Determinants of anemia and hemoglobin concentration in haitian school-aged children

Lora L. Iannotti
Washington University School of Medicine in St. Louis

Jacques R. Delnatus
Washington University School of Medicine in St. Louis

Audrey R. Odom
Washington University School of Medicine in St. Louis

Jacob C. Eaton
Washington University School of Medicine in St. Louis

Jennifer J. Griggs
Washington University School of Medicine in St. Louis

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Determinants of Anemia and Hemoglobin Concentration in Haitian School-Aged Children


Institute for Public Health, George Warren Brown School of Social Work, Washington University in St. Louis, St. Louis, Missouri; Meds and Food for Kids, Cap Haitien, Haiti; Department of Pediatrics Washington University School of Medicine, St. Louis, Missouri; Department of Medicine, University of Michigan, Ann Arbor, Michigan; Department of Molecular Microbiology, Washington University School of Medicine, St. Louis, Missouri

Abstract. Anemia diminishes oxygen transport in the body, resulting in potentially irreversible growth and developmental consequences for children. Limited evidence for determinants of anemia exists for school-aged children. We conducted a cluster randomized controlled trial in Haiti from 2012 to 2013 to test the efficacy of a fortified school snack. Children (N = 1,047) aged 3–13 years were followed longitudinally at three time points for hemoglobin (Hb) concentrations, anthropometry, and bioelectrical impedance measures. Dietary intakes, infectious disease morbidities, and socioeconomic and demographic factors were collected at baseline and endline. Longitudinal regression modeling with generalized least squares and logit models with random effects identified anemia risk factors beyond the intervention effect. At baseline, 70.6% of children were anemic and 2.6% were severely anemic. Stunting increased the odds of developing anemia (adjusted odds ratio [OR]: 1.48, 95% confidence interval [CI]: 1.05–2.08) and severe anemia (adjusted OR: 2.47, 95% CI: 1.30–4.71). Parent-reported vitamin A supplementation and deworming were positively associated with Hb concentrations, whereas fever and poultry ownership showed a negative relationship with Hb concentration and increased odds of severe anemia, respectively. Further research should explore the full spectrum of anemia etiologies in school children, including genetic causes.

INTRODUCTION

The hemoglobin (Hb) protein plays a fundamental role in health and development as the primary oxygen carrier in the human body. Anemia results when Hb falls below necessary levels to sustain cellular respiration and other vital processes. The World Health Organization (WHO) estimates that nearly half (48.8%) of the world’s population is anemic, with notable disparities by region and population group.1 Globally, school-aged children have a reported prevalence of 25.4%, below estimates of prevalence for preschool-aged children, pregnant, and nonpregnant women. Comparable rates have been found by various studies in low-income populations, but with relatively less evidence for this age group compared with other vulnerable groups.2–6

It is widely recognized that there are multiple causes of anemia, although the proportional representation of these various risk factors is less well characterized.7 Differences across populations are further complicated by environmental and demographic factors. A recent study of children aged 6–35 months in Nyanza Province, Kenya, identified malaria, iron deficiency, and homozygous α-thalassemia as risk factors most associated with anemia; malaria, inflammation, and stunting were associated with severe anemia.8 Another cross-sectional study in Côte d’Ivoire showed chronic inflammation and cellular iron deficiency to be associated with anemia in children aged 6–8 years, while Plasmodium falciparum was associated with anemia in infants aged 6–23 months, and cellular iron and riboflavin deficiencies in nonpregnant women aged 15–25 years.8 We hypothesized a spectrum of potential causes for this population by drawing on evidence from various sources and identified factors that could be playing a role in Haiti (Figure 1).

From 2012 to 2013, we conducted a cluster randomized controlled study in Cap Haitien, Haiti, to study the impacts of a fortified peanut butter snack, Mamba, on the nutrition of school-aged children.9 At the start of the study, anemia was found to be highly prevalent (73.3%) across all children. Although a small, positive effect was found for reduced odds of developing anemia among children receiving the Mamba nutrition intervention compared with the control (adjusted odds ratio [OR]: 0.72, 95% confidence interval [CI]: 0.57–0.91, P < 0.001), there were no evident differences by group for increased Hb concentration or for overall reduced anemia prevalence.9 These findings raised questions regarding other potential causes of anemia among Haitian school-aged children. In this analysis, we aimed to investigate the observed determinants of Hb concentration, anemia, and severe anemia collected from the intervention trial, in recognition of the limitations presented by applying proxy markers, but with the intent to use the findings as a basis for further study.

