Bioavailability of Iron from Western-Type Whole Meals

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The absorption of non-heme iron was measured in 10 meals designed to correspond to a whole main meal with an energy content of about 1000 kcal. The extrinsic tag method was used to label the non-heme iron, and two meals were compared in each subject by means of two radioiron isotopes. 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, a level corresponding to absorption in subjects who are borderline iron-deficient. In spite of the similar energy content of the meals and only a twofold variation in content of non-heme iron (3.9–7.8 mg), there was a fivefold difference in absorption of non-heme iron (0.33–1.80 mg). Considering also the content of heme iron in the meals, the calculated variation in absorption was sixfold (0.33–1.95 mg). The main part of this variation can be explained by a varying content of ascorbic acid and meat. The absorption of iron from meals can be expressed in different ways. The percentage absorption is a measure of the bioavailability, which can be markedly modified by several components of a meal. The amount absorbed is, moreover, related to the amounts of heme and non-heme iron present. The amount absorbed per unit energy in the meal, the bioavailable nutrient density, is an expression of great importance in the practical assessment of the nutritive value of a meal with respect to iron.

Key-words: Absorption; bioavailability; food; iron; man; meals

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In earlier papers it was reported that there was a marked variation in absorption between different Western-type breakfast, lunch, and dinner meals (1, 2). The variation observed was greater than could be anticipated from the content of factors known to influence the absorption of food iron, such as meat, fish, ascorbic acid, phytates, and tea. Although it is possible to discern a certain pattern in the interplay between these different factors, further studies are doubtless necessary to explain fully the variation in iron bioavailability from different meals. In the earlier studies there was a marked variation in the content of both energy and iron in the meals. The present studies were thus designed to provide about the same energy content in all meals, roughly proportionate to a whole main meal. Meals were chosen from menus in different Western countries. The reason for this was not that these meals were considered to be representative of the average diet in these countries but mainly to get a fairly wide spectrum of meal types in the hope of obtaining further information about factors affecting the bioavailability of dietary iron. In most diets non-heme iron compounds account for about 90% or more of the iron intake, whereas heme iron derived from hemoglobin and myoglobin only forms a minor part of the dietary iron. Heme iron is only affected to a minor extent by the meal composition and by the iron status of the subjects (3). The variation in bioavailability of iron in different meals is thus primarily related to the variation in absorption of non-heme iron. The present studies were therefore limited to measurements of non-

Table I. The material (mean values ± standard error of means)

Series no.	No. and sex of subjects	Age, years	Height, cm	Weight, kg	Hemoglobin, g/l	Hematocrit, %
1, 2	8, M	34 ± 2	182.0 ± 1.7	77.5 ± 2.5	149 ± 2	44.8 ± 0.6
	2, F	29	170.0	60.5 ±	139	43.0 ±
3, 4	8, M	27 ± 2	181.4 ± 1.5	74.5 ± 2.0	149 ± 3	45.9 ± 1.0
	2, F	35	167.5	66.5	139	43.5
5, 10	4, M	23 ± 1	182.0 ± 4.4	71.5 ± 4.4	149 ± 3	46.3 ± 0.5
	6, F	35 ± 4	165.0 ± 2.1	58.0 ± 2.5	129 ± 2	41.2 ± 0.7
6, 7	6, M	30 ± 3	181.7 ± 1.5	79.7 ± 6.0	149 ± 3	45.3 ± 0.9
	4, F	29 ± 4	171.3 ± 2.8	65.3 ± 4.5	134 ± 2	42.0 ± 0.6
8, 9	6, M	27 ± 1	185.8 ± 2.9	83.0 ± 4.4	154 ± 3	46.8 ± 1.2
	3, F	22 ± 1	163.0 ± 1.0	54.3 ± 0.9	123 ± 1	39.0 ± 0.6

heme iron absorption. The absorption of heme iron was calculated from analyses of the heme iron content of the meals and a fixed absorption percentage of 25%, as based on findings in previous studies (3).

MATERIALS AND METHODS

Subjects

Forty-nine subjects, 17 women and 32 men, between 21 and 48 years of age, volunteered for the present studies. Twenty-six of the men and nine of the women were regular blood donors and had given blood within the last year. Hematological and other data are given in Table I.

