

Absorption of iron from breakfast meals¹⁻³

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ABSTRACT The absorption of nonheme iron from nine common Western type breakfasts was studied in 129 subjects using extrinsic labeling with radioiron. In one group the iron absorption from a continental type of breakfast served with coffee was standardized against the absorption from a reference dose of ferrous ascorbate (3 mg Fe). In all subsequent experiments the absorption from this breakfast was compared with one of the other breakfast meals served on alternate days and each labeled with a different radioiron isotope. The bioavailability of iron in the different breakfast meals varied markedly. There was almost a 6-fold difference in absorption (0.07 to 0.40 mg) despite of the fact that the iron content only varied from 2.8 to 4.2 mg. The most marked effect was seen with tea which reduced the absorption to less than half and with orange juice which increased the absorption two and a half times. The present findings must be considered when giving dietary advice to groups of subjects who are known to have a critical iron balance. The present results also imply that an evaluation of the iron nutrition in a population cannot only be based on the daily dietary intake of iron but must also include the bioavailability of iron in frequently consumed meals. *Am. J. Clin. Nutr.* 32: 2484-2489, 1979.

There are two kinds of iron in the diet with respect to mechanism of absorption—heme iron derived from hemoglobin and myoglobin mainly in meat products and nonheme iron derived mainly from cereals, vegetables, and fruits. The nonheme iron forms the main part of iron, about 85 to 90%, in the Western type diets.

Until recently the absorption of iron from composite meals could not be measured. This is now possible by the introduction of the extrinsic tag technic to label food iron (1, 2). The heme iron absorption can be measured using hemoglobin labeled with radioiron as a tracer. The nonheme iron absorption can be measured by mixing the food with an inorganic radioiron labeled salt, which almost uniformly labels the nonheme iron components present. Recent studies have shown that valid measurements of nonheme iron absorption from composite meals can be obtained simply by mixing the tracer with some bulky component of the meal. As it is now possible to measure the absorption of iron from composite meals it is thus also possible to study to what extent the availability of iron is influenced by the composition of the meals.

The recently introduced pool concept in food iron absorption implies that the amount of iron absorbed from a meal is a net effect of several factors present that enhance and

inhibit iron absorption. Known factors are, for example, meat, fish, ascorbic acid (orange juice), eggs, tea, and phytates. The breakfast meal often contains much iron and thus forms an important part of the total daily iron intake. Breakfast meals vary considerably with respect to content of factors that may influence the absorption of iron. The purpose of the present study was, therefore, to examine the absorption of iron from several common breakfast meals.

Materials and methods

Material

One hundred twenty-nine normal subjects, 64 women and 65 men, between 17 and 46 years old volunteered for the present study. Hematological and other data are given in Table 1.

Experimental design

The study was divided into nine sections (see Table 2). In section one, iron absorption from a continental

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TABLE I
The material (mean values \pm SEM)

Experiment	Composition of breakfast	No. and sex of subjects	Age	Height	Weight	Hemoglobin	Hematocrit
			yr	cm	kg	g/liter	%
I	Basal breakfast (coffee)	12 M	29	182	74.3 \pm 3.3	142 \pm 4	43.8 \pm 1.0
		9 F	29	171	64.3 \pm 3.3	129 \pm 2	39.4 \pm 1.0
II	With orange juice	5 M	32	184	80.6 \pm 5.2	148 \pm 5	45.2 \pm 1.4
		7 F	26	163	56.4 \pm 2.1	127 \pm 3	38.9 \pm 1.0
III	With boiled egg	10 M	25	179	69.4 \pm 2.2	149 \pm 3	45.1 \pm 0.7
		2 F	20	170	67.5	135	41.5
IV	With scrambled egg and bacon	6 M	24	179	70.0 \pm 2.7	145 \pm 4	43.8 \pm 1.0
		6 F	25	164	57.2 \pm 3.5	128 \pm 3	39.5 \pm 0.5
V	With cornflakes and milk	1 M	18	180	65	134	42
		13 F	25	166	58.8 \pm 2.0	130 \pm 3	41.6 \pm 0.7
VI	Basal breakfast (tea)	5 M	29	183	77.4 \pm 4.6	136 \pm 4	41.8 \pm 1.0
		7 F	25	168	61.9 \pm 3.4	131 \pm 5	40.9 \pm 1.3
VII	With orange juice	5 M	28	176	69.4 \pm 3.4	144 \pm 5	44.6 \pm 1.3
		7 F	31	164	57.7 \pm 2.8	130 \pm 2	40.1 \pm 0.6
VIII	With scrambled egg and bacon	7 M	22	178	69.7 \pm 3.1	144 \pm 2	44.0 \pm 0.7
		5 F	30	165	56.2 \pm 3.2	129 \pm 6	40.6 \pm 1.8
IX	Basal breakfast (chocolate milk)	3 M	24	177	77.0 \pm 3.8	150 \pm 3	47.3 \pm 1.5
		9 F	25	168	58.2 \pm 2.6	133 \pm 3	40.4 \pm 0.9

