Pediatric Anemia in Rural Ghana: A Cross-Sectional Study of Prevalence and Risk Factors

by Kelley M. VanBuskirk, Anthony Ofosu,[1] Amy Kennedy,[2] *and* Donna M. Denno[3]
[1]*Policy Planning Monitoring and Evaluation Division, Ghana Health Service, Accra, Ghana*
[2]*School of Medicine, University of Washington, Seattle, WA 98195, USA*
[3]*Departments of Pediatrics and Global Health, University of Washington, Seattle, WA 98115, USA*

Correspondence: Donna M. Denno, Department of Pediatrics, University of Washington, 6200 NE 74th Street, Suite 110, Box 354920, Seattle, WA 98115-8160, USA, Tel: 206 296 8421. E-mail <ddenno@uw.edu>.

Summary

Objective: To assess anemia prevalence and identify associated parameters in children <3 years of age in a rural area of Ghana.
Method: Univariate and multivariate logistic regression of cross-sectional survey results from 861 children aged <3 years attending routine immunization services in Berekum district.
Results: Anemia prevalence was 73.1%; most were either mildly (31.2%) or moderately (38.7%) affected. Risk factors for anemia (hemoglobin < 11.0 g/dl) in multivariate analysis were malaria parasitemia and male sex; these factors and younger age were associated with anemia severity. A partial defect in glucose-6-phosphate dehydrogenase was associated with decreased severity. Height-for-age, but not weight-for-age, was associated with anemia and its severity.
Conclusions: Malaria parasitemia was strongly associated with anemia and its severity, suggesting that malaria control may be the most effective way to reduce the burden of anemia in rural Ghanaian children.

Key words: anemia, Ghana, children, malaria, hemoglobin, hemoglobinopathy.

Introduction

Approximately 25% of the global population suffers from anemia; the highest prevalence is among preschool-aged children at 47.4% [1]. The World Health Organization (WHO) defines the public health significance of anemia as severe if ≥40% of a population is affected [1–3]. Prevalence in the WHO African region is 47.5–67.6% among the general population and 68% among 2–5-year-olds [1]. In Ghana, anemia prevalence is 78 and 84% among 2–5-year-olds and under-twos, respectively [4]. Anemia etiology is multifactorial and context-dependent and can include malaria, intestinal parasites and malnutrition [1].

Childhood anemia is an important cause of morbidity and mortality. It accounts for up to half of malaria deaths in young children [5]. Anemia caused by iron deficiency has a long-term impact on physical and cognitive development [6–12].

The aim of our study was to determine the prevalence and severity of anemia in children <3 years of age in a rural area of Ghana, to assess associated risk factors and to determine the relationship between anemia and growth parameters.

Methods

Cross-sectional analysis was performed using baseline data from an intervention trial of sulfadoxine pyrimethamine for intermittent preventative

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treatment of malaria, ferrous sulfate and/or placebo. Subjects aged 4–33 months were randomly selected from attendees of 20 immunization clinics and routine outreach sites selected from 48 communities within the rural Berekum district between April and May 2005. Random selection from these sites was proportional to the population of children in each community. A consent form was read aloud to mothers of potential subjects and thumbprinted consent was obtained.

Recumbent lengths of subjects were measured to the nearest 0.1 cm on boards manufactured for the study. Weights were measured to the nearest 0.1 kg using hanging Salter scales, which were standardized using laboratory weights. Two readings of height and weight were taken for each child and the mean figure was used in analysis. *Z*-scores for height-for-age (HAZ) and weight-for-age (WAZ) were based on WHO standards and were calculated using the nutritional survey module of the WHO Anthro software (version 3.2.2). Questionable values were flagged based on WHO Anthro criteria (lower SD, upper SD): HAZ (−6, +6), WAZ (−6, +5) [13].

