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# Risk factors for low iron intake and poor iron status in a national sample of British young people aged 4–18 years

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## Abstract

*Objective:* To examine the prevalence and dietary, sociodemographic and lifestyle risk factors of low iron intake and poor iron status in British young people.
*Design:* National Diet and Nutrition Survey of young people aged 4–18 years.
*Setting:* Great Britain, 1997.
*Subjects:* In total, 1699 young people provided 7-day weighed dietary records, of which 11% were excluded because the participant reported being unwell with eating habits affected. Blood was obtained from 1193 participants, with iron status indicated by haemoglobin, serum ferritin and transferrin saturation.
*Results:* Iron intakes were generally adequate in most young people aged 4–18 years. However, low iron intakes (below the Lower Reference Nutrient Intake) occurred in 44% of adolescent girls (11–18 years), being less prevalent with high consumption of breakfast cereals. Low haemoglobin concentration ($<115\,g\,l^{-1}$, 4–12 years; $<120$ or $<130\,g\,l^{-1}$, 13+ years for girls and boys, respectively) was observed in 9% of children aged 4–6 years, pubertal boys (11–14 years) and older girls (15–18 years). Adolescent girls who were non-Caucasians or vegetarians had significantly poorer iron status than Caucasians or meat eaters, independent of other risk factors. The three iron status indices were correlated significantly with haem, but not non-haem, iron intake.
*Conclusions:* Adolescent girls showed the highest prevalence of low iron intake and poor iron status, with the latter independently associated with non-Caucasian ethnicity and vegetarianism. Risk of poor iron status may be reduced by consuming (particularly lean red) meat or enhancers of non-haem iron absorption (e.g. fruit or fruit juice) in vegetarians.

**Keywords**
Iron
Intake
Status
Children
Meat
Vegetarianism
Ethnicity

Young people in the UK may be at greater risk of iron deficiency (ID) than adults owing to their higher physiological requirements. ID is common during early childhood and adolescence in the UK[1,2] and other developed countries[3]. It is associated with anaemia, loss of appetite, lassitude, pallor, delayed psychomotor and cognitive development[4], and lowered resistance to infection[5]. ID may impair physical activity[6], attention span[7] and cognitive function/learning capacity[2,8,9], and thus lead to poor educational attainment[10]. ID and the more severe iron-deficiency anaemia (IDA) frequently occur during adolescence due to accelerated growth, rapid increase in blood volume and muscle mass, the onset of menstrual blood (and hence iron) loss in girls, and the adoption of slimming diets (more commonly in girls) or poor eating habits leading to low iron intake.

Poor iron status during adolescence may potentially also have long-term consequences. If the accompanying inactivity is prolonged, ID and IDA may be associated with poorer cardiovascular health and with lower bone mineral density and peak bone mass, and increased risk of osteoporosis and bone fractures in later adulthood[2]. These delayed manifestations of ID and IDA will then impose an extra economic burden on healthcare resources. Poorer outcomes from pregnancies of anaemic adolescent girls have also been noted, with increased risks of premature, low-birth-weight babies and neonatal infection[11]. Low birth weight may also result in higher health costs through its postulated association with higher risk of hypertension and heart disease later in life[12].

In the UK, low iron intakes (below the Lower Reference Nutrient Intake, LRNI) have been reported in only 4% of 4-year-olds[1], but are more common in adolescents, particularly in girls. Iron intakes were generally adequate in boys aged 16–17 years[13], while three-quarters of girls had intakes below the Reference Nutrient Intake (RNI)[14]. In a different study of 12- to 14-year-olds[15], 35% of girls had low iron intakes ($<8\,mg\,day^{-1}$) compared with only

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5% of boys ($<6.1\,mg\,day^{-1}$). The prevalence of poor iron status varies with the choice of indices and cut-off points, although it tends to be higher among adolescent girls. In the UK, 10–30% had ID or IDA[2,6,15], while 20% and 8% of pubertal boys had ID and IDA, respectively[16]. In Sweden, ID occurs in 15–40% of adolescent girls[17,18] compared with around 10% in the USA[3].

The present study investigated dietary, sociodemographic and lifestyle risk factors for poor iron intake and status in young people aged 4–18 years from a recent National Diet and Nutrition Survey[19].

## Methods

Full details of the National Diet and Nutrition Survey (NDNS) of young people aged 4–18 years living in mainland Britain (January–December 1997) are provided in the Survey Report[19]. Complete 7-day weighed dietary records were obtained for 80% of participants in the interview sample (1699/2127). Food and drink consumption was converted to nutrient intakes by using a nutrient databank originally compiled by the Ministry of Agriculture, Fisheries and Food. In order to assess adequacy of intake, average daily intakes of iron were compared with their respective UK RNI and LRNI[20].

In addition to sex and age group, the variation in iron intake and iron status indices (and percentages with low iron intake or poor iron status) were assessed according to other sociodemographic and lifestyle factors recorded in a questionnaire for each young person (Table 1). In boys and girls aged 11–18 years, iron intakes and status were also assessed according to cigarette smoking habit (smoker, non-smoker). In girls aged 11–14 years the impact of menarcheal status (premenarcheal, postmenarcheal) on iron status was assessed, while the impact of oral contraceptive pill use (no, yes) on iron status was assessed in girls aged 15–18 years.

Consumption of the main food groups (cereals and cereal products, breakfast cereals, dairy foods, eggs and egg dishes, fat spreads, meat and meat products, fish and fish dishes, vegetables (including potatoes and savoury snacks), fruit and nuts, sugar, preserves and confectionery) and tea, coffee and fruit juice consumption (each treated as a binary variable: non-consumption, consumption) were also related to iron intake and status. Iron status indices, and likelihood of poor iron status, were also examined according to total iron intake and the percentage of iron intake derived from haem iron, since intestinal absorption of this form of iron is much higher than that of non-haem iron and is hardly affected by other components of the diet[21]. The impact of suggested enhancers (total intakes of vitamins C[21–23] and A[24]) and inhibitors (dietary fibre[23] and calcium[25,26]) of mainly non-haem iron absorption were also examined, since they may impact on iron status.

