Current Methods for Estimating Dietary Iron Bioavailability Do Not Work in China

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ABSTRACT Three current equations for estimating iron bioavailability were evaluated, and adjustments were proposed that allow us to most effectively study iron bioavailability in China. Dietary intake data were obtained from 24-h dietary recalls taken over three consecutive days as part of the third Chinese National Nutrition Survey. Hemoglobin status was measured for 42,606 Chinese adults aged 18–60 y. The mean iron intake was 24.4 mg per capita per day, which was 177% of the Chinese RDA (209% of U.S. RDA). About 18% of the sample was classified as being anemic, indicating a large iron deficiency anemia and iron bioavailability problem in China. A number of methods proposed by World Health Organization and U.S. scholars were examined for adjusting iron bioavailability. Even the methods that consider several iron enhancers and inhibitors did not work adequately for the Chinese diet. The statistical assessment of the fit between bioavailability and hemoglobin status provided direction for adjusting the best of these predictive equations. We propose a new predictive approach for iron bioavailability which is more predictive of Chinese iron status. Consideration of additional dietary elements such as rice and bean consumption patterns are important. Our findings provide insight into additional factors which may influence iron bioavailability as well as possible improved methods for estimating the combined effect of multiple dietary factors on iron bioavailability, particularly in a vegetarian diet. J. Nutr. 130: 193–198, 2000.

KEY WORDS: iron bioavailability • iron intakes • iron deficiency anemia • China • adjustment

Although the etiology is well known and the measures to prevent and control it effective and inexpensive, iron deficiency anemia (IDA) is still one of the most common nutritional deficiencies worldwide (Mahan and Escott-Stump 1996). During the past two decades, the prevalence of IDA has decreased sharply in developed countries, while it has changed little in developing countries. Studies in China report that the prevalence of anemia is as high as 10–70% among adults, and 85–95% of anemia is due to iron deficiency (Cai and Yan 1990, Ge et al. 1996, He et al. 1994, Li et al. 1994, Wang et al. 1990, Zhang 1987). The health and behavioral consequences of IDA are serious among adults (Ziegler and Filer 1996) and may include adverse effects on work and cognitive function and poor obstetric outcomes (Beard and Borel 1988, Dallman 1987, Farthing 1989, Grantham-McGregor and Fernald 1997, Li et al. 1994, Lozoff and Brittenham 1986, Lozoff et al. 1991, Ma et al. 1997, Pollitt 1993, Scholl et al. 1992).


The main purpose of our study was to examine dietary factors which may affect iron bioavailability in a free-living population in China, and our specific goal was to develop an improved model to estimate iron bioavailability in a predominantly vegetarian diet. This study used a large national survey of dietary intake and IDA status to understand dietary factors that affect iron absorption.

METHODS

Study population and survey design. A total of 42,606 adults aged 18–60 y (19,584 males and 23,022 females) were selected from the Third Chinese National Nutrition Survey (CNNS-92), conducted in 1992. The CNNS-92 sample was obtained using a stratified multistage cluster random sampling method in 29 provinces, metropolises, and autonomous regions in China. There were four substrata for urban areas based on population size (big, medium, small city, and
town) and several substrata for rural areas based on average income level. Details of survey design are discussed elsewhere (Ge 1996).

**Measurement of diet.** Three 24-h recalls were collected for three consecutive days for each individual, combined with the weighing and measuring of household food consumed using a change in inventory method in which all foods purchased or brought into the household during the 3 d were weighed. Preparation waste was estimated when weighing was not possible. Individual dietary intake data for the same three consecutive days included data on both food consumed at home and away from home. The combination of these two methods, recall and weighing and measuring, allowed us to check the quality of data collection by comparing the two. When significant discrepancies were found between an individual’s average daily intake calculated from the household survey and his or her dietary intake based on 24-h recall data, the household and individual in question were revisited to resolve the discrepancies. This approach provided improved measurements on salt, oil, and other condiments added to the diet (during food preparation and at table).

The Chinese Food Composition Table (Wang 1991) was used to calculate iron and other nutrient intakes. Phytate content is not measured in the current Chinese food composition tables. Harland and Oberleas’ (1987) data on phytate content in foods in the U.S. were used in China. Knowledge of phytate content was particularly important in using Tseng et al’s (1997) method to estimate iron bioavailability. Individuals’ iron intakes were evaluated by using the Chinese and American recommended daily allowance (RDA). The Chinese RDA is 12 mg for male adults and females older than 45 y and 18 mg for females aged 18–45 y (Wang 1991), while the American RDA is 10 and 15 mg for males and females, respectively (National Research Council 1989).