Blood samples of 5 ml were collected by venipuncture into EDTA-containing tubes. Two hemoglobin (Hb) measures (by cyanmethemoglobin method and photometer reading) were taken per child; the mean of the two was used in analysis. Anemia was defined as Hb < 11.0 g/dl and severity was classified as (g/dl): mild 10.0–10.9, moderate 7.0–9.9 and severe <7.0 [2]. Thick smears for malaria detection were examined over 200 high-power fields. Hemoglobinopathies were assessed by cellulose acetate electrophoresis. Glucose-6-phosphate dehydrogenase (G6PD) deficiency was visually assessed by the methemoglobin reduction method, as previously described [14]. Partial defect describes an intermediate level of enzymatic function in the test; full defect describes the absence of detectable enzymatic activity.

Stool specimens were examined for ova and parasites by wet mount. Five percent of malaria smears and stool slides were randomly selected for independent assessment at the Sunyani Regional Hospital laboratory for quality control purposes; results did not meaningfully differ from those done by the Berekum Laboratory.

Data analysis

Caregivers of 901 children were approached for study enrollment; none refused participation. Hb data were collected for 869 children. Twenty-three children had outlier HAZ values as per WHO Anthro reference standards [13]. For these, we recalculated HAZ using height measurements from a 2-month follow-up visit; 8 of these 23 children were excluded based on missing ($n=6$) or outlier ($n=2$) second-month values. Our total sample for analysis included 861 subjects.

TABLE 1
Demographic characteristics of children in survey

Parameter	*n* (%)
Mother's occupation	
Professional	14 (1.6)
Farmer/trader/artisan	746 (86.6)
Housewife/other/unemployed	101 (11.7)
Father's occupation	
Professional	51 (5.9)
Farmer/trader/artisan	720 (83.6)
Other/unemployed	90 (10.5)
Highest level of education attained by mother	
Nil/primary	483 (56.1)
Junior secondary school	344 (40.0)
Senior secondary school/tertiary	32 (3.7)
Missing	2 (0.2)
Highest level of education attained by father	
Nil/primary	268 (31.1)
Junior secondary school	438 (50.9)
Senior secondary school/tertiary	155 (18.0)
Mother's religion	
Christian	779 (90.5)
Islam	59 (6.9)
Traditionalist/other	22 (2.6)
Missing	1 (0.1)
Father's religion	
Christian	677 (78.6)
Islam	72 (8.4)
Traditionalist/other/atheist	112 (13.0)

Statistical analysis was performed using STATA v.10 (College Station, TX). Univariate and multivariate analyses were carried out using logistic regression. Multivariate models incorporated variables that were statistically significant in univariate analyses at the $p<0.05$ level, and adjusted for confounders. A threshold of >10% change in the point estimate [from the crude odds ratio (OR)] was used to identify confounders. Anemia severity outcomes were analyzed by ordinal logistic regression; for these models, we confirmed that the assumption of proportional odds was not violated, by using the omodel package for STATA [15].

Results

Mean age was 15.7 months. Predominant reported parental demographic characteristics were Christian religion; less than senior secondary school education; and occupation of farmer, artisan or trader (Table 1).

Anemia prevalence was 73.1%, the majority to a mild (31.2%) or moderate (38.7%) extent (Table 2). Hb ranged from 4.6 to 15.9, with a mean of 10.1 (SD 1.6). AC and AS Hb variants were common (10.1%); 2.7% had CC, SC or SS hemoglobinopathies. A partial or full defect in G6PD was detected in 16.7 and 1% of children, respectively.