The extent and possible impact of likely underreporting in the dietary record were investigated, using the method based on estimated basal metabolic rate ($BMR_{est}$)[27], using height and weight values, with minimum cut-off points applied for plausible energy intakes. Minimum cut-off points used were[28]: boys and girls aged 1–5 years, $1.28 \times BMR_{est}$; girls aged 6–18 years, $1.30 \times BMR_{est}$; boys aged 6–18 years, $1.39 \times BMR_{est}$. This method does have some limitations and sources of inaccuracy, such as the use of $BMR_{est}$ instead of measured BMR, lack of consideration of physical activity levels, lack of assurance that body weight remained constant throughout the period of dietary assessment, and false attribution of low recorded energy intakes as 'underreporting'. Nevertheless, this method of assessing likely underreporting was used since it was considered to be the most practical and suitable.

**Table 1** Categories for sociodemographic and lifestyle factors

| | Category of sociodemographic or lifestyle factor | | | | |
|---|---|---|---|---|---|
| Sociodemographic or lifestyle factor | 1 | 2 | 3 | 4 | 5 |
| Region | Scotland | North | Central, SW and Wales | London and SE | – |
| Season | Winter | Spring | Summer | Autumn | – |
| Gross annual household income (£'000 s) | <8 | 8– < 14 | 14– < 20 | 20– < 30 | ≥ 30 |
| Family credit | Receiving | Not receiving | – | – | – |
| Income support | Receiving | Not receiving | – | – | – |
| Occupational social class of household head | Non-manual | Manual | – | – | – |
| Mothers' educational qualifications* | None | ≥ CSE | ≥ O level | A level | >A level |
| Ethnic group† | Caucasian | Non-Caucasian | – | – | – |
| Variety of diet | Eats most things | Reasonable | Fussy or faddy eater | – | – |
| Appetite rating | Good | Average | Poor | – | – |
| Slimming? | Yes | No | – | – | – |
| Vegetarian? | Yes | No | – | – | – |

* Educational qualifications (England and Wales): CSE (Certificate of Secondary Education) and O level (Ordinary level of General Certificate of Education) examinations, usually attained at 15–16 years. CSE (a lesser qualification than O level) and O levels have now been replaced by the GCSE (General Certificate of Secondary Education) examination. A (Advanced) level examinations are usually taken at age 17–18 years.
† Ethnic group: 'non-Caucasian' comprised Asians (mainly Indians), Blacks and others (including mixed race). Asians comprised around one-half of non-Caucasian participants included in statistical analyses presented in this paper.

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Venous blood samples (mostly fasting) were usually obtained within a few days of the dietary records. Three iron status indices (blood haemoglobin concentration, Hb; serum ferritin concentration, SF; and plasma percentage transferrin saturation, %TS) are reported here since they indicate different stages of ID. Low SF indicates reduced iron stores and is an early reflection of ID, while low Hb represents a more advanced stage of ID with accompanying anaemia (IDA). For these statistical analyses, 'low' Hb was defined as follows: 4–12 years, $<115\,g\,l^{-1}$; girls aged 13 years and over, $<120\,g\,l^{-1}$; boys aged 13 years and over, $<130\,g\,l^{-1}$. 'Low' SF was defined as $<15\,\mu g\,l^{-1}$ for girls and $<20\,\mu g\,l^{-1}$ for boys, while 'low' %TS was defined as <15% for all ages. Cut-off points for iron status indices agree with those reported in the Survey Report[19].

Iron status indices were adjusted for the acute-phase index, plasma $\alpha_1$-antichymotrypsin (ACT) concentration, since infection and inflammation can alter many blood nutrient indices in the absence of altered stores. Raised plasma concentrations of ACT have been associated with reduced Hb[29] and raised SF[30]. Although only two of the young people (two girls aged 7–10 years) had plasma ACT concentrations $>0.65\,g\,l^{-1}$, associations with iron status still exist below this cut-off point.

Dietary and blood analyses included 1520 participants, after excluding those who reported being unwell with eating habits affected (11% of those with food diary data, $n = 179$). Stratified statistical analyses were conducted by age group (4–6 years, 7–10 years, 11–14 years and 15–18 years) and by sex (for those aged 11–18 years).

Simple and forward stepwise multiple logistic regressions, stepwise multiple linear regressions, analyses of variance with *post hoc* Bonferroni tests, unpaired Student's *t*-tests, chi-squared tests, Mantel–Haenszel tests for linear trend and Pearson's correlations were performed; with $P < 0.05$ deemed significant throughout. Stepwise multiple regression models included the iron status indices as respective dependent variables, with sociodemographic and lifestyle factors, consumption of main food groups (g per MJ energy intake), nutrient intakes (units per MJ energy intake) and plasma ACT concentration as independent variables. Crude odds ratios (ORs) and adjusted ORs ($OR_{adj}$) are presented with 95% confidence intervals (CIs).

Where necessary, variables were transformed to give a normal distribution using natural logarithmic transformation. In this case, summary statistics presented are geometric means (95% CI), as a better measure of central tendency than arithmetic means (standard deviations). Consumption of food groups (expressed per MJ of energy intake, to account for the variation in absolute amounts consumed according to age, and hence body size) was divided into thirds (low, medium, high) for analyses relating food group consumption to low dietary iron intake within each age or sex/age group. Where more than one-third of participants had zero consumption of a particular food group, a binary variable (yes, no) was used, to indicate consumption or non-consumption during the recording period.

## Results

Likely underreporting of food consumption was estimated to occur in 39% (599/1520) of the young people. Although difficult to ascertain unequivocally from the data available, likely underreporting was not found to be selective across the range of food groups consumed nor, within the sexes, did 'underreporters' differ significantly from 'non-underreporters' in terms of sociodemographic or lifestyle characteristics.

Only 3% (42/1520) of participants reported taking iron-containing supplements during the 7-day period of dietary assessment. Dietary supplements provided no haem iron and negligible amounts of non-haem iron. For this reason, iron-containing supplement users were included in the statistical analyses. Associations were examined between low iron intake and sociodemographic, lifestyle and dietary risk factors, while iron status indices and poor iron status were examined according to these risk factors plus plasma ACT concentration.

