

Dietary treatment of iron deficiency in women of childbearing age¹⁻³

Amanda J Patterson, Wendy J Brown, David CK Roberts, and Michael R Seldon

ABSTRACT

Background: The Australian Iron Status Advisory Panel advocates dietary intervention as the first treatment option for mild iron deficiency [serum ferritin (SF) = 10–15 µg/L]. However, there appear to be no studies on the efficacy of dietary treatment for iron deficiency.

Objective: We compared the effects of iron supplementation and of a high-iron diet on serum ferritin (SF) and hemoglobin in iron-deficient women of childbearing age.

Design: Forty-four iron-deficient women (SF <15 µg/L or SF = 15–20 µg/L plus serum iron <10 µmol/L and total-iron-binding capacity >68 µmol/L) and 22 iron-replete women (hemoglobin ≥120 g/L and SF >20 µg/L) matched for age and parity categories were enrolled and completed 7-d weighed food records at baseline. The iron-deficient women were randomly allocated to receive iron supplementation (105 mg/d; supplement group) or a high-iron diet (recommended intake of absorbable iron: 2.25 mg/d; diet group) for 12 wk. Hematologic and dietary assessments were repeated at the end of the intervention and again after a 6-mo follow-up.

Results: Mean SF in the supplement group increased from 9.0 ± 3.9 µg/L at baseline to 24.8 ± 10.0 µg/L after the intervention and remained stable during follow-up (24.2 ± 9.8 µg/L), whereas the diet group had smaller increases during the intervention (8.9 ± 3.1 to 11.0 ± 5.9 µg/L) but continued to improve during follow-up (to 15.2 ± 9.5 µg/L). Mean hemoglobin tended to improve in both intervention groups, but the change was only significant in the supplement group.

Conclusions: In iron-deficient women of childbearing age, a high-iron diet produced smaller increases in SF than did iron supplementation but resulted in continued improvements in iron status during a 6-mo follow-up. *Am J Clin Nutr* 2001;74:650–6.

KEY WORDS Iron deficiency, anemia, dietary iron, women, childbearing age, iron supplements, iron supplementation

INTRODUCTION

Iron deficiency is the most common nutrient deficiency in the developed world, and women of childbearing age are at greatest risk because of the effects of menstruation and pregnancy (1). Reliable prevalence figures for Australian women are not available, but baseline data from the Australian Longitudinal Study of Women's Health suggest that 1 in 3 women have been diagnosed with iron deficiency by age 45–50 y (2). There is an overwhelming amount of research literature relating

to iron deficiency, but to our knowledge, no one has studied the role of dietary intervention in the treatment of iron deficiency. Despite this, a booklet produced by the Australian Iron Status Advisory Panel advocates the use of dietary intervention as the first treatment option in mild cases of iron deficiency (serum ferritin = 10–15 µg/L) (3).

The alternative to dietary intervention is iron supplementation, which may not be feasible for long-term use (ie, throughout a woman's reproductive years) because compliance is often poor (4) and side effects can be marked (5). Moreover, there is little evidence to suggest that iron supplementation has any long-term effect on the prevention of iron deficiency. One study showed that improved iron status persisted in supplemented children 2 y after completion of a supplementation trial (6). It is not known whether improved iron status would continue for 2 y in adults, especially during time periods that include menstruation and childbirth.

It appears that dietary intervention would have advantages over supplementation in relation to compliance, long-term acceptability, cost-effectiveness, risk of iron overload, and a beneficial effect on the iron intake of families. For example, if the woman in the household is responsible for selecting foods, and her selections include iron-rich foods for herself, other family members may increase their iron intake as well. However, the efficacy of dietary intervention for the treatment of iron deficiency needs to be confirmed before it can be recommended. Therefore, the aim of this study was to compare the effects of standard iron supplementation and a high-iron diet on iron deficiency in women of childbearing age.

¹From the Research Center for Gender and Health and the Discipline of Nutrition and Dietetics, Faculty of Science and Mathematics, The University of Newcastle, New South Wales, Australia; the School of Human Movement Studies, the University of Queensland, Brisbane, Australia; and the Hunter Hematology Unit, Hunter Area Health Service, New South Wales, Australia.