TABLE 2
Characteristics of study subjects (n = 861) by anemia severity

Parameter	Nonanemic (Hb ≥ 11.0 g/dl)	Mild anemia (Hb ≥ 10.0 and <11.0 g/dl)	Moderate anemia (Hb ≥ 7.0 and <10.0 g/dl)	Severe anemia (Hb < 7.0 g/dl)	All subjects
	n = 232 (26.9%)	*n* = 269 (31.2%)	*n* = 333 (38.7%)	*n* = 27 (3.1%)	*n* = 861
Age in months					
Mean (SD)	16.6 (6.4)	16.0 (6.2)	14.9 (5.9)	14.1 (6.6)	15.7 (6.2)
Range	5–33	5–29	5–30	6–27	5–33
Sex *n* (%)					
Female	127 (54.7)	131 (48.7)	145 (43.5)	11 (40.7)	414 (51.9)
Hemoglobin (g/dl)					
Mean (SD)	12.1 (0.8)	10.4 (0.3)	8.8 (0.7)	6.3 (0.6)	10.1 (1.6)
Range	11.3–15.9	10.0–10.9	7.1–9.6	4.6–6.7	4.6–15.9
Hemoglobin type					
AA	207 (89.2)	239 (88.9)	275 (82.6)	24 (88.9)	745 (86.5)
AC/AS	21 (9.1)	21 (7.8)	44 (13.2)	1 (3.7)	87 (10.1)
CC/SC/SS	3 (1.3)	7 (2.6)	11 (3.3)	2 (7.4)	23 (2.7)
Missing	1 (0.4)	2 (0.7)	3 (0.9)	0	6 (0.7)
G6PD					
Normal	152 (65.5)	210 (78.1)	249 (74.8)	24 (88.9)	635 (73.8)
Partial defect	50 (21.6)	46 (17.1)	47 (14.1)	1 (3.7)	144 (16.7)
Full defect	1 (0.4)	1 (0.4)	3 (0.9)	0	5 (0.6)
Missing	29 (12.5)	12 (4.5)	34 (10.2)	2 (7.4)	77 (8.9)
Height-for-age *Z*-score (HAZ)[a]					
Mean (SD)	−1.24 (2.1)	−1.13 (2.3)	−1.58 (2.0)	−2.2 (1.9)	−1.38 (2.1)
HAZ ≥ −2, *n* (%)	132 (61.7)	153 (62.2)	169 (52.8)	10 (40.0)	464 (57.6)
HAZ < −2, *n* (%)	82 (38.3)	93 (37.8)	151 (47.2)	15 (60.0)	341 (42.4)
Weight-for-age *Z*-score (WAZ)[a]					
Mean (SD)	−0.67 (1.3)	−0.64 (1.2)	−0.62 (1.1)	−1.0 (1.1)	−0.65 (1.2)
WAZ ≥ −2, *n* (%)	200 (86.6)	227 (85.3)	287 (87.2)	24 (88.9)	738 (86.5)
WAZ < −2, *n* (%)	31 (13.4)	39 (14.7)	42 (12.8)	3 (11.1)	115 (13.5)
Malaria blood smear, *n* (%)					
Positive	11 (4.7)	15 (5.6)	42 (12.6)	5 (18.5)	73 (8.5)
Missing data	3 (1.3)	3 (1.1)	3 (0.9)	0	9 (1.1)
Household ITN ownership[a]					
Yes	62 (26.7)	72 (26.8)	68 (20.4)	9 (33.3)	211 (24.5)
If ITN present, child slept under net					
All/most of time	49 (79.0)	54 (75.0)	52 (76.5)	7 (77.8)	162 (76.8)
Sometimes/never	13 (21.0)	18 (25.0)	16 (23.5)	2 (22.2)	49 (23.2)

[a]Data missing for two subjects.
ITN: insecticide-treated bednet; Hb: hemoglobin concentration.

The proportions that were underweight and stunted were 13.5 and 42.4%, respectively. Malaria parasitemia was detected in 8.5% of children. Almost 25% lived in a household with an insecticide-treated bednet (ITN); of those, just >75% of the children used an ITN most or all of the time. Stool microscopy was positive in only four children [*Strongyloides* (*n* = 3) and *Ascaris* (*n* = 1)].

Univariate analyses

Malaria parasitemia was associated with anemia presence and severity in univariate analyses (data not shown). Parameters associated with reduced risk of both presence and severity were older age, female sex, partial G6PD deficiency and maternal secondary or tertiary education. Maternal occupation was associated with anemia severity. Household ITN ownership, the child's ITN use and a full defect in G6PD were not associated with anemia status or severity. The relationship between hemoglobinopathy (SC, SS or CC) and increased anemia severity neared statistical significance ($p = 0.055$).

