Inhibition of non-haem iron absorption in man by polyphenolic-containing beverages

Richard F. Hurrell1*, Manju Reddy2 and James D. Cook3

1Laboratory for Human Nutrition, Swiss Federal Institute of Technology Zürich, PO Box 474,
CH-8803 Rüschlikon, Switzerland
2Iowa State University, Ames, IA, USA
3Kansas University Medical Center, Kansas City, KS, USA

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The effects of different polyphenol-containing beverages on Fe absorption from a bread meal were estimated in adult human subjects from the erythrocyte incorporation of radio-Fe. The test beverages contained different polyphenol structures and were rich in either phenolic acids (chlorogenic acid in coffee), monomeric flavonoids (herb teas, camomile (Matricaria recutita L.), vervain (Verbena officinalis L.), lime flower (Tilia cordata Mill.), pennyroyal (Mentha pulegium L.) and peppermint (Mentha piperita L.), or complex polyphenol polymerization products (black tea and cocoa). All beverages were potent inhibitors of Fe absorption and reduced absorption in a dose-dependent fashion depending on the content of total polyphenols. Compared with a water control meal, beverages containing 20–50 mg total polyphenols/serving reduced Fe absorption from the bread meal by 50–70 %, whereas beverages containing 100–400 mg total polyphenols/serving reduced Fe absorption by 60–90 %. Inhibition by black tea was 79–94 %, peppermint tea 84 %, pennyroyal 73 %, cocoa 71 %, vervain 59 %, lime flower 52 % and camomile 47 %. At an identical concentration of total polyphenols, black tea was more inhibitory than cocoa, and more inhibitory than herb teas camomile, vervain, lime flower and pennyroyal, but was of equal inhibition to peppermint tea. Adding milk to coffee and tea had little or no influence on their inhibitory nature. Our findings demonstrate that herb teas, as well as black tea, coffee and cocoa can be potent inhibitors of Fe absorption. This property should be considered when giving dietary advice in relation to Fe nutrition.

Iron absorption: Polyphenols: Coffee: Tea

Fe deficiency is the most common micronutrient deficiency in the world (World Health Organization, 1992). When severe, it leads to Fe-deficiency anaemia which is associated with poor health, increased risk of maternal perinatal death, and serious functional impairments that diminish human development and productivity (International Nutritional Anemia Consultative Group, 1993). A major cause of Fe deficiency is the impaired absorption of non-haem Fe (Charlton & Bothwell, 1983) due to the presence of potent inhibitors of absorption such as phytic acid or polyphenol compounds in many plant foods (Fairweather-Tait & Hurrell, 1996).

Polyphenol compounds are widely present in the human diet as components of fruits, vegetables, spices, pulses and cereals, and they are especially high in tea, coffee, red wine, cocoa and the different herb teas. In the USA, consumption of polyphenols is estimated at 1 g/d (Kuehnau, 1979) and in the UK as much as 0.5 g polyphenol/d is ingested from tea alone (Stagg & Millin, 1975). The phenolic compounds are released from the food or beverage during digestion, and can complex with Fe in the intestinal lumen making it unavailable for absorption. The consumption of black tea and coffee has been shown to strongly inhibit Fe absorption from composite meals (Disler et al. 1975; Hallberg & Rossander, 1982; Morck et al. 1983), with coffee having about half the inhibitory effect of tea.

Other beverages such as red wine (Bezwoda et al. 1985; Cook et al. 1995) and cocoa (Gillooly et al. 1984), as well as various vegetables with a high polyphenol content (Gillooly et al. 1983; Tuntawiroon et al. 1991), have also been reported to inhibit Fe absorption. Red wine polyphenols would appear to be less inhibitory than the phenolics of tea or coffee. They reduced Fe absorption from a simple bread-roll meal (Cook et al. 1995), but had little effect on Fe absorption from more complex composite meals (Hallberg & Rossander, 1982). On the other hand a serving of yod kratin (leaves of the lead tree, Leucaena glauca), a vegetable consumed widely in Thailand and that is high in phenolics, reduced Fe absorption...
from a composite meal of rice, fish and vegetables by almost 90% (Tuntawiroon et al. 1991). Fe absorption from other vegetables rich in polyphenols, such as spinach and aubergine, has also been observed to be low and a significant negative correlation has been reported between the total polyphenol content of vegetable foods and absorption of their Fe content in man (Gillooly et al. 1983).

