Low dietary iron availability is a major cause of anemia: a nutrition survey in the Lindi District of Tanzania1-3

Simon Tatala, Ulf Svanberg, and Benedicta Mduma

ABSTRACT  A nutrition survey was conducted in the rural Lindi District of Tanzania to determine the magnitude of anemia and iron deficiency in different age and sex groups as related to nutritional status, parasitic infections, food iron intake, and socioeconomic factors. In a 30-cluster sampling design, 660 households were randomly selected and a total of 2320 subjects aged 6 mo to 65 y were examined. Iron status was assessed by measuring hemoglobin and erythrocyte protoporphyrin in a finger-prick sample: 55% of the subjects had anemia and 61% of the anemia was associated with iron deficiency (erythrocyte protoporphyrin > 125 μmol/mol heme). Preschool children (aged < 5 y) were the most affected; 84% were anemic (hemoglobin < 110 g/L). Fifty percent of the nonanemic preschool children and ≈90% of all the severely anemic subjects were iron deficient. Hemoglobin was lower in schoolchildren (aged 5–14 y) and in adolescent and adult males (aged ≥15 y) with a low body mass index. Parasitic infections were only associated with anemia and iron deficiency in schoolchildren and adolescent and adult males. Malaria was associated with anemia (P < 0.001), whereas schistosomiasis was associated with anemia and iron deficiency (P = 0.001 and P < 0.05, respectively). Hookworm infestation was associated with iron deficiency (P < 0.05) and with anemia (P < 0.01) only in adolescents and adults. A mainly cereal-based diet with additional legumes and green vegetables was found by in vitro tests to contain high amounts of total iron but of low bioavailability. Estimation of the amount of iron absorbed confirmed inadequate iron nutrition. Although anemia is a result of a synergism of a variety of causes, iron deficiency remains the major cause. Am J Clin Nutr 1998;68:171–8.

KEY WORDS  Humans, anemia, iron deficiency, preschool children, schoolchildren, adults, parasitic infections, dietary iron, hemoglobin, erythrocyte protoporphyrin, adolescents, Tanzania

INTRODUCTION  Anemia is a worldwide problem that is highly prevalent in developing regions of the world. The highest incidence of anemia is reported in south Asia and sub-Saharan Africa, where a large proportion of women of reproductive age and preschool children are affected (1). Anemia in association with iron deficiency has serious implications in terms of increased morbidity and mortality rates in vulnerable groups, impaired growth and cognitive abilities in children (2), and reduced work capacity and poor obstetric performance in adults (3–5). Although many causes of anemia have been identified worldwide (6–8), it is agreed that nutritional deficiency due primarily to low bioavailability of dietary iron accounts for more than half the total number of cases (9).

Anemia in Tanzania is estimated to be present in about one-third of the population (10). Hospital records indicate that it is among the top 10 reasons for admission in obstetric as well as in pediatric wards. In the affected populations, nutritional deficiencies, especially iron deficiency, have been implicated most (10). There is, however, little documented information as to what extent iron deficiency can be attributed to anemia in the presence of other causes of anemia. Diets and dietary habits in most parts of Tanzania for both children and adults favor conditions of nutritional anemia. The United Nations Children’s Fund (UNICEF) in the United Republic of Tanzania identified inadequate food intake, a high prevalence of diseases, and increased physiologic need for nutrients as the immediate causes of nutritional anemia (11). Socioeconomic factors are the other causes identified as underlying because of their indirect influence on the health and nutrition of the population.

As a first step toward the initiation of a national program for the control and prevention of anemia, a nutrition baseline survey was conducted in a rural community on the southeast coast of Tanzania. The objectives were to determine the prevalence of anemia and iron deficiency in all age groups of the community as related to nutritional status, parasitic infections, dietary habits, and socioeconomic factors. The information gathered was intended to produce realistic estimates of anemia and its determinants so as to initiate appropriate interventions.