METHODS

Study schools, sample, and design. The cluster randomized controlled trial was carried out in Cap Haitien, the second largest city in Haiti located in the North Department. Approximately 1 million people live in Cap Haitien and the surrounding peri-urban areas. In collaboration with the national school feeding program of the Ministry of Education (Program National de Cantine Scolaire, Ministère de l’Éducation Nationale et de la Formation Professionnelle), formative research was carried out to identify and match schools on socioeconomic and nutrition factors. Six comparable schools were selected, including four public and two private schools, and randomized into three groups: control, cereal bar (Tablet Yo), and fortified peanut butter snack (Mamba). Details of the trial are described elsewhere.9

In brief, children were considered eligible based on the following criteria: aged 3–13 years; good health (no fever, congenital health condition, or peanut or soy allergy); not severely malnourished (weight-for-height z score [WHZ] < –3); and registration in study school for 2012–2013. Of the 1,169 eligible children, 1,167 were enrolled; for this analysis, we included
the children with Hb concentration measures at two or more time points \((N = 1,047)\). In this analysis, we refer to the sample as school-aged children, though 182 preschool-aged children were included. Children were followed longitudinally for Hb concentration, height, weight, and bioelectrical impedance measures at three time points: baseline (December 2012), midline (March 2013), and endline (June 2013). Parents were surveyed for household level socioeconomic, demographic factors and water, hygiene, and sanitation information, as well as child diet and morbidities at baseline and endline. In addition to household income, we assessed ownership of various assets, including livestock (cows, donkeys, goats, and poultry).

Children in the two intervention groups received the snack daily from January through June 2013. Mamba (50 g, 260 kcal) provided greater than 75% of Recommended Dietary Allowances (RDA) for critical micronutrients (vitamin A, B12, folate, copper, iron, selenium, and zinc) for children aged 4–8 years including those associated with anemia. The Tablet Yo cereal bar (42 g, 165 kcal) offered these nutrients at lower levels ranging from 0% to 62% of RDA. Children in the control group did not receive any snack during the study period. The study was approved by the National Bioethics Committee of the Ministry of Health (Ministère de la Santé Publique et de la Population, MSPP) in Haiti and the Institutional Review Board of the Human Research Protection Office of Washington University in St. Louis.

**FIGURE 1.** Potential causal pathways for determinants of anemia in school-aged children. The determinants in boldface are those hypothesized to be contributing to anemia among school-aged children in Cap Haitien, Haiti.

**Nutrition and health.** Child anthropometric measures of weight and height were taken using international protocols. Body mass index (BMI), anthropometric z scores, and prevalence of stunting (height-for-age z score \([HAZ] < -2\)), underweight (weight-for-age z score \([WAZ] < -2\)), wasting (\([WHZ] < -2\)), and thin (BMI z score \([BMIZ] < -2\)) were calculated based on WHO Growth Standards (2006) for children aged 3–5 years, and WHO Growth References (2007) for children aged 6–13 years.

Caregiver surveys, administered at baseline and endline, were used to collect information regarding child diet, supplementation, deworming, and morbidities. Caregivers were asked...
whether the child had received vitamin A, iron, zinc, multivi- 
mint, mineral supplements, or deworming tablets in the 
previous 6 months. Child diet was examined using a 24-hour food 
frequency of intake. Enumerators asked caregivers to recall 
the number of times the child had consumed various foods in 
the past day and night. Two indicators were generated to 
examine micronutrient nutrition and dietary quality; dietary 
diversity and animal source food (ASF) consumption. Dietary 
diversity was calculated by summing the number of food items 
consumed in 24-hour period. The ASF indicator was a 
dichotomous marker of whether the child had consumed any 
eggs, milk, meat, or fish in the past day and night. 