Multivariate model

The relationship between anemia status and G6PD deficiency varied by sex, so we included an interaction term for these parameters in our multivariate

TABLE 3
Multivariate models for predictors of/risk factors for anemia (presence/absence) and anemia severity

Model	Predictors	Adjusted OR	95% CI	*p*-value
Anemia status	Age > 12 months	0.63	0.44, 0.91	0.013
	Sex (female)	**0.68**	**0.47, 0.996**	**0.047**
	G6PD			
	Partial defect	0.58	0.34, 1.00	0.052
	Full defect	0.25	0.01, 4.13	0.332
	Malaria parasitemia	**3.04**	**1.35, 6.87**	**0.007**
	Mother's occupation			
	Farmer/trader/artisan	0.70	0.40, 1.23	0.219
	Professional	0.57	0.13, 2.57	0.463
	Mother's education			
	Junior secondary school	0.91	0.65, 1.28	0.575
	Senior secondary school/tertiary	0.49	0.20, 1.22	0.125
Anemia severity	Age > 12 months	**0.59**	**0.44, 0.78**	**<0.001**
	Female sex	**0.68**	**0.51, 0.91**	**0.010**
	G6PD			
	Partial defect	**0.60**	**0.38, 0.93**	**0.023**
	Full defect	0.48	0.02, 10.43	0.639
	Malaria parasitemia	**3.05**	**1.84, 5.07**	**<0.001**
	Mother's occupation			
	Farmer/trader/artisan	0.69	0.46, 1.06	0.088
	Professional	0.70	0.17, 2.85	0.620
	Mother's education			
	Junior secondary school	0.83	0.63, 1.09	0.178
	Senior secondary school/tertiary	0.50	0.22, 1.16	0.106

Values in bold represent statistically significant findings.

model that also included age, sex, G6PD deficiency, malaria parasitemia and maternal occupation and education. Older age was associated with lower risk of anemia [OR 0.63; 95% confidence interval (CI) 0.44, 0.91] (Table 3). Malaria parasitemia (OR 3.04; CI 1.35, 6.87) was associated with higher risk. Female sex (OR 0.68; CI 0.47, 0.996) and partial defect in G6PD expression (OR 0.58; CI 0.34, 1.00) showed borderline association with lower anemia risk.

In a model that included age, sex, G6PD, malaria parasitemia, maternal occupation, maternal education and an interaction term for sex and G6PD deficiency, three risk factors were associated with decreased anemia severity: older age (OR 0.59; CI 0.44, 0.78), female sex (OR 0.68; CI 0.51, 0.91) and G6PD partial defect (OR 0.60; CI 0.38, 0.93). Malaria parasitemia was associated with anemia severity (OR 3.05; CI 1.84, 5.07).

Relationship between anemia and growth parameters

Adjusting for sex, HAZ was associated with presence of anemia (OR 1.43; CI 1.03, 2.00) (Table 4); WAZ was not (OR 1.20; CI 0.76, 1.91). No confounders were identified for the relationship between HAZ and anemia severity; in an unadjusted model, HAZ was associated with moderate and severe anemia, with respective ORs of 1.44 (CI 1.01, 2.05) and 2.41 (CI 1.04, 5.63), but not with mild anemia. Adjusting for sex and child's ITN use, WAZ was not associated with anemia severity.

Discussion

Recruitment from routine immunization services in a setting with high immunization coverage rates [4] allowed for a community-based sample of asymptomatic children. However, children not reached by such services are likely at higher risk for health problems, including anemia; our results may reflect an underestimation of the scope of the problem.

We portray and compare data from published pediatric anemia studies from Ghana in Table 5. To our knowledge, the present study is the first to report prevalence of anemia among rural children at the end of the dry season in Ghana and addresses a paucity of such data from West Africa. Furthermore, this is one of few studies that examined the associations between anemia and its severity with hemoglobinopathies and G6PD deficiency along with other parameters such as anthropometrics, malaria parasitemia and ITN use. Thus our study addressed some of the gaps in knowledge about pediatric anemia in Ghana, and more broadly, in West Africa and sub-Saharan Africa.

