Impact of tea drinking on iron status in the UK: a review

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Abstract

Background The aims of this review are (1) to evaluate the literature on the likely impact of tea drinking on the iron status of different groups within the UK population and (2) to formulate targeted and evidence based advice on tea drinking in the context of iron nutrition in different groups of people.

Method A literature search identified 35 references specific to the effects of black tea on iron absorption and iron nutrition plus one recent review article. Each study was assessed in terms of methodological quality and relevance to the tea drinking patterns of the UK population.

Results There is clear evidence to show that tea drinking limits the absorption of nonhaem iron. However, there are few studies which have assessed the influence of tea drinking on indicators of iron status. There are no intervention studies and the conclusions reported in this review are based on 12 observational studies mostly from other countries. These studies have reported either significant negative correlations between tea drinking and blood indicators of iron status or more cases of anemia in tea drinkers compared with nontea drinkers. Many of the studies reviewed report additional relationships between iron status indices and other factors (both dietary and nondietary), highlighting the complexity of influences on iron absorption and iron status.

Conclusion From the available evidence there is no need to advise any restriction on tea drinking in healthy people with no risk of iron deficiency. In groups at risk of iron deficiency the advice should be to drink tea between meals and to wait at least 1 h after eating before drinking tea.

Introduction

Poor iron status is common in certain groups in the UK. Data from the National Diet and Nutrition Surveys (NDNS) and the 2000 Health Survey for England indicate that iron deficiency anaemia affects 8% of preschool children, between 10 and 20% of adolescent girls, around 16% of

premenopausal women and 11–30% of men and 9–20% of women over 65 years (Gregory *et al.*, 1990, 1995; Doyle *et al.*, 1999; Gibson, 1999; Falaschetti *et al.*, 2002).

The cut-off for defining anaemia varies with age. The World Health Organization (WHO) (2001) defines anaemia as a haemoglobin levels less than 11–11.5 g dL^{-1} in children under 12 years, 12 g dL^{-1} in adolescent boys and girls 12–14 years and nonpregnant adult women, 11 g dL^{-1} in pregnant women and 13 g dL^{-1} in men. Iron deficiency (with or without anaemia) is defined as a serum ferritin of less than 15 μg L^{-1} (less than 12 μg L^{-1} under 5 years of age) and is also widespread. Teenage girls and premenopausal women are particularly at risk (British Nutrition Foundation, 1995).

The causes of iron deficiency are multifactorial and include low dietary iron intake, poor iron bioavailability, and increased iron requirements due to physiological demands (menstruation and growth) (Hambraeus, 1999). Adaptation plays an important role (Cook, 1990), as iron absorption increases in the face of poor iron status (Gavin *et al.*, 1994) or increased physiological demand during pregnancy, lactation or growth spurts (Hallberg *et al.*, 2000).

Dietary factors influencing iron absorption are outlined in Table 1. Haem iron (mainly from animal sources) is better absorbed than nonhaem iron and its absorption is generally unaffected by other meal components or by the iron status of the individual. In contrast, nonhaem iron interacts with dietary constituents such as polyphenols, phytates, some proteins and amino acids, dietary fibre and other inorganic elements making it less soluble and hence less available than haem iron (FAO/WHO, 1988). In the average UK diet, iron is principally derived from cereal products (42%), meat and meat products (23%) and vegetables (15%) [Ministry of Agriculture, Fisheries and Food (MAFF), 1994]. Only about 40% of iron from animal sources is haem iron. Thus, approximately 90% of dietary iron in the UK is nonhaem iron. Currently it is estimated that between 10 and 15% of dietary iron is bioavailable, but variation within this range will depend on relative proportions within the diet of meat, phytate and other factors affecting nonhaem iron absorption (FAO/WHO, 1988).

Table 1 Factors influencing dietary iron absorption

Haem iron absorption
Amount of haem iron present in meat
Content of calcium in meal
Food preparation (time, temperature)
Nonhaem iron absorption
Iron status of subjects
Amount of bioavailable nonhaem iron (adjustment for fortification iron and contamination iron)
Balance between dietary factors enhancing and inhibiting iron absorption
Factors enhancing iron absorption
Ascorbic acid
Meat, fish seafood
Certain organic acids (citric, lactic, malic, tartaric)
Factors inhibiting iron absorption
Phytates in cereal products
Iron binding phenolic compounds in tea, coffee, red wine, some leafy vegetables, herbs, nuts and legumes
Calcium
Soy protein

Source: Hallberg *et al.* (2000).