**Hemoglobin (Hb) measurement.** Hb level was measured by the cyanmethemoglobin method, the international reference method used to determine the total Hb concentration in blood (Tatala et al. 1998). Blood sample collection, transportation, storage, and testing in standardized laboratories in each province were performed according to protocol developed by the Institute of Nutrition and Food Hygiene (INFH) in the Chinese Academy of Preventive Medicine. All reagents and blood-sampling tools were provided by the INFH, and the quality of examination was supervised by professionals from INFH. Individual’s IDA status was determined based on the WHO’s definition that anemia occurs when the Hb level is below 130 g/L for males and 120 g/L for females (FAO/WHO 1988, WHO 1988).

**Quality control.** All of the interviewers were trained for at least 10 d. Survey teams consisting of five members and a supervisor (responsible, among other things, for checking each interviewer’s work) went to each community in the survey. Households were interviewed when transcription or logical questions and missing values were found.

**Methods to estimate iron bioavailability.** Three methods have been proposed for estimating iron bioavailability. The simplest approach, used by WHO (FAO/WHO 1988), adjusts for heme and nonheme iron and ascorbic acid intake levels based on daily total dietary intakes. Monsen et al. (1987) developed a method that heme iron availability is about 25%, FAO/WHO determines nonheme iron availability based on Table 1. Intake of ascorbic acid is divided into three levels: <25 mg, 25–75 mg and >75 mg; intake of animal food sources is also divided into three levels: <30 g, 30–90 g and >90 g. Based on intake levels of food from animal sources and ascorbic acid, the rate of nonheme iron absorption can be calculated. The WHO’s committee estimated that total iron bioavailability is about 10% for most diets. This figure has been widely used to determine the RDA in many countries (FAO/WHO 1988).

**Monsen’s method.** Based on their laboratory results, Monsen and her colleagues suggested that heme iron bioavailability is 23%, and nonheme iron, 3–8%, varying according to the units of enhancing factors (EF), which were calculated as milligrams of ascorbic acid plus grams of animal tissues (Monsen et al. 1978, Monsen and Balnftny 1982). When no EF were present, only 3% of the nonheme iron would be bioavailable; the nonheme iron bioavailability could reach as high as 8% when EF were greater than or equal to 75. The equations were as follows:

\[
\text{When } EF < 75, \text{ nonheme iron bioavailability } (\%) = 3 + 8.93 \ln(\text{EF/100})/100
\]

\[
\text{When } EF \geq 75, \text{ nonheme iron bioavailability } (\%) = 8.
\]

**Tseng’s method.** Recently, Tseng et al. (1997) suggested estimating nonheme iron bioavailability by three steps: first, calculate using Monsen’s method; second, adjust it for intakes of phytates in the same meal. Based on the data from Hallberg’s study (Hallberg et al. 1989), Tseng and co-workers proposed an adjustment equation:

\[
\log_{10} [(\% \text{ nonheme iron availability})] = 0.2869 \log_{10} (\text{mg phytates in meal}) + 0.1293; \text{finally, adjust the bioavailability of nonheme iron for tea consumption: reduce the rate by 40% when the amount of tea consumed in the same meal exceeds 225 g.}
\]

**Our new method to estimate iron bioavailability in Chinese adults.** Our study began with these three approaches, tested them for their ability to predict iron status for Chinese adults and then refined them to fit Chinese eating patterns. Our new method was developed by the following three steps. First, we analyzed foods and nutrients which may affect the residuals from analyses of the three methods discussed above. We included intake levels of food from animals, ascorbic acid, vegetables and fruits, rice, beans, tea, and some other foods and nutrients as determinants of the residual. Second, we divided the factors which affected the residuals into two groups based on regression analysis between estimated iron bioavailability, Hb status, and these factors. We found as expected that food from animal sources and ascorbic acid enhanced nonheme iron bioavailability but also that fruit and vegetable intake acted as a further enhancer of nonheme iron bioavailability. In addition, not only did tea consumption inhibit iron bioavailability, but also rice and bean consumption had a similar inhibiting effect on nonheme iron bioavailability.

