Prevalence of iron deficiency with and without concurrent anemia in population groups with high prevalences of malaria and other infections: a study in Côte d'Ivoire[1–3]

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ABSTRACT

Background: Iron deficiency is highly prevalent in most developing countries. However, its detection is often obscured by infections and inflammatory disorders that are common in the same populations.

Objective: The aim of this study was to estimate the prevalence of iron deficiency with or without concurrent anemia in different population groups from Côte d'Ivoire and to evaluate the influence of infectious and inflammatory disorders on iron-status indexes.

Design: Blood samples from 1573 children, women, and men were analyzed for hemoglobin, serum ferritin, zinc protoporphyrin, and serum transferrin receptor. C-reactive protein was used as the indicator of inflammation or infection, and samples were screened for malarial parasites and hemoglobinopathies. Iron deficiency was defined as 2 of 3 iron-status indexes outside the cutoff values, and iron deficiency anemia (IDA) was defined as iron deficiency with concurrent anemia. Pearson's correlation coefficients were used to evaluate the influence of malaria and inflammation on iron-status indexes.

Results: The prevalence of iron deficiency was 41–63% in the women and children and 13% in the men, whereas the prevalence of IDA was 20–39% in the women and children and 4% in the men. The detection of iron deficiency and IDA was obscured by the high prevalence of inflammatory disorders.

Conclusions: Iron deficiency and IDA are highly prevalent in the women and children in Côte d'Ivoire. Iron deficiency was detected in ≈50% of anemic women and children, which indicates that hemoglobin alone is not a good indicator of iron status when inflammatory disorders are highly prevalent. The serum transferrin receptor is the most useful single indicator of iron deficiency because it was the only iron-status index unaffected by malaria or inflammation. *Am J Clin Nutr* 2001;74:776–82.

KEY WORDS Iron deficiency, anemia, serum transferrin receptor, serum ferritin, zinc protoporphyrin, infection, malaria, Côte d'Ivoire, children

INTRODUCTION

Iron deficiency with or without concurrent anemia affects ≈30% of the global population, making it the most widespread nutrient deficiency (1). The early stage of iron deficiency can be recognized by abnormalities in serum ferritin (SF), zinc protoporphyrin (ZP), and serum transferrin receptor (TfR), whereas the more advanced stage of iron deficiency, iron deficiency anemia (IDA), occurs when anemia develops. The detrimental public health effects of IDA include retarded infant development, increased morbidity and mortality at childbirth, and reduced work performance (2–4).

Traditionally, the prevalence of anemia was used to estimate the prevalence of iron deficiency and IDA. However, in many developing countries, anemia can also result from infections such as malaria (5), from chronic inflammatory disorders (6), or from other nutritional deficiencies of folate or vitamin B-12 or A (7, 8). In addition, it is well known that infection and inflammation influence hemoglobin and iron-status indexes such as ZP and SF (9, 10) and, thereby, obscure the detection of iron deficiency. Therefore, accurate estimates of the prevalence of iron deficiency and IDA are not available in many nonindustrialized countries. Some studies, however, indicate that TfR helps detect iron deficiency in the presence of inflammation or infection (11–13), but this iron-status indexes has not been used in large-scale surveys in developing countries.

The aim of this study was to estimate the prevalence of iron deficiency with and without concurrent anemia in different population groups in Côte d'Ivoire and to evaluate the confounding influence of infection and inflammation on these estimates. The study included measurements of hemoglobin, SF, ZP, TfR, and C-reactive protein (CRP) in blood drawn from 1573 subjects: preschool children, school-age children, women, and men from rural and urban areas of Côte d'Ivoire. In addition, all samples were screened for malarial parasites and hemoglobinopathies. The prevalence of iron deficiency and IDA was estimated by using hemoglobin and different combinations of iron-status indexes.