It has been long known that tea has a negative impact on the absorption of nonhaem iron in the diet because of its polyphenol content (Disler *et al.*, 1975). Polyphenols are also found in coffee, red wine and some leafy vegetables, legumes, nuts and herbs. The UK is a tea drinking nation. Data from the National Drinks Survey (Unilever Best Foods UK, 2000) suggests an average tea consumption of 2.6 cups per day, but this has been declining gradually over the last three decades, particularly in younger groups (under 25 years) due to the shift towards consumption of soft drinks. Tea represents just under 10% of total beverage consumption in younger children (2–9 years). This proportion increases steadily with age to around 60% in people aged 65 years and over. These data accord with findings from the NDNS. Around one-third of preschool children, 50% of school age children, 90% of adults rising to 95% of the over 65 years reported drinking tea at least once during a 4-day period (Gregory *et al.*, 1990, 1995, 2000; Finch *et al.*, 1998).

The purpose of this review is to summarize the evidence currently available concerning the effect of tea drinking on iron status in the UK population in order to formulate evidence based guid-

ance concerning tea drinking in the context of iron nutrition in different groups of people. The present review addresses three fundamental questions:

1 What evidence is there that tea inhibits *iron absorption*?

2 In the context of UK eating habits, what evidence is there that tea drinking is associated with *poor iron status*?

3 In the UK, how important is tea drinking as a cause of poor iron status, *given other factors* that influence iron status?

Methods

Between April 2001 and February 2002 searches of Medline and Web of Science databases were carried out to identify recent literature concerning tea drinking and iron status. Key words were tea, iron status, absorption, and (food or nutrition or diet). Searches were made for papers published since 1980. Thirty-five references were identified with specific reference to the effects of black tea on iron status of human subjects. Black tea (as opposed to green or oolong) is the type of tea normally consumed in the UK. Animal and *in vitro* studies were excluded. All of the remaining studies identified that provided relevant details of the relationships between tea drinking and iron status in humans were published in peer-reviewed scientific journals. The smallest studies involved only 15 or 20 subjects but were included because of the detail regarding diet–status relationships or were conducted in highly controlled environments. The remaining studies involved hundreds or thousands of subjects from large scale surveys. The majority of the studies are cross-sectional (assessing iron status and dietary intake in individuals at the same point in time) unless otherwise noted in the text. One recent review article was also identified.

Information on tea consumption in the UK was derived from the NDNS (Gregory *et al.*, 1990, 1995, 2000; Finch *et al.*, 1998) and the National Drink Survey (xxx, 2000). Information on nutrient intakes and iron status was derived mainly from the NDNS. Library searches were conducted for recent texts on iron, tea, polyphenols and flavonoids. Lists of relevant publications were also provided by Unilever Bestfoods UK.

Results

Effect of tea drinking on iron absorption

Studies using well accepted test meal protocols have consistently demonstrated an inhibitory effect of tea consumption on iron absorption. Following an overnight fast, subjects consume single meals labelled with iron radiotracer and percent absorption is determined 2 weeks later. Absorption of iron from a basal 'western breakfast' was 0.07 mg with 150 mL moderately strong black tea compared with 0.16 mg with coffee and 0.40 mg with orange juice (Rossander *et al.*, 1979) when assessed in a series of studies of between 12 and 21 men and women age 17–46 years. Similar findings were shown for a hamburger meal with 250 mL of strong tea (Hallberg & Rossander, 1982) and for wheat rolls served with 150 mL of medium strength tea (Brune *et al.*, 1989). Hurrell *et al.* (1999) demonstrated a profound inhibitory effect of tea on iron absorption from a bread meal (79–94%). Parallel tests on green tea resulted in a decreased nonhaem absorption from a pasta meal from 12.0 ± 4.5 to $8.9 \pm 5.2\%$ ($P < 0.01$) in the presence of green tea extract (Samman *et al.*, 2001).