TABLE 4
Models for relationship between anemia and growth parameters (logistic regression)

Model	Outcome	Unadjusted OR	95% CI	*p*-value	Adjusted OR[a]	95% CI	*p*-value
Anemia status	Height-for-age *Z*-score	1.26	0.91, 1.73	0.163	**1.43**	**1.03, 2.00**	**0.035**
	Weight-for-age *Z*-score	1.01	0.65, 1.57	0.974	1.20	0.76, 1.91	0.439
Anemia severity	Height-for-age *Z*-score						
	Mild anemia	0.97	0.67, 1.43	0.910	[b]	–	–
	Moderate anemia	**1.44**	**1.01, 2.05**	**0.043**	–	–	–
	Severe anemia	**2.41**	**1.04, 5.63**	**0.041**	–	–	–
	Weight-for-age *Z*-score						
	Mild anemia	1.11	0.67, 1.84	0.692	1.19[c]	0.40, 3.56	0.761
	Moderate anemia	0.94	0.57, 1.55	0.821	1.58[c]	0.54, 4.63	0.409
	Severe anemia	0.81	0.23, 2.84	0.738	0.69[c]	0.71, 6.74	0.750

Values in bold represent statistically significant findings.
[a]Adjusting for sex.
[b]No confounders were identified for the relationship between height-for-age Z score and anemia severity; therefore, we used an unadjusted model for the regression analysis.
[c]Adjusting for sex and subject ITN use.

Our finding of a high prevalence (73.1%) of anemia among under-threes in this setting was comparable with national estimates among preschool-aged children (78%) [4] and higher than findings from Ghanaian urban studies from the same time frame—47.1 and 61.1% among under-fives and 1–3-year-olds, respectively [16, 17].

Severe anemia prevalence in our study (3.2%) was similar to that observed by Ehrhardt *et al*. (2006) in Ghanaian children aged 6 months to 9 years from both urban and rural environments during the same time frame as our data collection [18]. However, it was almost twofold compared with urban Ghanaian 1–9-year-olds also assessed within the same time frame and season [17]; our rural setting and younger cohort likely explain the difference. A study in northern Ghana found that anemia severity varied with the malaria transmission seasonality, with prevalence of Hb < 6.0 g/dl ranging from 22.1% at the end of high season (November) to 1.4% at the end of low season (May) [19]. Our data collection occurred at the end of the low transmission season and therefore likely underestimates the scope of the problem.

Demographic risk factors for anemia were generally consistent with those found in other studies, including younger age [18–21] and male sex [20]. While others identified maternal education [22] and occupation [23] as risk factors, we found that anemia risk cut across these socioeconomic groups in our setting after adjusting for potential confounders. The low prevalence of intestinal worms was consistent with another study conducted in urban Ghana [16].

As far as we are aware, our study is the first to investigate the relationship of G6PD deficiency and hemoglobinopathies to pediatric anemia in Ghana. Our lack of an association between anemia and full defect in expression was likely owing to the small number of these individuals in our sample ($n = 5$). The associations between G6PD deficiency with anemia status and severity contrast with results from a Kenyan study that found no such association [24]. Furthermore, although the defect was found to be more prevalent among Senegalese children with anemia, the association was not statistically significant [25]. However, these studies focused on genetic variants rather than blood enzyme levels, complicating comparison. Partial protection against malaria from G6PD deficiency, in particular among males, may explain our unique findings of an association between partial defect in G6PD and decreased anemia severity [26, 27].The lack of a significant association between hemoglobinopathies and anemia was consistent with findings from some studies [24, 28], but not others [25].

We found a malaria parasitemia prevalence among our community-recruited asymptomatic subjects of 8.5% during low transmission season and at a period predating mass ITN distribution strategies. Pediatric parasitemia prevalence in other studies in Ghana (in urban settings) from the same period varied from 2 to 37.8% [16, 17]. Not surprisingly, and consistent with other studies [16, 28–30], we found that blood-stage malaria infection was strongly associated with anemia status and severity. In the current era of ITN mass distribution and increasing coverage of this prevention intervention, one might expect lowered anemia prevalence, as Preji *et al*. demonstrated in Tanzania [31, 32]. However, improved ITN coverage might not necessarily translate to improved Hb status; a Kenyan study found only a minor difference in anemia prevalence between a community with no utilization of ITNs and one with high coverage rates [33].