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³Reprints not available. Address correspondence to AJ Patterson, Research Center for Gender and Health, The University of Newcastle, University Drive, Callaghan, New South Wales 2308, Australia. E-mail: whajp@alinga.newcastle.edu.au.

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SUBJECTS AND METHODS

Fifty-two women with known iron deficiency were recruited to participate in the study. Women with iron deficiency were initially recruited by referral from medical practitioners, but when inadequate numbers were referred we also sought volunteers from the university campus and wider community. Twenty-four iron-replete control subjects, matched to the iron-deficient women by age and parity, were also recruited to assess any group differences in diet at baseline and to monitor any changes in iron status or dietary variables that might result from seasonal variations or the effects of being studied. Although an iron-deficient control group would have improved the study design significantly, it was deemed inappropriate to fail to offer treatment for iron deficiency during the 9-mo study. The recruitment and intervention protocols were approved by the University of Newcastle Human Ethics Committee. All subjects gave their written, informed consent.

Eligibility criteria for inclusion in the study were as follows: no major illnesses, childbearing age, nonpregnant, no hysterectomy, no amenorrhea, aged ≥ 18 y (or 16–17 y with parental consent), and a hemoglobin concentration ≥ 90 g/L. Iron deficiency was defined as either a serum ferritin concentration < 15 $\mu\text{g/L}$ or a serum ferritin concentration of 15–20 $\mu\text{g/L}$ plus a serum iron concentration < 10 $\mu\text{mol/L}$ and a total-iron-binding capacity > 68 $\mu\text{mol/L}$. Criteria for inclusion in the iron-replete control group were a hemoglobin concentration ≥ 120 g/L and a serum ferritin concentration > 20 $\mu\text{g/L}$.

After confirmation of iron status, each woman completed a background questionnaire and baseline dietary assessment. Dietary intake was measured by using 7-d weighed food records. A dietitian provided instructions to the subjects and analyzed the dietary data with DIET 1, version 4.22 (7). DIET 1 uses the NUTTAB 95 Nutrient Data Table designed for application in Australia (8). NUTTAB 95 does not include data on heme iron, nonheme iron, or phytate contents of foods or the proportion of meat, fish, and poultry (MFP) in composite foods. Therefore, each food item in the NUTTAB 95 database was assigned values for heme iron and nonheme iron on the basis of data for Australian meat and fish (9). MFP values were either taken as the total weight of whole flesh foods or were estimated by the researchers from standard recipes for the composite foods. Because phytate values were not available for Australian foods, the values of Harland and Oberleas (10) were used.

Calculation of bioavailable dietary iron

Bioavailable dietary iron (BDI) was calculated by using the methods of Mosen et al (BDI-M; 11), Mosen and Balintfy (BDI-MB; 12) and Tseng et al (BDI-T; 13). Because enhancers and inhibitors of iron absorption exert their influence only when consumed simultaneously with iron, BDI was calculated for individual meals. Food items consumed ≥ 20 min apart constituted separate meals. A computer program that applied each calculation to every meal for each subject was written, and individual meal values were summed for each day and averaged over the number of days available to provide an estimate of daily intake. All 3 calculation methods assume stores of 500 mg Fe for each individual. Although this is an overestimation for the iron-deficient women and an underestimation for some iron-replete women, it is suggested by Mosen et al (11) as appropriate for most calculations. Use of a standard amount for iron stores also

allows comparison of different diets and changes in BDI over time, independent of changing iron status.

The original algorithm of Mosen et al

This algorithm, published in 1978 (11), involves multiplying the heme iron content of the meal by an absorption factor (23% for stores of 500 mg Fe) to give the total heme iron available for absorption. Mosen et al assumed that the heme-iron content of all MFP was 40% (11), but we used the actual Australian heme contents (9) of the meat-containing foods consumed by our subjects.

For this calculation, nonheme-iron absorption varies according to the meat and ascorbic acid contents of the meal. A low-availability meal contains < 30 g MFP (lean, raw wt) or < 25 mg ascorbic acid. A medium-availability meal contains 30–90 g MFP or 25–75 mg ascorbic acid. A high-availability meal contains > 90 g MFP or > 75 mg ascorbic acid or 30–90 g MFP plus 25–75 mg ascorbic acid. Once the meal has been categorized by using these guidelines, the nonheme-iron value of the meal is multiplied by the appropriate absorption factor (3%, 5%, or 8%) to give an estimate of absorbed nonheme iron. BDI is the sum of the heme iron and nonheme iron absorbed (11).