Child morbidity outcomes were similarly assessed using a 
caregiver recall. Enumerators asked if the child had experi-
enced the following diarrheal morbidities in the past 2-week 
period: acute diarrhea (three or more semisolid or liquid stools 
in a 24-hour period), number of days with acute diarrhea, and 
bloody diarrhea. A 1-month recall period was applied for all 
other morbidities: malaria, fever, respiratory condition (cough 
and short, rapid breathing), eye infection, ear infection, skin 
conditions, and worm infection. All morbidity variables were 
assessed in the regression models. 

Statistical analysis. All statistical analyses were carried out 
using STATA software (version 13.1; StataCorp, College Station, 
TX). To begin, descriptive statistics were applied to character-
ize anemia prevalence and distributions among the school-age 
children. Next, univariate tests of analysis of variation, t tests, 
and χ² examined differences in socioeconomic, demographic, 
nutrition, and morbidity outcomes by anemia and severe ane-
mia status. We investigated Hb concentrations, distributions, 
and anemia status differences by child age. Age across the 
range of children included in this study (3–13 years) was strati-
fied according to common groupings in the nutrition and ane-
mia literature: preschool-aged (2–5 years), school-aged (6–8 and 
9–11 years), and preadolescence (12–13 years) children. Values 
for continuous outcomes are given as means ± standard devi-
ation, except for coefficient values in regression models 
presented as means ± standard error of the estimate. 

Longitudinal models were then constructed to identify deter-
minants of Hb concentration, anemia, and severe anemia. Ge-
genized least squares (GLS) with random effects was applied 
for the continuous outcome of Hb concentration, and logit 
models examined the adjusted odds for the dichotomous ane-
mia and severe anemia outcomes. We applied a Bayesian 
approach to constructing and interpreting the models. 

Variables representing conditions in the hypothesized causal 
pathways to anemia were first tested in the models (Figure 1). We 
included those related to nutrition (anthropometry, diet, and 
micronutrient supplementation), infection (all parent-recall 
morbidities including diarrhea, malaria, fever, and helminth 
infection), and chronic infection or conditions (child allergies, 
family history of chronic diseases). After this, the full set of 
available socioeconomic, demographic, nutrition, and health 
factors were incorporated into models as independent vari-
ables. Models including the variables collected at baseline and 
endline compared change in outcomes at two time points only. 
Those found to be significant (P < 0.05) and not highly corre-
lated with other terms (r ≤ 0.7) were retained. Separate 
models were run for each age group strata to test whether 
there were differences in the determinants of Hb concentra-
tion and anemia outcomes. All models were adjusted for 
treatment group and school cluster. 

RESULTS 

Socioeconomic, demographic, and health characteristics. Baseline 
characteristics were not statistically different by anemia status, except for prevalence of acute diarrhea in the previous 
2 weeks (Table 1). Trends for differences were observed for stunting and poultry ownership. Across all children, a greater 
proportion of children were reported receiving vitamin A supple-
mentation (19.8%) in the previous 6 months compared with iron supplementation (8.9%). At baseline, the proportion 
of children receiving vitamin A supplements did not differ 
significantly by age: 2–5 years (22.4%), 6–8 years (21.6%), 
9–11 years (17.0%), and 12–13 years (17.0%) (P = 0.28). Fever in the past 2 weeks was reported in 23.8% of all children; 
a greater, non-significant proportion was found in the anemia 
group. Across all children, 65.8% of households were in the 
lowest income quartile, and use of latrine and open defecation 
were the most common sanitation practices. 

Hb concentrations and anemia prevalence and trends. Mean 
Hb concentrations were statistically different by age group, 
with preschool-aged children showing the lowest levels 
(Table 2). Similarly, prevalence of anemia was also statistically 
different by age group. No statistical differences in Hb 
or anemia by sex were evident. With the exception of the 
age group 9–11 years, Hb concentration was lower at endline 
compared with baseline; anemia prevalence increased only in 
the youngest group. Severe anemia increased from baseline to 
endline across all age groups, again except in the 9- to 11-year 
olds. At the individual child level, 18.8% became anemic from 
baseline to endline, while 15.6% recovered, 65.6% did not 
move across categories. For severe anemia, 2.3% of the chil-
dren fell into this category by endline and 2.8% recovered. 