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SUBJECTS AND METHODS

Study area and study population

The study was conducted in June and July 1992 in Lindi District, which is on the southeast coast of Tanzania and has a population of \( \approx 317,000 \). The residents are predominantly subsistence farmers, with a few fishermen living along the coast. The area has a rainy season and a dry season; the rains end between May and June. The staple foods are mainly cereals, maize or sorghum, prepared as a stiff porridge, ugali, or rice, and in some areas the starchy tuber cassava. A variety of green vegetables, legumes, and occasionally fish (along the coastline) also form part of the diet. In these areas, little is being done in terms of animal husbandry, making meat a rare commodity. Coconuts, cashews, and sesame are the major cash crops. The exclusively plant-based diet with negligible amounts of animal protein suggests a diet with low iron availability.

The major health problems in the Lindi District are similar to those found in other parts of the country, with malaria taking the lead because of the high transmission rates common along the east African coast. Other health problems include acute respiratory infections, eye and skin infections, and diarrhea. The district was selected as a pilot area for the national anemia control program primarily because of the findings of a high infant mortality rate and anemia in a situational analysis by the government of Tanzania and UNICEF carried out in 1990 (11). The study population was categorized into preschool children aged 5 y, schoolchildren aged 5–14 y, and adolescent and adult males and females aged \( \geq 15 \) y.

The survey was cross-sectional and a recent population census was used as a base from which to calculate the sample size for a 30-cluster sampling survey design (12). The clusters represented wards from which a random selection of 1 village and 22 households was made. The national estimated prevalence of 32% for anemia was used in this calculation (10). This was expected to provide a prevalence estimate within the 95% CI and an error margin of 0.05 for each of the age and sex categories mentioned. The total number of subjects to be covered in the survey was then calculated to be 2785. A pretested questionnaire was used in an interview, which was conducted by visiting the randomly selected households; some of the variables, such as birth dates for young children and general profile information, were validated by actual observation by the interviewer. The survey protocol was reviewed and approved by the Tanzania Food and Nutrition Centre’s Research and Ethics Committee.

Assessment of health and nutritional status

Anemia in the population was assessed by hemoglobin determination, which is one of the most convenient screening methods, although the major limitation of this measurement is its low specificity. A hemoglobin concentration below a certain value does not distinguish between iron deficiency anemia and anemia due to infection or some other causes. To differentiate the other causes, screening tests for iron status and parasitic infections were also conducted. Of the iron-status indicators, serum ferritin (SF) and erythrocyte protoporphyrin (EP) are among the reliable indexes available for assessing iron nutrition in population groups (13–15). The amount of SF reflects the amount of stored iron in the body whereas high EP concentrations are more suggestive of iron deficiency due to an inadequate supply of iron for heme synthesis, reflecting the first stage of iron deficiency. An elevated EP concentration is associated with chronic inflammation and lead poisoning and thus it could be a false-positive indication of iron deficiency (16, 17). The advantages of measuring EP are that it increases only after several weeks of iron-deficient erythropoiesis and remains abnormal when there is an iron deficiency even if iron supplementation was initiated within the previous 1–2 wk (18). EP concentrations have also been shown to be a reliable indicator of iron status in populations with malaria infection, which is infrequently associated with disease (19). EP also has the advantage that it can be measured under field conditions with a portable hematofluorometer, it is simple and rapid, and can be performed on a capillary blood sample (20, 21).

In this study the EP cutoff value used to assess iron deficiency was 125 \( \mu \text{mol/mol heme} \) (4.5 \( \mu \text{g/g hemoglobin} \)), which is suggested for children in areas with a high prevalence of severe forms of anemia and high incidences of infections (22, 23). Finger-prick blood samples collected with disposable needles were used to determine iron status and to screen for malarial parasities. The hemoglobin concentration was determined by using the HemoCue B-Hemoglobin System (HemoCue AB, Angelholm, Sweden). This system consists of disposable microuncettes with sodium azide reagent in dry form. Undiluted blood samples applied to this reagent react to form azide methemoglobin and are then measured directly at 565 nm. The photometer is calibrated in the factory against the cyanmethemoglobin method, which is the international reference method used to determine the total hemoglobin concentration in blood. The EP concentration was measured with a portable hematofluorometer (Aviv Biomedical Inc, Lakewood, NJ). The machine used was a front-face fluorometer, which measures the reflected fluorescence from zinc protoporphyrin in a drop of whole blood and the instrument is calibrated to read out \( \mu \text{g EP/g hemoglobin} \) (24). The instrument was standardized daily by using control solutions (low, medium, and high EP control blood samples) provided by Aviv Biomedical. The CV for the assay was typically \( \approx 12\% \).

