Iron absorption in young Indian women: the interaction of iron status with the influence of tea and ascorbic acid

Prashanth Thankachan, Thomas Walczyk, Sumithra Muthayya, Anura V Kurpad, and Richard F Hurrell

ABSTRACT

Background: Ascorbic acid (AA) enhances and tea inhibits iron absorption. It is unclear whether iron status influences the magnitude of this effect.

Objective: We evaluated the influence of the iron status of young women on iron absorption from a rice meal with or without added tea or AA.

Design: Two stable-isotope iron absorption studies were made in 2 groups of 10 subjects with iron deficiency anemia (IDA) and 10 subjects who were iron replete (control subjects). In study 1, the reference rice meal was fed alone or with 1 or 2 cups of black tea. In study 2, the reference meal was fed alone or with AA (molar ratio to iron, 2:1 or 4:1). Iron absorption was measured by the erythrocyte incorporation of $^{57}$Fe and $^{58}$Fe labels at 14 d.

Results: Mean fractional iron absorption from the reference rice meal was $\approx 2.5$ times as great in the IDA group as in the control group ($P < 0.05$). The consumption of 1 or 2 cups of tea decreased iron absorption in the control subjects by 49% ($P < 0.05$) or 66% ($P < 0.01$), respectively, and in the IDA group by 59% or 67% ($P < 0.001$ for both), respectively. AA (molar ratio to iron, 2:1 or 4:1) increased iron absorption by 270% or 343%, respectively, in control subjects and by 291% or 350%, respectively, in subjects with IDA ($P < 0.001$).

Conclusions: The inhibitory effect of tea and the enhancing effect of AA on iron absorption were similar in the 2 groups. Overall differences in iron absorption in the 2 groups, however, continued to be dictated by iron status. Am J Clin Nutr 2008;87:881–6.

INTRODUCTION

It is estimated that 2 billion people worldwide are iron deficient, including 1 billion people who have iron deficiency anemia (IDA) (1). In India, 74% of the children <5 y old and 52% of young women have anemia (2). Young women are particularly vulnerable to iron deficiency because of their greater requirements of iron for menstruation and childbearing. Lower iron absorption could be a major mechanism by which nutritional iron deficiency affects populations (3). Plant-based diets commonly consumed in India and other developing countries contain an abundance of phytates and polyphenols that inhibit the absorption of dietary nonheme iron (4) by forming insoluble complexes, thereby making nonheme iron unavailable for absorption (5, 6). Nonheme iron constitutes 91% of the total iron present in the Indian diet (7).

Individual dietary inhibitory and enhancing factors exert profound influences on iron absorption (8–10). The potent inhibitory effect of phytic acid on nonheme-iron absorption is well known (11–13). Polyphenolic compounds such as chlorogenic acids, monomeric flavonoids, and polyphenol polymerization products widely present in coffee and tea also strongly inhibit dietary nonheme-iron absorption (14–16). The effects of ascorbic acid (AA) in dramatically improving iron absorption have consistently been observed (17–19). Heme iron found in animal foods is also an important iron source because of its high bioavailability (20). In addition, many studies have suggested that the enhancing effect of muscle tissue on iron absorption is due to cysteine-containing peptides (21–23).

Another physiologic factor that plays a major role in the amount of iron absorbed is the iron status of a person. Several studies have reported an inverse relation between body iron stores and iron absorption: that is, more iron is absorbed in an iron-deficient state and less iron is absorbed in an iron-replete state (24–26). Some reports on iron absorption showed it to be similar across a range of iron stores (26–28). These studies used mainly iron-replete subjects but also subjects with low iron stores, and, hence, the extent to which iron absorption responds to the presence of enhancers or inhibitors in subjects with IDA is not clear. Such information is crucial to an understanding of how modifying dietary enhancers and inhibitors could improve iron status in malnourished populations. The present studies used stable-isotope techniques to study whether iron absorption from a rice meal with or without added tea or AA would differ between iron-deficient anemic women and women with normal iron status.

SUBJECTS AND METHODS

Subjects

Two separate studies were performed in a total of 40 women aged 18–35 y. Each study contained 10 IDA and 10 control subjects, who were recruited from among the staff and students of St John’s Medical College (Bangalore, India). All subjects were in good health, none were pregnant or lactating, and none...
had a history of gastrointestinal or metabolic disorders. None of the subjects had donated blood within 6 mo of the start of the study. Subjects who regularly consumed vitamin-mineral supplements discontinued the supplementation 2 wk before the start of the study.