Experimental design

Absorption of non-heme iron from ten composite Western-type meals was studied. Each subject was served two different meals, A and B. After the subjects had fasted overnight the two meals were served on four consecutive mornings in the sequence ABBA or BAAB. Meals A and B were labeled with two different radioiron isotopes, ^{55}Fe and ^{59}Fe, respectively. A blood sample was drawn 2 to 4 weeks after the last test, to measure the relative iron absorption of the two tracers. At the same visit whole-body counting was also performed to measure the absolute retention of ^{59}Fe. A solution of ^{59}Fe-labeled ferrous sulphate containing 3 mg of elemental iron and ascorbic acid (reference dose R) was then given after an overnight fast on two consecutive mornings. Two weeks later a second whole-body counting was performed.

Preparation of meals

The meals were prepared and served as follows:

In *the pizza meal (no. 1)* the pizza was made from 84 g of unfortified wheat flour, yeast (7 g), water (50 g), oil (8 g), and salt (1 g). The dough was rolled out in a round shape about 3 mm thick, covered with 40 g of tomato puree, decorated with halves of black olives (25 g), fillets of anchovies (30 g), and tomatoes in slices (125 g) and finally covered with grated cheese (100 g). The pizza was baked in an oven at 250°C for 20 min. Each meal was labeled with 2 μCi ^{55}Fe. This radioiron was added to the wheat flour when kneading the dough. The pizza was served with 330 ml of beer (1.8% w/w alcohol).

In *the hamburger meal (no. 2)* the hamburger was made from 115 g ground round of beef, seasoned with salt and pepper, shaped into a round patty, and fried in a hot pan for 4 min. A roll was made from unfortified white flour (50 g), milk (37 ml), margarine (4 g), salt, and yeast.

A milkshake was made from 100 g of ice cream (12% fat), 200 ml of milk (3% fat), and 12 g of sugar and mixed in an electric blender. French-fried potatoes (90 g) were made from peeled potatoes, cut into thin strips, and fried with 10 g of oil in an oven for 10 min at 275°C.

Each meal was labeled with 1.5 μCi ^{59}Fe. The radioiron was added to the milk when making the wheat roll dough. The hamburger was served in the roll together with mustard (3 g), slices of onion (5 g), ketchup (8 g), and pickled cucumber (6 g).

The vegetable soup (no. 3) was made from onion (100 g), potatoes (175 g), tomatoes (50 g), and carrots (75 g). The vegetables were washed, peeled, and cut into pieces and then boiled in beef broth (500 ml) until tender, about 20 min.

Two rolls were made from 18 g of unfortified white wheat flour and 18 g of whole-meal rye. Each roll was labeled with 1 μCi ^{55}Fe, added to the water when making the dough. The rolls were served with margarine (12 g) and cheese (20 g). Water (150 ml) was served with the meal.

In *the spaghetti meal (no. 4)* 200 g of unfortified spaghetti from durum wheat was boiled for 8 min. Cooking oil (10 g), grated cheese (20 g), and ketchup (100 g) were poured over the hot spaghetti. The radioiron, 1 μCi ^{59}Fe per meal, was mixed into the ketchup. Water (150 ml) was served with the meal.

In *the fish meal (no. 5)* deep-frozen fillets of cod (150 g) were steamed with butter (5 g), salt, and lemon juice for 15 min. Horseradish sauce was made from 5 g of butter melted with wheat flour (5 g) and 100 g of fish stock. The sauce was seasoned with finely scraped horseradish. Two wheat rolls were made from 30 g of unfortified wheat flour. Each roll had a total iron content of 2.0 mg, 1.7 of which was added as ferrous sulphate fortification iron.

Curd cake (150 g) was made from milk, wheat flour, almonds, egg, sugar, and cream.

Each meal was labeled with 1.5 μCi ^{55}Fe. The radioiron was added to each portion of boiled mashed potatoes. The boiled fish was served with the horseradish sauce, mashed potatoes (150 g), boiled green peas (50 g), wheat buns with butter (15 g), card cake with strawberry jam (35 g), and beer (330 ml, 1.8% w/v alcohol).

In *the beef meal (no. 6)* a shrimp cocktail was served first. A dressing of ketchup (6 g), chili sauce (6 g), horseradish, and lemon juice was poured over the shrimps, 25 g, on a bed of lettuce (5 g). A muffin was made from 40 g of unfortified wheat flour, butter, milk, and sugar. The beef, 150 g, was grilled under moderate heat and cooked for about 5 min. The potato, 200 g, was baked at 225°C for 45 min. Lettuce (20 g), sliced tomato (50 g), and finely cut onion (10 g) were mixed with a dressing of blue cheese (6 g), oil (6 g), vinegar (2 g), salt, and pepper. The vanilla ice cream (65 g) was made from milk, butter, sugar, and egg.