Thick blood films stained with Giemsa stain were used to screen for malaria parasites, and only the presence or absence of the malaria parasites was reported. An advance survey team was used to transport stool containers so that the feces were brought to technicians the next day for examination without delay. Fresh urine was examined for Schistosoma on the collection day. Stool preparations and urine deposits after centrifugation were examined by direct microscopy in the field. A sodium metabisulfite screening test for sickle cell anemia was negative in a subsample of the preschool children examined.

The correct ages for subjects aged \( < 5 \) y were recorded as shown on their growth monitoring chart or birth cards kept by mothers in their homes; for the older age groups, a self-reported age was accepted. Children aged \( < 2 \) y were weighed with Salter scales (type 235; Salter Weigh-Tronix, West Bromwich, United Kingdom) and subjects aged \( \geq 2 \) y were weighed with Seca scales (Seca, Inc, Columbia, MD). The weighing scales were calibrated at the National Bureau of Weight Standards, Dar es Salaam, Tanzania. Length boards and height rods were used to measure lengths and heights. All measurements were recorded to the nearest 0.1 unit.

Household dietary information

A pretested, structured questionnaire was used in the household interviews to determine common foods, food availability, and feeding habits. This questionnaire was administered to the
mother or head of the household during the survey. Another questionnaire was administered to the village leader to obtain a village profile. The commonly consumed food items prepared in the area were collected in sealed plastic bags on separate days by one of the authors (ST). A cooler with ice packs was used to preserve the food samples in the field, which were then transported to the district laboratory for storage in a deep freezer until further transport to Gothenburg, Sweden, for measurement of total iron content and iron availability by an in vitro test.

**Determination of iron solubility at physiologic conditions**

A 1-g sample of freeze-dried food was suspended in 10 mL distilled water and 10 mL of a pepsin solution (3 g in 0.1 mol HCl/L) with physiologic amounts (25) of calcium (3.6 mmol/L added as CaCl₂ · 2 H₂O), magnesium (1.5 mmol/L added as MgCl₂ · 6 H₂O/L), and phosphate (3.5 mmol/L added as KH₂PO₄). The mixture was then incubated for 90 min at 37 °C. A solution of 1 mol NaOH/L was added drop by drop with a 5-mL syringe until the required pH of 2.0 was obtained. Three milliliters of pancreatin (4 g/L) and bile salt (25 g/L) dissolved in 0.1 mol NaHCO₃/L was then added. The pH was adjusted to 5.0 by adding 1 mol NaOH/L drop by drop as above and the sample was incubated again for 30 min. The sample was then adjusted to a pH of 6.0 with 1 mol NaOH/L and immediately centrifuged at 5000 × g for 20 min. The clear supernate was analyzed for soluble iron, including free ionizable iron and soluble complexes of iron, with an atomic-absorption spectrophotometer (PU9100X; Philips, Cambridge, United Kingdom). Soluble iron at pH 6.0/total iron in sample × 100 was expressed as the percentage of soluble iron. Solubility at a pH of 6.0 was used as an estimation of iron bioavailability in this model system because it showed a high correlation \((r^2 = 0.94)\) with results from human studies of iron absorption when 20 vegetable-based diets were compared (26); human iron absorption \((\%) = 0.53 \times \text{in vitro soluble iron (}) \%\) − 1.3. In vitro digestion of each sample was performed in duplicate.