type of breakfast (basal breakfast or "A") was compared with absorption of a reference dose of ferrous ascorbate ("R"). The subjects were given A or R after fasting overnight on 4 consecutive mornings in the sequence ARRA or RAAR. A and R were labeled with two different radioiron isotopes, ^{55}Fe and ^{59}Fe . A blood sample was drawn 2 weeks after the last test, to measure the relative iron absorption of the two tracers (3). At the same time a whole body counting was also performed to measure the absolute retention of ^{59}Fe (3). These initial experiments allowed us to standardize iron absorption from the basal breakfast against the reference ferrous ascorbate solution. In all subsequent experiments, the basal breakfast (A) constituted the standard against which iron absorption from other breakfast meals was compared.

In the following eight experiments the basal breakfast (A) was compared with a series of different breakfasts (B) in the sequence ABBA or BAAB. Again the radioiron isotopes were used to label the nonheme iron and the meals were served to fasting subjects on 4 consecutive mornings.

Preparation of food

In all experiments the continental basal breakfast consisted of coffee (150 ml), two wheat rolls with margarine (12 g), one with orange marmalade (10 g) and the other with cheese (15 g). The rolls were made from 20 g of unfortified white wheat flour, of 60% extraction. Each roll had a total iron content of 1.4 mg, 1.15 mg of which was added as ferrous sulphate fortification iron.

The orange juice added in experiments II and VII was 150 ml of freshly prepared frozen concentrate, reconstituted with water. It contained about 70 mg of ascorbic acid.

The egg was either boiled (experiment III) or scrambled (experiments IV and VIII) and weighed 60 g cooked. The bacon (experiments IV and VIII) was fried and weighed 50 g initially and 17 g after cooking.

The tea used in experiments VI, VII, and VIII was made from Ceylon breakfast tea (Twinings I) using 2.5 g of dry tea allowed to steep in 150 ml of boiled water for 5 min. The coffee was brewed using 8 g coffee to 150 ml water.

The chocolate milk served in experiment IX was prepared from 150 ml of milk (3% fat), 5 g sugar and 4 g unfortified cocoa (Droste, Haarlem, Holland). The sugar and cocoa powder were mixed with a small amount of the hot milk and then the rest of the milk was added.

The cereal used in experiment V was 21 g of unfortified cornflakes (Kellogg's) served with 250 ml of milk (3% fat).

In all experiments the radioiron added was ferric chloride in 0.01 M hydrochloric acid. Each meal was labeled with 1.5 μCi ^{59}Fe or 2 μCi ^{55}Fe . This radioiron was added to the wheat rolls when kneading the dough.

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 iron, phosphorus, and total and phytic acid content. The chemical composition of the meals is given in Table 2.

Oral reference doses of iron

The reference dose used in experiment I (R) consisted of 10 ml of 0.01 M HCl containing 3.0 mg of iron as ferrous sulphate and 30 mg of ascorbic acid. Each subject received a total of 2 μCi of ^{55}Fe . The 10-ml vials con-



TABLE 2
Composition of the breakfast meals

Experiment	Composition of breakfast	Energy <i>kcal</i>	Iron		Protein		Ascorbic acid	Phytic P
			Non heme	Heme	From meat	Total		
			<i>mg</i>		<i>g</i>			<i>mg</i>
I	Basal breakfast (coffee)	320	2.8			7		
II	With orange juice	390	3.1			8	70	
III	With boiled egg	405	4.1			13		
IV	With scrambled egg and bacon	490	4.2	0.03	5	18		
V	With cornflakes and milk	555	3.6			17		1.5
VI	Basal breakfast (tea)	320	2.8			7		
VII	With orange juice	390	3.1			8	70	
VIII	With scrambled egg and bacon	490	4.2	0.03	5	18		
IX	Basal breakfast (chocolate milk)	455	3.2			12		20

taining the iron solution were washed twice with water and this was also consumed. No food or drink was then allowed for 3 hr.