### *Iron intake*

Fifty-four per cent of 4- to 18-year-olds had dietary iron intakes below the RNI, with 12% of intakes below the LRNI. Adequacy of dietary iron intake (as %RNI) was significantly higher in boys than in girls for each age group. Dietary iron intakes were most adequate in boys and girls aged 4–6 years, but were lowest in 11- to 18-year-olds, especially in girls (Table 2). On average, girls aged 11–18 years were almost five times more likely to report low dietary iron intakes (<LRNI) than boys (OR 5.61, 95% CI 3.97–7.92; $P < 0.0001$). This difference became even greater after adjusting for 13 other sociodemographic and lifestyle factors ($OR_{adj}$ 7.16, 95% CI 4.52–11.34; $P < 0.0001$).

After excluding likely underreporters, adequacy of dietary iron intake remained lowest in girls aged 11–18 years, with percentages with low dietary iron intakes falling to 17% and 12% for those aged 11–14 years and 15–18 years, respectively (not shown). Even after excluding likely underreporters, 15% of the remaining 155 girls aged 11–18 years had low dietary iron intakes compared with none of the 158 boys of the same age ($P < 0.001$).

Reporting of low dietary iron intakes was less consistently associated with sociodemographic and lifestyle factors than with age and sex, especially after accounting for the significantly associated factor of likely underreporting. In addition, numbers of participants reporting low dietary iron intakes, and comprising some factor categories, were too small to enable reliable results to be obtained in all sex/age groups except for 11- to 18-year-old girls.

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**Table 2** Dietary intake and dietary reference values of iron in young people aged 4–18 years, by sex and age group

| Nutrient intake and DRV | Boys | | | | | Girls | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 4–6 years ($n = 167$) | 7–10 years ($n = 228$) | 11–14 years ($n = 212$) | 15–18 years ($n = 163$) | *P* | 4–6 years ($n = 151$) | 7–10 years ($n = 207$) | 11–14 years ($n = 209$) | 15–18 years ($n = 183$) | *P* |
| Iron RNI (mg day$^{-1}$) | 6.1 | 8.7 | 11.3 | 11.3 | | 6.1 | 8.7 | 14.8 | 14.8 | |
| Iron intake (as %RNI) | 131[a] (125–136) | 109[bd] (106–113) | 94[c] (90–97) | 105[d] (100–110) | <0.001 | 118[a] (113–123) | 96[b] (92–99) | 59[c] (56–61) | 56[c] (53–60) | <0.001 |
| Iron LRNI (mg day$^{-1}$) | 3.3 | 4.7 | 6.1 | 6.1 | | 3.3 | 4.7 | 8.0 | 8.0 | |
| % with low iron intake (<LRNI) | 0 | 0 | 2 | 2 | 0.02 | 1[a] | 2[a] | 40[b] | 48[b] | <0.001 |

DRV – Dietary Reference Value (i.e. recommended daily intake); RNI – Reference Nutrient Intake; LRNI – Lower Reference Nutrient Intake.
Only participants who reported eating habits to be unaffected during the 7-day period of dietary assessment were included in the above analyses.
Values for nutrient intakes (as %RNI) are geometric means (95% confidence interval), obtained by back-transformation of $\log_e$-transformed data.
Unlike superscripts ([a,b,c,d]) indicate significant differences ($P < 0.05$) between age groups for boys and girls separately.

One finding of interest was that girls aged 15–18 years who smoked were more likely to report low dietary iron intakes than non-smokers (62% vs. 41%, OR 1.55, 95% CI 1.12–2.13; $P = 0.008$). After excluding likely underreporters, this unadjusted difference became of borderline significance (25% vs. 6%, OR 2.34, 95% CI 0.94–5.83; $P = 0.07$). In the context of poor iron status findings described later, it is significant that adequacy of dietary iron intake and tendency to report low intakes were not associated with ethnic group or vegetarianism in 11- to 18-year-old girls.

With regard to the consumption of food groups, total breakfast cereal consumption (expressed in g per MJ energy intake) was significantly correlated with dietary iron intake ($r = 0.50$, $P < 0.001$). Young people aged 11–18 years who reported a high consumption of breakfast cereals were significantly less likely to report low dietary iron intake (Table 3). Other main food groups, with the possible exception of fruit and nuts and dairy foods (in 11- to 18-year-old girls), were not associated with higher dietary iron intake.

Overall, haem iron provided 4.0% of total iron intake. A higher proportion of total iron intake was provided by haem iron with increasing age in both sexes (each $P < 0.001$). Girls aged 7–10 years derived more of their iron intake from haem iron than did boys (3.9% vs. 3.4%, $P = 0.03$). The converse was true in boys aged 15–18 years compared with girls of the same age, although this was only of borderline significance (5.3% vs. 4.7%, $P = 0.07$).

Among the sociodemographic and lifestyle factors, only vegetarianism was consistently associated with percentage contribution of haem iron to total iron intake (0.9% in vegetarians vs. 4.1% in meat eaters, $P < 0.001$). However, children aged 4–6 years derived less iron from haem iron (3.0% vs. 3.5%, $P = 0.02$) when the head of household had a non-manual occupation and as the mothers' highest educational qualifications increased ($P < 0.001$). These associations remained significant after excluding likely underreporters.

### *Iron status*

Of the three reported iron status indices, Hb increased significantly with age in both sexes ($P < 0.001$) (Table 4). However, Hb approached a plateau in girls from early adolescence. They had significantly lower Hb at 15–18 years than boys ($P < 0.001$). This is also reflected in percentages of young people with 'low' Hb, below the cut-off point for normality. In girls, the highest percentages with low Hb occurred in those aged 4–6 years and 15–18 years. At 15–18 years, a significantly higher percentage of girls had low Hb compared with boys of the same age (9% vs. 1%, OR 3.64, 95% CI 1.30–10.16; $P = 0.01$). Conversely, at 11–14 years, a significantly higher percentage of boys had low Hb compared with girls (9% vs. 3%, OR 1.90, 95% CI 1.08–3.35; $P = 0.03$).