**Statistical analysis**

Anthropometric data \((z\) scores) were entered and analyzed by using EpiInfo (Centers for Disease Control and Prevention, Atlanta). Associations between the different anemia-related factors were made by using EpiInfo, SPSS-PC (SPSS Inc, Chicago), and SYSTAT software (SYSTAT Inc, Evanston, IL). The statistical methods used included Student’s \(t\) test, analysis of variance \((ANOVA)\), and bivariate and multivariate linear regression analysis with stepwise calculation. A BMI less than the 5th centile according to the sex- and age-specific tables of Must et al (27) was used to categorize stunting and wasting in schoolchildren and in adolescents and adults. Anemia was defined as a hemoglobin concentration below the World Health Organization \((WHO)\) cutoff for age and sex (28). Iron deficiency anemia was defined in all groups as anemia with an EP concentration > 125 \(\mu\)mol/mol heme. To assess the magnitude of association between exposure to risk factors and anemia, the relative risk for each risk factor was calculated. Relative risk is defined as the ratio of the prevalence of anemia in the exposed group divided by the corresponding prevalence of anemia in the nonexposed group. To express the proportion of anemia in the study population that was attributable to the exposure and thus could be eliminated if the exposure were eliminated, the population attributable risk percentage was calculated according to Khan (29).

**RESULTS**

**Characteristics of the study subjects**

Complete interview data were gathered on 652 households representing 99% of the expected study households. Descriptive data showed a mean household size of 4.9, with a ratio of females to males of 1 to 1.1; 14% of the children were aged < 5 y. The literacy rate was 48%, with no significant sex difference. The dependency ratio was 44% and most of the people were subsistence farmers. The staple foods included cassava, maize, sorghum, and rice, whereas different legumes and a variety of green vegetables constituted the common relish. People in this community consume an average of 3 meals per day. Breakfast consists mainly of maize flour porridge for young children and maize or cassava pieces in addition to the porridge for adults. In some households, tea with wheat buns are included occasionally. Lunch is the main meal and includes stiff porridge ugali (made of either maize, sorghum, or cassava) and a sauce prepared from green vegetables or legumes. Fish and meat are rarely eaten. The evening meal is usually light, consisting of a cereal porridge preparation, pieces of cassava, or rice cooked in coconut juice, and tea. The weaning period, ie, the period when the child is given complementary foods in addition to breast milk, may start as early as 2 mo of age and the mean age of infants at which breast-feeding is stopped is 29 mo. The commonest weaning food given is plain maize porridge, consumed daily by 72% of the weaning-age children. In general, living conditions are typical of a rural settlement with a primary school and 1 dispensary in each village. Three-fourths of the surveyed households had pit latrines and \(\approx 65\%\) of them depended on shallow wells for their drinking water; < 20% had access to tap water. More than 50% of the households could not produce enough food on their farms to sustain their families because they lived in flood-prone areas and were therefore forced to purchase additional food from neighboring districts.

**Prevalence of anemia and iron deficiency**

Of the 3196 subjects surveyed, 2320 (72.6%) were examined for anemia and iron deficiency. The overall prevalence of anemia in the study population was 55.3%, with 33.8% classified as having iron deficiency anemia \((Table 1)\). The highest prevalence rates of anemia were found in preschool children and schoolchildren: 83.9% and 66.8%, respectively, with no differences between boys and girls. Moderate and severe anemia were more prevalent in preschool children than in the rest of the population groups \((Table 2)\): 52.1% and 15.3%, respectively. When the preschool children were segregated into age groups, the prevalence was highest during the first and second years of life; > 90% were anemic and 50% of children aged < 1 y were severely anemic. In adults, women had significantly lower hemoglobin concentrations \((P < 0.01)\) \((Table 1)\) than men, and women had a higher proportion of severe forms of anemia \((Table 2)\). The same trend was found for iron status. Iron deficiency erythropoiesis \((EP > 125 \mu\)mol/mol heme) was present in 71.1% of the anemic preschool children and in \(\approx 50\%\) of the nonanemic children \((Figure 1)\); there were no differences between the sexes. Iron deficiency decreased progressively with age in both anemic and nonanemic subjects and was lowest in adolescent and adult males \((30.7\%)\), compared with 41.1% in adult females \((P < 0.001)\). The mean EP in adult males, 114 ± 95 \(\mu\)mol/mol heme.
TABLE 1
Prevalence of anemia and iron deficiency by population groups in the rural Lindi District of Tanzania