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 a modification of the method described by Eakins and Brown. All procedures and methods of calculations have been described previously (3).

Statistical methods

Standard statistical methods were used for calculating regression lines, mean values, and SEM. Mean values were compared using the Student's *t* test.

Calculation of absorption values

In experiment I the linear regression between absorption of food iron from the basal breakfast and the reference iron doses was calculated. For reasons outlined in the "Discussion section", the amount of iron absorbed from the basal breakfast that corresponded to an absorption of 40% from the reference doses was used as a basis of comparison of the iron absorption from the different breakfast meals. This amount was 0.16 mg.

In experiments II to IX no reference doses were given. The linear regression between the absorption of iron from the basal breakfast and from the other types of breakfast studied was calculated. The absorption values from the different breakfasts corresponding to an absorption of 0.16 mg from the basal breakfast were used in the comparisons.

Results

Results from all nine experiments are given in Table 3 and Figure 1. The absorption of nonheme iron from the basal breakfast meal corresponding to an iron absorption of 40%

from the reference doses was 0.16 mg. Adding orange juice more than doubled the iron absorption (0.40 mg; $P < 0.05$). The addition of an egg to the basal breakfast increased the iron intake from 2.8 to 4.1 mg, however, the iron absorption was unchanged (0.19 mg). By adding both an egg and bacon the absorption increased to 0.25 mg. This was significantly higher ($P < 0.01$) than from the basal breakfast alone. Serving milk and cornflakes with the basal breakfast reduced the percentage of iron absorption from 6.6 to 5.4%. However, the absolute amount absorbed (0.16 mg) was the same as from the basal breakfast alone.

If tea was served instead of coffee in the basal breakfast meal the absorption decreased from 0.16 to 0.07 mg ($P < 0.05$). The negative effect of tea could be counteracted by simultaneously serving orange juice; the absorption was then 0.21 mg. This figure, however, should also be compared with the absorption from the basal breakfast served with coffee and orange juice (0.40 mg). Serving tea instead of coffee in the breakfast containing egg and bacon reduced the absorption from 0.25 to 0.12 ($P < 0.01$). The iron absorption from the basal breakfast served with milk chocolate (0.11 mg) was significantly lower ($P < 0.05$) than from the basal breakfast with coffee.

Discussion

The main factors determining the absorption of nonheme iron from different meals are the iron status of the subjects studied, the

TABLE 3
Iron absorption from different breakfast meals

Experiment	Composition of breakfast	Nonheme iron content of test meal		Absorption				Statistical significance (A-B) ($P <$)
		mg	%	Test meal (B)	Reference dose (R)	B/A	Basal meal with coffee	
I	Basal breakfast (coffee)	2.8	7.6	52.0	0.21	0.16	0.05	
II	With orange juice	3.1	3.7	8.0	0.10	0.40	NS ^b	
III	With boiled egg	4.1	9.3	7.6	0.26	0.19	0.01	
IV	With scrambled egg and bacon	4.2	6.6	7.1	0.19	0.25	NS	
V	With cornflakes and milk	3.6	6.6	5.4	0.18	0.16	0.02	
VI	Basal breakfast (tea)	2.8	7.8	3.1	0.22	0.07	NS	
VII	With orange juice	3.1	5.6	6.8	0.16	0.21	0.05	
VIII	With scrambled egg and bacon	4.2	7.2	3.7	0.20	0.12	0.05	
IX	Basal breakfast (chocolate milk)	3.2	6.1	3.8	0.17	0.11	0.05	

^a Corrected to correspond to an absorption of 0.16 mg from basal breakfast with coffee. ^b Not statistically significant difference ($P > 0.05$).

iron content and the composition of the meals. There are several known and unknown components in a meal that enhance or inhibit the absorption of iron at physiological doses. The effect of the composition of the meal on the absorption is thus the net effect of all these components in a meal.