The present study was designed to investigate further the relative influence of the different polyphenolic-containing beverages on Fe absorption in man, by feeding beverages rich in either phenolic acids (coffee), monomeric flavonoids (herb teas) or complex polyphenol polymerization products (black tea and cocoa). Using the extrinsic tag radio-Fe technique, we have compared the effect of the herb teas, peppermint (Mentha piperita L.), vervain (Verbena officinalis L.), lime flower (Tilia cordata Mill.), pennyroyal (Mentha pulegium L.) and camomile (Matricaria recutita L.), with the influence of coffee, cocoa and different concentrations of black tea on Fe absorption from a bread meal. The effect of adding milk on the inhibitory nature of tea and coffee was also investigated.

**Subjects and methods**

**Subjects**

Eight separate Fe absorption studies were performed in a total of seventy-seven volunteer subjects. Each study contained between eight and ten subjects. The composite group included twenty-three males and fifty-four females ranging in age from 19 to 40 years. All subjects were in good health and denied a history of disorders known to influence the gastrointestinal absorption of Fe. None of the subjects was anaemic although serum ferritin concentrations ranged from 9 to 193 μg/l, indicating a wide variation in Fe status. Five female subjects were Fe-deficient as defined by a serum ferritin concentration ≤12 μg/l. Written informed consent was obtained from each volunteer before the investigation and all experimental procedures were approved by the Human Subjects Committee at the University of Kansas Medical Center.

**Absorption measurements**

Fe absorption was measured using the extrinsic tag radio-Fe technique with $^{55}$Fe and $^{59}$Fe (Cook et al. 1972). The added radio-Fe uniformly labels all the non-haem food Fe in the meal. Fe absorption was measured from different meals labelled with either $^{55}$Fe or $^{59}$Fe and consumed on consecutive days. At 2 weeks after consuming the labelled meals, Fe absorption was estimated from the radioactivity incorporated into circulating erythrocytes.

In our studies four separate Fe absorption measurements were performed in each subject by using radio-Fe tracers administered after an overnight fast and nothing but water was allowed for a further 3 h after the meal was given. The test meals were labelled as previously described (Cook et al. 1972) by adding either 37 kBq $^{55}$FeCl$_3$ or 111 kBq $^{59}$FeCl$_3$ to a 1 ml solution containing 0.1 mg Fe as FeCl$_3$ in 0.01 M HCl.

On the day preceding administration of the first test meal, 30 ml blood was obtained from each subject for measurement of packed cell volume, serum ferritin (Flowers et al. 1986), and background radioactivity. The first and second test meals, labelled with $^{55}$Fe and $^{59}$Fe respectively, were given on days 1 and 2 of the study. At 14 d after administration of the second of these meals (day 16), 30 ml blood was drawn for measurement of incorporated blood cell radioactivity. A third and a fourth test meal tagged with separate radio-Fe labels were given on days 16 and 17 and a final blood sample was obtained on day 31 to determine the increase in erythrocyte radioactivity. Measurements of blood radioactivity were performed on duplicate 10 ml samples of whole blood by a modification of the method of Eakins & Brown (1966). Percentage absorption was calculated on the basis of the blood volume estimated from height and weight (Wennesland et al. 1959; Brown et al. 1962) and an assumed erythrocyte incorporation for absorbed radioactivity of 80% (Hosein et al. 1967).

**Test beverages**

Ten different beverages were used in the absorption studies. The polyphenol and Fe contents of these beverages are shown in Table 1. Total polyphenols were measured in the tea, herb teas and cocoa beverages using the Folin-Ciocalteau method (Singleton & Rossi, 1965) with catechin as a standard. Coffee was analysed for chlorogenic acid by the AOAC method (Association of Official Analytical Chemists, 1990). Fe was determined by atomic absorption spectroscopy after dry ashing.

The Assam tea A (Camellia sinensis L.) and the herb teas, camomile, vervain and lime flower were purchased from local shops in Switzerland. Assam tea B was purchased from a local store in Kansas City as were the herb teas, peppermint A and B and pennyroyal. The instant coffee was Tasters Choice (Nestlé Beverage Company, San Francisco, CA, USA).

The black tea and the herb teas were prepared in an identical way. Boiling water (300 ml) was added to 3 g tea, and the mixture was left to infuse for 10 min before straining and serving. The coffee and cocoa were prepared by adding 2 g and 5 g powder respectively to 275 ml boiling water.