The revised algorithm of Mosen and Balintfy

In this algorithm, published in 1982 (12), heme-iron absorption remains at 23% but the absorption rates for nonheme iron were replaced with a formula that is dependent on the quantity of enhancing factors (EF) present in the meal (12). The quantity of EF is equal to the milligrams of ascorbic acid plus the grams of cooked MFP.

$$\text{When } \Sigma \text{EF} < 75: \% = 3 + 8.93 \log_n (\text{EF} + 100) / 100 \quad (1)$$

$$\text{When } \Sigma \text{EF} \geq 75: \% = 8 \quad (2)$$

The algorithm of Tseng et al

This algorithm, published in 1997, uses the 1982 algorithm of Mosen and Balintfy (12) and further adjusts the absorption of nonheme iron for the inhibiting effects of phytate and tannin found in tea (13). If the amount of tea consumed with a meal exceeds 225 g, the nonheme-iron-absorption rate is reduced by 40%. Phytate further reduces nonheme-iron absorption from the meal according to the following formula:

$$\text{Log}_{10}(\% \text{nonheme availability}) = -0.2869 \times \log_{10}(\text{mg phytate in meal}) + 0.1295 \quad (3)$$

Treatment

Women with iron deficiency were randomly allocated within their age groups (< 20 , 20–29, 30–39, and 40–50 y) and parity categories (0, 1–2, and 3–4 children) to either the diet or supplement intervention.

The supplement intervention was designed to represent the currently accepted, standard treatment for iron deficiency and was also planned on the basis of results of a preliminary study of medical practitioners in the Newcastle and greater Hunter areas. Subjects allocated to the supplement group were asked to take a 350-mg slow-release ferrous sulfate tablet (equivalent to 105 mg inorganic Fe) on an empty stomach each day for 12 wk. Compliance was measured by using a diary system, and subjects completed an evaluation at the end of the treatment period. No dietary advice was given to this group.

TABLE 1
High-, medium-, and low-iron foods (cooked weight) used in the dietary intervention¹

High iron	Medium iron	Low iron
Lean beef, 120 g	Leg ham, 60 g (2 slices)	Breakfast cereal, 1 cup (250 mL)
Rump steak, 90 g	Lean pork, 50 g	Bread, 1 slice
Beef mince, 120 g	Chicken breast, 120 g	English muffin, 1/2
Liver paté, 60 g	Chicken drumstick, 50 g	Bread roll, 1/2
Lamb, 120 g	Fish, 150 g	Rice, 90 g (1.33 cups)
Mussels, 40 g	Canned tuna, 60 g	Egg, 1 medium
	Beans or lentils, 60 g (1/3 cup)	Vegetables, (broccoli, cauliflower, cabbage, peas, beans), 1/2 cup (118 mL)
	Tofu, 50 g	Dried fruit, 40 g (2 Tbs)
	Pasta, 150 g (1 cup)	Nuts, 15 g (1 Tbs)
		Nut paste, 1 Tbs (20 mL)

¹Suggested daily combinations to supply ≈ 2.25 mg bioavailable dietary iron were as follows: 1 high + 1 medium + 5 low, 4 medium + 6 low, 3 medium + 8 low, 2 medium + 10 low, or 1 high + 7 low.

Subjects allocated to the diet group were asked to follow a high-iron diet for 12 wk. The dietary intervention was designed on the basis of a high-iron-diet pamphlet that was in use across Australia at the time of the trial. The diet was planned to provide approximately the recommended intake of absorbable iron (2.25 mg/d) (14) because it was thought that higher intakes would be unrealistic for many women. Calculations of absorbable iron provided by various foods were derived from previous absorption studies (14). Iron-containing foods were defined as high-, medium-, or low-iron foods, and participants were asked to consume any one of the following combinations of these foods daily: 1 high + 1 medium + 5 low; 4 medium + 6 low; 3 medium + 8 low; 2 medium + 10 low; or 1 high + 7 low (Table 1). We encouraged subjects to consume iron-absorption enhancers (meat or vitamin C-rich foods) at each meal, and consumption of tea, coffee, and milk were discouraged at lunch and dinner (the main iron-containing meals) and for 1 h afterward.

