 1.5 μCi ^{55}Fe, was added to each portion of soup.

The *sole au gratin meal* (no. 10) was prepared from fresh fillets of sole (125 g) which were placed in an aluminum pan greased with butter. White wine (40 ml), onion (4 g), parsley (2 g), mustard (1 g), and tomato purée (7 g) were mixed together, heated until boiling, and then poured over the fillets. The dish was covered with an aluminum foil and than baked in the oven at 200°C for 15 min. The stock was poured into a pan and boiled for 5 min. The pasta made from white flour (2 g) and margarine (4 g) was added to the fish stock and allowed to boil for another 2 min. The sauce was poured over the fish, covered with cheese (3 g), and gratinated for 5 min. The fish was served together with boiled potatoes (150 g). The radioiron, 1.5 μCi ^{59}Fe, was added dropwise to each portion of fish.

The *hamburger meal* (no. 11) consisted of hamburgers (110 g), green beans (60 g), and mashed potatoes (150 g). The hamburger was a commercial product containing 82 g of minced beef. The green beans were boiled for a few minutes and were then finely cut. The radioiron, 1.5 μCi ^{59}Fe, was added dropwise to the three foods.

Meal no. 12 was the same meal as meal 11 but the hamburger contained only half the amount of meat.

The hamburger meal (no. 13) was identical to meal 11 but was served with a fresh vegetable salad consisting of lettuce (50 g), tomatoes (35 g), cucumber (35 g), and sweet green pepper (25 g). A dressing (0.5 ml of vinegar, 2 ml of oil, salt, pepper) was poured over the vegetables.

In the *vegetarian "low ascorbate" meal* (no. 14) dried navy beans (45 g) were soaked overnight in water and boiled for 1 h. Brown rice (45 g) was cooked with 125 ml of water. A bread was made from cornflour (25 g) and unfortified wheat flour (25 g) and spread with margarine (14 g). The meal also contained sliced apples (55 g), walnuts (8 g), almonds (8 g), and 225 g yoghurt (3% fat). Two-thirds of the radioiron was added to the water when boiling the rice and one-third was mixed into the dough of the bun. Each meal was labeled with 1.5 μCi ^{59}Fe.

In series no. 15 the same low ascorbic vegetarian meal was served with the addition of 90 g of ground beef. The meat was served grilled, seasoned with salt and pepper.

The low ascorbate vegetarian meal was also served in meal no. 16 but with the addition of 125 g of boiled cauliflower.

In the *"high ascorbate" vegetarian* (no. 17) dried red kidney beans (42 g) were soaked overnight in water and then boiled for 1 h. The boiled beans (90 g) were mixed with tomato sauce (30 g), made from punched canned tomatoes. A bread roll was made from unfortified wheat flour. Each roll had a total iron content of 0.9 mg, 0.6 mg of which was added as ferrous sulphate fortification iron. The bread was served with margarine (15 g). The cauliflower (125 g) was boiled for 10 min. Cottage cheese (55 g), canned pineapple (125 g), and a banana (37 g) were also included in the meal. Two-thirds of the radioiron was added to the tomato sauce before mixing it with the beans and one-third was mixed into the dough of the wheat bun. Each meal was labeled with 1.5 μCi ^{59}Fe.

In series 18 the "high ascorbate" vegetarian meal was given but the cauliflower was excluded.

In series 19, steamed fish, 110 g of deep-frozen fillets of cod, was added instead of cauliflower, to the vegetarian "high ascorbate" meal.

In series 20 the original vegetarian—"high ascorbate" meal, identical with no. 17, was served but 90 g of grilled beef (round), seasoned with salt and pepper was added.

All meals included 150 ml of water except for meal 1 to 6.

Chemical composition of meals

Aliquots of the different meals were freeze-dried and then finely ground to a powder in a porcelain mortar. Weighed amounts of this powder were analyzed for total iron (5), nonheme iron (5), phosphorus (6), phytic acid (6, 7), and ascorbic acid (8). Due to the difficulties in determining heme directly in mixtures containing other chromogens, heme iron in the meals was calculated as the difference between total iron and nonheme iron. The chemical composition of the meals is shown in **Table 2**.