Results from Dislers's initial investigation are summarized in Fig. 1 (Disler *et al.*, 1975) and suggest that tea's inhibitory effect is tempered by both the meal matrix and its components. In 12 volunteers, absorption of nonhaem iron from meals consumed with water was 10–13% but only 2–3% when the same foods were consumed with 200 mL moderately strong tea served either with 40 mL whole cows milk or an additional 40 mL of water. Ascorbic acid (100 mg) enhanced absorption from aqueous solution (41%) but did not overcome the effects of tea (13%). Adding milk to tea allowed more iron to be absorbed (16%), but milk itself inhibited absorption from solution with added ascorbic acid compared with water (19% versus 41%). Tea did not affect the absorption of cooked haem iron (constant around 14%).

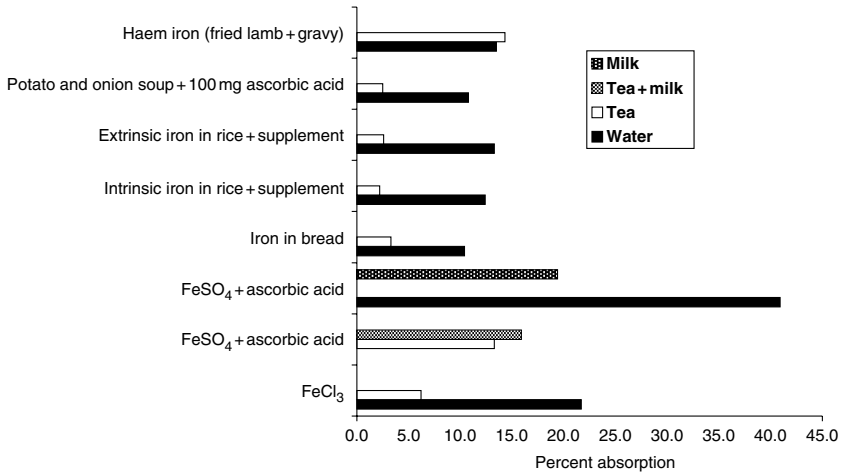

Figure 1 Effect of tea on haem and nonhaem iron absorption.

It is doubtful, however, that results relating to single test meals reflect iron absorption from complete diets (Powell *et al.*, 1994; Hunt, 2001). The method has been criticized for not reflecting normal conditions, as the meals were usually given as the first meal of the day after an overnight fast (Benito & Miller, 1998). Thus Cook *et al.* (1991) introduced a method of labelling the complete diet during a 2-week period. Their results indicated a less pronounced effect (2–5-fold) of the most enhancing diet when compared with inhibitory diets, while a sixfold difference was observed between the two diets using the single meal technique. The results from the single meal technique may exaggerate the effect of inhibitors and enhancers.

A number of studies have attempted to derive algorithms for estimating the influence of a number of different factors known to affect bioavailabilty. Reddy *et al.* (2000) showed that after controlling for iron status, animal tissue was positively correlated with nonhaem iron absorption ($r = 0.34$) and that phytic acid, calcium and polyphenols were negatively correlated ($r = -0.30$, -0.38 and -0.16, respectively). In a multiple regression analysis, animal tissue, phytic acid and ascorbic acid were significantly associated with iron absorption. The percentage of variation in iron absorption explained was 9.17, 8.65 and 1.8%, respectively. No analysis of the specific effect of tea was undertaken, although of course tea is likely to be the primary source of polyphenols. However, these estimations were based on single meal test results and iron absorption was measured using extrinsically labelled iron. Cook *et al.* (1972) demonstrated that extrinsically labelled iron provides a good approximation of the absorption of intrinsic iron, although some of the variability in the absorption of intrinsic iron may not be fully captured using extrinsically labelled iron as the basis for measurement.

Hallberg & Hulthen (2000) examined the influence on iron absorption of phytate, polyphenols, ascorbic acid, meat, fish and seafood, calcium, egg, soy protein and alcohol. In extensive analyses, they demonstrate that even in the context of a whole diet, a 150 mL cup of strong black tea taken within an hour of a meal will reduce absorption by 75–80%, although other factors (e.g. ascorbic acid) can partially compensate for this effect. Black tea is almost twice as inhibiting as green tea or peppermint tea and over three times as inhibiting as herbal tea.