Forty women were selected on the basis of their hemoglobin and iron status and the absence of inflammation or infection during the initial screening. The criteria for the IDA group were hemoglobin values < 11.0 g/dL, serum ferritin (SF) concentrations < 12 μg/L, and zinc protoporphyrin concentrations > 40 μmol/mol heme or soluble transferrin receptors (TfRs) > 8.5 mg/L; criteria for the control group were hemoglobin values > 12.0 g/dL and measures of iron status (SF, zinc protoporphyrin, and TfRs) in the normal range. At the close of study, all IDA group subjects were supplemented with ferrous sulfate according to the standard of care.

Written informed consent was obtained from all women after they were given a full oral and written description of the aims and procedures of the study and the associated risks. The experimental protocol was approved by the ethics committees of St John’s Medical College (Bangalore, India) and the Swiss Federal Institute of Technology (Zurich, Switzerland).

## Test meals

### Test meal preparation and composition

The reference meal consisted of a rice meal (tomato rice), which was designed so that it contained small amounts of both enhancers and inhibitors of iron absorption (Table 1). The meal was prepared in a single large batch for all subjects in both studies, divided into individual weighed portions (200 g), and kept frozen at −80 °C until use. All ingredients were weighed out. Oil was heated in a pan, and tomato purée was added and sautéed in the oil for 5 min. Turmeric, chili powder, and salt were added to the purée while it was constantly stirred. Rice was added into this mixture, which was stirred over heat for a further 2 min. Finally, water was added, and the mixture was cooked with constant stirring until done. All of the utensils used in the preparation and cooking were made of either aluminum or plastic, and they had been washed with filtered water and dried before use.

The 4 test meals administered for each study are shown in Table 2. One gram of the solution of isotope label containing 3 mg 57Fe or 58Fe iron was dispensed (sprayed) onto the surface of the test meal before administration. In study 1, iron absorption from the meal, in the absence and presence of tea (1 or 2 cups) was assessed on consecutive days by the erythrocyte incorporation of 57Fe and 58Fe over a 29-d period. In study 2, iron absorption from the meal, in the absence and presence of AA (at molar ratios of 2:1 or 4:1 with iron) was studied.

### Preparation of tea and ascorbic acid solution

A local brand of Indian tea (Taj Mahal; Hindustan Lever Ltd, Mumbai, India) was procured. Boiling nanopore water (1000 mL) was added to 10 g tea in a glass beaker, and the mixture was left to infuse for 3 min on a magnetic stirrer before straining. The strained tea was kept in a thermos flask until it was served. The total polyphenol content of tea was measured by using the Folin-Ciocalteau method (29) with gallic acid as a standard. Each cup of black tea (150 mL) served with the test meals in study 1 contained 78 mg polyphenols. Food-grade L-AA was procured locally, and a stock solution was prepared so that 1 mL of the stock solution corresponded with the 2:1 molar ratio and 2 mL of the stock solution corresponded with the 4:1 molar ratio. Depending on the type of test meal in study 2 (B or C), 1 or 2 mL of the AA stock solution was pipetted into tared glasses, which were then filled with ultrapure water to a final volume of 150 mL in each glass.

## Study design

Each subject received 2 reference rice meals (meal A) and 2 test meals (one each of B and C) that were labeled with either 57Fe or 58Fe, as shown in Table 2. Within each study, a randomized crossover study design was used, in which each subject acted as her own control. Each subject was assigned to meals A or B or A and C on paired test days 1 and 2 and 15 and 16, so that each pair of meal administrations always had reference meal A with test meal B or reference meal A with test meal C. Reference meal A was always labeled with 57Fe. The added iron in test meals B and C was labeled with 58Fe. Iron absorption was based on the

### Table 1

Composition of the standard (reference) tomato rice meal

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Amount</th>
<th>Energy</th>
<th>Protein</th>
<th>Fat</th>
<th>Carbohydrate</th>
<th>Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>60</td>
<td>207</td>
<td>4.1</td>
<td>0.3</td>
<td>46.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Tomato</td>
<td>45</td>
<td>10</td>
<td>0.9</td>
<td>0.0</td>
<td>1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Turmeric</td>
<td>0.125</td>
<td>&lt;1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Chili powder</td>
<td>0.125</td>
<td>&lt;1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Cooking oil</td>
<td>9</td>
<td>81</td>
<td>&lt;1</td>
<td>9.0</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Salt</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>298</td>
<td>5.0</td>
<td>9.3</td>
<td>48.6</td>
<td>1.3</td>
<td></td>
</tr>
</tbody>
</table>