<table>
<thead>
<tr>
<th>Beverage</th>
<th>Polyphenols* (mg/serving)</th>
<th>Iron (μg/serving)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assam tea A</td>
<td>274</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Assam tea B</td>
<td>396</td>
<td>12</td>
</tr>
<tr>
<td>Peppermint A</td>
<td>177</td>
<td>173</td>
</tr>
<tr>
<td>Peppermint B</td>
<td>209</td>
<td>83</td>
</tr>
<tr>
<td>Pennyroyal</td>
<td>121</td>
<td>204</td>
</tr>
<tr>
<td>Vervain</td>
<td>116</td>
<td>NA</td>
</tr>
<tr>
<td>Lime flower</td>
<td>58</td>
<td>NA</td>
</tr>
<tr>
<td>Camomile</td>
<td>52</td>
<td>NA</td>
</tr>
<tr>
<td>Cocoa</td>
<td>116</td>
<td>NA</td>
</tr>
<tr>
<td>Instant coffee</td>
<td>120</td>
<td>66</td>
</tr>
</tbody>
</table>

* For details of analytical methods see p. 290. Polyphenol content of instant coffee is given as mg chlorogenic acid per 275 ml serving, values for all other beverages are given as mg catechin equivalents per 275 ml serving.

**Table 1. Polyphenol and iron contents of test beverages**
Test meals

The four test meals for each of the eight studies are shown in Table 2. In studies 1–3 the inhibitory effects of various herb teas on Fe absorption were compared with the inhibitory effects of black tea and cocoa. Fe absorption from an Fe-fortified bread roll, consumed together with water, was compared with Fe absorption from a similar roll consumed together with either black tea, cocoa, peppermint tea, pennyroyal tea or infusions of vervain, lime flower or camomile. In studies 4 and 5 the influence of the concentration of black tea on Fe absorption was investigated by progressively diluting the full strength tea with water to give 50, 25, 10 and 5 % of the original concentration. Fe absorption from an Fe-fortified bread roll, consumed together with water, was compared with Fe absorption from a similar bread roll consumed together with different concentrations of black tea. In study 6, we studied whether the addition of milk to tea and coffee influenced their inhibitory effects on Fe absorption. Fe absorption from an Fe-fortified bread roll consumed together with black tea or coffee was compared with Fe absorption from a similar bread roll consumed together with tea or coffee plus 30 ml homogenized regular whole milk. In study 7, we investigated whether bread influenced Fe absorption from tea or water and in study 8, we compared the relative inhibitory nature of the different beverages on Fe absorption in the absence of the bread meal.

Except in study 8, all test meals contained 50 g bread, 10 g butter and 275 ml either water, herb tea, black tea, cocoa or instant coffee. In study 8, the beverages only were consumed. Sugar (10 g) was added to all beverages except water. The four test meals for each of the eight studies are shown in Table 2. In studies 1–3 the inhibitory effects of various herb teas on Fe absorption were compared with the inhibitory effects of black tea and cocoa. Fe absorption from an Fe-fortified bread roll, consumed together with water, was compared with Fe absorption from a similar roll consumed together with either black tea, cocoa, peppermint tea, pennyroyal tea or infusions of vervain, lime flower or camomile. In studies 4 and 5 the influence of the concentration of black tea on Fe absorption was investigated by progressively diluting the full strength tea with water to give 50, 25, 10 and 5 % of the original concentration. Fe absorption from an Fe-fortified bread roll, consumed together with water, was compared with Fe absorption from a similar bread roll consumed together with different concentrations of black tea. In study 6, we studied whether the addition of milk to tea and coffee influenced their inhibitory effects on Fe absorption. Fe absorption from an Fe-fortified bread roll consumed together with black tea or coffee was compared with Fe absorption from a similar bread roll consumed together with tea or coffee plus 30 ml homogenized regular whole milk. In study 7, we investigated whether bread influenced Fe absorption from tea or water and in study 8, we compared the relative inhibitory nature of the different beverages on Fe absorption in the absence of the bread meal.