Zijp *et al.* (2000) compared a number of models for estimating iron absorption from test meals and whole diets. In a proposed new model, they identify a factor associated specifically with tea drinking (60% inhibition of absorption when at least 150 mL of tea is consumed with a meal), as well as other inhibiting dietary factors (phytate, coffee and calcium consumed in the meal) and

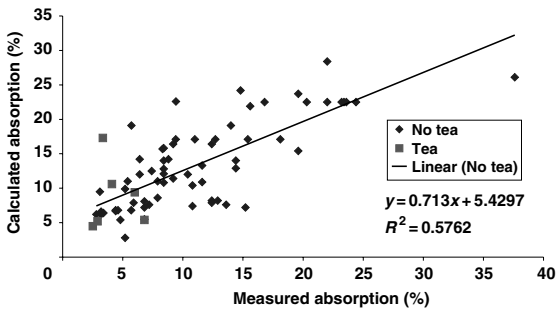

Figure 2 Calculated versus measured iron absorption showing values for test meals with or without tea (source: Zijp *et al.*, 2000).

enhancing factors (animal tissue and ascorbic acid). Fig. 2 shows a plot of the calculated versus measured iron absorption results for 72 test meals, six of which included tea, based on a summary of work by a number of authors given in the Appendix to the Zijp paper. The iron content of the meals ranged from 1.4 to 6.9 mg, the majority being in the range 2–4 mg. It can be seen that the percentage of measured absorption in test meals without tea ranges from 2.8% (wheat rolls plus 250 mg phytate) to 37.6% (wheat rolls plus 50 mg ascorbic acid). For test meals with tea, the range of measured absorption was 2.5% (wheat rolls plus 150 mL tea) to 6.8% (wheat rolls plus 150 mL tea plus 150 mL orange juice). Tea provided the greatest inhibition of iron absorption compared with all other inhibitors, and adding ascorbic acid (orange juice) only partly compensated. The linear regression line shows that the model slightly underestimates measured absorption (especially at higher values) but accounts for 58% of the variation in measured absorption ($R^2 = 0.576$). The model tends to overestimate the percentage iron absorption from test meals containing tea.

Effect of tea drinking on iron status

The following section discusses evidence relating to the effects of tea drinking on iron status in different age groups.

Preschool children

Three analyses of the NDNS data on 1675 children aged 1.5–4.5 years provide insight into the relationship between tea drinking (based on 7d weighed records of consumption) and iron status in preschool children in the UK. Gibson (1999) found that above median consumption of cereal (especially fortified breakfast cereal) coupled with above median consumption of meat and ascorbic acid was associated with higher iron status. This study also revealed a weak but statistically significant negative correlation ($r = -0.09$, $P < 0.007$) between log ferritin values and tea intake. Watt *et al.* (2000) focused on the nutritional impact of drinks consumption. They found that the diets of tea drinkers (37%) were lower in iron and vitamin C than those of nontea drinkers ($P < 0.005$). They had lower levels of haemoglobin ($P < 0.05$) but not ferritin. Children under 4 years old were less likely to meet the RNI for iron if they were tea drinkers ($P < 0.005$) but no more likely to have low blood ferritin levels. The authors point out that the iron status indices should be interpreted with caution due to methodological aspects of the data collection in this study. They conclude that iron absorption in this group was put at risk because of tea drinking coupled with low iron and vitamin C intakes of the tea drinkers.

Thane *et al.* (2000) found iron status measures to be positively associated with meat and citrus consumption and negatively associated with milk and milk products, even after controlling for age, gender, sociodemographic variables, energy intake and body weight. The authors concluded that milk was displacing other iron rich foods to the detriment of iron status. Similarly, Cowin *et al.* (2001) describe the association between food and nutrient intakes based on 3d unweighed food records at 18 months in 796 children taking part in the Avon Longitudinal Study of Pregnancy and Childhood (ALSPAC) and iron status measures. They described a negative association with milk consumption and ferritin levels and a positive association with meat and fruit and vegetable consumption. Neither paper describes a significant association between iron status and tea drinking.

Two smaller studies similarly implicate tea drinking as an aggravating factor in the aetilogy of iron deficiency in very young children. Amongst 122 apparently healthy Israeli children aged 6–12 months, prevalence of anaemia

(Hb < 11 g dL^{-1}) was 48.4%; prevalence of confirmed microcytic anaemia (Hb < 11 g dL^{-1} and MCV < 70 μm^3) was 19% (Merhav *et al.*, 1985) Prevalence of microcytic anaemia amongst tea drinkers however, was significantly greater (32.6%) than amongst nontea drinkers (3.5%). The daily amount of tea drinking was 50–750 mL (median 250 mL) assessed by 24 h recall with the mother and an estimate of usual frequency of tea consumption. This association persisted after allowing for differences in social class and age between the two groups.