Mean SF was significantly lower in girls aged 4–6 years and 15–18 years than in boys of the same age (Table 4).

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SF decreased in girls from 7 to 18 years, whereas concentrations increased in boys. However, low SF was significantly more prevalent in boys aged 7–10 years than in girls (OR 2.51, 95% CI 1.36–4.65; $P = 0.003$), even independent of plasma ACT concentration and other sociodemographic, lifestyle and dietary risk factors ($OR_{adj}$ 2.08, 95% CI 1.08–4.01; $P = 0.03$). The increases in SF with age were correlated with %TS in boys. Like Hb and SF, %TS at 15–18 years was significantly lower in girls than in boys. Although %TS increased with age in boys ($P < 0.001$), this was not observed in girls.

The likelihood of low Hb, SF and/or low %TS was examined according to iron and vitamin C intake, with each nutrient intake expressed as being either above or below its RNI according to age and sex (Table 5). Percentages of boys having poor iron status were not associated significantly with the three variants of iron and vitamin C intake. In contrast, girls were significantly more likely to have low Hb and low Hb combined with low SF if both iron and vitamin C intakes were below the RNI, compared with when this applied only to iron intake. Paradoxically, however, the percentages of girls with low SF did not differ significantly when iron intake alone was below the RNI compared with when this applied to both iron and vitamin C intakes.

When the tendencies to have low Hb, SF and/or low %TS were examined more rigorously (with sociodemographic and lifestyle factors, consumption of main food groups, selected nutrient intakes and plasma ACT concentration all included as independent variables in stepwise multiple logistic regressions), ethnic group and vegetarianism in girls aged 11–18 years were two factors found to be most consistently and independently associated with poor iron status.

Low SF was significantly more prevalent in non-Caucasian girls aged 11–18 years than in their Caucasian counterparts (31% vs. 13%, OR 1.60, 95% CI 1.04–2.46; $P = 0.03$), and was little affected by adjustment for other confounding factors (41% vs. 15%, $OR_{adj}$ 1.73, 85% CI 0.99–3.04; $P = 0.054$) (Table 6). The greatest ethnic difference in the prevalence of low SF was observed in girls aged 11–14 years. Crude comparisons also found low Hb to be more prevalent in non-Caucasian girls, although the differences after adjusting for other sociodemographic, lifestyle and dietary factors, and plasma ACT concentration, became non-significant and were probably influenced greatly by reduced sample sizes affecting the ability to detect statistical significance. Crude comparisons also found non-Caucasian girls aged 11–14 years, but not those aged 15–18 years, to be more likely to have low %TS (38% vs. 16%, $P = 0.04$) than their Caucasian counterparts. Ethnic differences in poor iron status were not observed in boys of any age or in girls aged 4–10 years.

Girls aged 11–18 years who reported being vegetarians were also more likely to have low Hb, SF and %TS than their meat-eating counterparts (Table 7). Poor iron status in this group was typically twice as prevalent among vegetarians compared with meat eaters. After adjusting for plasma ACT concentration and the complete range of other sociodemographic, lifestyle and dietary factors, the higher prevalence of low Hb, SF and %TS remained only in vegetarian girls aged 15–18 years. Associations between vegetarianism and poor iron status were not observed in boys, probably since so few reported being vegetarians.

Differences in the consumption of main food groups, and drinking versus non-drinking of tea, coffee and/or fruit juice, were not consistently associated with the three iron status indices. Although most factors were not consistently or independently associated with poor iron status, some are worthy of mention since they may be relevant to a particular age/sex group and where plausible explanations exist for their association with iron status.

**Table 3** Consumption of food groups inversely associated with low dietary iron intake (<LRNI), by age group and sex

| | Age group and sex | | | | | |
|---|---|---|---|---|---|---|
| | 4–6 years | 7–10 years | 11–14 years | | 15–18 years | |
| Food group consumed* | All ($n = 318$) | All ($n = 435$) | Boys ($n = 212$) | Girls ($n = 209$) | Boys ($n = 163$) | Girls ($n = 183$) |
| Cereals and cereal products | N/A | N/A | NS | ✓✓✓ | NS | NS |
| Subgroup: breakfast cereals | N/A | N/A | ✓ | ✓✓✓ | ✓ | ✓✓✓ |
| Dairy foods | N/A | N/A | NS | ✓✓✓ | NS | ✓ |
| Fruit and nuts | N/A | N/A | NS | ✓ | ✓✓ | NS |
| Eggs and egg dishes (no, yes) | N/A | N/A | NS | ✓✓✓ | NS | NS |

LRNI – Lower Reference Nutrient Intake; N/A – not applicable (indicating overall prevalence of low dietary iron intakes too low for meaningful associations). Tick marks indicate lower percentage reporting low dietary iron intake with increasing consumption of food group (✓, $P < 0.05$; ✓✓, $P < 0.01$; ✓✓✓, $P < 0.001$; NS – not significant, $P > 0.05$). Consumption of other main food groups (meat and meat products; fish and fish dishes; vegetables and vegetable products; sugar, preserves and confectionery; fat spreads; fruit juice (no, yes), coffee (no, yes), tea (no, yes)) were not significantly associated with prevalence of low dietary iron intake in any of the age/sex groups.

Only values for participants who reported eating habits to be unaffected were included in the above statistical analyses.

* Food group consumption was expressed in g per MJ of energy intake (to account for differences in absolute amounts consumed with age) and categorised into increasing thirds (low, medium, high) for the respective age/sex groups. The exceptions are marked '(no, yes)' indicating no consumption or some consumption when less than one-third consumed the particular food group in that age/sex group.

