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The Effect of Malaria and Intestinal Helminth Coinfection on Birth Outcomes in Kumasi, Ghana

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Abstract. This study was conducted to investigate the effect of *Plasmodium falciparum* and intestinal helminth coinfection on maternal anemia and birth outcomes. A cross-sectional study of 746 women who delivered in two hospitals in Kumasi was conducted. Data were collected using an investigator-administered questionnaire and from patients' medical records. Blood was collected for determination of *P. falciparum* and hemoglobin levels. Adverse pregnancy outcomes were high (44.6%). Coinfection (versus no infection) was associated with 3-fold increase in low birth weight. For women with anemia, coinfection was 2.6 times and 3.5 times as likely to result in preterm deliveries and small for gestational age infants. The odds of having anemia was increased almost 3-fold by coinfection. Coinfection (versus helminth only) resulted in increased risks of anemia, low birth weight, and small for gestational age infants. This study demonstrates that women with malaria and intestinal helminth coinfection are at particular risk of adverse birth outcomes.

INTRODUCTION

It is estimated that over a third of the world's population, mainly in the tropics and sub-tropics, is infected with parasitic helminths and *Plasmodium* species (*P. falciparum, P. malariae, P. vivax,* and *P. ovale)*,[1] often leading to coinfections.[2] Malaria has been recognized as a significant cause of anemia in pregnant women.[3] There are many hypotheses for the pathophyisiology of malaria-related anemia. These include: hemolysis or direct destruction of parasitized red blood cells both intravascularly and by sequestration in the microcirculation, mainly in the spleen;[3,4] nonspecific, defective red cell production, which depresses erythropoiesis, inhibits reticulocyte release, and prematurely destructs red cells during maturation in the bone marrow;[3,4] shortened red cell survival through specific or nonspecific immune responses; and malaria-related hypersplenism which is associated with reduction in blood cells, causing anemia, thrombocytopenia, and leucopenia.[3,4]

In settings where malaria is highly endemic, pregnant women, especially primigravid women, are at increased risk of *P. falciparum* infection.[5,6] The infection causes intrauterine growth retardation, low birth weight (LBW), pre-term delivery (PTD), and neonatal mortality.[7] In fact, LBW is known to be the most important risk factor for infant mortality. [7–9] In sub-Saharan Africa, malaria contributes to as much as 15% of maternal anemia, 14% of LBW infants, 30% of preventable LBW, 70% of intrauterine growth retardation, 36% of premature deliveries, and 8% of infant mortality.[7] There is evidence that *P. falciparum* strains exist that have specifically high affinity for placental receptors such as choriondroitin sulfate A, and therefore are sequestered in the placenta.[10] With successive pregnancies, women are subsequently exposed to a variety of these strains and develop efficient mechanisms to control infection and prevent disease.[10,11] Women who are pregnant for the first or second time have little or no immunity against the strains and hence have poor pregnancy outcomes.[12]

Intestinal helminth infections, specifically infections with hookworms and *Trichuris trichura,* have been demonstrated to be associated with anemia.[13,14] The mechanism by which hookworm is believed to cause anemia in pregnancy or otherwise is through intestinal blood loss in addition to impaired nutrient absorption.[15] Although *Trichuris trichura* may consume blood as part of their food, the greatest loss of blood occurs as a result of dysentery and damage to the mucosal lining of the cecum.[14] It has been suggested that both iron deficiency anemia and hookworm infection inhibit appetite, resulting in low pregnancy weight gain, intrauterine growth retardation, and subsequently, low birth weight.[16]

Although intestinal helminths are an important cause of anemia in developing countries, there is lack of consensus regarding the risks and benefits of treating helminths in pregnancy, and this has, until recently, led to the exclusion of pregnant women from deworming programs.[17] In a community-based study in Nepal, a two-dose albendazole regimen during pregnancy was associated with improved birthweight and noticeable reduction in early infant mortality compared with no albendazole, and the albendazole was not associated with adverse side effects.[18]

In countries of sub-Saharan Africa, both malaria and intestinal helminth infections are endemic, and coinfection commonly occurs. A study examining malaria and helminth coinfection in pregnancy in Nigeria demonstrated that over 45% of *Plasmodium*-infected pregnant women also harbored various intestinal helminths. This coinfection was associated with low hemoglobin level especially among primigravid women.[19] There are many hypotheses that have been presented to explain potential coinfection with malaria and intestinal helminths. It has been suggested that in malaria-helminth coinfection, helminth infection stimulates the Th2 cytokine response which