In a similar study in New Zealand children aged 9–23 months admitted to hospital for nondietary disorders (e.g. infections, wheeze), 29% were identified as anaemic (Wilson *et al.*, 1999). Diet was assessed by interview with the parents. Prolonged breast feeding, early introduction of cow's milk and delayed introduction of meat, and daily tea drinking were factors associated with increased risk of anaemia. Rates were higher in children of non-European family origin.

Adults

There has been no systematic analysis of NDNS adult data of the effect of tea drinking in the context of other factors that affect the risk of anaemia. However, the analysis by Doyle *et al.* (1999) found that tea drinking (assessed by 4d weighed record) was statistically negatively associated with mean corpuscular volume in men and women over 65 years and with mean cell haemoglobin in men. In this study, other potential factors both dietary and nondietary were not fully taken into account and so it is difficult to isolate the relative importance of tea drinking in overall context. This is highlighted in a further study of this age group showing lower consumption of total iron (haem and nonhaem) and ascorbic acid and higher intakes of calcium, dietary fibre, tea and coffee intakes in 19 healthy subjects aged 60 and over with low iron stores compared with 108 subjects with good iron status (Roebothan & Chandra, 1996). Diet was assessed using three 24 h recalls.

These findings are in contrast to a large scale study, which failed to demonstrate any significant association between tea drinking and serum ferritin concentrations in an elderly sample of the Framingham Heart Study (Fleming *et al.*, 1998). A total of 634 free living elderly 67–93 years of age reported usual food consumption over the previous year using a food frequency questionnaire. Haem iron, supplemental iron, dietary vitamin C and alcohol were positively associated with serum ferritin, whereas coffee intake had a negative association. It is possible that coffee was a significant source of iron binding polyphenols in this American group of elderly people where tea intake was only seven to eight cups per week in 55% of the sample.

Throughout the NDNS reports, analysis by social class shows the greatest dietary differences between subgroups and is therefore most likely to reveal an effect of diet on iron status. Table 2 shows intakes of iron, vitamin C, and tea by age, gender and social class, together with iron status measures (mean values for Hb and ferritin). The data show that mean intakes of iron and vitamin C are consistently lower in Manual than in nonmanual social classes. Tea consumption is higher in nonmanual social class children (by about 200 g $week^{-1}$) but higher in Manual social class adults (by 369 and 541 g $week^{-1}$ in women and men, respectively). The differences in consumption are small, but there are virtually no differences in mean haemoglobin levels. Ferritin values are in fact higher in Manual social class males age 4–64 years (in spite of lower intakes of iron and vitamin C). Tea intakes in Manual social class males are lower in the male children but higher in the adults. More consistent with the dietary data, ferritin values are lower in females 16 and over and in men and women age 65 years and over. The mean values here are likely to conceal differences in the distribution of dietary intakes and iron status measures between rich and poor, and the extent to which tea drinking per se may contribute to poor iron status needs investigation. The data were based on published findings and not analysed specifically for this review. These analyses also need to take into account the likely under-reporting of diet, more prevalent in Manual social class households (Pryer *et al.*, 1994). Thus, there is no clear evi-

Table 2 Social class differences in diet and blood iron measures, by age and gender. National Diet and Nutrition Surveys, UK

	Diet								Blood			
	Iron (mg day^{-1})†		Vitamin C (mg day^{-1})		Tea (g week^{-1})		% who drank tea		Hb (g dL^{-1})		Ferritin (μg L^{-1})	
Age (years) Social class*	NM	M	NM	M	NM	M	NM	M	NM	M	NM	M
1.5–4.5	5.7 (5.1)	5.4 (5.2)	49.9	37.7	559	767	29	44	12.2	12.1	25	22
Males												
4–18	10.7 (10.3)	10.3 (9.8)	84.6	67.4	1324	1116	41	48	13.5	13.6	36	42
16–64	14.7	13.5	90.5	60.6	3538	3907	87	87	14.8	14.8	103	112
65 and over	12.4 (11.7)	10.9 (10.2)	85.6	60.3	4347‡	4785‡	96‡	94‡	14.6	14.5	134	112
Females												
4–18	8.5 (8.2)	8.2 (7.8)	80.0	64.3	1392	1060	46	49	13.0	12.9	31	31
16–64	13.0	11.7	90.4	55.4	3275	3816	87	90	13.2	13.3	49	44
65 and over	9.5 (9.0)	8.4 (7.9)	85.2	54.2	4347‡	4785‡	96‡	94‡	13.5	13.5	84	79