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**Table 4** Iron status indices in young people aged 4–18 years, by sex and age group

| | Boys | | | | | Girls | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Iron status index | 4–6 years | 7–10 years | 11–14 years | 15–18 years | *P* | 4–6 years | 7–10 years | 11–14 years | 15–18 years | *P* |
| | ($n = 79$) | ($n = 167$) | ($n = 163$) | ($n = 152$) | | ($n = 72$) | ($n = 126$) | ($n = 156$) | ($n = 140$) | |
| Blood haemoglobin concentration* ($g\,l^{-1}$) | $125^{a}$ (9) | $130^{b}$ (8) | $134^{c}$ (10) | $149^{d}$ (9) | <0.001 | $125^{a}$ (9) | $128^{a}$ (9) | $133^{b}$ (9) | $131^{b}$ (10) | <0.001 |
| % with low blood haemoglobin | $8^{ab}$ | $2^{a}$ | $9^{b}$ | $1^{a}$ | 0.001 | 10 | 4 | 3 | 9 | 0.05 |
| | ($n = 71$) | ($n = 161$) | ($n = 160$) | ($n = 150$) | | ($n = 69$) | ($n = 118$) | ($n = 147$) | ($n = 138$) | |
| Serum ferritin concentration† ($\mu g\,l^{-1}$) | $30^{a}$ (9–83) | $31^{a}$ (9–82) | $30^{a}$ (8–79) | $45^{b}$ (15–166) | <0.001 | $24^{a}$ (4–82) | $33^{b}$ (13–112) | $29^{ab}$ (9–72) | $25^{a}$ (5–99) | <0.001 |
| % with low serum ferritin | $17^{a}$ | $16^{a}$ | $18^{a}$ | $5^{b}$ | 0.005 | $13^{a}$ | $3^{b}$ | $11^{a}$ | $22^{c}$ | <0.001 |
| | ($n = 55$) | ($n = 135$) | ($n = 149$) | ($n = 138$) | | ($n = 52$) | ($n = 105$) | ($n = 141$) | ($n = 133$) | |
| Plasma transferrin saturation* (%) | $20^{a}$ (10) | $23^{a}$ (9) | $22^{a}$ (8) | $26^{b}$ (11) | <0.001 | 21 (8) | 22 (8) | 22 (8) | 22 (10) | 0.84 |
| % with low transferrin saturation | 22 | 19 | 20 | 12 | 0.17 | 21 | 21 | 18 | 29 | 0.23 |

Only participants who reported eating habits to be unaffected during the 7-day period of dietary assessment were included in the above analyses.
Low blood haemoglobin: 4–12 years, $<115\,g\,l^{-1}$; girls aged 13 years and over, $<120\,g\,l^{-1}$; boys aged 13 years and over, $<130\,g\,l^{-1}$; low serum ferritin: girls, $<15\,\mu g\,l^{-1}$; boys, $<20\,\mu g\,l^{-1}$; low transferrin saturation, <15% (for all ages).
Unlike superscript letters ($^{a,b,c,d}$) indicate significant differences ($P < 0.05$) between age groups for boys and girls separately.
* Arithmetic mean (standard deviation).
† Geometric mean (2.5–97.5 percentile range).

**Table 5** Percentage of young people aged 4–18 years with poor iron status, by iron and vitamin C intake

| | Boys | | | | Girls | | | |
|---|---|---|---|---|---|---|---|---|
| Iron status index | Neither Fe nor VitC intake < RNI | Fe intake < RNI but VitC intake > RNI | Both Fe and VitC intakes < RNI | *P* | Neither Fe nor VitC intake < RNI | Fe intake < RNI but VitC intake > RNI | Both Fe and VitC intakes < RNI | *P* |
| | ($n = 299$) | ($n = 155$) | ($n = 39$) | | ($n = 199$) | ($n = 263$) | ($n = 69$) | |
| % with low blood haemoglobin (Hb) | 3 | 6 | 8 | 0.20 | $4^{a}$ | $4^{a}$ | $16^{b}$ | <0.001 |
| | ($n = 291$) | ($n = 150$) | ($n = 35$) | | ($n = 113$) | ($n = 252$) | ($n = 65$) | |
| % with low serum ferritin (SF) | 13 | 13 | 17 | 0.77 | $5^{a}$ | $15^{b}$ | $17^{b}$ | 0.02 |
| | ($n = 247$) | ($n = 136$) | ($n = 33$) | | ($n = 98$) | ($n = 232$) | ($n = 51$) | |
| % with low transferrin saturation | 19 | 14 | 21 | 0.59 | 22 | 24 | 19 | 0.69 |
| | ($n = 291$) | ($n = 150$) | ($n = 35$) | | ($n = 113$) | ($n = 251$) | ($n = 65$) | |
| % with low Hb and SF | 3 | 2 | 6 | 0.17 | $0^{a}$ | $2^{a}$ | $8^{b}$ | 0.007 |

Fe – iron; VitC – vitamin C; RNI – Reference Nutrient Intake.
Only participants who reported eating habits to be unaffected during the 7-day period of dietary assessment were included in the above analyses.
Low blood haemoglobin: 4–12 years, $<115\,g\,l^{-1}$; girls aged 13 years and over, $<120\,g\,l^{-1}$; boys aged 13 years and over, $<130\,g\,l^{-1}$; low serum ferritin: girls, $<15\,\mu g\,l^{-1}$; boys, $<20\,\mu g\,l^{-1}$; low transferrin saturation: <15% (for all ages).
Unlike superscript letters ($^{a,b}$) indicate significant differences ($P < 0.05$, $\chi^2$ test) in percentages between categories for boys and girls separately.

For example, low Hb was more prevalent in 4- to 6-year-old children who drank coffee versus non-drinkers (25% vs. 7%, $P = 0.01$; Fisher's exact test). Similarly, adolescent girls aged 11–18 years who consumed fruit juice were less likely to have low Hb than non-consumers (2% vs. 10%, OR 0.36, 95% CI 0.17–0.76; $P = 0.008$). However, this was not observed for SF or %TS.

Plasma ACT concentration was independently associated with smaller percentages of young people having low SF and higher percentages with low %TS, while Hb was not affected significantly. These independent relationships with the three iron status indices were quantified by forward stepwise multiple linear regressions, as shown in Table 8. For each age/sex group, plasma ACT concentration was independently associated with higher SF and with lower %TS, although independently only in 11- to 14-year-olds.