1 The reference meal also contained a total of 47.6 mg phytate.

### Table 2

Study design and test meal administration

<table>
<thead>
<tr>
<th>Day (meal type)</th>
<th>1 (A)</th>
<th>2 (B)</th>
<th>15 (A)</th>
<th>16 (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isotope label</td>
<td>57FeSO4</td>
<td>58FeSO4</td>
<td>57FeSO4</td>
<td>58FeSO4</td>
</tr>
<tr>
<td>Tea study</td>
<td>Test meal + 300 mL water</td>
<td>Test meal + 150 mL water + 150 mL tea</td>
<td>Test meal + 300 mL water</td>
<td>Test meal + 300 mL tea</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>Test meal + 300 mL water</td>
<td>Test meal + 150 mL water + 150 mL water + AA at 2:1 molar ratio</td>
<td>Test meal + 300 mL water</td>
<td>Test meal + 150 mL water + AA at 4:1 molar ratio</td>
</tr>
</tbody>
</table>

1 Test meal composition is shown in Table 1. Test meal A, reference meal; AA, ascorbic acid.
erythrocyte incorporation of isotope labels 14 d after intake of the iron-labeled reference and test meals. On all study days, subjects reported to the laboratory in a fasted state. On day 1, body weight was measured to the nearest 0.1 kg (Soehnle, Murrhardt, Germany), and height was measured to the nearest 1.0 cm by using a stadiometer. After these measurements, subjects consumed the first meal (A). The test meal containers were washed 3 times with 10 mL ultrapure water to ensure complete consumption of the meal and the isotope label. No intake of food or fluids was allowed for 3 h thereafter. The second meal (B or C) was administered the next day (day 2) under identical conditions. A venous blood sample was drawn 14 d after the second meal to measure isotopic composition. The second pair of reference and test meals (A and B or C) was administered on days 15 and 16, respectively, under conditions identical to those on days 1 and 2. A final blood sample was drawn on day 29, 14 d after the second pair of meal administrations, to measure isotopic composition. All test meals were administered as a breakfast meal under supervision.

**Stable-isotope labels**

The preparation of the isotopic labels was similar to the method described by Walczyk et al (30). Briefly, the labels of $^{57}$Fe-$\text{FeSO}_4$ and $^{58}$Fe-$\text{FeSO}_4$ were prepared from isotopically enriched elemental iron ($^{56}$Fe at 95.9% enrichment and $^{57}$Fe at 93.2% enrichment: Chemgas, Boulogne, France) by dissolution in 0.1-mol H$_2$SO$_4$/L solution. The isotopic composition of the iron in solution was determined by using negative thermal ionization–mass spectrometry. Iron concentrations were measured by isotope dilution–mass spectrometry against an iron isotope reference material (IRM-014; EU Institute of Reference Material, Geel, Belgium). The dose was calculated on the basis of the estimated amount of circulating iron in the subjects, the expected range of fractional iron absorption, and the attainable precision of the isotopic analysis. The administered dose was determined by weighing the test meal before and after the isotope label was sprayed onto the test meal.

**Measurements of hemoglobin and iron status**

Hemoglobin concentrations were measured in whole blood by using a Coulter counter (AcT Diff2; Beckman Coulter, Krefeld, Germany) with 3-level quality-control material (Liquichek; Bio-Rad, Irvine, CA). SF and TIRs were calculated by using commercial enzyme-linked immunosorbent assays (Ramco Laboratories, Stafford, TX) in plasma samples. Assays were calibrated by using the standards provided by the manufacturer (Ramco Laboratories for SF and purified TIR solutions). World Health Organization–traceable quality-control material (Ramco Laboratories) was processed with each batch of samples for validation of the SF assay. C-reactive protein was measured in plasma samples by using a particle-enhanced turbidimetric immunosassay (Dimension RXL Chemistry Analyzer; Dade, Deerfield, IL). Control materials (Lyphochek; Bio-Rad) were analyzed within each run. Zinc protoporphyrin was measured in red blood cells after the cells were washed with normal saline with the use of a hematofluorometer (Aviv Biomedical, Lakewood, NJ) and 3-level control material provided by the manufacturer. Measurements were made in stored refrigerated blood within 1 d of collection.