Longitudinal regression modeling. Longitudinal modeling of 
Hb concentration showed that age of the child, vitamin A 
supplementation, and deworming were associated with posi-
tive change in Hb, while stunting and fever negatively affected 
change in Hb concentration for individual children (Table 3). 
Malaria morbidity was found to significantly increase the odds 
of anemia, but because it was positively correlated with fever 
morbidity and explained overlapping variance in the anemia 
outcomes with fever, it was not retained in the model. A posi-
tive trend for consumption of ASFs was evident in association 
with changes in Hb concentration and for protecting against 
severe anemia. Stunting increased the odds of anemia by 48% 
and severe anemia by 147%. Increasing age of the child reduced 
the odds of anemia but was not associated with severe anemia 
outcomes. Girls were at greater risk for severe anemia. Chil-
dren whose parents reported owning poultry were at increased 
ods of severe anemia. In the substrata analyses by age group, 
trends suggested comparable determinants of Hb concentra-
tion and anemia outcomes to the larger sample. 

DISCUSSION 

The prevalence of anemia among these Haitian children was 
70.6% at trial baseline. This longitudinal, cohort study offers 
epidemiological evidence for determinants of anemia as a 
foundation for future research in an understudied age 
demographic and context. Stunting was strongly and consis-
tently related to change in Hb concentration, anemia, and 
severe anemia outcomes in these children. Other nutrition 
factors played a role, including vitamin A supplementation
and dietary intake of ASFs. Markers of infection (fever and deworming) and potential pathogen exposure (poultry ownership) were associated with Hb concentration and anemia in the expected directions.

To our knowledge, anemia has not been previously evaluated in Haitian school-aged children. Evidence comes largely from children 6 to 59 months and women of reproductive age, with some parallel findings to this analysis. A recent, nationally representative study in Haiti showed urban women and children are at higher risk for anemia than those in rural areas. A study from the south of Haiti showed 38.8% children aged 6–59 months were anemic, in association with young age, stunting, and low maternal Hb status. A third study, applying a convenience sample and cross-sectional design in the Central Plateau of Haiti, found 80.1% of preschool-aged children to be anemic. Prevalence varied by context, but similar to our findings age, stunting, and female sex were associated with increased anemia risks.

Age and sex of the child. Age was protective for Hb concentration and anemia, suggesting a need to target younger children both within and outside the school system. Girls were