In the present study the iron absorption from the basal breakfast served with coffee was the basis of comparison for the different types of breakfast. In this way the effect of single components in the different breakfasts could be evaluated. The absorption of iron from a meal may differ markedly between subjects due to differences in their iron status. In order to get meaningful absorption figures for the different meals the relationship was studied between the absorption from a reference dose of ferrous ascorbate. Present knowledge indicates that subjects who are on the borderline between normality and iron deficiency (nonanemic subjects with no iron stores) absorb about 40% from these reference iron doses. The absorption from the basal breakfast served with coffee corresponding to this 40% value was 0.16 mg. This value was, therefore, used as a basis of comparison in all later experiments.

A great variation was observed in the absorption from the different breakfast meals (Fig. 1). The highest absorption figure was almost six times greater than the lowest—0.40 and 0.07 mg. The inhibiting effect of tea on nonheme iron absorption was first demonstrated for a rice meal (4). The present studies clearly show that tea has an inhibiting effect of the same magnitude on a Western type of meal. This negative effect of tea could be counteracted by the positive effect of bacon (meat) or orange juice (ascorbic acid) on iron absorption. Nonetheless, the negative effect of tea still persists, for instance the positive effect of orange juice on the iron absorption from a breakfast meal is almost twice as high when the meal is served with coffee rather than tea—(0.40 and 0.21 mg, respectively). The same is true for the effect of bacon where coffee versus tea was 0.25 and 0.12 mg, respectively.

Egg yolk is a well-known inhibitor of iron absorption. Egg albumin, however, does not affect iron absorption (5, 6). In the present study the absorption decreased from 9.3 to

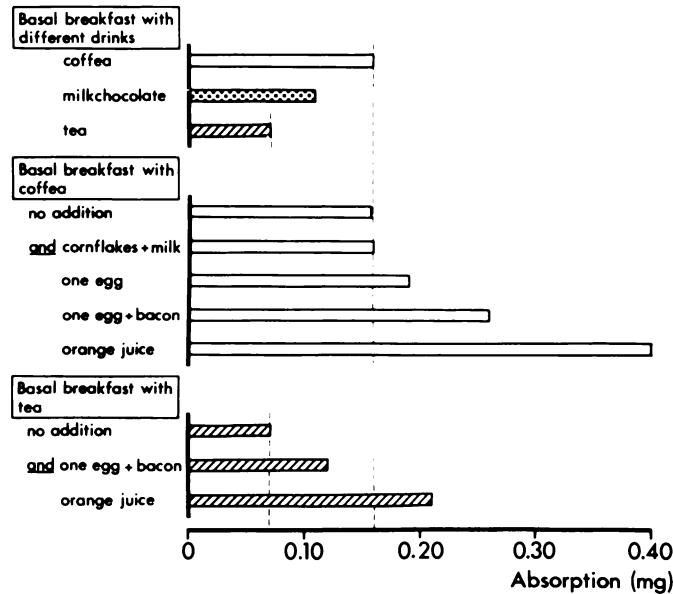


FIG. 1. Absorption of iron from different breakfast meals. The values represent absorption in subjects having a 40% absorption from oral reference doses of ferrous ascorbate (3 mg Fe) (see text).

7.6% when an egg was served with the breakfast; however, the amount of iron absorbed was almost unchanged as the iron content of the meal was increased by the addition of the egg. The negative effect of an egg on iron absorption is thus negligible when served with the present type of composite meal. This observation is in accordance with results of Cook and Monsen (7) on the effect of eggs on the iron absorption from a semisynthetic diet.

When bacon was also added (basal breakfast with bacon and egg) the nonheme iron absorption increased significantly. This was unexpected as the iron content of bacon is low, its meat content is low and fat, as such, has not been found to increase iron absorption (L. Rossander, L. Hallberg, and E. Björn-Rasmussen, unpublished observations). The iron absorption from the breakfast was lower with chocolate milk than with coffee, this might imply a negative effect of chocolate milk due to milk or phytates in the cocoa. However, coffee might stimulate the secretion of hydrochloric acid in the gastric juice. The present studies were not designed to allow an analysis of the observed differences.

The main findings in the present study reaffirm that dietary iron has to be evaluated according to its availability from food rather than simply by the iron content of food. Clearly there is a marked effect of the composition of the breakfast meal on the absorption of iron. Tea and orange juice have the greatest negative and positive effects.

Knowledge about these facts must be considered when giving dietary advice to subjects who are known to have a critical iron balance, for example pregnant women and women with heavy menstrual losses, or school children, especially at periods of rapid growth.

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