**Isotopic analysis of the blood samples**

The method used to analyze the enriched blood samples was similar to our previously described technique (31). All isotopic analysis was carried on a negative thermal ionization–mass spectrometer (MAT 262; Finnigan MAT, Bremen, Germany) equipped with a multicollector system for simultaneous ion beam detection.

**Calculations**

The amount of circulating label was calculated on the basis of the shift in the isotopic ratios and the amount of circulating iron in the blood. Calculations were based on principles of dilution, and the nonmonoisotopic nature of the labels was taken into consideration (31). Circulating iron was calculated on the basis of blood volume and hemoglobin concentration; 80% incorporation of the absorbed iron into erythrocytes was assumed. The observed shift in iron isotope ratios was converted to fractional iron absorption by using standard algorithms (31). The shift in isotope ratios measured on day 15 was used as a new baseline for measurement of isotope ratio shifts on day 29.

**Statistical analysis**

All statistical analyses were conducted with SPSS statistical software (version 13; SPSS Inc, Chicago, IL). Iron absorption values were logarithmically transformed for statistical analysis. To account for intra-individual and inter-individual variations in iron absorption, iron absorption from a given test meal (with added tea or AA solution) was normalized to iron absorption from the reference meal in each individual subject. This study design with 10 subjects per study group had 80% power to detect a significant difference of 50% in iron absorption between 2 test meals with a significance level of 0.05. Paired Student’s t tests were used to test differences between iron absorption from the reference meal with or without tea or AA within the IDA and control groups. Comparisons of iron absorption between IDA and control subjects were made by using the unpaired Student’s t test. For identification of a dose-response effect, absorption ratios were compared between study intervals by using a paired Student’s t test. Differences were considered significant at $P < 0.05$.

**RESULTS**

**Subject characteristics and iron status**

Anthropometric and iron status measurements of the subjects in the 2 studies are summarized in Table 3. Within each study, the age and anthropometric measures of the subjects were comparable in the IDA and control groups, and all iron status indicators differed significantly between the groups ($P < 0.001$ for both studies).

**Iron absorption from reference and test meals**

**Reference meal: effect of iron status**

All test meals contained 1.3 mg native nonheme iron (Table 2) and 3 mg of the added isotope label. The measured AA content of the meal after cooking was negligible. The results are presented in Table 4 as geometric means and as absorption ratios. Mean fractional iron absorption from the reference meals in both studies was moderate to high; it ranged between 15.6% and 19.7% in the IDA group and between 5.2% and 9.4% in the control group. Mean iron absorption from both reference meals
TABLE 3
Anthropometry and iron status indicators of the study groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Tea study</th>
<th>Ascorbic acid study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IDA group (n = 10)</td>
<td>Control group (n = 10)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>22.6 ± 3.5</td>
<td>24.3 ± 2.9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>52.3 ± 7.5</td>
<td>51.2 ± 7.1</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.58 ± 0.05</td>
<td>1.56 ± 0.04</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>21.0 ± 2.7</td>
<td>21.0 ± 2.2</td>
</tr>
<tr>
<td>Blood hemoglobin (g/dL)</td>
<td>10.4 ± 0.9</td>
<td>12.7 ± 0.6</td>
</tr>
<tr>
<td>CRP (mg/L)</td>
<td>2.4 ± 1.4</td>
<td>3.2 ± 1.4</td>
</tr>
<tr>
<td>Serum ferritin (µg/L)</td>
<td>2.9 (0.62; 13.66)</td>
<td>50.2 (39.43; 63.84)</td>
</tr>
<tr>
<td>Serum transferrin receptor (mg/L)</td>
<td>9.9 ± 7.0</td>
<td>3.7 ± 1.3</td>
</tr>
<tr>
<td>Whole-blood zinc protoporphyrin (µmol/mol heme)</td>
<td>97.4 ± 77.7</td>
<td>26.6 ± 5.9</td>
</tr>
</tbody>
</table>

1 Tea study, study 1; ascorbic acid study, study 2; CRP, C-reactive protein.
2 Values presented as geometric mean (95% CI).
3 Significantly different between IDA and control groups: 4P < 0.001, 5P < 0.05.
4 Values presented as geometric mean; SD and 95% CI in parentheses.
5 Student’s t test was performed on log-transformed values.

(denoted as “A” in Table 4) was comparable in each of the iron status groups. Iron absorption was 1.8–3.7 times as high in the IDA group as in the control group in studies 1 and 2 (P < 0.05 for both).