Subjects in the diet group were given meat vouchers sufficient to purchase 120 g high-quality beef or lamb per day for the 12 wk at the current market rates. They also received counseling from the dietitian on the diet regimen. Compliance was assessed from diet diaries kept by the subjects regarding their consumption of iron-containing foods and enhancers during 3 of the 12 wk of the intervention (weeks 1, 5, and 9). Participants also completed an evaluation about their experience while following the high-iron diet.

Blood tests and 7-d weighed food records were repeated after the 12-wk intervention and again after a subsequent 6-mo follow-up phase. Subjects in the iron-replete control group completed all the assessments but received no intervention.

Data analysis

Linear mixed models (15) were used to investigate the main effects of group (control, diet, and supplement) and time (at baseline, after intervention, and after follow-up). This type of model allowed the correlation between observations for each individual to be taken into account, so that the differences between each group at each time point could be tested (16). If the main effects of group and time and their interaction were significant, the following individual comparisons were made by using the contrast option (*F* test approximation) of the mixed procedure in SAS, version 8: differences between the control, diet, and supplement groups at baseline and after follow-up; changes over time for each

group; and differences between the diet and supplement groups after the intervention and after follow-up. The significance level for all main effects and their interactions was set at 0.05. For the 8 simultaneous contrasts, Bonferroni correction ($P = 0.00625$) was used to maintain an overall significance level of 0.05.

Serum ferritin, tea intake, and alcohol consumption values were not normally distributed; therefore, although the means and SDs from the raw data are presented, the natural logs of these variables were used in the statistical analyses.

RESULTS

Subjects

Sixty-six (22 in each of the 3 groups) of the 76 women enrolled at baseline completed the entire study and are included in the analyses. Two women in the control group and 4 each in the diet and supplement groups did not finish the study. The reasons for noncompletion were that the subjects had relocated ($n = 2$), were too busy to complete the assessments ($n = 3$), and were unreachable ($n = 3$). In addition, one woman in the diet group ceased participation because she found it difficult to follow the high-iron diet, and one woman in the supplement group was unable to tolerate the iron supplement.

Iron status

Iron status improved in both the diet and supplement groups during the intervention, whereas iron status in the control group did not change significantly (Table 2). Serum ferritin values changed over time in both intervention groups, but the pattern of change differed between the groups. Mean serum ferritin in the supplement group increased by 15.8 $\mu\text{g/L}$ from baseline to the end of the 12-wk treatment phase but then remained stable until the end of the 6-mo follow-up phase. In the diet group, serum ferritin increased by 2.1 $\mu\text{g/L}$ during the intervention and increased an additional 4.2 $\mu\text{g/L}$ during follow-up. Therefore, mean serum ferritin increased significantly in both groups, but was significantly higher at follow-up in the supplement group than in the diet group. Mean serum ferritin at baseline was significantly higher in the control group than in the diet and supplement groups and did not change significantly during the trial.

Mean hemoglobin was significantly higher at baseline in the control group than in the diet and supplement groups, which were

TABLE 2

Values for iron-status indicators in control, diet, and supplement groups at baseline, after the 12-wk intervention, and at the 6-mo follow-up¹

	Group		
	Control (<i>n</i> = 22)	Diet (<i>n</i> = 22)	Supplement (<i>n</i> = 22)
Serum ferritin ($\mu\text{g/L}$) ^{2,3}			
Baseline	49.4 \pm 28.8 ^a	8.9 \pm 3.1 ^b	9.0 \pm 3.9 ^b
After intervention	44.5 \pm 26.7	11.0 \pm 5.9 ^a	24.8 \pm 10.0 ^b
Follow-up	51.1 \pm 30.8 ^a	15.2 \pm 9.5 ^b	24.2 \pm 9.8 ^c
Hemoglobin (g/L) ^{2,4}			
Baseline	135.9 \pm 6.4 ^a	127.6 \pm 8.5 ^b	125.2 \pm 9.1 ^b
After intervention	134.0 \pm 6.2	130.6 \pm 7.1	130.4 \pm 6.8
Follow-up	134.9 \pm 5.7	130.8 \pm 6.9	131.4 \pm 6.6
Serum iron ($\mu\text{mol/L}$)			
Baseline	18.2 \pm 4.4	12.4 \pm 5.5	12.1 \pm 6.2
After intervention	16.2 \pm 3.9	11.9 \pm 5.6	16.1 \pm 5.9
Follow-up	15.9 \pm 5.4	16.5 \pm 6.4	13.5 \pm 5.5
TIBC ($\mu\text{mol/L}$)			
Baseline	63.9 \pm 9.7	70.4 \pm 12.8	75.8 \pm 12.2
After intervention	64.2 \pm 8.1	69.7 \pm 12.6	62.4 \pm 8.5
Follow-up	66.9 \pm 8.5	71.0 \pm 13.1	68.2 \pm 8.3