TABLE 5
Comparison of pediatric anemia data across studies from Ghana

Reference/Subject age range/Setting	Dates of data collection[a]/Sample size	Anemia prevalence/ Severe anemia prevalence	Anemia association with ITN usage, G6PD status or hemoglobinopathies[b]	Anemia association with growth outcomes[b]	Other factors associated with anemia status	Other factors associated with anemia severity
Koram *et al.*, 2000 6–24-month-olds Rural	November 1996 and May 1997 Total: 633 November: 347 May: 286[a]	NR November: 22.1% May: 1.4% Severe anemia defined as Hb < 6.0 g/dl	ITN data – NR (however, ITN coverage in 1996–1997 was minimal at best) Reported G6PD deficiency and hemoglobinopathy prevalences, but not relationships to anemia	NR	Univariate analysis only: significantly lower Hb values at the rainy season compared with the dry season collection point Hb levels were associated with febrile illness in the rainy but not the dry season	Univariate analysis only: rainy season was associated with increased anemia severity
Koram *et al.*, 2003 [40] All ages with age stratification; we present data for 6–24-month-olds, unless otherwise noted Urban and rural	May 2001 and November 2001 Total: 376 May: 153 November: 223	May: 18.3% November: 39.9% Anemia defined as Hb < 8.0 g/dl May: 3.9% November: 5.4% Severe anemia defined as Hb < 6.0 g/dl	ITN use was significantly associated with higher Hb levels in the November survey Analysis for May sample was not reported G6PD – NR Hemoglobinopathies – NR	NR	Univariate analysis only: significantly lower Hb values were reported at the rainy season compared with the dry season collection point Malaria parasitemia was associated with lower Hb during the rainy season survey; assessment not reported during the dry season	Univariate analysis only: malaria parasitemia (Based on the article, we are uncertain if this finding was for all age groups or specifically among children)
Owusu-Agyei *et al.*, 2002 6–24-month-olds Rural	November 1996 and November 2000 Total: 1036 1996: 341 2000: 695	>98% Anemia defined as <11.0 g/dl 1996: 22% 2000: 12.5% Severe anemia defined as Hb < 6.0 g/dl	NR	Univariate analysis only: severe anemia and weight were not associated; Assessment of anemia association with other anthropometric indicators, including assessment of weight by age (e.g. WAZ or SD below the median), was not reported	Univariate analysis only: Hb levels were significantly higher in 2000 compared with 1996	Univariate analysis only: older age, malaria parasitemia, reported febrile illness, male sex, later collection point (smaller proportion of severely anemic children in the 2000 survey) and location within the district Authors speculate that differences in factors such as distance to health facilities or economic circumstances may account for the differences seen across three different sectors within the same district

(continued)

TABLE 5
Continued

Reference/Subject age range/Setting	Dates of data collection[a]/Sample size	Anemia prevalence/ Severe anemia prevalence	Anemia association with ITN usage, G6PD status or hemoglobinopathies[b]	Anemia association with growth outcomes[b]	Other factors associated with anemia status	Other factors associated with anemia severity
Ronald *et al.*, 2006 1–9-year-olds Two urban sites: Manhyia and Moshie Zongo, a community with lower SES level and higher malaria burden (32.7% prevalence per previous study) compared with Manhyia (3.8% prevalence)	April–May 2005 Total: 296 Manhyia: 148 Moshie Zongo: 148	Manhyia: 34.5% Moshie Zongo: 66.2% Anemia defined as <11.0 g/dl Manhyia: 2.0% Moshie Zongo: 2.7% "Moderate to severe" anemia defined as Hb < 8.0 g/dl	No association of anemia with ITN use G6PD – NR Hemoglobinopathies – NR	Univariate analysis only: anemia was not associated with wasting, underweight or mid-upper arm circumference Testing for association with severe anemia was not reported	Multivariate analysis: malaria parasitemia, residence in Moshie Zongo, male sex and younger age	NR
Klinken-berg *et al.*, 2006 6–60-month-olds Kumasi and Accra – the two most populous cities in Ghana	April 2002 and February 2003 Total: 3525 Accra: 1744 Kumasi: 1781	Accra: 51.0% Kumasi: 43.2% Anemia defined as <11.0 g/dl Accra: 4.0% Kumasi: 3.1% Severe anemia defined as Hb < 8.0 g/dl	32.8% (Accra) and 27.5% (Kumasi) ITN use prevalence, but assessment for association with anemia was not reported G6PD, hemoglobinopathies – NR	NR	Multivariate analysis, both sites: younger age, lower SES	Multivariate analysis, both sites: malaria parasitemia; Accra only: reported febrile illness
Ehrhardt *et al.*, 2006 6-month- to 9-year-olds Rural and urban	January–April and July–October 2002 Total: 4228 January–April: 2109 July–October: 2119	64.1% (results by season were not reported) Anemia defined as <11.0 g/dl 4% Severe anemia defined as Hb < 7.0 g/dl	NR	Multivariate analysis: WAZ (but not HAZ) was associated with anemia* The relationship of growth parameters to severe anemia was not reported *Based on the article, it appears that HAZ was not associated with anemia, but we were not able to definitively ascertain if it was actually included in the model	Multivariate analysis: age <5 years, rainy season, malaria parasitemia (both *Plasmodium falciparum* infection and *Plasmodium malariae* co-infection) and rural residence	Univariate analysis only: rainy season