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### Table 2. Iron absorption from test meals consisting of a polyphenol-containing beverage with or without bread

<table>
<thead>
<tr>
<th>Study, no. of subjects, sex and mean age</th>
<th>Serum ferritin† (µg/l)</th>
<th>Meals</th>
<th>Iron absorption‡ (% dose)</th>
<th>Absorption ratio v. meal D (water)‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (n 2M, 7F, 25 years) 34 (9–90)</td>
<td>A Bread, Assam tea A</td>
<td>0.74 (0.57, 0.95)</td>
<td>0.06*** (0.04, 0.07)</td>
<td></td>
</tr>
<tr>
<td>B Bread, peppermint tea A</td>
<td>2.01 (1.50, 2.70)</td>
<td>0.16*** (0.13, 0.19)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Bread, pennyroyal tea</td>
<td>3.53 (2.52, 4.96)</td>
<td>0.27*** (0.23, 0.33)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Bread, water</td>
<td>12.9 (10.7, 15.6)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 (n 5M, 5F, 23 years) 39 (18–144)</td>
<td>A Bread, Assam tea A</td>
<td>0.89 (0.68, 1.16)</td>
<td>0.16*** (0.13, 0.19)</td>
<td></td>
</tr>
<tr>
<td>B Bread, vervain tea</td>
<td>2.32 (1.99, 2.70)</td>
<td>0.41*** (0.37, 0.46)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Bread, lime flower tea</td>
<td>2.71 (2.17, 3.39)</td>
<td>0.46** (0.41, 0.57)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Bread, water</td>
<td>5.63 (4.64, 6.84)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 (n 6M, 4F, 27 years) 61 (13–193)</td>
<td>A Bread, Assam tea B</td>
<td>0.92 (0.72, 1.18)</td>
<td>0.21*** (0.17, 0.25)</td>
<td></td>
</tr>
<tr>
<td>B Bread, camomile tea</td>
<td>2.35 (1.75, 3.14)</td>
<td>0.53*** (0.45, 0.61)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Bread, cocoa</td>
<td>1.29 (1.02, 1.63)</td>
<td>0.29*** (0.26, 0.33)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Bread, water</td>
<td>4.46 (3.47, 5.72)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 (n 3M, 6F, 23 years) 33 (20–59)</td>
<td>A Bread, Assam tea B (100%)§</td>
<td>0.59 (0.45, 0.78)</td>
<td>0.09*** (0.08, 0.11)</td>
<td></td>
</tr>
<tr>
<td>B Bread, Assam tea B (50%)</td>
<td>1.05 (0.72, 1.53)</td>
<td>0.16*** (0.12, 0.21)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Bread, Assam tea B (25%)</td>
<td>1.18 (0.84, 1.66)</td>
<td>0.18*** (0.14, 0.23)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Bread, water</td>
<td>6.58 (4.76, 9.10)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 (n 9F, 22 years) 50 (13–104)</td>
<td>A Bread, Assam tea B (25%)</td>
<td>0.66 (0.45, 0.96)</td>
<td>0.15*** (0.11, 0.21)</td>
<td></td>
</tr>
<tr>
<td>B Bread, Assam tea B (10%)</td>
<td>1.48 (0.99, 2.21)</td>
<td>0.34* (0.25, 0.47)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Bread, Assam tea B (5%)</td>
<td>1.47 (1.03, 2.12)</td>
<td>0.34* (0.27, 0.43)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Bread, water</td>
<td>4.33 (3.31, 5.67)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 (n 1M, 9F, 28 years) 47 (12–76)</td>
<td>A Bread, Assam tea A</td>
<td>0.71 (0.51, 0.98)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>B Bread, Assam tea, milk</td>
<td>0.96 (0.76, 1.20)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Bread, coffee</td>
<td>2.81 (2.04, 3.86)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Bread, coffee, milk</td>
<td>2.88 (2.18, 3.18)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 (n 2M, 8F, 29 years) 35 (12–156)</td>
<td>A Bread, Assam tea B</td>
<td>0.83 (0.56, 1.23)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>B Assam tea B</td>
<td>1.00 (0.73, 1.38)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Bread, water</td>
<td>8.64 (6.00, 12.4)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Water</td>
<td>29.4 (24.4, 35.3)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 (n 4M, 6F, 26 years) 36 (9–48)</td>
<td>A Assam tea B</td>
<td>0.75 (0.58, 0.96)</td>
<td>0.03*** (0.02, 0.03)</td>
<td></td>
</tr>
<tr>
<td>B Peppermint tea B</td>
<td>4.66 (3.41, 6.37)</td>
<td>0.16*** (0.13, 0.21)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Cocoa</td>
<td>1.61 (1.19, 2.18)</td>
<td>0.06*** (0.05, 0.07)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Water</td>
<td>28.5 (21.8, 37.1)</td>
<td>–</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

M, male; F, female.