Each meal was labeled with 1.5 μCi ^{55}Fe, added dropwise to the baked potato.

The beef was served with seasoned butter (20 g), baked potato, mixed salad, muffin with butter (15 g), ice cream, and ice water (250 ml).

In *the English meal (no. 7)* fresh, boneless, chicken meat (20 g) was boiled for 20 min in clear soup made from a soup cube and water (300 ml). White bread was made of 30 g unfortified white flour. The steak and kidney pie was made from 38 g of steak and 63 g of calf's kidney, cut into thin slices and rolled in 5 g of wheat flour, mixed with salt and pepper. The meat was put into a pan together with enough water to cover and boiled for 45 min. Pastry, 85 g, made from wheat flour, salt, and margarine, was rolled out to fit a small aluminium dish. The tender meat was placed in the dish and covered with pastry, glazed with egg yolk. The pie was baked at 250°C for 20 min. Canned green peas and carrots, 50 g, were heated for 30 min. Jelly was made from mandarin fruit syrup (50 g), water (100 g), and gelatin.

The radioiron, 1 μCi ^{59}Fe, was added to the boiled meat in the pie, before covering with pastry. The meal began with the hot chicken soup with bread and butter, followed by the steak and kidney pie with boiled vegetables and beer, 330 ml (2.2% w/v alcohol). The meal ended with jelly with whipped cream (30 g).

One of the two Spanish meals consisted of *Galician soup (no. 8)* with bread and wine. White dried beans (35 g) were soaked in water overnight. The beans were put in a kettle with water (150 ml), 20 g of beef, and 35 g of smoked ham, all cut into small strips, and 25 g of salt pork, cut into cubes. Onion (15 g), tomatoes (35 g), garlic, salt, and pepper were added to taste. The soup was allowed to simmer for 1 h. Boneless chicken meat (20 g) was added together with potatoes (75 g) and white turnips (30 g), peeled and cut into cubes, and white cabbage (75 g), cut into squares. The soup was allowed to simmer for another 20 min. Bread was made from 76 g of unfortified white flour.

The radioiron, 1.5 μCi ^{55}Fe per portion, was added to the dough. The soup and bread were served together with 300 ml of Spanish red Rioja wine (iron content, 7.9 mg/l).

In the other *Spanish meal (no. 9)* gazpacho soup was made from tomatoes (150 g), cucumber (75 g), garlic, water (20 g), mayonnaise (5 g), vinegar (10 ml), and white bread (8 g), all combined in an electric blender at high speed. The mixture was poured into a sieve and pressed and stirred to extract as much of the juices as possible. The soup was chilled before serving. Chicken pieces (200 g), seasoned with salt and pepper, were browned in oil (4 g). Chopped onion (50 g), half a clove of finely minced garlic, seeded, cored, and chopped green (50 g) and red (20 g) peppers, a cup of cauliflower (75 g) were all combined in a skillet with oil (3 g). The fried chicken pieces were added together with chicken stock. The vegetables and chicken was allowed to simmer for 20 min. Bread was made from 30 g of unfortified wheat flour. For caramel custard, sugar (20 g) and a teaspoon of water was placed in a heavy skillet and heated over low heat until the sugar turned into a golden syrup. The caramel syrup was poured into a glass beaker. Milk (150 ml) was brought to the boil and then added to an egg (60 g), beaten with sugar (5 g). The mixture was poured into the glass beaker, placed in a baking dish half filled with water, and then baked at 175°C for 30 min. The meal included 300 ml of red wine, Rioja tinto (iron content, 7.9 mg/l). Each meal was labeled with 1.5 μCi ^{55}Fe per portion, added to the water when making the dough.

In *the Italian meal (no. 10)* unfortified spaghetti (75 g) made from durum wheat was boiled for 8 min. Minced, smoked ham (25 g) was fried in oil (3 g) together with finely chopped onion (40 g), carrot (35 g), celery (15 g), and thin slices of garlic. Minced beef (60 g), tomato puree (5 g), beef bouillon (75 ml), and salt were added. This ragout was allowed to simmer for 2 h. White bread was made from 75 g of unfortified wheat flour. The radioiron, 1.5 μCi ^{55}Fe, was mixed into each portion of the meat sauce.