Other independent correlates of iron status appeared sporadically, although associations were more common between higher values of the iron status indices and meat consumption or amount of iron intake derived from haem iron (provided mainly by meat), particularly in adolescents. Up to one-quarter of the variation in the iron status indices of adolescents was typically explained by variation in just a handful of independent factors, including plasma ACT concentration and meat consumption (in both sexes) plus ethnic group and vegetarianism in girls.

## Discussion

Dietary iron intake (as %RNI) was significantly higher in boys than in girls for each of four age groups between 4 and 18 years, and lowest in adolescent girls (11–18 years) of whom 44% reported low iron intakes (<LRNI). Iron intake was correlated with breakfast cereal consumption while the contribution to iron intake from haem iron was significantly lower in vegetarians (non-meat eaters). Iron status indices were strongly correlated with haem iron intake, but not with total or non-haem iron intake, and improved with increasing meat consumption. Low Hb was observed in 9% of children aged 4–6 years, pubertal boys (11–14 years) and older girls (15–18 years). Poor iron status was generally more prevalent in adolescent girls of non-Caucasian ethnic origin or in those who were vegetarians.

Dietary iron intakes in 4-year-old girls did not differ significantly between 1997 and 1992–93[1], although they were higher (expressed as mg $day^{-1}$, mg $MJ^{-1}$ and %RNI) in 1997 compared with 1992–93 for boys of the same age. A similar finding was obtained for boys and girls aged 10–11 years and 14–15 years when intakes were compared with those of the same ages from 1983[31]. Estimated iron intakes were similar in British children aged 11–12 years in 1997 and in 1990[32], and also in 16- to 17-year-olds compared with 1986–87[13,14]. Surveys of mainly adolescent children living in Northern Ireland[33], Ireland[34], The Netherlands[35] and Hungary[36] reported similar iron intakes to those from this NDNS, while higher intakes were reported in Sweden[18,37,38] and, to a lesser extent, in the USA[39].

However, it should be remembered that estimates of iron intake obtained from the different studies might not be directly comparable. Although matched by age and sex, iron intake estimates may vary merely by the type of dietary methodology employed. For example, different studies may use 24-hour recall, food-frequency questionnaires or,

**Table 6** Poor iron status in girls aged 11–18 years, by ethnic group

| Age group and poor iron status index | Crude differences | | | | Adjusted differences | | | |
|---|---|---|---|---|---|---|---|---|
| | Caucasians *n* (%) | Non-Caucasians *n* (%) | *P* | OR (95% CI) | Caucasians *n* (%) | Non-Caucasians *n* (%) | *P* | $OR_{adj}$ (95% CI) |
| 11–14 years | | | | | | | | |
| Low haemoglobin* | 126 (2) | 16 (12) | 0.04 | 2.98 (1.08–8.24) | 93 (1) | 10 (20) | 0.87 | NS |
| Low serum ferritin† | 130 (8) | 17 (29) | 0.01 | 2.12 (1.16–3.89) | 91 (9) | 10 (40) | 0.006 | 4.48 (1.54–13.04) |
| Low transferrin saturation‡ | 125 (16) | 16 (38) | 0.04 | 1.77 (1.01–3.11) | 94 (15) | 10 (40) | 0.21 | NS |
| 15–18 years | | | | | | | | |
| Low haemoglobin* | 127 (7) | 12 (25) | 0.05 | 2.09 (1.001–4.36) | 87 (7) | 7 (29) | N/A | N/A |
| Low serum ferritin† | 125 (22) | 12 (33) | 0.36 | NS | 86 (22) | 7 (43) | N/A | N/A |
| Low transferrin saturation‡ | 120 (30) | 12 (17) | 0.34 | NS | 87 (30) | 7 (14) | N/A | N/A |
| 11–18 years | | | | | | | | |
| Low haemoglobin* | 253 (4) | 28 (18) | 0.007 | 2.19 (1.24–3.88) | 180 (4) | 17 (24) | 0.12 | NS |
| Low serum ferritin† | 255 (13) | 29 (31) | 0.03 | 1.60 (1.04–2.46) | 177 (15) | 17 (41) | 0.054 | 1.73 (0.99–3.04) |
| Low transferrin saturation‡ | 245 (23) | 28 (29) | 0.50 | NS | 181 (22) | 17 (29) | 0.81 | NS |

*n* (%) – sample size of subgroup (percentage of subgroup with low iron status index); OR – crude odds ratio (from simple logistic regression); $OR_{adj}$ – adjusted odds ratio (from forward stepwise multiple logistic regression, using plasma $\alpha_1$-antichymotrypsin concentration and sociodemographic, lifestyle and dietary factors listed in the Methods section as independent factors); NS – not significant ($P > 0.05$, OR and $OR_{adj}$ not significantly different from 1.00); N/A – not applicable due to *n* (%) being too small for result to be reliable.
Only participants who reported eating habits to be unaffected during the 7-day period of dietary assessment were included in the above analyses.
'Caucasians' is the reference category; 'non-Caucasians' comprise Asians (mainly Indians), Blacks and others (including mixed race).
* Low haemoglobin: 4–12 years, $<115\,g\,l^{-1}$; 13 years and over, $<120\,g\,l^{-1}$.
† Low serum ferritin: $<15\,\mu g\,l^{-1}$ (all ages).
‡ Low transferrin saturation: <15% (all ages).