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SUBJECTS AND METHODS

Location

The survey was conducted from November to December 1996 in 4 different regions of Côte d'Ivoire, including Abidjan, the commercial capital where the population consumes a mixture of traditional African and Western foods, and 3 rural areas where the population consumes different dietary staples. The rural areas were Kolia in the north, where the staple foods are cereals, Bouaké in the central region, where yam is widely consumed, and Guitry in the south, where the major staple foods are cassava and plantain. From each of these 3 rural areas, 1 county and then 1 subcounty were randomly selected. Finally, from each subcounty with >500 inhabitants, 4 villages were selected. In Abidjan, the same procedure was used but with the districts of Abidjan instead of subcounties and villages. A total of 16 different locations were surveyed.

Subjects and enrollment

Within each of the 16 locations, the target enrollment was 25 preschool children aged 2–5 y, 25 school-age children aged 6–15 y, 25 nonpregnant and nonlactating females aged 16–50 y (women), and 25 males aged 16–50 y (men). The enrollment was targeted at 100 subjects from each population group in each region for a total of 1600 subjects. Permission to conduct the survey was obtained from the village chiefs in the rural areas and from the district elders in Abidjan. These community leaders then invited all members of their community to attend a meeting where the survey was presented. Information was given orally by one of the investigators (PA) with the assistance of local interpreters. Volunteers were enrolled in the order in which they presented themselves until the required number of subjects was obtained. Each adult volunteer and parent of the participating children gave oral consent before being enrolled. The survey protocol was reviewed and approved by the Ministry of Research in Abidjan, Côte d'Ivoire, and by the Swiss Academy of Sciences in Bern, Switzerland.

Blood sampling

Venous blood samples (5 mL) were drawn in the morning into EDTA-treated evacuated tubes from each of the 1573 subjects, and an additional 5 mL blood was drawn into tubes without added anticoagulants. Blood samples were kept on ice during transport to a local laboratory. On the day of sampling, serum was separated by centrifugation at room temperature for 10 min at $2000 \times g$ and divided into aliquots that were stored frozen at −20°C until further analyzed. In some of the preschool children, only 5 mL blood was drawn into EDTA-treated evacuated tubes, and plasma was used for analysis of SF, TfR, and CRP.

Iron-status indexes

Hemoglobin

Whole blood was analyzed within 12 h of blood sampling with the use of the cyanmethemoglobin technique (Sigma Diagnostics kit; Sigma, St Louis). All samples were analyzed in duplicate. With each series of samples, a 3-level quality control material (DiaMed, Cressier sur Morat, Switzerland) was analyzed in parallel. Analyses were repeated when the difference between duplicates was >5%.

Serum ferritin

Frozen serum or plasma samples were transported in dry ice to Kansas University Medical Center and measured with an enzyme-linked immunoassay with monoclonal antibodies (14).

Serum transferrin receptor

Serum TfR concentrations were measured at Kansas University Medical Center with the use of an enzyme-linked immunoassay with dual monoclonal antibodies (15).

Zinc protoporphyrin

ZP was measured within 7 d of blood sampling. Washed red blood cells were measured in duplicate with a hematofluorometer (16) (Aviv Biomedical, Lakewood, NJ). Commercial quality-control material from the same company was analyzed at the same time.

Malaria screening

Thick blood smears were prepared on glass slides within 12 h of blood sampling for the quantitative determination of malarial parasites (17). The blood smears were stained with Giemsa buffer solution (18) and the number of parasites was counted in relation to leukocytes. Parasite counts were converted to the number of parasites/μL whole blood by using the conversion factor 8000 leukocytes/μL whole blood (17, 18).

C-reactive protein

CRP was analyzed by nephelometry (Turbox nepholometer; Oxoid Ltd, Bedford, United Kingdom) by using commercial kits (Turbox kit; Orion Diagnostica, Espoo, Finland). Two levels of quality-control material (Orion) were analyzed together with each series of samples. Samples were analyzed in duplicate and the analysis was repeated if there was a difference >5%. The cutoff value (>10 mg/L) was used to indicate the presence of inflammation or infection (19, 20) as recommended by the manufacturer.