*NM, nonmanual; M, manual.
†Iron intakes are from all sources (food plus supplements). Values in brackets show nonhaem iron intakes.
‡For men and women combined: values in report not given separately by gender.

dence from the NDNS that the higher levels of tea consumption found in Manual social class households are specifically associated with poorer iron status.

In the USA, Mehta *et al.* (1992) found a negative association between total cups of coffee and tea consumed and risk of anaemia in participants in the NHANES II study (i.e. the more coffee and tea consumed the lower the risk of anaemia). The data were based on a single 24 h recall of diet, and the range of consumption from 0–35 cups of coffee and 0–20 cups of tea per day. Data based on a single day will be less representative of usual intakes, and the extraordinarily high values for some subjects suggest a degree of unreliability in some of the dietary data. The inverse association between tea and coffee consumption and risk of anaemia cannot be regarded as a robust finding. The authors suggest that any inhibition of iron absorption by tea and coffee may have been negated by higher consumption of iron and vitamin C in those subjects, but there is no clear evidence for this interpretation. There was no analysis looking at the effect of tea alone. Root *et al.* (1999) found no association between measures of iron status and tea consumption (based on 3 day records of consumption) in 405 women age 32–66 years in China, but the method of dietary assessment (interviewer weighing of selected foods before and after meals) may not have provided robust data on iron intakes. Moreover, most tea drunk in China is green tea, so there is less relevance to an understanding of the effect of black tea drinking in the UK.

In contrast, Razagui *et al.* (1991) showed that in a group of 15 closely observed long-stay mentally handicapped women aged 19–43 years, meal time tea drinking (based on 7 day weighed inventories of diet kept by an independent observer) was strongly negatively associated with serum ferritin levels ($r = -0.67$, $P < 0.0025$), especially amongst those with poor iron status. The six women in the anaemic group had significantly higher intakes of tea at meal time (563 mL versus 184 mL) and lower intakes of vitamin C, whereas energy, iron, and coffee intakes did not differ. Menstrual iron loss, a potential confounder, was not measured. This suggests that more robust dietary measurements are likely to reveal an effect of tea on iron status in the context of entire diets (not just test meals). Similarly, Galan *et al.* (1985) showed in a simple univariate analysis a negative correlation between serum ferritin levels and tea consumption ($r = -0.18$, $P < 0.05$) in a group of French female students. Food consumption was measured by trained interviewers using diet histories. In a study of 3525 Kazakhstani women, iron deficiency anaemia (Hb < 12 day dL) was detected in 40.2% of the sample (Dangour *et al.*, 2001). Significant negative associations were found between haemoglobin concentrations and the duration of menses, use of the intrauterine contraceptive

device and the consumption of tea assessed by diet history interview.

Vegetarians

In a comparison of Australian adult male ovolactovegetarians (39) and vegans (10) with omnivores (25), Wilson & Ball (1999) report lower mean haemoglobin (14, 15.8 and 17.3 g dL^{-1}, respectively) and serum ferritin levels (64, 65, and 121 μg L^{-1}) in spite of higher iron intakes (20.4, 22.9, and 15.8 mg L^{-1}), based on 12 day semi-quantitative food records. They attribute the lower iron status to lack of animal products and higher intakes of phenolic compounds in spite of higher vitamin C intakes. Tea was not reported as a separate influence on status. A group of 50 Australian vegetarian women had significant lower serum ferritin levels (25.0 ± 16.2 μg L^{-1}) compared with meat eating controls (45.5 ± 42.5 μg L^{-1}) although similar numbers of vegetarians (18%) and omnivores (13%) had serum ferritin concentrations <12 μg L^{-1}. Both groups had similar iron intakes when assessed using 12 day weighed records, although haem iron intake was greater in vegetarians (Ball & Bartlett, 1999). Again, tea was not implicated as a determinant factor in this study.