Oral reference doses of iron

A solution of 10 ml 0.01 *M* hydrocholoric acid containing 3 mg of iron as ferrous sulphate and 30 mg of ascorbic acid was used as a reference in all studies. Each subject received a total of 1.5 μCi ^{59}Fe. The 10-ml vials containing the iron solution were washed twice with water and this was also consumed. Each subject received two reference doses on 2 consecutive mornings after an overnight fast. No food or drink was allowed after the reference dose for 3 h.

TABLE 2
Composition of meals

Meal	Energy	Iron (mg)			Protein (g)		Ascorbic acid	Phytic P
		Nonheme*	Heme	Total	From meat, fish	Total		
	kcal						*mg*	*mg*
1. Meatballs, potatoes, lingonberry, milk	600	2.6	0.5	3.1	12	26	0	0
2. Pea soup with pork, milk	425	3.5	0	3.5	2	24	0	107
3. Brown beans with pork, milk	750	5.4	0.3	5.7	7	32	0	58
4. Pancakes and strawberry jam, milk	630	5.1 (4.0)	0	5.1	0	22	0	0
5. Roast beef, green beans, potatoes, milk	480	3.1	1.0	4.1	23	38	3	0
6. Sandwiches (cheese, sausage, Swedish caviar)	620	4.6 (3.2)	0	4.6	0	22	0	6
7. Spagetti with meat sauce, water	600	2.7	0.6	3.3	15	25	0	6
8. Sauerkraut with sausage, water	470	2.0	0.6	2.6	13	21	18	0
9. Beetroop soup with meat, water	300	2.8	1.1	3.9	15	21	2	0
10. Sole au gratin, potatoes, water	330	2.1	0.1	2.2	22	26	6	0
11. Hamburger, mashed potatoes, string beans, water	450	3.0	0.5	3.5	14	19	2	0
12. Hamburger (½ portion meat), mashed potatoes, string beans, water	320	2.3	0.2	2.5	7	11	2	0
13. Hamburger meal with fresh salad	490	3.6	0.5	4.1	14	20	47	0
14. Vegetarian "low" (see text)	730	5.8	0	5.8	0	22	7	271
15. Vegetarian "low" with meat	850	6.8	1.2	8.0	20	42	7	271
16. Vegetarian "low" with cauliflower	760	6.5	0	6.5	0	25	67	271
17. Vegetarian "high" (see text)	620	5.8 (0.5)	0	5.8	0	22	74	82
18. Vegetarian "high" without cauliflower	590	5.1 (0.5)	0	5.1	0	19	14	82
19. Vegetarian "high" without cauliflower with fish	690	5.6 (0.5)	0.1	5.7	20	39	14	82
20. Vegetarian "high" with meat	740	6.8 (0.5)	1.2	8.0	20	42	74	82

Iron absorption measurements

The relative absorption of ^{55}Fe and ^{59}Fe was calculated from analyses of blood samples. The absolute absorption was measured using whole body counting of ^{59}Fe. The analyses of ^{55}Fe and ^{59}Fe in blood was made by means of modification of the method described by Eakins and Brown (9). All procedures and methods of calculation have been described previously (10).

Expression of iron absorption results

To correct for intersubject difference in iron absorption due to their different iron status, the absorption of iron from meals was compared with the subjects absorption of the ferrous ascorbate reference dose. Since there is a high linear correlation between the subjects absorption of iron from meals and the reference ferrous ascorbate all meal values were normalized to the amount corresponding to 40% of the reference dose. This is the level that reflects absorption when the subject is in a critical balance with total depletion of iron stores but no anemia (1). Since the regression line can be assumed to go through the origin the mean absorption of iron from meals was related to the mean absorption from the reference doses. The ratio of these two mean values was then multiplied by 40 to get the mean food iron absorption value corresponding to a 40% absorption from the reference doses (3, 11, 12). To facilitate a comparison of results obtained in the different series the mean values and their SEs of the individual absorption ratios meal/reference dose are included in **Table 3**.