Hemoglobinopathies

Whole blood was screened for hemoglobinopathies within 1 wk of blood sampling by using electrophoresis on cellulose acetate membranes (21).

Prevalence of iron deficiency and iron deficiency anemia

Iron deficiency was defined by a multiple criteria model based on ≥2 of 3 iron- status indexes outside the cutoff values (22). The chosen cutoff values were <30 μg/L for SF (23), >40 μmol/mol heme for ZP (24), and >8.5 mg/L for TfR (25). IDA was defined as iron deficiency concurrent with anemia. The latter was defined as hemoglobin concentrations below the World Health Organization cutoff values (26) minus 10 g/L to allow for the normally lower hemoglobin concentrations reported in blacks (27). The hemoglobin cutoff values used in this study were 100 g/L for the preschool children, 110 g/L for the school-age children and the women, and 120 g/L for the men. The ratio of TfR to SF was calculated as previously described (28).

Statistical evaluation

Hemoglobin concentrations and subjects' ages were normally distributed and, therefore, are presented as means ± SDs. All other data were skewed and, therefore, are presented as geometric means + or −1 SD. Analysis of variance was used to test for differences in iron-status indexes, CRP, and malaria among the different geographic areas. Pearson's correlation coefficients were used to examine the relation between iron-status indexes and malaria or inflammation. Statistically significant differences were indicated by $P < 0.05$. Log-transformed data were used for

TABLE 1

Iron-status indexes and C-reactive protein (CRP) concentrations in different population groups in Côte d'Ivoire[1]

	Preschool children (n = 312)	School-age children (n = 531)	Women (n = 406)	Men (n = 324)
Age (y)[2]	4.1 ± 1.1	10.0 ± 2.9	33.9 ± 11.9	33.5 ± 11.8
Transferrin receptor[3]				
(mg/L)	10.6 (6.4, 17.3)	8.5 (5.8, 12.4)	7.6 (4.9, 11.8)	7.2 (5.0, 10.4)
(% above cutoff)	65	47	35	29
ZP[3]				
(μmol/mol heme)	77.5 (36.5, 164.0)	48.4 (22.9, 102.5)	44.7 (20.5, 97.5)	23.3 (10.7, 50.9)
(% above cutoff)	83	61	58	18
Serum ferritin[3]				
(μg/L)	46.5 (17.6, 122.7)	38.1 (16.4, 88.4)	34.1 (13.7, 84.7)	65.4 (27.9, 152.9)
(% below cutoff)	30	34	40	17
Hemoglobin[2]				
(g/L)	99 ± 15	112 ± 15	111 ± 16	134 ± 19
(% above cutoff)	50	46	42	18
CRP[3]				
(mg/L)	10.3 (3.0, 35.5)	5.0 (1.5, 16.4)	4.0 (1.3, 12.3)	4.4 (1.4, 13.9)
(% above cutoff)	46	21	12	16

[1] Cutoff values: transferrin receptor, >8.5 mg/L; zinc protoporphyrin (ZP), >40 μmol/mol heme; serum ferritin, <30 μg/L; hemoglobin, <100 g/L for preschool children, <110 g/L for school-age children and women, and <120 g/L for men; C-reactive protein (CRP), >10 mg/L.

[2] Arithmetic $\bar{x}$ ± SD.

[3] Geometric $\bar{x}$ (−1 SD, +1 SD).

the statistical evaluation, except for Pearson's correlation coefficients. SAS (version 6.12; SAS Institute Inc, Cary, NC) was used for all the statistical calculations.

RESULTS

Because the 4 different geographical areas had only minor differences among them, the results were pooled for each population group.