¹ $\bar{x} \pm \text{SD}$. Values in the same row with different superscript letters are significantly different, $P < 0.05$. TIBC, total-iron-binding capacity.

²Significant group-by-time interaction, $P < 0.05$ (F test).

³Significant time effect within groups for the diet and supplement groups, $P < 0.05$ (linear mixed models).

⁴Significant time effect within the supplement group, $P < 0.05$ (linear mixed models).

not significantly different from each other (Table 2). The control group had no significant changes in mean hemoglobin throughout the study. There was a significant increase in mean hemoglobin from baseline to 12 wk in the supplement group but not in the diet group. Despite this, there was no significant difference in mean hemoglobin between these 2 groups at 12 wk or follow-up. There were also no significant differences in mean hemoglobin between the control group and the 2 treatment groups at follow-up.

Dietary intake

Despite measurable improvements in iron-status indicators in the diet group, no significant changes in mean dietary intakes of heme iron, nonheme iron, or any enhancers (vitamin C, alcohol, and meat) or inhibitors (phytate, calcium, and tea) of iron absorption were found for this group during the trial (Table 3). There were no significant differences in intakes of protein, fat, or carbohydrate among the 3 groups at either baseline or follow-up (data not shown). However, we detected a reduction over time in the mean energy intake of the 3 groups combined. For this reason, additional analyses were performed on nutrient density data (ie, nutrients/MJ), but this did not alter any of the findings significantly (data not shown).

There were no significant interactions between group and time for BDI intakes (Table 4). BDI calculations for the supplement group excluded the iron from the tablets, which would have provided ≈ 3.15 mg bioavailable Fe/d on the basis of the algorithms used.

Compliance with dietary reporting

Eighteen of the 66 participants were considered to have underreported their dietary intakes according to the criteria of

Goldberg et al (17). We determined that 6 participants (1, 2, and 3 in the control, diet, and supplement groups, respectively) underreported their dietary intakes at all 3 of the dietary assessments; therefore, we excluded their data and performed additional analyses. There were still no significant differences between groups or between time points for any of the dietary variables.

Compliance with treatment

Compliance scores for the supplement group represent the proportion of days, out of a total of 84, that each subject reported taking the supplement. Compliance scores for the diet group represent the percentage of days, out of a total of 21 when food records were kept, that each subject consumed one of the correct combinations of high-, medium-, and low-iron foods and also managed to include an enhancer of iron absorption with all food sources of nonheme iron. Mean compliance in the diet group (58 \pm 22%; range: 10–95%) was lower than mean compliance in the supplement group (93 \pm 10%; range: 61–100%).

Subject evaluations

In the supplement group, 84% of subjects reported no difficulty remembering to take the iron supplement. However, 76% experienced side effects such as constipation, diarrhea, and bloating. Of those women who experienced side effects, 55% considered the side effects to be mild and <33% felt that the side effects interfered with their ability to take the supplement daily. When women were asked in an open-ended question about their feelings regarding their allocation to the supplement group, the most common response (62% of subjects) was that the supplement intervention was preferred because it was easier.

In the diet group, 65% of subjects found it difficult to consume the required amounts of iron-containing foods. The combination of foods preferred by 65% of women was 1 high- + 1 medium- + 5 low-iron foods. Ninety-one percent of women in the diet group had no trouble combining enhancers of iron absorption with nonheme-iron sources, but 59% found it difficult to avoid consuming tea, coffee, and milk at their main meals. More than 65% of the subjects in the diet group were happy with their allocation; however, almost one-third of these subjects felt that following the high-iron diet was more difficult than taking a daily supplement. About 20% of the subjects in the diet group would have preferred allocation to the supplement group, although 50% of these women were initially happy to be in the diet group but then found the intervention too difficult. Despite these concerns, >90% of the women reported that they would continue to follow a high-iron diet beyond the study period, either in part or in full.