Test meal: effect of tea

The addition of a tea drink to the reference meal resulted in a dramatic reduction in iron absorption in both iron status groups (Table 4). Iron absorption from the reference meal consumed with 1 cup of tea was decreased by 59% (P < 0.001) and 49% (P < 0.05) in the IDA and control groups, respectively. Consumption of 2 cups of tea with the reference meal decreased iron absorption by 67% (P < 0.001) and 66% (P < 0.01), respectively, in the same subjects. A comparison of the absorption ratios in the IDA and control groups showed no significant between-group differences with the addition of either 1 cup (P = 0.26) or 2 cups (P = 0.87) of tea, respectively. Thus, whereas the magnitude of the inhibition was similar irrespective of iron status, the increased iron absorption remained in the IDA subjects even after the consumption of tea. In the control subjects, a dose-related inhibitory effect of tea, expressed as a comparison of absorption ratios between the reference meal and the test meals, was noted; a significantly higher inhibition of iron absorption was seen with consumption of 2 cups of tea than with that of 1 cup of tea (P < 0.05). However, such a dose response was not observed in the IDA subjects (P = 0.29).

Test meal: effect of ascorbic acid

When added to the meal at a molar ratio to iron of 2:1, AA increased iron absorption by 29% in the IDA group and by 270% in the control group (P < 0.001 for both). A further increase in iron absorption was observed in both the groups with

TABLE 4
Fractional iron absorption from the reference meal with or without tea and ascorbic acid (AA)

<table>
<thead>
<tr>
<th>Study and test meal</th>
<th>IDA group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fractional iron absorption</td>
<td>Iron absorption ratio</td>
</tr>
<tr>
<td>Tea study</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Meal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A: reference meal</td>
<td>18.2 (12.6; 26.4)</td>
<td>0.41 ± 0.15</td>
</tr>
<tr>
<td>B: reference meal + 150 mL black tea</td>
<td>7.1 (4.3; 11.7)</td>
<td></td>
</tr>
<tr>
<td>A: reference meal</td>
<td>19.7 (13.5; 29.0)</td>
<td>0.33 ± 0.17</td>
</tr>
<tr>
<td>C: reference meal + 300 mL black tea</td>
<td>5.6 (3.1; 10.1)</td>
<td></td>
</tr>
<tr>
<td>AA study</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A: reference meal</td>
<td>15.6 (8.5; 28.6)</td>
<td>2.91 ± 0.99</td>
</tr>
<tr>
<td>B: reference meal + AA (2:1 molar ratio)</td>
<td>42.8 (22.4; 81.8)</td>
<td></td>
</tr>
<tr>
<td>A: reference meal</td>
<td>16.5 (8.7; 31.5)</td>
<td>3.50 ± 0.77</td>
</tr>
<tr>
<td>C: reference meal + AA (4:1 molar ratio)</td>
<td>56.8 (35.0; 92.3)</td>
<td></td>
</tr>
</tbody>
</table>

1 n = 10 in both iron-deficient anemia (IDA) and control groups in each study. Absorption values within each study interval (B/A or C/A) are compared as absorption ratios normalized to iron absorption from the reference meal. An absorption ratio ≤ 1 indicates an inhibiting effect of tea; an absorption ratio > 1 indicates an enhancing effect of ascorbic acid.
2 SD and 95% CI in parentheses.
3 SD and 95% CI in parentheses (all such values).
4 SD and 95% CI in parentheses (all such values).
AA added at a molar ratio to iron of 4:1 (350% and 343%, respectively; P < 0.001 for both). A dose-related effect between the 2 levels of AA intake, however, was not observed in either of the iron status groups. Comparison of absorption ratios between the different iron status groups showed no significant differences in the enhancing effect of AA between IDA and controls, which indicated that the enhancing effect is likely to be independent of iron status.

DISCUSSION

This study showed mean fractional iron absorption from the rice meal to be 17.5% in the IDA subjects and 7.0% in the control subjects. This is consistent with earlier rice studies from other countries that have reported a range of iron absorption values from 0.4% to 9.1% (32–37). Iron absorption was increased to be ≈2.5 times (range: 1.8–3.7) as high in IDA subjects than in control subjects in the present study, in association with meals with or without enhancers or inhibitors of iron absorption, which showed that body iron status primarily dictates the physiologic demand for iron. Several studies have shown the inverse relation that exists between iron stores and nonheme-iron absorption in humans (24–26). This is due to increases or decreases in iron absorption at the mucosal surface brought about by modulation of the expression of DMT1 and other iron transport proteins according to the iron stores (38, 39). Hepcidin is also thought to play a regulatory role in iron metabolism by directly affecting the ferroportin transporter within the mucosal basolateral membrane and by preventing iron efflux into the blood (40). Higher iron absorption values have been reported in blood donors with low iron stores than in nondonors (41). However, there are indications from other studies that the effects of enhancers and inhibitors are probably independent of iron status (26–28). In long-term studies, adaptive responses were observed in iron-replete subjects given meals with low and high iron bioavailability, to which they adapted by absorbing less iron from the high-bioavailability diet and more iron from the low-bioavailability diet, so as to stay in balance (27).