The meal was started with antipasto misti: artichoke hearts (25 g), pickled peppers (30 g), anchovies (10 g), black olives (14 g), and giardiniera (25 g mixed vegetables in wine vinegar). Pasta with ragout Bolognese followed. Bread and 300 ml Italian red wine (Chianti type) were served with the meal (iron content, 9.7 mg/l). The meal was ended with an orange (175 g).

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 (4), non-heme iron (4), phosphorus (5), phytic acid phosphorus (6), and ascorbic acid (7). Owing 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 non-heme iron. The chemical composition of the meals is given in Table II.

Oral reference doses of iron

A solution of 10 ml 0.01 M hydrochloric acid containing 3 mg iron as ferrous sulphate and 30 mg ascorbic acid was used as a reference in all studies. Each subject received a total of 1.5 μCi of ^{59}Fe. The 10-ml vials containing the iron solution were washed twice with water, and this was also drunk.

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 were made with liquid scintillation by means of a modification of the method described by Eakins and Brown. All procedures and methods of calculations have been described previously (8).

Table II. Composition of the meal

Study no.	Composition	Energy, kcal	Iron, mg			Protein, g		Ascorbic acid, mg	Phytic acid, mg
			Non-heme	Heme	Total	From meat, fish	Total		
1	Pizza with tomato puree, black olives, anchovies, tomatoes, cheese, beer	1040	4.2	0	4.2	4	43	0	0
2	Hamburger, bread, tomato ketchup, mustard, French-fried potatoes, milkshake	1030	3.9	1.2	5.1	26	47	0	0
3	Vegetable soup, rye bread, butter, cheese, water	1010	7.0	0	7.0	0	26	10	25
4	Spaghetti, cheese, tomato ketchup, water	1020	4.9	0	4.9	0	32	20	130
5	Boiled cod, potatoes, bread butter, curd cake, beer	1050	7.8	0	7.8	28	47	10	19
6	Shrimps, beef, vegetable salad, potato, ice cream, water	980	6.2	1.2	7.4	32	45	26	0
7	Chicken soup, steak and kidney pie, peas, carrots, bread, butter, beer, jelly	1010	5.7	0.9	6.6	26	43	0	0
8	Galician soup (meat with beans, onion, tomatoes etc.), bread, wine	980	7.2	0.8	8.0	18	37	21	96
9	Gazpacho, chicken, vegetables, flan (caramel custard), bread, wine	1040	7.6	0.1	7.7	22	43	100	0
10	Antipasti misti, spaghetti, meat, bread, wine, orange	1150	7.8	0.6	8.4	16	36	85	49

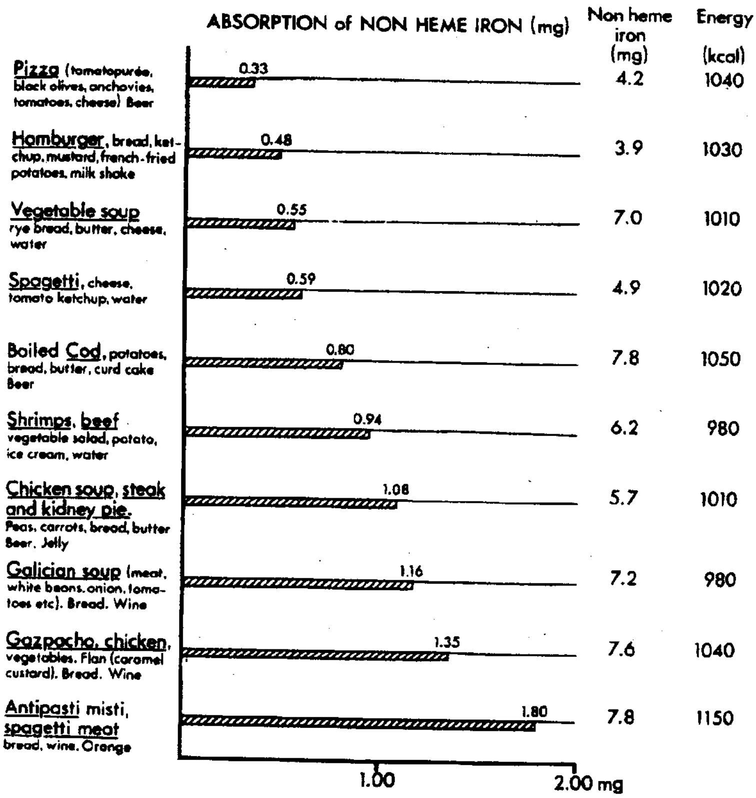

Fig. 1. Absorption of non-heme iron from 10 different whole meals with a similar energy content. The content of non-heme iron in the meals is also given. The calculated heme iron absorption figures are given in Table III.