Third, we examined how we could combine some of these additional enhancing and inhibiting factors to predict individual’s Hb status based on their dietary iron intakes. We assumed that 40% of iron from animal food sources was heme iron and heme iron bioavailability was 23%. Based on these results, our further analyses indicated that the best predictive model to estimate nonheme iron bioavailability was:

**TABLE 1**

<table>
<thead>
<tr>
<th>Animal food sources in a meal, g</th>
<th>Ascorbic acid in a meal, mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;25 mg</td>
<td>5</td>
</tr>
<tr>
<td>25–75 mg</td>
<td>10</td>
</tr>
<tr>
<td>&gt;75 mg</td>
<td>15</td>
</tr>
</tbody>
</table>

1. Adapted from Tseng et al. 1997.
Daily energy and iron intakes and prevalence of anemia for Chinese adults aged 18–60 y

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Energy Intakes (kJ)</th>
<th>Iron Intakes (mg)</th>
<th>% of the Chinese RDA</th>
<th>% of the US RDA</th>
<th>Anemia (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Heme</td>
<td>Nonheme</td>
<td>&lt;100 RDA</td>
<td>&lt;100 RDA</td>
</tr>
<tr>
<td>Urban</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>6465</td>
<td>9684.1 ± 938.9</td>
<td>24.5 ± 1.3</td>
<td>1.4 ± 0.1</td>
<td>23.1 ± 0.5</td>
<td>2.5 ± 0.9</td>
</tr>
<tr>
<td>Female</td>
<td>7840</td>
<td>8132.1 ± 632.2</td>
<td>21.4 ± 1.3</td>
<td>1.2 ± 0.9</td>
<td>20.2 ± 0.3</td>
<td>2.6 ± 0.1</td>
</tr>
<tr>
<td>Subtotal</td>
<td>14305</td>
<td>8830.4 ± 879.8</td>
<td>22.8 ± 1.4</td>
<td>1.3 ± 0.0</td>
<td>21.5 ± 0.5</td>
<td>2.6 ± 0.0</td>
</tr>
<tr>
<td>Rural</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>13119</td>
<td>11049.2 ± 258.9</td>
<td>27.1 ± 2.4</td>
<td>0.5 ± 0.2</td>
<td>26.6 ± 2.3</td>
<td>2.5 ± 0.9</td>
</tr>
<tr>
<td>Female</td>
<td>15182</td>
<td>9428.7 ± 768.7</td>
<td>23.6 ± 1.6</td>
<td>0.4 ± 0.0</td>
<td>23.2 ± 1.4</td>
<td>2.5 ± 0.0</td>
</tr>
<tr>
<td>Subtotal</td>
<td>28301</td>
<td>10176.7 ± 111.6</td>
<td>25.2 ± 2.1</td>
<td>0.5 ± 0.1</td>
<td>24.7 ± 2.0</td>
<td>2.5 ± 0.5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>19584</td>
<td>10597.9 ± 221.3</td>
<td>26.2 ± 2.1</td>
<td>0.8 ± 0.6</td>
<td>25.4 ± 1.9</td>
<td>2.5 ± 0.9</td>
</tr>
<tr>
<td>Female</td>
<td>23022</td>
<td>8986.5 ± 791.4</td>
<td>22.8 ± 1.5</td>
<td>0.7 ± 0.4</td>
<td>22.1 ± 1.2</td>
<td>2.6 ± 0.0</td>
</tr>
<tr>
<td>Total</td>
<td>42606</td>
<td>9724.0 ± 101.5</td>
<td>24.4 ± 1.9</td>
<td>0.7 ± 0.5</td>
<td>23.7 ± 1.6</td>
<td>2.5 ± 0.0</td>
</tr>
</tbody>
</table>

1 Means ± are presented.
2 The Chinese recommended dietary allowance (RDA) is 12 mg for males and females over 45 y and 18 mg for females aged 18–45 y.
3 The US RDA is 10 mg for males and 15 mg for females.
4 Proportion below the WHO cutoff (WHO 1968, CDC 1998). Anemia is defined as hemoglobin <130 g/L for males and <120 g/L for females.