### Table 1
Socioeconomic and demographic characteristics, by anemia status at baseline

<table>
<thead>
<tr>
<th>Child characteristics</th>
<th>Controls (nonanemic children, N = 309)</th>
<th>Cases (anemic children, N = 738)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child age, years*</td>
<td>8.0 ± 2.5</td>
<td>8.2 ± 2.5</td>
<td>0.26</td>
</tr>
<tr>
<td>Sex of child, % female</td>
<td>51.5</td>
<td>51.6</td>
<td>0.96</td>
</tr>
<tr>
<td>Undernutrition, %</td>
<td>11.1</td>
<td>15.0</td>
<td>0.13</td>
</tr>
<tr>
<td>Stunted (HAZ &lt; –2)</td>
<td>9.5</td>
<td>9.0</td>
<td>0.82</td>
</tr>
<tr>
<td>Thin (BMIz &lt; –2)</td>
<td>50.2</td>
<td>53.3</td>
<td>0.35</td>
</tr>
<tr>
<td>ASFs consumption, %</td>
<td>21.3</td>
<td>18.9</td>
<td>0.38</td>
</tr>
<tr>
<td>Iron</td>
<td>9.5</td>
<td>9.0</td>
<td>0.81</td>
</tr>
<tr>
<td>Deworming in previous 6 months, %</td>
<td>78.4</td>
<td>75.7</td>
<td>0.35</td>
</tr>
<tr>
<td>Acute diarrhea, %†</td>
<td>15.6</td>
<td>11.0</td>
<td>0.04</td>
</tr>
<tr>
<td>Fever, %</td>
<td>21.6</td>
<td>25.1</td>
<td>0.23</td>
</tr>
<tr>
<td>Caregiver characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal education, years*</td>
<td>4.5</td>
<td>3.5</td>
<td>0.98</td>
</tr>
<tr>
<td>Maternal BMI (N = 945)*</td>
<td>23.2</td>
<td>4.8</td>
<td>0.93</td>
</tr>
<tr>
<td>Household characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of household members*</td>
<td>6.4</td>
<td>2.4</td>
<td>0.64</td>
</tr>
<tr>
<td>Sol savings club participation, %</td>
<td>68.6</td>
<td>67.4</td>
<td>0.77</td>
</tr>
<tr>
<td>Monthly income (Haitian dollar), %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100–500</td>
<td>65.0</td>
<td>66.4</td>
<td>0.71</td>
</tr>
<tr>
<td>501–800</td>
<td>13.4</td>
<td>14.5</td>
<td></td>
</tr>
<tr>
<td>801–1,000</td>
<td>9.8</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>&gt; 1,000</td>
<td>11.8</td>
<td>11.4</td>
<td></td>
</tr>
<tr>
<td>Poultry ownership, %</td>
<td>10.5</td>
<td>14.4</td>
<td>0.09</td>
</tr>
<tr>
<td>Toilet type, %</td>
<td></td>
<td></td>
<td>0.26</td>
</tr>
<tr>
<td>Open defecation/other</td>
<td>20.5</td>
<td>18.7</td>
<td></td>
</tr>
<tr>
<td>Latrine</td>
<td>70.7</td>
<td>74.9</td>
<td></td>
</tr>
<tr>
<td>Automatic flush</td>
<td>8.8</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>Share toilet with other households, %</td>
<td>41.0</td>
<td>37.9</td>
<td>0.34</td>
</tr>
<tr>
<td>Drinking water source, %</td>
<td></td>
<td></td>
<td>0.94</td>
</tr>
<tr>
<td>Public pump</td>
<td>8.8</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>Tap or faucet inside home</td>
<td>25.8</td>
<td>25.7</td>
<td></td>
</tr>
<tr>
<td>Bottled or potable water</td>
<td>61.8</td>
<td>60.6</td>
<td></td>
</tr>
<tr>
<td>Other (truck, well, spring, surface)</td>
<td>3.6</td>
<td>4.4</td>
<td></td>
</tr>
</tbody>
</table>

ASFs = animal source foods; BMIz = body mass index z score; HAZ = height-for-age z score; SD = standard deviation.

* Values are mean ± SD.
† Groups were significantly different by analysis of variance or χ², P < 0.05.