Method for expressing iron absorption results

Since there is a high linear correlation between the absorption of iron from meals and from reference doses in a group of subjects, and since the regression line can be assumed to go through the origin, the mean absorption of iron from a meal was related to the mean absorption from the reference doses. The ratio of these two mean values was then multiplied by 40 to obtain the mean food iron absorption value corresponding to a 40% absorption from the reference doses. The details of the rationale of this technic have been described (9, 10).

RESULTS

The results of the absorption measurements from the ten meals are given in Table III and in Fig. 1. The absorption of non-heme iron varied from 0.33 mg in the pizza meal (no. 1) to 1.80 mg in the Italian whole meal containing antipasti misti, spaghetti with meat sauce, white bread, orange, and wine (no. 10). The absorption of non-heme iron thus varied more than fivefold in spite of the similar energy content of the meals. Only a minor part of this variation in absorption can be related to differences in content of non-heme iron in the meals. The content of heme iron was analyzed, and the absorption of heme iron was calculated using a fixed percentage absorption of 25%. This figure was derived from a previous study (3). The calculated absorption of heme iron in the different meals is also included in Table III. This table also shows the bioavailable nutrient density of iron in the different meals, both for non-heme iron alone and for heme and non-heme iron combined. Bio-

Table III. Iron absorption from different meals

Study no.	Composition of meals	Iron content, mg		Iron absorption from meals: None-heme iron, %			Heme iron calculated (see text), mg	Reference dose absorption (mean and range), %	Bioavailable nutrient density, mg/1000 kcal	
		Heme iron	Non-heme iron	Mean and range	Corrected to 40% reference dose absorption: %	Corrected to 40% reference dose absorption: mg			Non-heme iron	Total iron
1	Pizza with tomato puree, black olives, tomatoes, anchovies, cheese, beer	—	4.2	9.0 (0.5–12.9)	7.9	0.33	—	45.3 (9.6–68.6)	0.32	0.32
2	Hamburger, bread, ketchup, mustard, French-fried potatoes, milkshake	1.2	3.9	13.8 (1.0–22.6)	12.2	0.48	0.28	45.3 (9.6–68.6)	0.47	0.75
3	Vegetable soup, rye bread, butter, cheese, water	—	7.0	7.2 (1.5–13.9)	7.9	0.55	—	36.4 (13.4–73.3)	0.54	0.54
4	Spaghetti, cheese, ketchup, water	—	4.9	11.0 (1.2–20.4)	12.1	0.59	—	36.4 (13.4–73.3)	0.58	0.58
5	Boiled cod, potatoes, green peas, bread, butter, curd cake, beer	—	7.8	8.1 (1.4–24.9)	10.4	0.80	—	31.2 (16.5–55.8)	0.76	0.76
6	Shrimps, beef, vegetable salad, potato, ice cream, water	1.2	6.2	15.3 (2.7–27.0)	15.1	0.94	0.30	40.6 (9.5–87.7)	0.96	1.27
7	Chicken soup, steak and kidney pie, green peas, carrots, bread, butter, jelly	0.9	5.7	19.2 (4.3–37.3)	18.9	1.08	0.23	40.6 (9.5–87.7)	1.07	1.30
8	Galician soup (meat, white beans, onion, tomatoes, etc), bread, wine	0.8	7.2	13.4 (2.1–26.6)	16.2	1.16	0.20	33.0 (11.8–73.2)	1.18	1.38
9	Gazpacho, chicken, vegetables, flan (caramel), bread, wine	0.1	7.6	14.5 (2.2–29.4)	17.6	1.35	0.03	33.0 (11.8–73.2)	1.30	1.32
10	Antipasti misti, [illegible]	0.6	7.8	18.0 [illegible]	23.1	1.80	0.15	31.2 [illegible]	1.57	1.70

available nutrient density is defined (11) as the amount of iron absorbed (mg) per 1000 kcal in subjects who are borderline iron-deficient (that is, have a reference dose absorption of 40%).