% (nonheme iron bioavailability) = 1.7653 + 1.1252 ln(EFs/IFs)

Where, EFs = ascorbic acid (mg) + foods from animal sources (g) + vegetables and fruit (g) + 1, and IFs = rice (g) + beans (g) + tea (g, dry) + 1

Statistical analysis. Statistical methods included student's t test, correlation, and linear regression models. Correlation and linear regression models were used to test the association between estimated bioavailability, Hb, and dietary factors after adjustment for gender, urban or rural, and resident area (north vs. south). Dietary factors were log-transformed in regression models. We could not use log transformation to describe the estimated amount of iron bioavailability and some other results because the statistical properties of log transformation require no zeros as dependent variables, and the sign and general level of impact of the log-transformed coefficient were comparable with the nonlog-transformed one. SAS (version 6.12; Cary, NC) was used for all analysis.

RESULTS

Daily intake of iron. The mean daily iron intake in adults aged 18–60 y was 24.4 mg (Table 2). On average, it was about 177% of the Chinese RDA or 209% of the U.S. RDA. Men's iron intake was significantly higher than women's. Unexpectedly, mean iron intake of rural residents was 2.4 mg higher than that of urban residents (25.2 vs. 22.8 mg). We found that 4.1% of males and 29.2% of females had iron intakes below the Chinese RDA (only 1.8% of males and 17.6% of females were below the US RDA level).

Nonheme iron was the main form consumed by this population. Based on the widely accepted assumption that 40% of iron from meats is heme iron (Monsen and Balintfy 1982), the proportion of heme iron was only 3.3% in the whole sample, and the mean daily heme iron intake was 0.8 mg compared with about 16% of total dietary iron from heme sources in the U.S. (Carpenter and Mahoney 1992). Heme iron intakes were not significantly different in males and females (0.8 vs. 0.7 mg) and were significantly higher in urban areas than in rural areas (1.3 vs. 0.5 mg). We also found that about one-third of the sample consumed no heme iron during the 3-d period studied.

About 77% of the dietary iron as estimated in Table 2 came from wheat, rice, vegetables, and fruit, and only about 9% of iron came from meat, poultry, and fish. Heme iron was mainly from pork, pork liver, and beef. More than 50% of heme iron came from pork and pork liver. In urban areas about 17.3% of dietary iron came from meat, poultry, and fish as compared with 5.4% among rural residents. The sources and proportions of iron intakes were the same for men and women.

Prevalence of anemia. Although the population's average iron intake was about twice the Chinese RDA, the prevalence of IDA was still very high (Table 2). About 18% of adults were anemic, with an average of 12.4% in males and 22.8% in females. It is interesting that the prevalence of IDA in rural areas was similar to that in urban areas, although intake of iron from foods is much lower in rural areas. This is particularly because rural residents had a much higher total iron intake than their urban counterparts.

Evaluation of the three current methods. The methods proposed by FAO/WHO (FAO/WHO 1988), Monsen et al. (1978, 1982), and Tseng et al. (1997) were used to estimate the amount of bioavailable iron intake (Tables 3 and 4). WHO's method estimated that the average daily bioavailable iron intake was about 2.9 mg for males and 2.4 mg for females. Monsen's method estimated that intake was 1.8 and 1.5 mg for males and females, respectively. These are much higher than the estimated requirements in China, which are 1.0 mg for males and 1.5 mg for females (Wang 1991). They are also higher than the WHO/FAO/WHO's estimates, 0.9 mg for men and 1.3 mg for menstruating women (FAO/WHO 1988). But the estimation based on Tseng's method was very low, only 0.6 mg were bioavailable in both males and females (Tables 3 and 4). The results (except the estimation based on WHO's method) showed that dietary iron bioavailability was strikingly low in the Chinese diet.

To compare the approaches, we calculated the sensitivity and specificity of the three methods to predict individuals' IDA. We used the WHO cutoff (WHO 1968) for anemia as our gold standard, and estimated iron bioavailability as the estimated amount of iron intake that was bioavailable.
The amount of bioavailable iron estimated by three current methods and our equation

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<tbody>
<tr>
<td>Urban</td>
<td>14148</td>
<td>11.5 ± 0.7</td>
<td>7.1 ± 0.6</td>
<td>3.2 ± 0.3</td>
<td>3.9 ± 0.3</td>
</tr>
<tr>
<td>Rural</td>
<td>27926</td>
<td>10.4 ± 0.8</td>
<td>6.4 ± 0.5</td>
<td>2.2 ± 0.0</td>
<td>3.3 ± 0.0</td>
</tr>
<tr>
<td>Total</td>
<td>42074</td>
<td>10.8 ± 0.8</td>
<td>6.6 ± 0.5</td>
<td>2.5 ± 0.2</td>
<td>3.5 ± 0.3</td>
</tr>
</tbody>
</table>