<table>
<thead>
<tr>
<th>Population group</th>
<th>Hemoglobin g/L</th>
<th>Erythrocyte protoporphyrin μmol/mol heme</th>
<th>Anemia</th>
<th>Iron deficiency</th>
<th>Iron deficiency anemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preschool children (6 mo to 5 y; n = 261)</td>
<td>90 ± 19(^1)</td>
<td>195 ± 117</td>
<td>83.9</td>
<td>67.8</td>
<td>59.7</td>
</tr>
<tr>
<td>Schoolchildren (5–14 y; n = 727)</td>
<td>113 ± 18</td>
<td>153 ± 95</td>
<td>66.8</td>
<td>53.6</td>
<td>40.9</td>
</tr>
</tbody>
</table>

Adolescents and adults

| Males (n = 649)        | 133 ± 22\(^2\) | 114 ± 95\(^3\) | 41.4   | 30.7           | 24.0                   |
| Females (n = 683)      | 120 ± 19       | 134 ± 92                                 | 45.4   | 41.1           | 25.5                   |
| All subjects (n = 2320) | 118 ± 23       | 142 ± 100                               | 55.3   | 45.1           | 33.8                   |

\(^1\) Individuals with hemoglobin values below WHO cutoffs and erythrocyte protoporphyrin > 125 μmol/mol heme. Iron deficiency and anemia were significantly correlated in all age groups, \(P < 0.001\).

\(^2\) Anemia with protoporphyrin > 125 μmol/mol heme.

\(^3\) \(\bar{x} \pm SD\).

\(^4\) Significantly different from adolescent and adult females, \(P < 0.001\).

(4.1 ± 3.4 μg/g hemoglobin), was significantly lower than that in females, 134 ± 92 μmol/mol heme (4.8 ± 3.3 μg/g hemoglobin) \((P < 0.001)\). There was a significant correlation of iron deficiency with anemia \((P < 0.02)\) in all age groups and the prevalence of iron deficiency was ≥ 68% in those with moderate and severe anemia in the different age groups (Table 2).

Factors associated with anemia and iron deficiency

Several of the health and nutritional risk factors showed strong associations with anemia in those aged ≥ 5 y (Table 3). Of the parasitic infections, malaria and schistosomiasis had a population attributable risk of anemia ranging from 5% to 12%, and multiple regression with hemoglobin as a dependent factor showed significant correlations for both \((P < 0.001)\). In preschool children the prevalence of schistosomiasis and hookworm infections was low and therefore no significant correlation was found with anemia. In adolescents and adults and schoolchildren, however, the prevalence of hookworm infestations was higher and showed a significant association with anemia in adolescents and adults \((P < 0.01)\). In the stepwise multiple regression model, iron deficiency remained the strongest explanatory variable for anemia in all age groups, with a population attributable risk of 12–26%, whereas malaria and schistosomiasis were additional variables in schoolchildren and adults. Malaria, stunting, and wasting were highly prevalent in preschool children but were not significantly correlated with anemia. In adolescent and adult males and schoolchildren, underweight (BMI < 5th percentile) was significantly correlated with anemia and iron deficiency; however, only in adult males was the population attributable risk high (14%).

In women of childbearing age (Table 4), anemia was found in 45.1% of the uneducated women but educational attainment had no significant correlation with anemia. Fifty-four percent of the women who had delivered babies within the past year had anemia \((P < 0.02)\). Of these women, some were taking hematinics regularly \((n = 61)\) and the prevalence of anemia was 40.0%.

Dietary iron content and availability for absorption

The relation of anemia and iron deficiency in this community became apparent when the diet of these people was analyzed for iron content and its availability for absorption. The total iron content in the collected food items prepared for consumption was considerably high, with average values of 11.7 ± 4.0 mg Fe/100 g dry matter for cereals, 5.9 ± 1.3 mg Fe/100 g dry matter for legumes, and 95 ± 73 mg Fe/100 g dry matter for vegetables. The iron availability, measured as iron solubility after in vitro digestion, was on average 1.7% (0.17 mg/100 g dry matter) in cereal preparations, 24.7% (1.51 mg/100 g dry matter) in legume sauces, and 10.0% (5.6 mg/100 g dry matter) in vegetables (Table 5). In the mixed foods, cereals mixed with legumes or vegetables, the percentage of iron available for absorption ranged from 0.9% to 7.5% (0.31–1.17 mg/100 g dry matter).