Prevalence of iron deficiency

Many of the preschool children, school-age children, and women had elevated ZP and TfR concentrations, which indicated iron deficiency (**Table 1**). ZP was elevated in 83% of the preschool children, 61% of the school-age children, 58% of the women, and 18% of the men. Similarly, TfR was elevated in 65% of the preschool children, 47% of school-age children, 35% of the women, and 29% of the men. By contrast, fewer subjects had depleted iron stores, which was indicated by low SF concentrations. The prevalence of storage iron depletion was 30%, 34%, 39%, and 17% in preschool children, school-age children, women, and men, respectively. When the more commonly used cutoff value for SF (12 μg/L) was used, the corresponding prevalence of depleted iron stores was 9%, 10%, 13%, and 3% in preschool children, school-age children, women, and men, respectively. The prevalence of iron deficiency, determined on the basis of the multiple criteria model, was 63% in the preschool children, 47% in the school-age children, 41% in the women, and 13% in the men (**Figure 1**). The prevalence of iron deficiency, on the basis of an elevated ratio of TfR to SF (500 μg/L), was 18% in the preschool children and women, 16% in the school-age children, and 5% in the men.

Prevalence of iron deficiency anemia

About 50% of the women and children (preschool and school-age) and ≈30% of the men with iron deficiency were also anemic (Figure 1). The prevalence of IDA, on the basis of the multiple criteria model plus hemoglobin concentration below the specific cutoff values, was 39% in the preschool children, 25% in the school-age children, 20% in the women, and 4% in the men (Figure 1). When IDA was defined as anemia plus elevated ZP, the prevalence became higher by 49% in the preschool children, 34% in the school-age children, 30% in the women, and 5% in the men. However, when IDA was defined as anemia plus a low SF concentration, the prevalence fell to 15% in the preschool children, 18% in the school-age children and women, and 4% in the men. When IDA was defined as anemia plus an elevated TfR, the prevalence of IDA was almost identical to that found with the multiple criteria model in the women and children.

Prevalence of malaria infection

The prevalence of malaria infection was very high in the preschool children (62%) and the school-age children (54%) compared with that in the women (19%) and the men (17%) (**Table 2**). The parasite load was low, although 8% of the preschool children and 3% of the school-age children had clinical malaria, which was defined as a parasite load >5000/μL blood (17, 29). The parasite load was significantly lower in Abidjan than in the rural areas in all the population groups (data not shown). The malaria parasite load was positively correlated with SF in the preschool and school-age children (**Table 3**) but was not correlated with ZP or with TfR in any population group (Table 3 and **Table 4**).

Prevalence of inflammation or infection

The prevalence of inflammation or infection, which was indicated by elevated CRP concentrations, was high in all the population groups, especially in the preschool (46%) and school-age (21%) children, but was also frequently observed in the women (12%) and men (16%) (Table 1). CRP was positively correlated with the malaria parasite load in the preschool children, the school-age children, and the men, but not in the women (Tables 3 and 4). In addition, CRP was positively correlated with SF in all