Our results confirm earlier findings that tea inhibits iron absorption to a considerable extent (14, 16). In our study, we observed a 50–70% reduction in iron absorption with the addition of either 78 or 156 mg polyphenols in black tea to the rice meal. This strong interaction between iron and polyphenols in the tea within the gut lumen was irrespective of iron status. Fractional iron absorption, in absolute terms, however, was higher in the IDA subjects consuming either amount of tea than in the control subjects, proportional to the existing higher absorption in this group. Our results also indicated that, in the IDA group, there was no further inhibition of iron absorption with the consumption of >1 cup of tea, whereas, in the control subjects, a dose effect of the 2 amounts of tea was observed. This suggests a stronger physicochemical interaction of polyphenols and iron in the gut for a given amount of tea in the IDA subjects. However, the possibility that a dose effect was not observed because of an inadequate sample size cannot be disregarded. In the early 1970s, Disler et al (14) found a significant inhibitory effect of tea on iron absorption from iron salts (FeCl3 and FeSO4), bread, a rice meal, or uncooked hemoglobin; they ascribed this finding to the effective sequestration of a good proportion of the iron in unabsorbable tannin complexes. More recently, the effects of different polyphenol-containing beverages on iron absorption from a bread meal were estimated by Hurrell et al (16) from the erythrocyte incorporation of radio-iron. All beverages reduced iron absorption depending on the content of total polyphenols, with the inhibition of black tea the greatest at 79–94%. Amounts of only 20 mg polyphenols from black tea per meal reduced iron absorption by as much as 66%, possibly because of the higher content of galloyl esters in black tea and possibly because the simple bread meal was devoid of any enhancers of iron absorption to counteract the polyphenols.

The strong enhancing effect of AA on iron absorption observed in the present study confirms previous evidence that AA increases iron absorption in a variety of meals (8, 18, 42–45). The increase in absorption due to the addition of AA was similar in both iron status groups. As observed in study 1, absolute absorption values in the IDA group were significantly higher and proportional to the increase due to the lower iron status. No significant dose-response effects of AA when added at molar ratios of 2:1 and 4:1 relative to iron on iron absorption were noted in either group—again, possibly because of the small sample size or a ceiling effect on absorption even at a molar ratio of 2:1. With a more inhibitory meal, this lack of dose-response effect might not have been seen. Single-meal studies, such as the present one, have been criticized because they tend to exaggerate the effect of enhancers of iron absorption.

Long-term controlled trials have reported conflicting results with respect to changes in iron status after increasing dietary AA intake, which indicate more physiologic complexity (46–49). In those studies, the effects either were not seen or were far less than those seen in single-meal studies. One study carried out in Mexico, in which limeade containing 25 mg AA was added twice daily to typical Mexican meals for 2 wk, showed that iron absorption increased in iron-deficient women by as much as 345% (50); the effect was significantly stronger with increasing severity of iron deficiency. Two studies done at the population level also showed that, in children, AA supplementation taken with meals improved the children’s iron status (49, 51). The Indian diet, with its abundance of phytate and polyphenolic compounds, is likely to make iron more available for absorption when supplemented with AA-rich foods. Improving AA intake in the form of fruit and citrus juice in the diet could be a culturally relevant and practical approach to improving iron status in Indian populations; studies on the adaptive effects of greater AA intake on both iron absorption and status have the potential to develop future dietary interventions. Therefore, long-term studies of the adaptability of iron absorption in response to enhancement of food components are clearly needed in the Indian context.

In conclusion, fractional iron absorption in Indian women was relatively high from a simple rice meal. The strong inhibitory effect of tea and the beneficial effects of AA on iron absorption were of a similar magnitude in iron-replete women and women with IDA. Overall differences in iron absorption in the 2 groups, however, continued to be dictated by iron status. Dietary modifications could perhaps be used to address the needs of iron-deficient women in this population.

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