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**Table 7** Poor iron status in girls aged 11–18 years, by vegetarianism

| Age group and poor iron status index | Crude differences | | | | Adjusted differences | | | |
|---|---|---|---|---|---|---|---|---|
| | Meat eaters *n* (%) | Vegetarians *n* (%) | *P* | OR (95% CI) | Meat eaters *n* (%) | Vegetarians *n* (%) | *P* | $OR_{adj}$ (95% CI) |
| 11–14 years | | | | | | | | |
| Low haemoglobin* | 132 (3) | 10 (0) | 0.86 | NS | 98 (3) | 5 (0) | N/A | N/A |
| Low serum ferritin† | 138 (9) | 9 (33) | 0.04 | 2.19 (1.04–4.64) | 96 (11) | 5 (20) | N/A | N/A |
| Low transferrin saturation‡ | 133 (18) | 8 (25) | 0.62 | NS | 99 (17) | 5 (20) | N/A | N/A |
| 15–18 years | | | | | | | | |
| Low haemoglobin* | 124 (6) | 15 (27) | 0.02 | 2.30 (1.17–4.51) | 84 (6) | 10 (30) | 0.004 | 6.04 (1.78–20.51) |
| Low serum ferritin† | 122 (19) | 15 (53) | 0.05 | 2.22 (1.27–3.87) | 83 (20) | 10 (50) | 0.009 | 2.95 (1.31–6.61) |
| Low transferrin saturation‡ | 119 (24) | 13 (69) | 0.002 | 2.64 (1.41–4.94) | 84 (25) | 10 (60) | 0.007 | 2.77 (1.32–5.82) |
| 11–18 years | | | | | | | | |
| Low haemoglobin* | 256 (5) | 25 (17) | 0.03 | 1.97 (1.07–3.64) | 182 (4) | 15 (20) | 0.29 | NS |
| Low serum ferritin† | 260 (14) | 24 (46) | <0.001 | 2.29 (1.48–3.56) | 179 (16) | 15 (40) | 0.72 | NS |
| Low transferrin saturation‡ | 252 (21) | 21 (52) | 0.002 | 2.03 (1.29–3.20) | 183 (21) | 15 (47) | 0.20 | NS |

*n* (%) – sample size of subgroup (percentage of subgroup with low iron status index); OR – crude odds ratio (from simple logistic regression); $OR_{adj}$ – adjusted odds ratio (from forward stepwise multiple logistic regression, using plasma $\alpha_1$-antichymotrypsin concentration and sociodemographic, lifestyle and dietary factors listed in the Methods section as independent factors); NS – not significant ($P > 0.05$, OR and $OR_{adj}$ not significantly different from 1.00); N/A – not applicable due to *n* (%) being too small for result to be reliable.
Only participants who reported eating habits to be unaffected during the 7-day period of dietary assessment were included in the above analyses.
'Meat eaters' is the reference category.
* Low haemoglobin: 4–12 years, $<115\,g\,l^{-1}$; 13 years and over, $<120\,g\,l^{-1}$.
† Low serum ferritin: $<15\,\mu g\,l^{-1}$ (all ages).
‡ Low transferrin saturation: <15% (all ages).

as in the present study, weighed dietary records as their means of deriving average iron intakes – with each technique varying in its appropriateness, acceptability and accuracy. The results presented here have been compared, wherever possible, with those from other national samples or with regional samples containing sufficient numbers of subjects for their results to be robust.

With regard to the assessment of iron status, since no single index alone is adequate, the present study used Hb, SF and %TS to indicate different stages of ID. In the UK, the present study showed iron status indices from this NDNS sample to be comparable with those obtained in 1990 from 12- to 14-year-olds living in Epsom, UK[15], and those from a representative sample of 11- to 15-year-olds in 1996[40]. Similar average values and percentages with low values for Hb, SF and/or %TS were also noted between NDNS young people, mainly adolescents, and those studied in Sweden[37,38], Hungary[36], the USA[3,39], Australia[41] and Korea[42]. In accord with a previous finding[43], iron status was largely independent of socio-economic factors.

The poorer iron status (low Hb, SF and/or %TS) observed in non-Caucasian adolescent girls in the present study corroborates a previous finding in 11- to 14-year-old girls studied in Wembley, north London[6]. In the present study, the poorer iron status observed in 11- to 18-year-old non-Caucasian girls compared with their Caucasian counterparts was independent of vegetarianism, which is often more common among Indians in particular. Ethnic differences in ID and IDA have also been reported in New Zealand between female adolescents of European and non-European (including Asian) origins[44], while Mexican-American females aged 12–39 years had significantly poorer iron status than their non-Hispanic counterparts, even after adjusting for potential confounders such as poverty level, iron intake, iron supplement use, serum vitamin C concentration and oral contraceptive use[45,46].

It is conceivable that non-Caucasian females of reproductive age may be at increased risk of poor iron status due to a greater influence of non-dietary risk factors, such as longer duration and/or amount of menstrual blood loss, as observed in a study of African-American girls aged 12–14 years compared with their European-American counterparts[47]. A similar difference may exist between the postmenarcheal non-Caucasian girls and their Caucasian counterparts in the present study, although such an assessment was not made. To the best of our knowledge no substantial evidence exists in the literature comparing menstrual characteristics by ethnic group or among Asians compared with Caucasians.

Vegetarian girls aged 11–18 years, particularly those aged 15–18 years, were also more likely to have poorer iron status than their meat-eating counterparts. The poorer iron status observed among adolescent vegetarian girls in the present study corroborates other findings in children living in the UK[15,48] and Slovakia[49]. Although total iron intakes in the present study were not significantly different between vegetarians and omnivores, vegetarians derived a much lower proportion of their iron intake from haem iron (on average 0.9%, from fish and fish dishes).

The poorer iron status observed with vegetarian diets may, at least in part, be due to lower iron bioavailability since non-haem iron is less well absorbed than haem iron[50]. Iron status depends on the form of ingested iron (i.e. haem vs. non-haem), the presence of enhancers (e.g. meat, fish, vitamins C and A) and inhibitors of