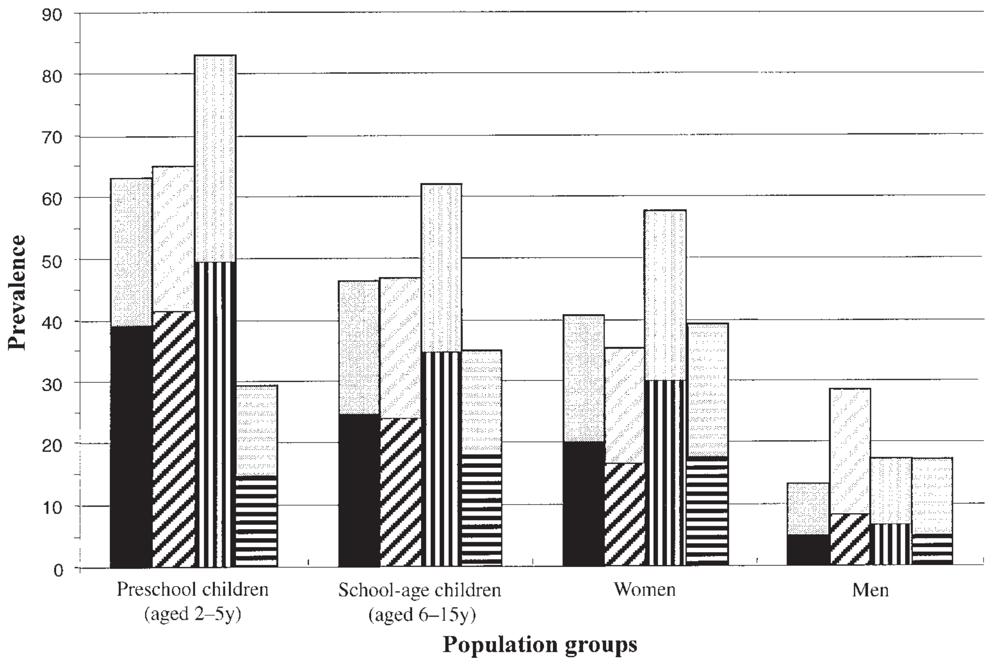

FIGURE 1. Prevalence of iron deficiency, with and without concurrent anemia, determined on the basis of different combinations of iron-status indexes: ▨, iron deficiency on the basis of a multiple criteria model [2 of 3 iron-status indexes outside the cutoff values for serum ferritin (SF; <30 μg/L), serum transferrin receptor (TfR; >8.5 mg/L), and zinc protoporphyrin (ZP; >40 μmol/mol heme)]; ■, iron deficiency anemia (IDA) on the basis of a multiple criteria model with concurrent anemia (hemoglobin: <100 g/L for preschool children, <110 g/L for school-age children and women, and <120 g/L for men); ▨, TfR > 8.5 mg/L; ▨, TfR > 8.5 mg/L with concurrent anemia; ▥, ZP > 40 μmol/mol heme; ▥, ZP > 40 μmol/mol heme with concurrent anemia; ▤, SF < 30 μg/L; and ▤, SF < 30 μg/L with concurrent anemia.

the population groups and was correlated with ZP in the preschool children. There was no significant correlation between CRP and TfR in any of the population groups.

Prevalence of anemia

The prevalence of anemia was high in all the population groups. It averaged 50% in the preschool children, 46% in the school-age children, 42% in the women, and 18% in the men (Table 1). The prevalence of anemia was 5–10% higher in Abidjan than in the rural areas for all population groups, except in the preschool children (results not shown).

Note that ≈50% of the observed anemia was associated with iron deficiency. Iron deficiency was the most common cause of anemia only in the preschool children (anemia: 50%; IDA: 39%). IDA and anemia due to other causes were more or less evenly distributed in the school-age children (anemia: 46%; IDA: 25%) and women (anemia: 42%; IDA: 20%), whereas in the men, most of the anemia was not due to iron deficiency (anemia: 18%; IDA: 4%) (Table 1 and Figure 1). When the anemic subjects were evaluated further, it was clear that the high prevalence of infection or inflammation in the population groups was an important factor in the cause of the anemia. As shown in **Figure 2**, the complex cause of anemia and the overlap between IDA and anemia associated with infection or inflammation (elevated CRP) was very high, particularly in preschool children (49%). A large proportion of anemia cases in the school-age children, the women, and the men (32%, 54%, and 56%, respectively) could not be attributed to iron deficiency or infection or inflammation.

Hemoglobinopathies

Nine percent of the study population was identified as carriers of the sickle-cell trait, and 9% had hemoglobin-C trait. Less than 1% of the subjects had other hemoglobinopathies. No subjects were identified with sickle cell disease.