DISCUSSION

Community assessment of iron deficiency anemia

The smaller number of subjects screened for anemia compared with the estimated sample size and the actual prevalence of anemia...
noted in this community raised our set error margin of 5–6% for children aged > 5 y and 7% for preschool children. A high prevalence of anemia in association with iron deficiency based on low hemoglobin and high EP concentrations in this study indicated a deficiency in iron nutrition among the study population. Note, however, that low hemoglobin is a nonspecific indicator for anemia because it is also influenced by blood-depleting parasites, chronic infections, and some physiologic and hematologic conditions (6, 16). Assessment of the iron content and its availability for absorption in the collected food samples further indicated the role of diet in the poor iron nutrition observed in the community studied and it implies that the iron deficiency in this community could be a long-term manifestation.

Anemia and iron deficiency distribution by age and sex

This study showed that iron deficiency correlated significantly with anemia ($P < 0.001$) across all age groups, and the high prevalence rates, especially in children, agreed with findings from other studies (30–32). The tendency for more severe anemia in the preschool children suggested an imbalance between iron intakes and increased iron requirements because of a high growth rate (33). Early childhood is also a period when complementary feeding begins and, if the weaning foods have low amounts of iron available for absorption, depleted iron stores are likely to develop. The importance of iron deficiency as a contributing factor to the anemia was also shown by the high proportion of iron-deficient children among those with moderate and severe anemia (Table 2). Up to the age of 15 y, there was no sex difference in the prevalence of anemia and iron deficiency anemia. In the adolescent and adult group, iron deficiency remained the most significant factor associated with anemia and as reported in other studies (34, 35), women of childbearing age were the most affected. Our results also showed a higher prevalence of anemia in lactating women than in nonpregnant women, indicating anemia that developed during pregnancy did not go away (Table 4).

Nutritional risk factors for anemia

The nutritional nature of anemia in this community was indicated by a significant association between iron deficiency and low BMI in schoolchildren and adolescent and adult males. This was further reflected in the low iron availability from the common food items consumed (Table 5). Although no assessment of dietary intake was made, a 24-h dietary recall showed a predominantly cereal- and vegetable-based diet in the surveyed households. This type of diet provides low amounts of bioavailable iron (28, 36) because of the high content of iron-absorption inhibitors such as phytate and polyphenols. This diet may there-

<table>
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<th>TABLE 3</th>
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<table>
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<tr>
<th>Risk factor in different age groups</th>
<th>Prevalence of risk factor</th>
<th>Relative risk</th>
<th>Population attributable risk</th>
<th>Correlation with anemia ($P$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preschool children (aged &lt; 5 y)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hookworms ($n = 184$)</td>
<td>3.8</td>
<td>1.0</td>
<td>1</td>
<td>NS</td>
</tr>
<tr>
<td>Urinary schistosomiasis ($n = 178$)</td>
<td>5.1</td>
<td>1.2</td>
<td>1</td>
<td>NS</td>
</tr>
<tr>
<td>Malaria ($n = 250$)</td>
<td>34.1</td>
<td>1.0</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>Low weight-for-age$^1$ ($n = 261$)</td>
<td>49.9</td>
<td>1.2</td>
<td>3</td>
<td>NS</td>
</tr>
<tr>
<td>Low height-for-age$^1$ ($n = 261$)</td>
<td>57.0</td>
<td>1.0</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>Iron deficiency$^2$ ($n = 261$)</td>
<td>67.8</td>
<td>1.6</td>
<td>16</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td><strong>Schoolchildren (aged 5–14 y)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hookworms ($n = 547$)</td>
<td>13.0</td>
<td>1.1</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>Urinary schistosomiasis ($n = 612$)</td>
<td>19.4</td>
<td>1.3</td>
<td>5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Malaria ($n = 648$)</td>
<td>23.8</td>
<td>1.3</td>
<td>5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Body mass index$^3$ ($n = 678$)</td>
<td>23.4</td>
<td>1.1</td>
<td>1</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Iron deficiency$^2$ ($n = 678$)</td>
<td>53.6</td>
<td>1.3</td>
<td>12</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Adolescents and adults (aged ≥ 15 y)</strong></td>
<td></td>
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</tr>
<tr>
<td>Hookworms ($n = 1129$)</td>
<td>16.0</td>
<td>1.2</td>
<td>2</td>
<td>&lt;0.01</td>
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<tr>
<td>Urinary schistosomiasis ($n = 1256$)</td>
<td>14.6</td>
<td>1.4</td>
<td>12</td>
<td>&lt;0.001</td>
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<tr>
<td>Malaria ($n = 1294$)</td>
<td>19.6</td>
<td>1.3</td>
<td>12</td>
<td>&lt;0.001</td>
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<tr>
<td>Body mass index$^3$</td>
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<td></td>
</tr>
<tr>
<td>Males ($n = 622$)</td>
<td>34.1</td>
<td>1.4</td>
<td>14</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Females ($n = 664$)</td>
<td>18.7</td>
<td>1.0</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>Iron deficiency$^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males ($n = 622$)</td>
<td>30.7</td>
<td>1.9</td>
<td>21</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Females ($n = 683$)</td>
<td>41.1</td>
<td>1.7</td>
<td>26</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