Results

The results of the absorption measurements from 20 meals are given in Table 3 and in **Figures 1 and 2**. In Table 3 both relative percentage of ingested amount and absolute amounts of iron absorbed are given.

The absorption of nonheme iron varied from 0.13 mg in the vegetarian—"low ascorbate" meal (no. 14) to 0.98 in the vegetarian—"high ascorbate" meal (no. 17). The absorption of non-heme iron thus varied more than 7-fold.

The percentage absorption was highest in the meals with sauerkraut and sausage (45.8%) and with borscht soup with meat (30.3%).

Reducing the amount of meat in the hamburger by half (80 to 40 g: series 11 and 12,

TABLE 3
Absorption of nonheme iron from different meals, reference doses, and nonheme iron absorption corrected to 40% reference dose absorption

Series	Composition of meals	Nonheme iron content	Absorption					A corrected to 40% reference dose absorption
			Meal		Reference doses	A/R·100 ± SEM		
		mg	%	mg (A)	% (R)			mg
1.	Meatballs, potatoes, lingonberry jam, milk	2.6	5.4	0.19	19.5	0.77 ± 0.13		0.29
2.	Pea soup with pork, milk	3.5	4.8	0.17	19.5	0.87 ± 0.10		0.35
3.	Brown beans and pork, milk	5.4	4.0	0.22	20.4	1.06 ± 0.22		0.43
4.	Pancake and jam, milk	5.1*	1.7	0.09	20.4	0.43 ± 0.09		0.18
5.	Roast beef, potatoes, green beans, milk	3.1	11.6	0.36	24.8	143 ± 0.30		0.58
6.	Sandwiches, milk	4.6*	4.4	0.20	24.8	0.78 ± 0.23		0.32
7.	Spagetti with meatsauce, water	2.7	11.3	0.31	40.7	0.76 ± 0.15		0.31
8.	Sauerkraut with sausage, water	2.0	45.8	0.91	40.7	2.51 ± 0.37		0.90
9.	Beetroot soup with meat, water	2.8	30.3	0.85	41.6	2.01 ± 0.33		0.81
10.	Sole au gratin, potatoes, water	2.1	18.7	0.39	41.6	0.89 ± 0.20		0.38
11.	Hamburger, mashed potatoes, green beans	3.0	10.9	0.33	36.4	0.84 ± 0.05		0.36
12.	Hamburger (½ portion meat), mashed potatoes, green beans	2.3	9.9	0.23	46.9	0.47 ± 0.06		0.19
13.	Hamburger, fresh salad, mashed potatoes, green beans	3.6	12.7	0.46	27.6	1.65 ± 0.23		0.66
14.	Vegetarian "low"	5.8	2.5	0.14	43.2	0.34 ± 0.08		0.13
15.	Vegetarian "low" with meat	6.8	1.7	0.16	26.4	0.60 ± 0.08		0.25
16.	Vegetarian "low" with cauliflower	6.5	5.1	0.32	39.9	0.79 ± 0.32		0.32
17.	Vegetarian "high"	5.8 (0.5)	13.5	0.77	31.5	2.44 ± 0.25		0.98
18.	Vegetarian "high" with cauliflower	5.1 (0.5)	5.3	0.27	33.6	0.81 ± 0.17		0.32
19.	Vegetarian "high" without cali-flower, with fish	5.6 (0.5)	6.5	0.37	33.6	1.05 ± 0.23		0.44
20.	Vegetarian "high" with meat	6.8 (0.5)	15.4	1.05	29.6	3.50 ± 0.41		1.42

* The amount of fortification iron in the pancakes was 4.0 mg, in the sandwiches 3.2 mg, and the vegetarian "high" meals 0.5 mg.

respectively) reduced the non-heme iron content by 25%, (3.0 to 2.25 mg), however, the absorption of nonheme iron was reduced about 50% (0.36 to 0.19 mg).

A fresh vegetable salad containing 45 mg of ascorbic acid given to the hamburger meal increased the nonheme iron absorption from 0.36 to 0.66 mg.