DISCUSSION

The main finding in the present study is the surprising variation in iron absorption between the different meals, in spite of their very similar energy content of about 1000 kcal. Most of the meals contained various amounts of heme iron but, if the amount of heme iron absorbed was disregarded, the variation in absorption of non-heme iron between the meals was very marked. Fig. 1 shows that there was more than a fivefold difference in absorption of non-heme iron, ranging from 0.33 to 1.80 mg.

As mentioned in the introduction, the absorption of heme iron was not measured in the present study but estimated to be 25% on the basis of results from earlier studies in which different amounts of heme iron were given in different meals to subjects with different iron status (3). The error introduced by the calculation of heme iron absorption, simply using one figure, is probably quite small with the present types of meal. If the amounts of heme iron estimated to be absorbed is added to give a total iron absorption, the variation between meals was even greater, ranging from 0.33 mg to 1.95 mg, or sixfold.

There are two main factors known to enhance the absorption of non-heme iron: 1) ascorbic acid and 2) meat and fish. None of these factors was present in the two meals with the lowest percentage absorption (7.9% and 7.9%)—the vegetable soup and the pizza meal. The amount of iron absorbed from the vegetable soup was considerably higher because of the high iron content of the meal.

Considering the percentage absorption, an intermediate group was formed by meals 5, 4, and 2 (cod, spaghetti, and hamburger meals). The absorption was 10.4%, 12.1% and 12.2%, respectively. In the cod and hamburger meals there was one enhancing factor present (fish or meat) but no ascorbic acid. The spaghetti meal did not contain meat, but there was a small amount (20 mg) of ascorbic acid present, which may be the reason for the higher absorption compared with the other two non-heme-containing meals (vegetable soup and pizza).

In the present study the absorption of non-heme iron from the fish meal (no. 5) was only 10%. In an earlier report iron absorption from a similar meal was 19% (2). It is possible that the curd cake eaten with the fish meal had an inhibiting effect on the iron absorption, perhaps because of its content of eggs.

Four meals (nos. 6 and 8–10) contained both meat and ascorbic acid, and the absorption in this group ranged from 15% to 23%. Three of these meals (8–10) were served with wine. As shown in a previous study (12), wine *per se* has only a slight effect on iron-promoting absorption. However, it often contains, as in the present study, considerable amounts of iron, thus increasing significantly the absorption of iron. The highest absorption of non-heme iron (23%) was from the Italian-type meal (no. 10). It is possible that this reflects a combined effect of the acidity of the antipasti misti, the ascorbic acid in the orange, the meat, and possibly the wine.

Heme iron is generally considered to be absorbed better than non-heme iron. It is therefore of interest that the absorption of non-heme iron from this meal is of the same magnitude (25%) as the absorption of heme iron from meat-containing meals (3). A very high absorption (18.9%) was found from the meal (no. 7) containing only meat as an enhancing factor. The meat content was not greater than for the cod or hamburger meals. There may be some other unknown factor enhancing the absorption in this meal.

Meal composition and meal patterns vary greatly from one country to another, and in Europe, for example, the intake of vegetables, fruits, meat, and wine are often markedly different in northern and southern countries. In comparative assessments of the iron nutrition in different countries or population groups, it is not sufficient to base the comparison on the intake of iron or the intake of heme and non-heme iron; differences in meal composition must also be taken into account. It was recently suggested that

Table IV. Comparison of different measures of iron absorption* from two seemingly similar hamburger meals

Meal composition	Energy, kcal	Non-heme iron mg	Non-heme iron absorption %	Non-heme iron absorption mg	Bioavailable nutrient density, mg Fe/1000 kcal
Hamburger with bread, mustard, ketchup, French-fried potatoes, milkshake	1030	3.9	12.2	0.48	0.47
Hamburger, mashed potatoes, string beans, water	450	3.0	12.7	0.38	0.84

* Absorption figures are corrected to 40% reference dose absorption.

in comparing the bioavailability of iron in different meals, the results should be expressed as the amount of iron absorbed per unit energy, and the concept of bioavailable nutrient density was introduced (11). In Table III the bioavailable nutrient density is also included. Fig. 2 shows the present results and the bioavailable nutrient density of Western-type breakfasts and lunch/dinner meals given in previous reports (1, 2).

In menstruating women 10% have iron losses exceeding 2.2 mg/d (13). Thus with an energy intake of 2000 kcal an average absorption of 1.1 mg Fe per 1000 kcal is needed to cover the iron requirements in 90% of women. In Fig. 2 a horizontal dotted line indicates this critical value to make this comparative analysis of the bioavailability of iron from different meals more concrete.