DISCUSSION

Even though this study did not include an iron-deficient control group and the study design did not allow for blinding regarding the type of intervention, the results suggest that dietary treatment of iron deficiency is feasible for women of childbearing age. In fact, it may result in long-term dietary modifications, as suggested by the continued improvements in iron status that we measured during the follow-up phase. To our knowledge, this is the first time that dietary treatment of iron deficiency has been investigated, although Lyle et al (18) showed that meat consumption was superior to iron supplementation for maintaining hemoglobin and serum ferritin concentrations in college women.

TABLE 3

Dietary intakes of the control, diet, and supplement groups at baseline; after the 12-wk intervention; and at the 6-mo follow-up¹

Dietary intake	Group		
	Control (n = 22)	Diet (n = 22)	Supplement (n = 22)
Energy (kJ/d)			
Baseline	7797.5 ± 1544.6	8175.6 ± 1461.2	7688.4 ± 2071.5
After intervention	7228.2 ± 1425.9	7201.1 ± 1773.5	6983.5 ± 1425.7
Follow-up	7380.4 ± 1573.0	6947.7 ± 1849.9	7033.8 ± 1839.3
Non-heme iron (mg/d)			
Baseline	10.4 ± 2.3	11.2 ± 3.8	12.2 ± 4.8
After intervention	9.5 ± 2.0	10.5 ± 3.2	12.0 ± 3.9
Follow-up	9.8 ± 2.1	9.9 ± 3.4	11.8 ± 4.5
Heme iron (mg/d)			
Baseline	1.1 ± 0.4	1.1 ± 0.6	0.9 ± 0.7
After intervention	1.2 ± 0.4	1.3 ± 0.7	0.8 ± 0.8
Follow-up	1.0 ± 0.5	1.1 ± 0.6	0.9 ± 0.8
MFP (g/d)			
Baseline	107.0 ± 42.9	101.3 ± 52.0	85.6 ± 63.9
After intervention	120.9 ± 40.0	110.5 ± 47.6	76.9 ± 58.6
Follow-up	97.6 ± 42.7	98.1 ± 43.0	76.7 ± 59.3
Vitamin C (mg/d)			
Baseline	121.8 ± 52.1	118.5 ± 48.7	133.0 ± 56.9
After intervention	113.7 ± 50.2	174.6 ± 108.8	131.2 ± 60.6
Follow-up	106.2 ± 56.6	125.9 ± 83.7	99.4 ± 53.4
Alcohol (g/d)			
Baseline	13.0 ± 15.4	3.3 ± 3.7	4.6 ± 8.7
After intervention	9.8 ± 9.5	5.0 ± 6.1	3.7 ± 7.7
Follow-up	9.4 ± 8.4	4.1 ± 5.4	3.1 ± 4.5
Phytate (mg/d)			
Baseline	1010.9 ± 362.2	1217.7 ± 545.3	1358.2 ± 627.4
After intervention	905.0 ± 363.6	1175.8 ± 496.5	1330.6 ± 716.4
Follow-up	972.1 ± 431.1	982.3 ± 450.8	1474.3 ± 1157.1
Calcium (mg/d)			
Baseline	836.2 ± 229.2	1010.0 ± 260.2	925.9 ± 342.6
After intervention	828.1 ± 199.0	815.5 ± 314.4	837.5 ± 249.8
Follow-up	856.3 ± 268.0	775.5 ± 285.4	792.1 ± 267.0
Tea (g/d)			
Baseline	265.0 ± 314.0	343.5 ± 400.5	334.6 ± 473.6
After intervention	221.2 ± 271.1	193.1 ± 252.6	219.9 ± 319.2
Follow-up	253.1 ± 330.4	239.7 ± 278.1	285.5 ± 497.1

¹ $\bar{x} \pm SD$. MFP, meat, fish, and poultry.