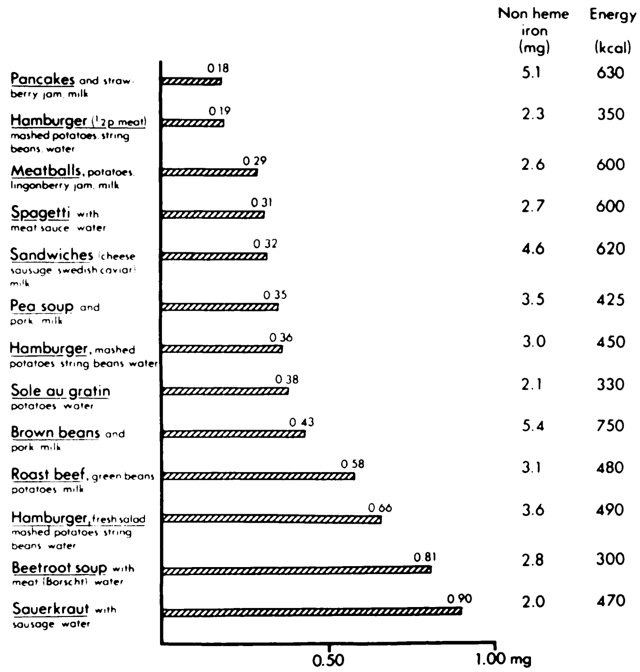

FIG. 1. Absorption of nonheme iron from 13 different meals.

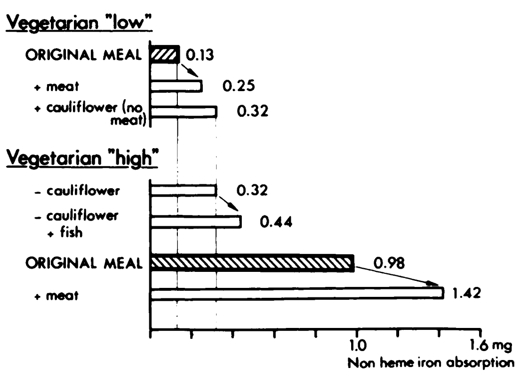

FIG. 2. Absorption of nonheme iron from two vegetarian meals (nos. 14 and 17) and the effect of subtracting or adding various food components (meal 15 to 16 and 18 to 20).

Discussion

There are two kinds of iron in the diet with respect to mechanism of absorption—heme iron derived from Hb and myoglobin and nonheme iron derived from cereals, fruits, vegetables, etc. The present studies on the absorption of iron from different meals are limited to the absorption of nonheme iron, which forms about 85 to 90% of the dietary iron intake in Western type diets. Another reason for this limitation is that heme iron absorption is relatively little affected by the meal composition whereas the absorption of nonheme iron is markedly influenced by several components in the diet (14).

An important finding in the present series of studies is the great variation in absorption of nonheme iron between different meals. As all absorption measurements are corrected for individual variations in ability to absorb iron, by using the absorption from reference doses of iron as a basis of comparison, it can be concluded that the observed variation must mainly be due to a variation in bioavailability of iron in the different meals.

This conclusion is further supported by the fact that the amount of iron absorbed varied seven times (range 0.13 to 0.98 mg) and the percentage absorption about 20 times (range 2.2 to 45%). The observed variation in absorption of nonheme iron in the meals of different composition is thus much greater than was predicted in a previous paper in which the variation was estimated to be two to four times at a given iron status (4).

Factors known to influence nonheme iron

absorption, such as the content of ascorbic acid or meat and fish, may explain some of the observed variation in absorption. Other explanations, however, are also needed. The two meat-containing meals showing the highest absorption figures—sauerkraut with sausage and borscht soup with meat—did not have a very high content of meat or ascorbic acid but had another common property, namely a high acidity with pH values of 3.6 and 5.2, respectively. It is probable that these meals had a good buffering capacity which may counteract and delay the formation of less soluble and less available iron compounds, such as ferric hydroxide, in the upper part of the intestinal tract. An alternative explanation might be that some of the organic acids present facilitated the absorption of iron. Studies on these possibilities are in progress.