$^1$ 2.0 SD below the median value for the reference population.
$^2$ Erythrocyte protoporphyrin > 125 µmol/mol heme.
$^3$ Body mass index [wt (kg)/ht$^2$ (m)] less than the 5th centile for respective age group (27).
fore, in the long run, significantly contribute to poor iron nutrition as evidenced in the high prevalence rates of iron deficiency. Absorption of iron is a function of the amount of bioavailable dietary iron and the iron status of the individual. In the food samples collected from the study area, the total iron content was relatively high but the content of soluble iron was very low, as measured by an in vitro method (Table 5). Only when legumes or vegetables were included in the cereal-based diet did iron availability improve, a three-fold increase on average. A usual diet reflecting the daily intake for an average school-age child with an estimated energy intake of \( \approx 8350 \) kJ (2000 kcal/d) is as follows: maize porridge with \( \approx 200 \) g maize flour for breakfast, \( \approx 200 \) g maize flour with either legumes or green vegetables as a sauce or relish for lunch and dinner, and an additional evening snack of 100 g cereal (dry wt). These meals provide a total daily iron intake of \( \approx 80–90 \) mg/d, with \( \approx 1.6 \) mg Fe available for absorption on the basis of our results from the in vitro analysis (Table 5). The iron content of these meals is well above the recommended dietary allowance (RDA; 37) for school-age children of \( \approx 29–50 \) mg/d for a diet with low iron bioavailability (< 5%), which is needed to meet the requirement of \( \approx 1 \) mg absorbed Fe/d throughout most of childhood (28). However, 1.6 mg available Fe/d for absorption (soluble iron) results in \( \approx 0.64 \) mg absorbed Fe/d, which is below the required amount (\( \approx 1.0 \) mg/d) of absorbed iron for a child with depleted iron stores.

A large part of the iron in the collected cereal and vegetable food items seemed to be contamination iron. Compared with data in the Food Composition Table for Use in Africa (38), contamination iron constituted \( \approx 30–86\% \) of the total iron in the cereals and \( \approx 18–63\% \) of the total iron in the vegetables. The iron content in the collected legumes, however, agreed with the food-composition data. The large amount of contamination iron was probably not available for absorption (ie, it is nonsoluble) and explains the extremely low percentage of bioavailable iron found in the cereal samples. The data show the need for dietary modifications to improve iron availability, either by traditional processing techniques such as soaking, germination, or lactic acid fermentation of the cereals (39), or by adding iron-absorption enhancers, eg, ascorbic and citric acids from fresh fruit and vegetables (26, 40). Iron nutrition in the other population groups is likely to be similarly affected because the physiologic iron needs of infants and pregnant women are higher than those of school-age children. The situation posed by the monotonous plant-based diet, with its low iron availability, puts the entire population at risk for iron deficiency and the magnitude observed in this study reflects this situation.