1 Means ± are presented.
2 Each rate is bioavailable iron estimated by three current methods and our equation divided by total dietary iron intakes.
3 Heme iron bioavailability was assumed as 25% in WHO’s method, 23% in Monsen’s and Tseng’s method, and our equation.
4 Iron bioavailability was adjusted for enhancers and inhibitors.
5 Iron bioavailability were adjusted for both enhancers and inhibitors.

Diagnostic test. With our approach, we determined the amount of iron bioavailability estimated by each method < 100% of the estimated requirements; otherwise, it was determined to be negative. When we calculated sensitivity and specificity for the unadjusted method, we used dietary iron intake as diagnostic test. We determined positive as iron intakes < 100% RDA, and negative as iron intakes no < 100% RDA. The sensitivity of both the WHO’s and Monsen's methods was low, but that of Tseng's method was high while its specificity was very low (Table 5).

Another way to evaluate the methods is to see how individuals' bioavailable iron being estimated by each method predicts their Hb level. The bioavailable iron coefficients from the models relating bioavailable iron (estimated by each approach) are presented in Table 6. The results show that the coefficients related to Hb level and the estimated bioavailable iron intake were very low in both WHO’s and Monsen’s. The effect of bioavailable iron estimated by these two methods on individual's Hb status was very small. The largest effect was found for Tseng’s method, but each one mg increase in bioavailable iron was only associated with a 0.07-U increase in Hb.

Our new method. Results based on our revised model indicated that the daily average bioavailable iron intake in this population was 0.9 mg in males and 0.8 mg in females. The sensitivity of our method was close to Tseng’s method, which was the best of the three methods; but its specificity was about three times that of Tseng’s method. The regression coefficient between Hb level and the amount of bioavailable iron intake estimated by using our method was 0.11, which almost doubled the coefficient of Tseng’s method (Tables 4–6).

**DISCUSSION**

This research shows that in China, as in many other developing countries, dietary iron intake was high, but much of the iron consumed came from food sources with low bioavailability. Heme iron intake was very low, accounting for about 3% of total iron intake. Moreover, consumption of foods from animal sources was much lower in rural areas than in urban areas, and a sizable proportion of households consumed no foods from animal sources. IDA was still prevalent. About a fourth of women of childbearing age had IDA. Low bioavailability of dietary iron appears to be the main cause of IDA in China. Research in China shows that infectious and parasitic diseases are not likely causes of IDA. Parasite prevalence is very low and is steadily decreasing in China (Year Book of Public Health 1993).

Three current methods for estimating iron bioavailability were compared. Although these methods considered both enhancing factors and inhibiting factors and may be suitable for the Western diet, they did not adequately predict iron status in Chinese adults. The Chinese dietary pattern is quite different from that of Western countries. Cereal grains and vegetables are the staple foods of Chinese, and vegetables are cooked before being consumed. Stir-frying and boiling are the main cooking methods, which may diminish the effects of phytates, polyphenol and other inhibiting factors as well as ascorbic acid (Svanberg et al. 1993). In addition, there is the potential that

**TABLE 3**

Iron bioavailability estimated by three current methods and our equation

<table>
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3 Heme iron bioavailability was assumed as 25% in WHO’s method, 23% in Monsen’s and Tseng’s method, and our equation.
4 Iron bioavailability was adjusted for enhancers and inhibitors.
5 Iron bioavailability were adjusted for both enhancers and inhibitors.