In contrast, in a group of 21 premenopausal American women taking part in an 8 week crossover intervention trial of ovolactovegetarian versus omnivore diets, mean haemoglobin and ferritin levels did not differ between dietary groups at the end of each phase of the study in spite of lower absorption of iron on the vegetarian diets (1.1% versus 3.8%) (Hunt & Roughead, 1999). The authors attribute the similarity in iron status to an adaptive response, which limits faecal losses of ferritin, but there was no analysis of the effects of tea drinking on iron status.

The conclusion from the available evidence is that vegetarians in the UK on average have worse iron status than omnivores, nor that tea drinking in vegetarians is a contributor to poor iron status to any greater extent than it is in omnivores on similar intakes of iron and other dietary factors relating to iron absorption.

Discussion

The findings presented in this review confirm the inhibitory effect of tea drinking in test meals on nonhaem iron absorption. Given this evidence, it is not unreasonable to assume that tea drinking may in turn have an impact on body iron status. However, the complexity of the factors that affect nonhaem iron absorption (including, for example, the timing of the consumption of tea drinking in relation to consumption of dietary sources of nonhaem iron as well as iron stores themselves (Gavin *et al.*, 1994)) and markers of iron status make it very difficult to disentangle the effects of tea drinking *per se*. The best observed data (Razagui *et al.*, 1991) suggest that there is an association between tea drinking and poor iron status. The findings may not be wholly relevant, however, to noninstitutionalized free-living human populations. Population-based studies provides some evidence of the effect of tea drinking on iron status, but it is less consistent, and the effects of adaptation and genetic influences (for example, the HFE gene mutations H63D and C282Y that strongly predispose to haemochromatosis in homozygous individuals (Kaltwasser *et al.*, 1998)) have not been explored. Moreover, there are no analyses of population based data which focus on the timing of consumption of meals and tea drinking that take genetic characteristics into account.

The question as to whether tea drinking is a determinant factor in the development of poor iron status in the UK is still open to question. Analysis of the most representative UK data (NDNS) provides mixed results regarding the effects of tea drinking on iron status. Significant negative correlations were observed between tea drinking and indices of poor iron status in preschool children and the elderly. Analysis of the NDNS data by socioeconomic status based on published findings, however, did not show significant differences in iron status between higher tea drinkers and lower tea drinkers (Table 2). Ecological data are generally less robust than individual correlation analyses, and this may in part account for the apparent inconsistency in the results.

Table 3 Mean iron intake (mg day^{-1}), percentage subjects below the LRNI or RNI, and percentage of subjects below cut off points for anaemia and low ferritin

	Diet						Blood			
	Intake (mg day^{-1})*		% <LRNI		% <RNI		Hb cut-off†		Ferritin <15 μg L^{-1}	
Age (years)	M	F	M	F	M	F	M	F	M	F
1.5–2.5	5.0		24		89		12		28‡	
2.5–3.5	5.6		12		84		6		18‡	
3.5–4.5	6.2	5.9	7	9	70	75	4	8	16‡	14‡
4–6	8.3	7.4	<1	1	14	28	3	8	11	9
7–10	9.8	8.5	1	3	39	59	4	16	6	2
11–14	10.8	9.1	3	44	60	100	8	4	5	14
15–18	12.6	8.9	2	48	43	100	<1	9	2	27
16–24	13.0	11.8	–	–	36§	93§	2¶	21¶	2**	13**
25–34	14.1	11.1	–	–	12§	89§	2¶	24¶	1**	13**
35–49	14.5	12.9	–	–			2¶	23¶	2**	21**
50–64	14.1	12.9	–	–	12§	34§	2¶	13¶	2**	5**
65–74	11.9	9.3	<1	4	25	52	7	6	5	6
75–84	11.1	8.5	2	6	32	58	16	13	6	12
85 and over	10.6	7.9	4	10	35	68	37	16	7	14

*Iron intakes are from all sources (food plus supplements).
†Cutoff = 11.0 g dL^{-1} for children under 6 years, 12.0 for girls and adult females, 12.0 for boys 7–15, 13.0 for adult males.
‡Ferritin <10 μg L^{-1} for children under 4 years.
§Age groups are: 16–18 years, 19–50 years and 51–64 years.
¶Values show percent below 12.5 g dL^{-1}.
**Ferritin <13 μg L^{-1}.
–, Data not given in published report.