TABLE 2
Malarial prevalence and parasite load in different population groups in Côte d'Ivoire

	Preschool children	School-age children	Women	Men
Prevalence of malaria (% infected)	62	54	19	17
Malaria parasites (no./μL blood)[1]	101 (2, 4093)	46 (1, 1628)	4 (0, 50)	3 (0, 45)
Percentage of subjects infected (%)				
1–999 malaria parasites	18	27	13	12
1000–1999 malaria parasites	23	17	5	3
2000–4999 malaria parasites	13	7	<1	1
≥5000 malaria parasites	8	3	<1	1

[1] Geometric $\bar{x}$ (−1 SD, +1 SD).

TABLE 3
Correlation coefficients between hemoglobin, zinc protophorphyrin (ZP), serum ferritin (SF), serum transferrin receptor (TfR), C-reactive protein (CRP), and malaria in the preschool and school-age children[1]

	Hemoglobin	ZP	TfR	SF[2]	CRP	Malaria
Hemoglobin		−0.500[3]	−0.509[3]	−0.089	−0.369[3]	−0.166[4]
ZP	−0.336[3]		0.455[3]	−0.215[3]	0.205[3]	0.062
TfR	−0.309[3]	0.499[3]		−0.072	0.091	0.007
SF[2]	0.107[5]	−0.345[3]	−0.278[3]		0.264[3]	0.132[5]
CRP	−0.163[3]	0.041	0.065	0.221[3]		0.236[3]
Malaria	−0.053	−0.015	−0.013	0.094[5]	0.236[3]	

[1] Correlations for preschool children (aged 2–5 y) are shown in the upper right of the table and those for school-age children (aged 6–15 y) in the lower left of the table.
[2] Based on log-transformed values.
[3] $P < 0.001$.
[4] $P < 0.01$.
[5] $P < 0.05$.

Correlation analysis

CRP was negatively correlated with hemoglobin in the preschool children, the school-age children, and the men, but not in the women (Tables 3 and 4). Malaria parasite load was negatively correlated with hemoglobin in preschool children. There was a significant correlation between hemoglobin and other iron-status indexes; hemoglobin was negatively correlated with ZP and TfR in all population groups and positively correlated with SF in the school-age children and the women (Tables 3 and 4). There was also a significant correlation between the different iron-status indexes. ZP was correlated positively with TfR and negatively correlated with SF in all population groups, and TfR and SF were negatively correlated in all population groups except the preschool children (Tables 3 and 4).

DISCUSSION

According to our results, the prevalence of iron deficiency is high in Côte d'Ivoire, reaching 63% in preschool children, 47% in school-age children, 41% in women, and 13% in men. About 66% of the preschool children, ≈50% of the school-age children and women, and ≈30% of the men with iron deficiency were anemic. Nevertheless, IDA accounted for only ≈50% of the anemia, which agrees with the results from an earlier study in the population of Benin, another West African country (30). The proportion of anemic to iron-deficient-anemic individuals varied with age and sex. About 80% of the anemic preschool children had IDA compared with ≈50% of the school-age children and women and ≈20% of the men.

Malaria and the prevalence of inflammation or infection were also widespread in the study population, particularly in both groups of children. Because CRP was strongly associated with malaria in the preschool children, school-age children, and men, any correlation of malaria to iron-status indexes could partially be caused by associated inflammation.

Our results indicate that the high prevalence of malaria and inflammatory disorders complicated the detection of iron deficiency because of their influence on laboratory indexes of iron status, such as SF and to a lesser extent ZP. The common cutoff value for SF (12 μg/L) is often used to indicate reduced iron stores. SF, however, is an acute phase protein that increases with inflammation. In an attempt to adjust for the observed high prevalence of inflammation, we increased the SF cutoff to 30 μg/L (23). Despite this adjustment, the percentage of subjects with low SF (17–39%) was still much lower than the percentage of subjects with elevated TfR (29–65%) or elevated ZP (18–83%) (Table 1). The finding in the present study that CRP was positively associated with SF in the men, women, and in both groups of the children is similar to the results of other studies that reported elevated SF with inflammatory disorders (10, 31, 32). In our study population, the women and both groups of children had ZP concentrations that were higher than any of the other iron-status indexes (Figure 1). CRP was positively associated with ZP only in the preschool children (Tables 3 and 4), which was the population group with the highest prevalence of inflammation. Earlier data from Hastka et al (9) reported elevated ZP in subjects with chronic inflammatory disorders.