**TABLE 5**

Sensitivity and specificity of the methods for predicting anemia

<table>
<thead>
<tr>
<th>Method</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unadjusted</td>
<td>24.2</td>
<td>82.5</td>
</tr>
<tr>
<td>WHO (1968)</td>
<td>25.9</td>
<td>80.8</td>
</tr>
<tr>
<td>Monsen (1978,1992)</td>
<td>58.5</td>
<td>52.2</td>
</tr>
<tr>
<td>Tseng (1997)</td>
<td>96.3</td>
<td>5.9</td>
</tr>
<tr>
<td>Our equation</td>
<td>91.4</td>
<td>17.2</td>
</tr>
</tbody>
</table>

1 The classification based on each individual’s hemoglobin value and the WHO’s definition for anemia is used as the gold standard.
2 Estimated requirements are used as diagnostic test. Individuals were classified as iron deficiency anemia (IDA) cases when their estimated iron bioavailability was less than the estimated requirement; otherwise, non IDA cases.
3 Crude iron intakes without adjusting for enhancing factors and inhibitors were used to predict anemia; diagnostic test is recommended dietary allowance.
body iron storage, another important factor which affects the bioavailability of both heme and nonheme iron, may differ. Studies of iron stores indicated much higher levels for persons from industrialized nations than from countries like China (Anonymous 1985, Hallberg et al. 1997, Ho et al. 1987, Looker et al. 1991, Root et al. 1999).

Each currently reviewed method had some limitations. First, these methods considered either i) the effects of enhancing factors only or ii) the effects of both enhancing factors and inhibiting factors, but not simultaneously, although usually many kinds of foods are consumed in a meal and many of them contain both enhancing and inhibiting factors (Siegenberg et al. 1991, Tuntawiroon et al. 1990). Second, these methods ignored other potential important factors which may affect iron bioavailability (such as vitamin A, β-carotene, calcium, fiber, types of dietary carbohydrate and dietary factors which may affect pH values in the GI track). The possibility that the type of dietary carbohydrate may change iron metabolism is perhaps the greatest importance for China (Johnson and Gratzek 1986). Third, the fact that phytate content is not measured in the current Chinese food composition tables may have hampered the use of Tseng’s method of assessing iron bioavailability in the Chinese diet. To measure phytates in our analysis, we linked the U.S. food composition table with our Chinese food composition table and used American values. These values may not have accurately reflected the true phytate content of the food supply in China. Finally, no method is able to adjust the influence of iron status on iron availability. Iron status is one of the main factors that affects iron bioavailability, since absorption is negatively associated with storage (FAO/WHO 1988).

The method we propose is based on cross-sectional data. The influence of ordinary diet on iron bioavailability is difficult to evaluate from short-term studies with preselected meal components. In general, the use of one measure of iron status does not deal with the complex timing and lagged relationships between dietary intake and iron status. In addition, the dietary data used do not measure the amount of iron obtained when iron pots were used in food preparation, although some studies in China indicate that this practice could increase daily iron intake considerably (Liu et al. 1990).

However, the large-scale nature of this study allows us to more definitively examine the issue of iron bioavailability. In more in-depth analyses with a full array of iron parameters, other factors might emerge as determinants of iron bioavailability. There are some unique features that lend weight to this study. One is the detailed weighing and measuring of household food consumption in combination with the collection of three 24-h recalls for each subject. Second, the day-to-day variation of Chinese dietary intakes (i.e., intraindividual variation) for this sample is small relative to that in many populations, especially for those who lived in rural areas (which account for about three-quarters of our sample). Another strength of our study is the large sample size. Furthermore, the method we developed for China was developed with data from a free-living nationally representative sample. In contrast, many of the components of the other three methods come from smaller unrepresentative clinical studies. This study provides insights not only into methods to predict iron bioavailability, but also directions to study and improve iron bioavailability in primarily vegetarian diets.

We feel the association between dietary fat intake and iron bioavailability found in our study should be interpreted cautiously. Very few studies have explored the effect of dietary fat on iron bioavailability in human subjects (Van Dokkum et al. 1983). A small number of studies in rats suggest that dietary fat may enhance iron bioavailability. However, the findings are inconsistent regarding the effects of amount and types of fat (Joseph et al. 1981, Kapsokelos and Miller 1993, Mahoney et al. 1980). Further studies are needed to examine the possible biological mechanisms.

In conclusion, we found that the previously proposed methods may not be applicable to estimated dietary iron bioavailability in the Chinese diet because of the unique patterns of Chinese diet and the limitations of these methods. For population studies, our new method is more useful for linking people’s dietary iron intake and iron utility. We found that considering additional dietary elements such as rice and bean consumption patterns are important. Our findings indicate a need to study new factors which may influence iron bioavailability as well as to estimate the combined effect of multiple dietary factors on iron bioavailability, particularly in a vegetarian diet.

**LITERATURE CITED**