### Table 2
Mean Hb concentration and anemia prevalence at three time points, by age group

<table>
<thead>
<tr>
<th>Age group</th>
<th>Hb concentration (g/dL)</th>
<th>SD</th>
<th>WHO-defined anemia</th>
<th>Severe anemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>2–5 years (N = 182)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>10.2 ± 1.4</td>
<td>66.6</td>
<td>1.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Midline</td>
<td>10.2 ± 1.4</td>
<td>71.3</td>
<td></td>
<td>1.7</td>
</tr>
<tr>
<td>Endline</td>
<td>10.1 ± 1.1</td>
<td>70.3</td>
<td></td>
<td>3.3</td>
</tr>
<tr>
<td>6–8 years (N = 388)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>10.4 ± 1.3</td>
<td>73.4</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>Midline</td>
<td>10.7 ± 1.3</td>
<td>69.1</td>
<td></td>
<td>3.1</td>
</tr>
<tr>
<td>Endline</td>
<td>10.3 ± 1.3</td>
<td>71.4</td>
<td></td>
<td>4.1</td>
</tr>
<tr>
<td>9–11 years (N = 365)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>10.8 ± 1.3</td>
<td>66.9</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Midline</td>
<td>11.1 ± 1.2</td>
<td>59.6</td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Endline</td>
<td>10.8 ± 1.3</td>
<td>63.6</td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>12–13 years (N = 112)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>10.9 ± 1.2</td>
<td>81.3</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Midline</td>
<td>10.7 ± 1.6</td>
<td>80.4</td>
<td></td>
<td>6.3</td>
</tr>
<tr>
<td>Endline</td>
<td>10.7 ± 1.4</td>
<td>75.0</td>
<td></td>
<td>4.5</td>
</tr>
<tr>
<td>All (N = 1,047)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baselines</td>
<td>10.6* ± 1.2</td>
<td>70.6*</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Midline</td>
<td>10.7* ± 1.4</td>
<td>67.3*</td>
<td>2.3*</td>
<td>3.2</td>
</tr>
<tr>
<td>Endline</td>
<td>10.5* ± 1.3</td>
<td>68.9*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Hb = hemoglobin; SD = standard deviation; WHO = World Health Organization.
* Age groups were significantly different by analysis of variance or χ², P < 0.05.
at significantly greater risk for severe anemia compared with boys. In our subgroup analyses examining anemia in girls and boys, we found a trend for increased anemia among older girls, 12–13 years of age. In an older study, average age at menarche in Haiti was found to be 15.4 years, with a secular trend of declining age by 0.36 years per year. Thus, it is plausible that some older girls were at greater risk for anemia because of the blood loss associated with menses.

**Stunting.** Stunting significantly increased the odds of anemia and severe anemia in these school-aged children. Changes in HAZ were also found to be positively associated with changes in Hb concentration and negatively related to anemia status. The relationship was strong and consistent across models, with a trend of declining age by 0.36 years per year. Thus, it is plausible that some older girls were at greater risk for anemia because of the blood loss associated with menses.

**Dietary intakes.** The fortified snack, Mamba, reduced the odds of anemia by 28% compared with control for individual children. Mamba contains higher levels of critical micronutrients than the cereal bar, suggesting a potential role for nutrient supplementation and ASF consumption and Hb concentration and anemia outcomes.

Parent-reported vitamin A supplementation of the child in the past 6 months was found to significantly increase Hb concentration by 0.18 g/dL after adjusting for all other covariates. In Haiti, the MSPP protocol is to provide high-dose vitamin A supplementation every 6 months for children 6 months–6 years. Although higher proportions of children in the younger age groups received vitamin A than older children, the difference was not significant. Approximately one-fifth (19.8%) of all the school children in our study were reported to have received vitamin A supplements. Evidence suggests vitamin A influences anemia primarily through mechanisms to regulate erythropoiesis and mediate iron metabolism (iron storage and release).

Iron deficiency has previously been thought to comprise the largest proportion of anemia, with estimates ranging from 50% for malaria-endemic regions to 60% in other developing countries. However, this has not been verified in other epidemiological studies and was not indicated in our findings. Iron supplementation, albeit only reported in 9% of the children, was not associated with anemia outcomes or Hb concentration. The Kenya study showed the fractional prevalence of iron deficiency anemia to be only 8.3% among preschool-aged children. In Thailand, iron deficiency anemia was prevalent only among the preschool-aged children (19%), while there was no evidence of anemia related to iron deficiency in the school-aged children. The Côte d’Ivoire analyses found an association with cellular iron deficiency and anemia in school-aged children at baseline, and a negative association with Hb concentration in the prospective study. Importantly, the iron parameters (ferritin and soluble transferrin receptor) were associated with inflammatory biomarkers.

Vitamin B12 and folate deficiencies result in macrocytic anemia, a condition in which hematopoietic stem cells in the bone marrow and red blood cells in circulation are larger than normal. This results from the asynchronous growth of cytoplasm and nucleic material. One study among school-aged children in Colombia found that Hb concentration was inversely related to erythrocyte folate concentrations, in particular, among children with low vitamin B12 status. Although we were not able to directly examine status for these nutrients, consumption of ASF as the only dietary source of vitamin B12 might be considered a proxy marker. We found a positive trend for ASF and Hb concentrations (P = 0.07) and for ASF reducing the odds of severe anemia (P = 0.06) in longitudinal modeling. ASF consumption may also be protective for other nutrients implicated in anemia risk including vitamin A, iron, and zinc.