TfR, on the other hand, was not associated with CRP in any population group (Tables 3 and 4) and thus, appeared to be the

TABLE 4
Correlation coefficients between hemoglobin, zinc protophorphyrin (ZP), serum ferritin (SF), serum transferrin receptor (TfR), C-reactive protein (CRP), and malaria in the women and men[1]

	Hemoglobin	ZP	TfR	SF[2]	CRP	Malaria
Hemoglobin		−0.380[3]	−0.225[3]	0.160[4]	−0.030	−0.043
ZP	−0.296[3]		0.561[3]	−0.405[3]	−0.006	−0.040
TfR	−0.193[3]	0.383[3]		−0.248[3]	−0.032	−0.058
SF[2]	−0.030	−0.339[3]	−0.170[4]		0.204[3]	0.081
CRP	−0.143[4]	0.010	−0.065	0.197[3]		0.044
Malaria	−0.058	0.004	0.047	0.070	0.348[3]	

[1] Correlations for women are shown in the upper right of the table and those for men in the lower left of the table.
[2] Based on log-transformed values.
[3] $P < 0.001$.
[4] $P < 0.01$.

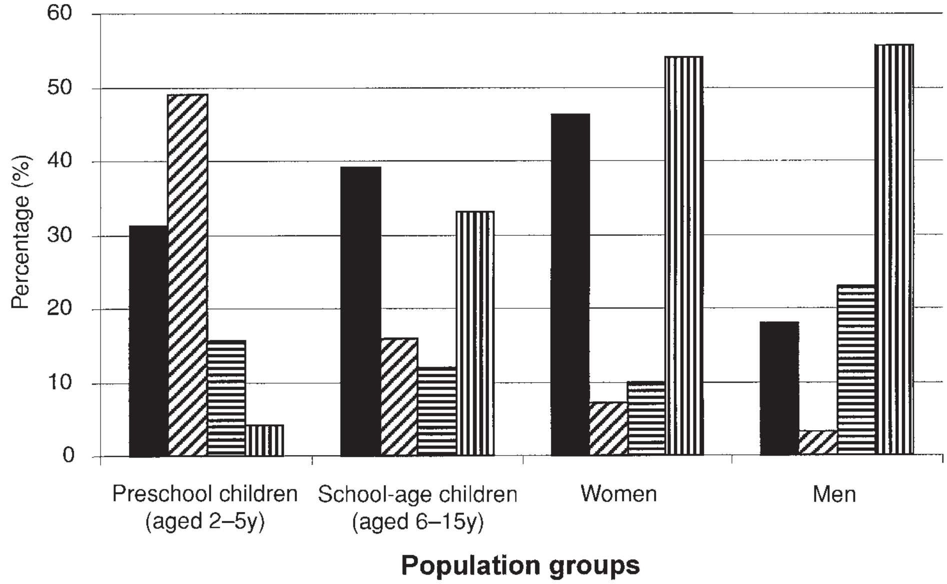

FIGURE 2. Percentage of anemic subjects with iron deficiency on the basis of a multiple criteria model [2 of 3 iron-status indexes outside the cutoff values: serum ferritin (SF) < 30 μg/L, serum transferrin receptor (TfR) > 8.5 mg/L, and zinc protophorphyrin (ZP) > 40 μmol/mol heme] with elevated C-reactive protein (CRP), a combination of iron deficiency and elevated CRP, or with neither. ■, Anemic subjects with iron deficiency and normal CRP concentrations (<10 mg/L); ▨, anemic subjects with iron deficiency and elevated CRP concentrations (>10 mg/L); ▤, anemic subjects with elevated CRP concentrations (>10 mg/L) and no iron deficiency; and ▥, anemic subjects with normal CRP concentrations (<10 mg/L) and no iron deficiency.