Of course, these inconsistent findings have their roots in the complex aetiology of iron deficiency. This is illustrated by comparing data on iron intake with prevalence of iron deficiency. Table 3 summarizes by age and gender mean iron intake, and percentage with iron intakes below the Dietary Reference Values (Department of Health, 1991) or with blood measures indicative of poor iron status (WHO, 2001). There is an apparent association between low iron intake [even allowing for under-reporting (Pryer *et al.*, 1994)] and a high proportion of women with low haemoglobin and low ferritin levels. This implies a direct relationship between poor iron status and insufficient intake of dietary iron. Simple correlations between blood analytes and dietary iron intakes are generally nonsignificant, however, reinforcing the notion of a more complex interaction of factors influencing iron status. Nevertheless, there are examples in which individual dietary factors and iron status measures are correlated. In the analysis of the elderly sample of the NDNS data carried out by Doyle *et al.* (1999), for example, intakes of alcohol, vitamin C, protein, haem and nonhaem iron and fibre were positively associated with iron status. Consumption of meat, fish, poultry, vegetables and potatoes were positively associated with measures of iron status, and calcium, dairy foods and tea were negatively associated.

It is not clear whether tea drinking is a marker of other dietary practices which lead to poor iron status or whether tea has an independent detrimental effect on haemoglobin and ferritin levels. If tea drinking is associated with poverty, early weaning, under-nutrition, low consumption of animal products, parasitic infections and duration of menses (British Nutrition Foundation, 1995) then it would also appear to be associated with poor iron status. Moreover, there are no published analyses of population based studies from any country that take into account the influence of genetic factors on iron absorption and iron status in the context of dietary and nondietary factors. Thus, it is difficult to quantify the relationship between tea drinking and iron status in the absence of long-term randomized controlled trials.

Findings from studies in developing countries are less relevant to a discovery of the influence of tea drinking on iron status in the UK.

Finally, it is important to consider the sensitivity of blood markers of iron status. Serum ferritin concentrations correlate well with body stores and it is therefore a good indirect indicator of an iron deficient state. It responds slowly to dietary change (Hunt & Roughead, 2000), however, and may not be useful in helping us to understand about the role of adaptation. Haemoglobin and red cell indices, on the other hand, tend to show overlap between normal and iron deficient subjects and thus are less useful as indicators of the associations between dietary intake and iron status.

More work needs to be done to elucidate the role of tea drinking in iron nutrition in the UK. The NDNS of the UK now include studies at all ages in the population. A new survey on adults has recently been completed. These data are ideal for further analysis of the effects of tea drinking on iron status, as they include data on food consumption, nutrient intake, and iron status. In addition, they could provide a basis for estimating total polyphenol consumption and for looking at the influence of these substances from tea and other sources on iron status and other aspects of health. They also have the potential for the analysis of genetic influences on iron status.

Conclusions and practical guidance

There is consistent evidence from test meal studies showing that tea drinking inhibits the absorption of nonhaem iron. Population studies, on the other hand, reveal less consistent associations between tea drinking and iron status. There is some agreement in findings of negative correlations between tea drinking and blood markers of poor iron status in different populations, but associations with other dietary and nondietary factors have also been described that potentially confound the apparent association with tea drinking. The role of adaptation has not been fully described.

It is reasonable to conclude that tea drinking influences bioavailability and due to its potency as an inhibitor of absorption is likely to aggravate poor iron balance at times of increased physiological need or when iron nutrition is precarious. The following practical advice takes into account the current available evidence:

1 In the context of a normal British diet consumed by apparently healthy people with no risk of iron deficiency, there is no need to restrict tea drinking.

2 People with poor iron status should avoid drinking tea with meals as it is likely to inhibit nonhaem iron absorption. By allowing at least 1 h to elapse between the end of the meal and the consumption of tea, any adverse effects of tea on iron absorption are likely to be minimized. This restriction should apply to people at all ages who are in the following at-risk groups (children under 6 years of age, adolescent girls, women aged 18–49 years and women aged 75 years and over) and those who are known to have poor iron status.

3 Although not proven, it is likely that the adverse effects of tea on iron status are associated with its consumption at mealtimes. Moderate tea drinking at other times of the day is unlikely to have an adverse effect on iron status. Moreover, the inhibiting effects of tea on iron absorption can be partially overcome by the concurrent consumption of animal tissues and vitamin C.

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