Absorption from different hamburger meals can be compared to illustrate the usefulness of bioavailable nutrient density (Table IV). The percentage absorption from the hamburger meal in the present study was 12.2, very similar (12.7%) to a similar hamburger meal, previously reported, not containing milkshake and containing mashed potatoes instead of French-fried potatoes. The content of energy and non-heme iron of the present meal was 1030 kcal and 3.9 mg, respectively, compared with 450 kcal and 3.0 mg in the hamburger meal reported earlier. When common methods of comparison are used, the present hamburger meal would turn out to be superior, having a higher content of non-heme iron, 3.9 instead of 3.0 mg, and showing a higher absorption of iron, 0.48 instead of 0.38 mg. But when the absorption is related to the energy intake, the present high-energy hamburger meal has a bioavailable nutrient density of only 0.47 mg, compared with 0.84 mg absorbed iron per 1000 kcal in the low-energy hamburger meal.

The present study illustrates several factors that need to be taken into account when comparing the iron absorption from different meals. First, the studies must be designed so that differences in iron status of the subjects served different meals has no determining effect on the results. Other factors being the same, the *amount* of iron absorbed from a meal is of course related to the

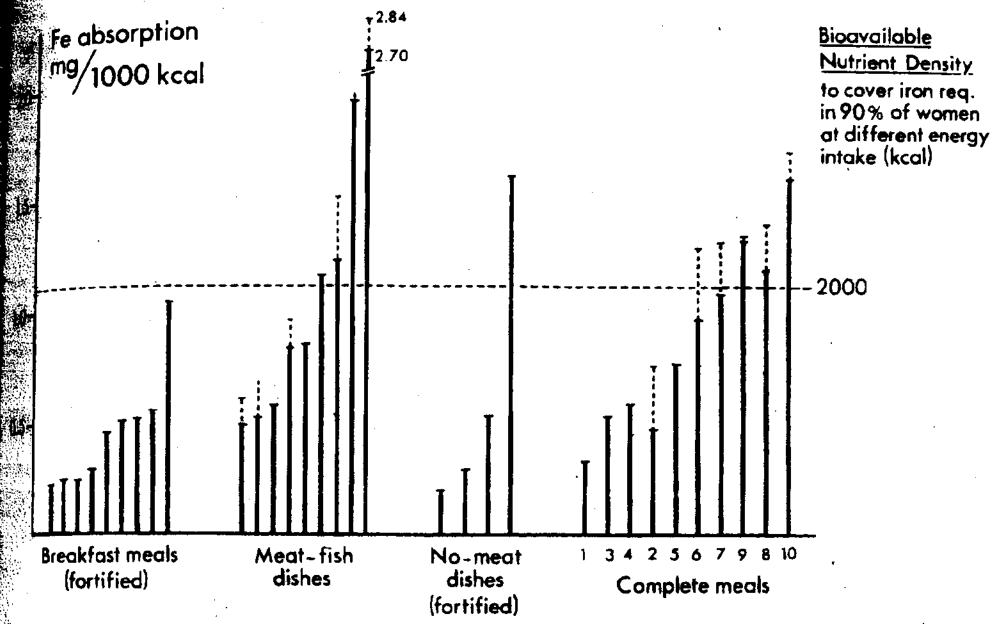

Fig. 2. Bioavailable nutrient density (milligrams iron absorbed per 1000 kcal by borderline iron-deficient subjects) of meals served in the present study and in previous studies (see text). The dotted vertical lines represent calculated heme iron absorption. The numbers below the bars are the meal numbers used in the text. The dotted horizontal line is a critical value for bioavailable nutrient density in menstruating women with an energy intake of 2000 kcal (see text).

amounts of heme and non-heme iron present in the meal. Several components of the meal can markedly modify the *bioavailability* of its iron and especially of the non-heme iron; thus the composition of a meal plays a decisive role in nutrient bioavailability. The *percentage absorption* can be considered as a measure of the bioavailability. However, both the amount absorbed and the percentage absorbed are insufficient as a basis for the practical assessment of the nutritive value of a meal with respect to iron. As the average daily intake of energy is limited, it is necessary to relate the absorption of iron from a meal to its energy content, to define the *bioavailable nutrient density*. The iron absorption from a meal can then be assessed in relation to iron requirements and energy expenditure and intake.

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