Mean values were significantly different from one: *P < 0.05, **P < 0.01, ***P < 0.001.

† Geometric mean values with ranges in parentheses.

‡ Geometric mean values with the variance (±1 se, ±1.5 se) in parentheses.

§ Assam tea contained 396 mg polyphenols/275 ml serving, 5–50 % concentrations were made by diluting 100 % Assam tea with hot water and giving as a 275 ml serving.
Dinner Roll, Interstate brand, Kansas City, KS, USA), enriched with FeSO₄ and containing 2·1 mg Fe per 50 g serving, was used. In study 2, a similar commercial FeSO₄-enriched roll (Wonder Brown and Serve Enriched Roll, Continental Bakery Company, St Louis, MO, USA) was used. For study 7, the bread roll was prepared and baked in the laboratory from 60 % extraction non-enriched wheat flour (Nestlé Research and Development Centre, Orbe, Switzerland), salt, sugar, yeast and water. Each 50 g roll contained 2·1 mg Fe, of which 1·72 mg was added as FeSO₄ during preparation.

### Statistical methods

Percentage absorption values were converted to logarithms before performing statistical analysis and the results were re-transformed to antigilogarithms to recover the original units (Cook et al. 1969). Paired tests were used to compare absorption from selected test meals within each study by determining whether the mean log absorption ratios differed significantly from zero.

### Results

There was a wide variation in the total polyphenol content which ranged from 52 mg per serving of camomile tea to 396 mg in one sample of black Assam tea (Table 1). The beverages all contained a small amount of Fe (<4–204 µg/serving) which increased slightly the Fe intake of 2·1 mg coming from the Fe-fortified bread roll.

In studies 1–3 (Table 2) which compared peppermint teas, cocoa and black tea, the black tea had the greatest inhibitory effect on Fe absorption. The Fe absorption ratio of the black tea meals compared with water control meals was 0·06–0·21, with the absolute Fe absorption from the water meal varying from 4·46 % in study 3, to 12·9 % in study 1. All herb teas and cocoa also significantly reduced Fe absorption from the bread meal. Compared with the water control meal, the absorption ratios were: peppermint 0·16, pennyroyal 0·27, cocoa 0·29, vervain 0·41, lime flower 0·48 and camomile 0·53.

Black tea was very inhibitory even at low concentrations. In studies 4 and 5, Fe absorption and the Fe absorption ratio compared with the water meal increased as the tea was progressively diluted. However, even a 5 % concentration of the original black tea, containing only 20 mg polyphenol/serving, still reduced Fe absorption by almost 70 % (absorption ratio compared with the water meal 0·34), demonstrating the potent inhibitory effect of black tea polyphenols on Fe absorption.

The addition of milk had little or no effect on the inhibitory nature of tea or coffee (study 6). Unlike studies 1–5, study 6 did not include a water control meal. Fe absorption from the bread meal with black tea was 0·71 % compared with 2·81 % with coffee. Adding milk to tea increased absorption slightly to 0·96 % (absorption ratio 1·36; P < 0·05) but had no influence on Fe absorption from coffee (absorption ratio 1·04; P > 0·05).

Bread likewise had little influence on the inhibitory effect of black tea although adding it to water greatly reduced Fe absorption (study 7). Fe absorption from black tea and bread was similar to that from tea alone (0·83 v. 1·00 %; absorption ratio 1·21; NS). Fe absorption from bread and water however (8·64 %) was 3-fold lower than from water alone.
(29.4%; absorption ratio 3.40; \( P < 0.001 \)). In the absence of
the bread roll, Fe absorption from black tea, peppermint and
cocoa was still far lower than from water alone, the absorption
ratios being 0.03 for black tea, 0.16 for peppermint and
0.06 for cocoa (study 8).