In the present study, diet was found to be an effective treatment: mean serum ferritin improved from 8.9 to 15.2 $\mu\text{g/L}$ over the 9 mo of the trial. On an individual basis, this would be an improvement from what is defined by the Australian Iron Status Advisory Panel as serious iron deficiency (serum ferritin $<10 \mu\text{g/L}$) to probable iron depletion (serum ferritin = 15–20 $\mu\text{g/L}$). The iron supplement increased serum ferritin concentrations more quickly than did dietary intervention, but this was not surprising because the estimated available iron from the supplement was ≈ 3 –5 times that from the diet. However, diet may have had long-term advantages for improving iron stores because serum ferritin in the diet group continued to increase during the follow-up phase of the study.

The iron supplement used in the present study was chosen because it was found to be the supplement most commonly prescribed by medical practitioners in the Newcastle and Hunter areas. It supplied 350 mg ferrous sulfate daily, which is equivalent to 105 mg elemental Fe. The BDI algorithms suggest that the absorption rate for nonheme iron consumed in isolation (ie, on an empty stomach) is 3% in individuals with iron stores of 500 mg and 5% when there are no iron stores. Thus, the amount of iron

absorbed from the supplement was most likely 3.15–5.25 mg/d. This is consistent with the findings of Cook et al (19), who reported that the iron absorption from a controlled-release iron sulfate preparation was 4.38%.

The diet was designed to provide approximately the recommended intake of absorbable iron for women of childbearing age (2.25–2.35 mg/d) (14). The calculated amounts of absorbable dietary iron ranged from 1.9 to 2.2 mg/d; we reached these estimates by using the results of absorption studies with individual foods. However, these calculations did not take into consideration any further improvements in absorption resulting from inclusion of enhancers of nonheme-iron absorption, or any positive effect on iron absorption resulting from exhausted iron stores. Nonetheless, it was clearly likely that the supplement group would outperform the diet group during the 12-wk intervention phase. It was also thought, however, that the diet group might continue to improve during the follow-up phase because of continued higher iron intakes.

Because the mean increase in serum ferritin in the diet group was 6.3 $\mu\text{g/L}$ over the duration of the study, dietary intervention

TABLE 4

Bioavailable dietary iron (BDI) intakes of the control, diet, and supplement groups at baseline; after the 12-wk intervention; and at the 6-mo follow-up¹

	Group		
	Control (n = 22)	Diet (n = 22)	Supplement (n = 22)
BDI-M (mg/d)			
Baseline	0.72 ± 0.17	0.74 ± 0.28	0.73 ± 0.25
After intervention	0.71 ± 0.19	0.88 ± 0.42	0.68 ± 0.21
Follow-up	0.67 ± 0.21	0.70 ± 0.25	0.71 ± 0.20
BDI-MB (mg/d)			
Baseline	0.84 ± 0.19	0.86 ± 0.34	0.83 ± 0.29
After intervention	0.83 ± 0.21	0.98 ± 0.44	0.78 ± 0.25
Follow-up	0.78 ± 0.24	0.79 ± 0.27	0.81 ± 0.21
BDI-T (mg/d)			
Baseline	0.44 ± 0.12	0.47 ± 0.40	0.40 ± 0.17
After intervention	0.48 ± 0.18	0.66 ± 0.32	0.41 ± 0.20
Follow-up	0.41 ± 0.15	0.44 ± 0.21	0.40 ± 0.18

¹ $\bar{x} \pm$ SD. BDI-M was calculated by using the method of Monsen et al (11), BDI-MB was calculated by using the method of Monsen and Balintfy (12), and BDI-T was calculated by using the method of Tseng et al (13).

alone may be best limited to individuals with mild iron deficiency (serum ferritin >10 µg/L and hemoglobin >120 g/L). However, because dietary intervention addresses part of the cause of iron deficiency, namely inadequate BDI intake, treatment should always involve a dietary intervention component. Because of the time required (ie, ≥9 mo) to achieve large improvements in serum ferritin, supplementation should be used in addition to diet in cases of serious iron deficiency (serum ferritin <10 µg/L) and iron deficiency anemia; this would limit the amount of time that any individual would suffer adverse consequences associated with iron deficiency. In a management guide provided to medical practitioners, the Australian Iron Status Advisory Panel suggests that the best treatment strategy is dietary treatment, with additional iron supplementation for serious iron deficiency and iron deficiency anemia (3). This research provides evidence of the appropriateness of these recommendations.