Of the associative factors contributing to anemia, nutritional status is often mentioned. Our results showed a significant association between low BMI and iron deficiency anemia in schoolchildren and adolescent and adult males. In preschool children the prevalence of stunting and wasting was high (\( \approx 50\% \)); however, neither correlated significantly with anemia or iron deficiency. This diet obviously did not provide enough absorbable iron even though it met the energy and protein requirements to support an adequate growth rate. Iron deficiency anemia per se is also known to suppress appetite and growth rate (height-for-age), the latter being reversed by iron supplementation (41). In the young children these mechanisms may not have been fully developed. In the older age groups, however, low nutritional status associated with iron deficiency likely was due to a long-term manifestation of inadequate dietary iron and a low food intake or the result of a hookworm infection and schistosomiasis, which were also significantly associated with low BMIs.

**Diseases as a risk factor for iron deficiency anemia**

Except for malaria, parasitic infections in this community were relatively less prevalent in the preschool children than in the other age and sex groups, and none of the parasites correlated with iron deficiency or with anemia. Chronic or recurrent infections with malaria may be associated with an impairment of hematopoiesis and this is one of the mechanisms whereby malaria can cause anemia (42). Other mechanisms include parasitic destruction of red cells and a complement-mediated immunohemolytic process (43). The lack of an association in this study differs from findings of other studies of preschool children in Tanzania (30, 31, 44) and may have been due to the lower prevalence of malaria in the present study. However, malaria is commonly associated with anemia among young children hospitalized in Tanzania (11). In schoolchildren, hookworm infection did not correlate significantly with anemia, which differs from the finding in Zanzibari schoolchildren (45) of a strong association between hookworm infection intensity and iron deficiency. Possible reasons for the lack of an association may have been the low worm load and the relatively low prevalence of this parasite in this particular community.

Anemia, on the other hand, was significantly associated with malaria and similar findings in children are reported from studies in Zanzibar (45) and South America (46). The anemia seen in the current study may have been malaria induced in the presence of folate deficiency (43), a nutritional deficiency that may exist among children in this community because of their monotonous diet, which provides a low intake of fruit and fresh vegetables. Studies conducted elsewhere have indicated folate deficiency in undernourished children (47) living under similar conditions.

Urinary schistosomiasis in this study was strongly associated with anemia—a finding also shown in other studies conducted elsewhere (32, 48). Schistosomiasis, whether intestinal or urinary, may be associated with blood loss that can cause a loss of up to 6 mg Fe/d (42, 48). *Schistosoma hematoium* was the most common type of schistosomiasis in this geographic area. In adults, all parasitic infections were significantly correlated with anemia and iron deficiency, except for malaria that, as in preschool and schoolchildren, showed no association with iron deficiency.

**Interventions for iron deficiency anemia**

The findings above show that nutritional anemia is a public health problem in this community and probably many others in...
Tanzania, with iron deficiency being a major contributory factor. The low bioavailability of dietary iron needs to be addressed so that the high prevalence of anemia and iron deficiency during childhood and pregnancy is reduced. Appropriate breast-feeding and timely introduction of weaning foods with high amounts of bioavailable iron should be promoted. In general, an increased intake of bioavailable iron is a useful strategy for this community. Ways to achieve this may include the consumption of fresh fruit and vegetables rich in vitamin C and the use of common household food processing methods such as soaking, germination, and fermentation, which enhance iron absorption. In vitro studies have shown that these methods are effective in reducing the phytate content in cereals and thereby the availability of iron can be improved 2–10 times (49, 50). Tea, which has become a common part of evening meals in villages along the coast, is known to be a strong inhibitor of iron absorption (51). It is thus important that tea not be part of meals, especially children’s meals. A combination of legumes or vegetables should be considered in cereal-based meals.

Supplementation with haematinics in pregnant women should be strengthened and extended to children. With respect to the other causes of anemia, intervention measures should be directed appropriately to the contributing factors in a given situation. Health and nutrition education should be a continuous activity to help the community adapt to new behavior and food habits that may result from these interventions.

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