In Fig. 1, the relative inhibitory effects of the different
polyphenol-containing beverages have been compared by
plotting the polyphenol content of the beverages (mg/
serving) against relative Fe absorption. Fig. 1 also includes
data on red wine from the study of Cook et al. (1995) which
we made using exactly the same methodology. Polyphenols
from the different beverages inhibited Fe absorption in a
dose-dependent fashion and relative Fe absorption from
different concentrations of polyphenols fitted best onto the
curve following a potential law (relative Fe absorption = \( 2 \times 
\) (mg polyphenol/serving)\(^{-0.5}\)). At low polyphenol concentra-
tions (about 50 mg/serving) black tea was more inhibitory
to Fe absorption than the herb teas, camomile and lime
flower, however, at higher polyphenol concentrations (about
200 mg/serving), black tea and peppermint tea were equally
inhibitory. At equivalent polyphenol concentrations, black
tea was more inhibitory than white wine, red wine and cocoa.

Discussion

Plant polyphenols

The functional group of polyphenol compounds is an aro-
matic ring structure with one or more hydroxyl groups, and
at least 5000 different compounds have been described in
plant tissues (Harborne, 1993) including over 2000 naturally
occurring flavonoids. The smaller molecules may poly-
erize either in the plant tissue or during food processing
with the largest polymers having a molecular mass in the
region of 5000 kDa (Gupta & Haslam, 1980). Due to their
widely different structures, the different compounds could
be expected to bind more or less strongly to Fe in the
intestinal lumen and influence Fe absorption in different
ways. Dietary polyphenols can be divided into three main
groups; the phenolic acids, the flavonoids and the complex
polymerization products formed from flavonoids alone or
from a combination of flavonoids and phenolic acids. In
relation to the polyphenol composition of the common
beverages, the main phenolic compound in coffee is caf-
feoyl-quinic acid, or chlorogenic acid, which is a phenolic
acid (Clifford & Ramirez-Martinez, 1991), whereas herb
teas such as peppermint, contain mainly the monomeric
flavonoids (Lallement & Bezanger, 1970). Flavonoids are
also the major phenolics present in green tea leaves, the
cocoa bean and red wine. Green tea flavonoids also contain
gallic acid esters and during fermentation to black tea
complex polymers are formed containing both flavonoids
gallic acid esters (Ballentine, 1991). The flavonoids
present in the raw cocoa bean similarly undergo complex
polymerization processes during fermentation and roasting
(Shahidi & Naczk, 1995), whereas red wine contains all
three classes of polyphenols including phenolic acids,
monomeric flavonoids and a variety of polymerization
products including dimers and trimers (Lunte et al. 1988)
and larger molecules with molecular masses from 2000 to
4000 kDa (Somers, 1966).

Influence of polyphenols on iron absorption

Brune et al. (1989) looked at the relative inhibitory effect of
the different polyphenol structures on Fe absorption. They
measured Fe absorption in subjects given a bread meal to
which they added equivalent amounts of gallic acid, chloro-
genic acid and catechin, as an example of a flavonoid. They
also added increasing amounts of tannic acid, a phenolic
compound containing ten galloyl residues and glucose,
which they used as a model for the larger polymerized
polyphenol structures. Gallic acid, in an amount commonly
found in foods, reduced Fe absorption from the bread meal
by about 50%, compared with 30% for chlorogenic acid
and no effect with catechin. Tannic acid inhibited Fe
absorption in a dose-dependent fashion equivalent to its
content of gallic acid.

Our results indicate that all major types of food poly-
phenols can strongly inhibit dietary non-haem Fe absorp-
tion. The inhibitory phenolic compounds would appear to
include phenolic acids, such as chlorogenic acid from
coffee, monomeric flavonoids such as found in herb teas,
and the complex polymerization products found in black tea
cocoa. We have previously demonstrated a similar
inhibitory effect of red wine on Fe absorption from an
identical bread meal (Cook et al. 1995). Our results agree
only in part with those of Brune et al. (1989) who, using
model compounds, demonstrated that phenolic acids, such
as gallic acid and chlorogenic acid, inhibited Fe absorp-
tion from a bread meal. However, these workers could show
no effect of the monomeric flavonoid catechin on Fe absorp-
tion, and they suggested that flavonoids and their polymers
would not interfere with Fe absorption in man. Our results
with cocoa, red wine and herb teas would not support this
conclusion.