(continued)

TABLE 5
Continued

Reference/Subject age range/Setting	Dates of data collection[a]/Sample size	Anemia prevalence/ Severe anemia prevalence	Anemia association with ITN usage, G6PD status or hemoglobinopathies[b]	Anemia association with growth outcomes[b]	Other factors associated with anemia status	Other factors associated with anemia severity
VanBuskirk *et al.*, 2014 (present study) 4–33-month-olds Rural	April–May 2005 861	73.1% Anemia defined as Hb < 11.0 g/dl 3.1% Severe anemia defined as Hb < 7.0 g/dl	Household ITN and child's ITN use were not associated with anemia presence or severity Full defect in G6PD was not associated with anemia or its severity. Partial defect was not associated with anemia, although the relationship neared statistical significance ($p = 0.052$); the partial defect was associated with decreased odds of severe anemia Hemoglobinopathy (SC, SS or CC) was not associated with anemia. The relationship with increased anemia severity neared statistical significance ($p = 0.055$)	Multivariate analysis: HAZ was associated with presence of anemia; WAZ was not Multivariate analysis: HAZ was associated with moderate anemia (defined as Hb ≥ 7.0 and <10.0 g/dl) and severe anemia, but not mild anemia (defined as Hb ≥ 10.0 and <11.0 g/dl); WAZ was not associated with anemia severity	Multivariate analysis: malaria parasitemia, male sex	Multivariate analysis: malaria parasitemia, male sex and HAZ; G6PD partial defect was associated with decreased severity

[a]In Ghana, November marks the end of the rainy and high malaria transmission season; May marks the end of the dry/beginning of the rainy season and low malaria transmission season.
[b]These parameters are reported separately from other risk factors in our table to emphasize the scarcity of such data in Ghanaian studies.
HAZ: height-for-age *Z*-score; Hb: hemoglobin; ITN: insecticide-treated net; NR: not reported; G6PD: glucose-6-phosphate dehydrogenase; SES: socioeconomic status; WAZ: weight-for-age *Z*-score.
Univariate results are only presented when multivariate results were not reported.

Consistent with the potential contribution of iron deficiency to long-term stunting outcomes [2, 34–38], anemia and its severity were significantly associated with HAZ but not WAZ in our models. Stunting is a known contributor to lower attained schooling and reduced adult income [39]. Underweight prevalence in our study population (13.5%) was comparable with that found nationally in rural Ghana in 2008 (16%) [4]; however, stunting was notably higher (42.4% in our sample vs. 32% in rural Ghana).

Overall, the strong and consistent associations we found between blood-stage malaria infection and anemia, as well as its severity, suggest that malaria control may be the most effective way to reduce the burden of anemia in Ghanaian children. Reduction of anemia should in turn translate to better cognitive development outcomes. Evaluation of the impact of malaria interventions such as ITNs on not only malaria-related morbidity and mortality but also on anemia and cognitive outcomes is critical.

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