Two vegetarian meals were evaluated in the present study. These meals had the same content of iron and protein and about the same energy content. They both contained beans, bread, fruits, and one milk product. In spite of the similarities in composition the iron absorption from the meals differed markedly—0.13 and 0.98 mg. This latter absorption was actually higher than the nonheme iron absorption from any of the meat-containing meals in the present study. The difference in bioavailability of iron between the two vegetarian meals was so great that it was considered important to try to clarify its cause by subtracting or adding various food components (Fig. 2). An important difference between these two vegetarian meals was their content of ascorbic acid (7 and 74 mg, respectively). This was mainly due to the cauliflower which is very rich in ascorbic acid and which was present in one of the meals. By adding cauliflower to the vegetarian meal with the low initial iron absorption the absorption increased 2½ times from 0.13 to 0.32 mg and when excluding cauliflower from the vegetarian meal with the high absorption a decrease was noted from 0.98 to 0.32 mg, i.e., to about one-third (Fig. 2). These results indicate that there must be some factor other than the difference in content of ascorbic acid explaining about half of the observed difference in absorption between these two meals. At present it is impossible to say how much of this remaining difference may be accounted for by differences in phytate content of the two meals. Other factors such as type and amount of fiber in the two meals may also contribute.

Earlier studies have shown the marked enhancing effect of ascorbic acid or orange juice taken with breakfast meal on nonheme iron absorption (3). Ascorbic acid present in solid foods such as vegetables might have a less marked effect on iron absorption, as this mainly occurs in the upper part of the gastrointestinal tract. The present results clearly indicate, however, that solid foods with a high content of ascorbic acid, such as cauliflower, affect the absorption of iron to about the same extent as when the ascorbic acid is added in a pure form to foods or as orange juice.

The relative role of meat/fish and ascorbic acid in stimulating the absorption of nonheme iron was also studied in the present paper. Meat had a marked effect on the absorption of nonheme iron when added both to the vegetarian meal with a low absorption and to the one with a high absorption. The effect of meat seemed to be quite independent of the content of ascorbate speaking in favour of independent mechanisms for action for meat and ascorbate in enhancing the nonheme iron absorption. In assessing the bioavailability of dietary iron great emphasis has earlier been put on the content of meat and fish in the diet. The present results clearly show that the iron absorption can be equally good from a vegetarian diet in which the content of ascorbic acid may be as important as meat. This was evident both from the very high absorption from the vegetarian meal with the high content of ascorbate and from the observation that the addition of cauliflower to the vegetarian meal showing the lowest absorption actually increased the absorption more than the addition of 90 g of meat. These observations on vegetarian meals suggest the possibility of finding effective and realistic ways of improving iron nutrition in developing countries where the supply of fish and meat is often scarce. It was previously shown that the absorption promoting effect of fish or meat was related to the amount of these foods given in a certain meal (13). This is a probable explanation for the higher percentage absorption observed from the steak meal and the fish meal than from the meals containing hamburgers, meatballs, or spaghetti with meat sauce. Reducing the amount of meat given in the hamburger meal by half, decreased absorption of nonheme iron by about 50%, even though the content of nonheme iron was reduced only 25%.

Meals containing neither ascorbic acid nor meat or fish, such as the pancake meal and one of the vegetarians meals showed the lowest absorption of iron.

The sandwich meal and the meal containing pancake had a rather high content of iron due to the fact that the flour was fortified. The level of fortification of the flour was the same as in Sweden (6.5 mg Fe/100 g of flour) although ferrous sulphate is substituted for carbonyl iron to ensure a complete isotopic exchange with the extrinsic tracer. Despite the high iron content, the absorption from these meals was rather low.

It is probable that there are several factors influencing the bioavailability of nonheme iron in the diet besides the factors discussed so far. Examples are the content of tannins, as in tea, different fibers in vegetables, cereals, and fruits, phytates and phosphates. The great variation in absorption observed herein clearly shows that further studies are needed on the role of the meal composition for the absorption of nonheme iron.

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