Our results (Fig. 1) indicate that black tea polyphenols are
more inhibitory than the polyphenols from herb teas, cocoa
or wine. This could be due to their higher content of galloyl
esters. Unlike the different concentrations of Assam tea, the
different concentrations of herb tea represented in Fig. 1
would be expected to contain different types of polyphenols
and this could explain the less clear relationship that was
obtained between polyphenol concentrations and relative Fe
absorption for herb teas than was obtained for Assam tea.
Despite these differences, our results would indicate that
any beverage providing 20–50 mg total polyphenols would
reduce Fe absorption from a bread meal by 50–70%,
whereas beverages containing 100–400 mg total polyphenols
would reduce Fe absorption by 60–90%. Other workers
have also demonstrated a dose-dependent inhibitory effect of
polyphenols on Fe absorption either with model compounds
such as tannic acid (Brune et al. 1989; Siegenberg et al. 1991)
or with a green leafy vegetable (Tuntawiroon et al. 1991).

Based on these findings, it is tempting to suggest that the
approximate inhibitory effect of a food or a meal on Fe
absorption can be predicted by measuring its content of total
polyphenols, and that it would not be necessary to specify
the levels of different types of polyphenols. Our studies,
however, were made using a simple bread meal and it may
not be possible to extrapolate our results directly to more
complex meals containing a wider range of Fe absorption
inhibitors and enhancers. While both tea and coffee have
been shown to strongly inhibit Fe absorption from both simple bread meals and more complex composite meals (Hallberg & Rossander, 1982; Morck et al. 1983), red wine had little influence on Fe absorption from a composite meal containing meat and vegetables (Hallberg & Rossander, 1982). There is a possibility, therefore, that herb teas and cocoa may similarly have a less inhibitory effect on a composite meal even though they strongly reduced Fe absorption from the bread meal. The explanation could lie in the interactions that take place between the inhibitors and enhancers of Fe absorption in the intestinal tract, and it could be that the enhancers of Fe absorption, such as ascorbic acid and muscle tissue, are more or less effective depending on the type of polyphenol present.

**Influence of milk on iron absorption from tea or coffee**

In study 6 (Table 2) we also investigated whether adding milk to coffee or black tea, as is the custom in many countries, could decrease their inhibitory effect on Fe absorption. Some polyphenols are well known to bind strongly to proteins (Hagerman & Butler, 1981; Kumar & Singh, 1984), and it was hypothesized that such binding might prevent the polyphenols from complexing with Fe. Unfortunately this did not seem to be so, and there was little or no improvement in Fe absorption from the bread meal with tea or coffee when milk was added. As in other studies (Hallberg & Rossander, 1982; Morck et al. 1983), we found coffee to be less inhibitory to Fe absorption than tea.

**Iron absorption from beverages alone**

Assam tea, peppermint tea and cocoa inhibited Fe absorption by 84–97 % in the absence of the bread roll (study 8, Table 2). This is much higher than the 20–25 % inhibition reported for red wine in our previous study (Cook et al. 1995) but indicates that a polyphenol–Fe complex was formed in the intestinal lumen and that Fe within the complex was unavailable for absorption. We had hypothesized that perhaps the peptide degradation products formed on the digestion of wheat proteins might also be necessary to form a polyphenol–Fe–peptide complex. Percentage Fe absorption from black tea with bread (0.83 %) (study 7, Table 2) was slightly but not significantly (P > 0.05) lower than from black tea alone (1.00 %). Although the white bread rolls would be expected to contain little or no phytic acid, Fe absorption from water was reduced from 29.4 to 8.6 % when consumed with bread. This could be due to the presence of the digestion products physically reducing access of Fe to the brush-border cells.

**Influence of polyphenolic-containing beverages on iron status**

In relation to public health, the important question is whether regular consumption of polyphenol-containing beverages could influence Fe status. Tea-drinking by infants in Israel (Merhav et al. 1985) and coffee-drinking by pregnant women in Costa Rica (Munoz et al. 1988) have been shown to have a negative effect on Fe status. However these population groups presumably consume a more simple and less varied diet than do people in the USA or Europe. In the USA, coffee and tea drinking could not be found to contribute significantly to the 5.3 % anaemia that was diagnosed in the >11 000 participants of the Second National Health and Nutrition Education Survey (NHANES II) (Mehta et al. 1992). Polyphenol-containing beverages, however, do strongly inhibit Fe absorption in the single meal studies and, even though this inhibition may be less pronounced when averaged over the many meals of a whole diet (Cook et al. 1991), it would still seem wise to consider this property when giving dietary advice to individuals who are most susceptible to developing Fe deficiency. On the other hand, the consumption of polyphenol-containing beverages, and in particular black tea with meals, could be a useful strategy in reducing Fe absorption in patients with Fe overload disorders (deAlareon et al. 1979).

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**References**