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**Table 8** Sociodemographic, lifestyle, dietary and physiological factors associated* with iron status indices in young people aged 4–18 years, by age group and sex

| | 4–6 years | 7–10 years | 11–14 years | | 15–18 years | |
|---|---|---|---|---|---|---|
| | Boys and girls | Boys and girls | Boys | Girls | Boys | Girls |
| Iron status index (units) | ($n = 70–75$) | ($n = 181–185$) | ($n = 109–111$) | ($n = 101–104$) | ($n = 94–96$) | ($n = 93–94$) |
| Blood haemoglobin ($g l^{-1}$) | Vitamin C/MJ†<br>Season (–)<br>Iron/MJ† | Age<br>Fruit & nuts/MJ<br>Income support<br>Calcium/MJ<br>Season | Meat/MJ<br>Age<br>Smoking | Sugar, p & c (–)<br>Ethnic group (–) | Age<br>Fat spreads/MJ | Region<br>Vegetarianism<br>Vitamin C/MJ<br>NSP/MJ<br>Season (–)<br>Eggs/MJ (–) |
| | Adj. $r^2 = 0.16$ | Adj. $r^2 = 0.17$ | Adj. $r^2 = 0.17$ | Adj. $r^2 = 0.17$ | Adj. $r^2 = 0.17$ | Adj. $r^2 = 0.17$ |
| Serum ferritin† ($\mu g l^{-1}$) | ACT†<br>Fruit juice (–)<br>Age | ACT†<br>Haem iron as % total iron<br>Appetite | ACT†<br>Family credit<br>Fat spreads/MJ | Ethnic group (–)<br>Meat/MJ<br>Vitamin A/MJ<br>ACT† | Age<br>ACT†<br>Meat/MJ<br>Cereals/MJ | Sugar, p & c (–)<br>Haem iron as % total iron<br>Fruit & nuts/MJ<br>ACT†<br>OC use |
| | Adj. $r^2 = 0.17$ | Adj. $r^2 = 0.12$ | Adj. $r^2 = 0.11$ | Adj. $r^2 = 0.26$ | Adj. $r^2 = 0.28$ | Adj. $r^2 = 0.24$ |
| Plasma transferrin saturation (%) | Dairy foods/MJ | Dairy foods/MJ | ACT† (–) | ACT† (–)<br>Ethnic group (–) | Age<br>Fat spreads/MJ<br>Variety<br>Meat/MJ<br>NSP/MJ<br>Fruit & nuts/MJ (–) | Meat/MJ<br>Region<br>Breakfast cereals/MJ |
| | Adj. $r^2 = 0.05$ | Adj. $r^2 = 0.03$ | Adj. $r^2 = 0.04$ | Adj. $r^2 = 0.16$ | Adj. $r^2 = 0.25$ | Adj. $r^2 = 0.21$ |

ACT – plasma $\alpha_1$-antichymotrypsin concentration (indicator of recent or current infection or inflammation); Sugar, p & c – sugar, preserves and confectionery; NSP – non-starch polysaccharides, OC, oral contraceptives.
Only participants who reported eating habits to be unaffected during the 7-day period of dietary assessment were included in the above analyses.
Nutrients given in the table are expressed as intake (units per MJ) while foods are expressed as consumption (g per MJ). Both nutrient intakes and consumption of food groups are expressed per MJ in order to make them independent of differences in energy intake that are generally related to age.
Associations shown are direct except where marked (–), indicating inverse associations.
Adj. $r^2$ (adjusted $r^2$) refers to the amount of variation in the appropriate iron status index explained by all of the independent factors included in the final multiple regression model.
* Forward stepwise multiple linear regression analyses examined associations between the three iron status indices (dependent factors) and plasma ACT concentration and sociodemographic, lifestyle and dietary factors (independent factors) outlined in the Methods section. Only associations that reached statistical significance ($P < 0.05$) and were included in the final regression model are shown in the table, with the order of variables determined by the order in which they were entered into the final stepwise regression model.
† $Log_e$-transformed values.

non-haem iron absorption (e.g. phytate in whole grains, legumes, lentils and nuts; soya protein and non-cellular proteins found in eggs and dairy foods; calcium, phosphorus, tannins and other polyphenols in tea and coffee) and on the extent of iron losses from the body. Overall, the greater bioavailability of haem iron may explain why haem iron intake in the present study was correlated significantly with Hb, SF and %TS, while total iron intake (on average comprising 96% non-haem iron) was not.

The lack of significant correlation between total or non-haem iron intake and iron status reported here from the NDNS survey corroborates findings from the 1988–94 third National Health and Nutrition Examination Survey in the USA[39] and other studies of females during adolescence[15,18,51–53] and early adulthood[54]. Similarly, several studies have reported lower risks of ID ($SF < 12\,\mu g\,l^{-1}$)[18,54], or linear associations with SF[53], with higher haem iron intake. Meat is a good source of haem iron and so its consumption (particularly of lean red meat) may help to reduce the prevalence of ID or IDA, particularly in vulnerable adolescent girls who are at greatest risk.

For non-meat eaters, the risk of poor iron status may be reduced by increasing the amount of non-haem iron intake (which is often low among adolescent girls), increasing fish consumption (to increase haem iron intake, which can also improve non-haem iron absorption), or by simultaneous ingestion of enhancers of non-haem iron absorption (such as vitamin C contained in citrus fruit and fruit juice) and by limiting inhibitors of non-haem iron absorption (e.g. foods with high amounts of insoluble fibre) at mealtimes.

While some studies have found no association between vitamin C intake and iron status[18,52–54], direct associations have been reported by others[15,51]. Findings from the present study also corroborate those reported from a smaller regional UK study[15], with respect to vitamin C intake having a greater impact on Hb than on SF. Following significant improvements in three iron status indices, one notable study with Indian vegetarians even concluded that vitamin C supplementation was a better way to improve iron status than iron supplementation[55].

## Conclusions

Dietary intakes and status of iron were generally adequate in the majority of this national sample of 4- to 18-year-old British young people. However, almost one-half of adolescent girls aged 11–18 years had low iron intakes (below the LRNI), coupled with a high proportion with low iron status indices (Hb, SF and/or %TS). Low iron intakes and poor iron status were not generally associated with indicators of poorer socio-economic conditions (e.g. household receipt of income support and/or family credit, and lower household income). Poor iron status was significantly more prevalent in adolescent girls of non-Caucasian origin and in non-meat eaters. Advice to reduce the risk of low iron intake and/or poor iron status in young people should target adolescent girls, and highlight not only rich sources of iron in the diet (e.g. meat and iron-fortified breakfast cereals) but also dietary components (e.g. vitamin C-rich food and drinks) that may improve iron absorption.

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