**Acute infection.** Deworming and fever showed important associations with Hb concentration in our regression analyses. A recent MSPP study on helminth infection in Haitian children 6–15 years of age found a national prevalence of 14% (95% CI: 13.1–15.0%), and a prevalence of 15.9% in the North Department where our study was conducted. Interestingly, this study showed limited infection with hookworm, 0.4% (95% CI: 0.3–0.7%), a known contributor to anemia. Trichuris trichiura and Ascaris lumbricoides in 9.2% (95% CI: 8.4–10.0%) of Haitian children, nationally. Although T. trichiura...
is more directly related to anemia through blood losses, *A. lumbricoides* could be contributing through inflammation mechanisms.\(^3\) One study from Leogane in southern Haiti reported infection rates between 11% and 37% for *A. lumbricoides*, between 19% and 62% for *T. trichiura*, and between 6% and 21% for hookworm.\(^3\)

The negative relationship of fever with Hb concentration after adjusting for deworming in our analyses suggests a role for other types of infection. Malaria was the leading cause of anemia and severe anemia in the Kenya study looking at multiple etiologies.\(^8\) However, prevalence in Haiti is estimated to be only 1–3% with variability by season and region of the country.\(^36,37\) There was a sharp increase in cases from 2009 to 2011, but rates have dropped and stabilized since; approximately half of the population lives in high-transmission (> 1 case per 1,000 population) areas.\(^38\) The Côte d'Ivoire studies also showed both acute and chronic inflammation markers to be associated with anemia.\(^39,40\) Other gastrointestinal infections may be playing a role in Haiti. Though acute diarrhea was not significantly related to anemia in the school-aged children, poultry ownership, a potential exposure variable, was associated with a 2-fold higher odds of severe anemia.\(^39,40\)

**Strengths and limitations.** To our knowledge, this is the first known analysis to examine the determinants of anemia among school-aged children in Haiti. Although the study was designed to test the effectiveness of a snack intervention on anemia and other nutrition outcomes, the data collected allowed for exploration of a range of hypothesized factors. There were key pathways, however, that we were not permitted to explore, such as genetics. Small studies have been carried out in Haiti that suggest the importance of the hereditary hemoglobinopathies such as sickle Hb in the anemia pathway.\(^41–43\) Other potential mechanisms were assessed only through the use of proxy markers that lacked precision and specificity. More ideally, we would have tested for helmint and *Plasmodium* infections through methods such as the Kato-Katz or FLOTAC methods and blood films or rapid diagnostic tests, respectively.\(^44–46\) Biomarkers of micronutrient status also may have improved precision for the distinct contributions of various vitamins and minerals.\(^46\)

These analyses were intended to serve as a basis for further exploration of anemia etiologies in Haiti and elsewhere. Findings clearly suggest a very high prevalence of anemia in Haiti using the WHO cutoff. As a longitudinal study, we were able to examine drivers of change in Hb concentration and anemia status through the use of powerful regression models. Stunting, which could indicate micronutrient deficiencies as well as infection, was strongly associated with all Hb concentration, anemia, and severe anemia outcomes. Other nutrition factors identified, including vitamin A supplementation and ASF dietary intakes, are suggestive of an important role for micronutrient deficiencies in Haiti. There was also clear evidence for infection-related determinants.

**CONCLUSIONS**

Anemia encompasses several different conditions, unified by the definition of low Hb concentration. The etiologic range may reflect the vital importance of the Hb protein as oxygen carrier, and similarly, multiple mechanisms that can compensate when deficits arise. Although anemia is commonly examined as the outcome of interest, we want to emphasize that it is a condition that can lead to serious and possibly irreversible impairments in growth, development, and reproductive health. For school-aged children undergoing rapid brain development and underlying physiological processes of growth and development, the consequences may be severe. Moving forward, research is still needed to understand the full range of causes of anemia using valid markers of potential risk factors, and to test interventions related to nutrition and infection to reduce this problem in Haiti and elsewhere.