most reliable indicator of iron status in these conditions. By contrast, the ratio of TfR to SF was not a sensitive indicator of iron deficiency, presumably because of the elevated SF values associated with concurrent inflammation. Thus, our results agree with the growing body of evidence that indicates that TfR is not affected by inflammatory disorders. Kuvibidila et al (33) reported a lack of correlation between CRP and TfR in Zairian women, and Nielson et al (34) found no correlation between inflammatory status determined on the basis of CRP and TfR concentrations in patients with arthritis. In addition, several investigators reported that TfR concentrations are useful in identifying iron deficiency in patients with anemia of chronic disease (12, 35, 36).

In the present study, TfR like ZP was also not associated with malaria in any population group. SF, on the other hand, was positively correlated with the malarial parasite load in the preschool and school-age children. Previous reports on the influence of malaria on iron-status indexes are inconsistent and include reports of elevated SF (31, 37) and ZP (38) concentrations although malaria was reported to have no influence on TfR concentrations (39). However, Stoltzfus et al (29) reported that malaria elevated SF, ZP, and TfR concentrations in young Zanzibar children (<30 mo) but not in older children.

Traditionally, the prevalence of anemia has been used to estimate the prevalence of iron deficiency and IDA. However, the cause of anemia is multifactorial (40), and our results show that hemoglobin alone is not a reliable variable to estimate the prevalence of IDA in West African populations in which inflammatory disorders and malaria are common. Anemia can be caused by malaria (5), general inflammatory disorders (6), or nutritional deficiencies of folate and vitamin B-12 or A. Our results indicate that malaria and general inflammatory disorders contribute significantly to the high prevalence of anemia in the Ivory Coast and that considerable overlap exists between IDA and infection or inflammation, particularly in preschool children (Figure 2). A large proportion of anemia cases could not be explained by iron deficiency or by elevated CRP concentrations in the school-age children, the women, or the men, and the importance of other factors (nutritional and nonnutritional) in the cause of anemia in these individuals could not be evaluated in this study. Hemoglobin was negatively correlated with CRP in all population groups, except in the women, and was negatively correlated with malaria in the preschool children. The negative influence of inflammation is thought to be due to hemoglobin's lower absorption and utilization of iron (32). In addition, hemoglobin may have been lowered in individuals with malaria because of lysis of infected erythrocytes (40). In the Ivorian populations studied, iron deficiency was the major cause of anemia only in the preschool children. In school-age children and the women, 50% of the anemic subjects had iron deficiency and 50% had anemia from other causes. In the men, 80% of the anemia was of an unknown origin and only 20% was due to iron deficiency. Although 9% of the subjects carried the sickle cell trait, this abnormality is not associated with anemia (41–43).

On the basis of our results, the use of only SF as an indicator could underestimate the prevalence of iron deficiency considerably, whereas the use of ZP alone as an indicator could overestimate its prevalence somewhat in populations with a high prevalence of inflammation or infection. TfR appears to be largely unaffected by inflammatory disorders; therefore, the combination of TfR and hemoglobin concentrations might be a good indicator of IDA in developing countries. Although the cost of TfR analysis is still high, it can be expected to approach that of the SF assay as demand and availability of the technique grow (4).

In conclusion, iron deficiency is a serious public health problem in Côte d'Ivoire; the prevalence is high in preschool children, school-age children, and women in Abidjan as well as in rural areas. However, when considering strategies to provide additional iron, remember that only ≈50% of the anemic subjects in this study were iron deficient and that malaria and inflammatory disorders are widespread in Côte d'Ivoire. Inflammation can influence iron- status indexes, and thus complicate the accurate detection of iron deficiency, and may decrease the effect of additional dietary iron by reducing the body's ability to absorb and utilize it.

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