The fact that the diet group showed a significant increase in mean serum ferritin concentration, but that no significant changes in any of the variables of iron intake were found, suggests that there was insufficient power to detect changes in the dietary data. Inaccuracies in the dietary data or the BDI calculations also may have contributed to the nonsignificant results. Although no significant changes were found, all of the targeted intakes tended to improve more in the diet group than in the supplement group. Heme iron, MFP, and vitamin C intakes and the measures of BDI all increased during the intervention period in the diet group; in addition, calcium and tea intakes decreased. Together, these changes may well account for the improvements in iron status.


Poor compliance in the diet group may have accounted in part for the failure to find any significant dietary changes. Compliance with the dietary intervention was ≈60%, and there was also higher variability in the dietary measures at the end of the intervention for this group than for the other groups. The cost of purchasing red meat was thought initially to be a barrier to compliance, but provision of meat vouchers did not result in most of the participants consuming the recommended amount of red meat daily. Had they done so, the mean heme-iron intake would have approached 2–3 mg/d, rather than the 1.3 mg/d that we measured.

This was the first time that BDI calculations were performed in any Australian population group. Although the BDI intakes calculated agree with those for other populations (20–23), they are well below the recommended BDI intakes for menstruating women.

The results, therefore, highlight possible problems with either the accuracy of the BDI algorithms or the basis for setting recommended dietary intakes (RDIs). Currently, the Australian RDI for iron for menstruating women is 12–16 mg/d (14). The baseline mean intakes of total iron were close to this, at 11.5, 12.3, and 13.1 mg/d for the control, diet, and supplement groups, respectively. The RDI is based on a requirement of 2.25–2.35 mg/d, which is estimated to cover the 90th percentile of menstrual blood loss and assumes an absorption rate (for all men, women, and children) of 15–20% (14). However, in this study, mean BDI at baseline, calculated by using the algorithms of Monsen et al (11), Monsen and Balintfy (12), and Tseng et al (13), ranged from 0.40 to 0.86 mg/d, which represented an absorption rate of only 3–7%. Estimates made with the method of Tseng et al were all at the lower end of this range, even for the iron-replete women. Because physiologic iron losses for men and postmenopausal women are ≈1 mg/d, it seems improbable that menstruating women could absorb so little iron and remain iron replete.

Discrepancies also exist between estimates of available iron from studies of food-iron absorption and the 3 algorithms discussed above (11–13). For example, on the basis of averages from studies of food-iron absorption, full compliance with the dietary intervention would have provided ≈2 mg available Fe/d. Calculations made by applying the algorithms to the iron content of the recommended diet, assuming 3 meals/d and using retrospective observed average values for meat, vitamin C, tea, and phytate, resulted in estimated BDI intakes of 0.8–1.6 mg/d for both the Monsen et al algorithm (11) and the Monsen and Balintfy algorithm (12) and 0.46–0.56 mg/d for the Tseng et al algorithm (13).

One explanation for these discrepancies may be the inability of these algorithms to incorporate the effects of other enhancers and inhibitors of iron absorption because of inadequate knowledge about their effects. In support of this view, Hallberg and Hulthen (24) recently combined the results of the extensive radiolabeled iron absorption studies performed by their research group and others and developed a new series of algorithms for the estimation of BDI. In addition to the enhancers and inhibitors of iron absorption considered in the Monsen et al (11), Monsen and Balintfy (12), and Tseng et al (13) algorithms, these algorithms incorporate the effects of polyphenols (in addition to tannin in tea), calcium, egg, soy protein, and alcohol, and may therefore provide a more precise estimate of BDI.

The main aims of this intervention trial were to determine whether treatment of iron deficiency with diet alone is effective and to compare this effect with that of the current conventional treatment method, iron supplementation. Although a high-iron diet produced smaller increases in serum ferritin than did iron supplementation, it resulted in continued improvements in iron status after the intervention. Despite these results, significant changes in dietary variables influencing iron intake (heme and nonheme iron) and iron absorption (vitamin C, phytate, and meat) were not detected. The BDI algorithms of Monsen et al (11), Monsen and Balintfy (12), and Tseng et al (13) did not explain the observed increases in serum ferritin. 

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