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possibly predominates, and down-modulates Th1 cytokines.[20] Inhibition of the Th1 response prevents protective effects of IFN-γ during the blood and liver stages of malaria infection.[20] This could explain the worsening of anemia in malaria-helminth coinfection.[21] Helminth infection thus creates a cytokine milieu favorable to the production of non-cytophilic antibodies, thus making individuals more susceptible to clinical malaria.[22] The presence of T regulatory cells is amplified during helminth infection, and if present in sufficient numbers, could induce a non-specific suppression,[23] making individuals susceptible to infections such as malaria; however, malaria may also exacerbate the consequences of helminth infection.[22]

Few studies have assessed the occurrence of malaria and helminth coinfection in pregnancy and its effects on maternal anemia and birth outcomes. Thus, we investigated the effect of *P. falciparum* and intestinal helminth coinfection on maternal anemia and birth outcomes in Ghana. To our knowledge, this has not been previously reported.

MATERIALS AND METHODS

Study design and population. The study methods have been described elsewhere.[24] Briefly, a cross-sectional study was conducted in Kumasi, Ghana. All women presenting for delivery in November or December 2006 at one of two large hospitals were asked to participate in the study if they had a singleton, uncomplicated pregnancy. After informed consent was obtained, a questionnaire was completed to collect socio-demographic information, medical, and obstetric histories. Body weight and mid upper arm circumference were measured for each woman. Obstetric information was also obtained from the mothers' antenatal care (ANC) charts. This included: gestational age at first ANC visit, number of antenatal care visits, gestational age as assessed by palpation at first ANC visit or ultrasound at first ANC visit, tetanus shots, malaria prophylaxis, antihelminth medications, hemoglobin level, and illnesses and treatments during pregnancy. Blood was drawn by venipuncture for determination of hemoglobin and serum folate levels, malaria antigen, and HIV tests. Stool samples were obtained for determination of intestinal helminths. At delivery, state of the newborn (alive or stillbirth), sex, weight, and length were obtained as recorded by the midwives. The Institutional Review Board of the University of Alabama at Birmingham and the Committee on Human Research, Publications and Ethics, School of Medical Sciences, Kwame Nkrumah University of Science and Technology, Kumasi reviewed and approved the study protocol before its implementation.

Laboratory methods. Determination of malaria Antigen in plasma was done using the Malaria Antigen CELISA (Cellabs, Brookvale, Australia). Determination of Hookworms, *Ascaris lumbricoides* and *Trichuris trichura* was done using the Kato-Katz thick smear technique,[25] while samples for *Strongyloides stercoralis* were processed using the Baermann method.[26] Stool samples were processed within 12 hours of collection and examined microscopically within one hour of preparation to avoid missing hookworm eggs. Hemoglobin level was measured in an automatic cell counter (Sysmex M-2000; Digitana AG, Hamburg, Germany) about 30 minutes after blood sampling.

Definition of terms. The following definitions were used. Uncomplicated pregnancy: absence of hypertension, pre-eclampsia, history of a previous caesarean section and hemorrhage, and a normal presentation of the fetus.[26] Malaria infection: presence of malaria antigen in the mother's peripheral blood at the time of delivery. Intestinal helminth infection: presence of helminth eggs or larvae in stool at the time of delivery. Coinfected: positive for both malaria and intestinal helminths at delivery. Anemia: hemoglobin levels < 11 g/dL of blood and severe anemia as hemoglobin level < 8 g/dL.[27] Low birth weight: weight less than 2500 g.[27] Preterm delivery: delivery occurring before 37 completed weeks of gestation.[27] Small for gestational age: sex-specific birth weight at or below the 10th percentile for the weight-for-gestational-age of an international reference population.[28] An adverse pregnancy outcome was defined as a LBW, PTD, or SGA infant, or maternal anemia at delivery.

Statistical analysis. Differences in socio-demographic and obstetric characteristics by coinfection status were assessed by χ^2 or *t* test. To determine the effect of malaria and helminth coinfection on birth outcomes, we used multiple logistic regression. Variables that were statistically significant in bivariate analysis and those known to be associated with adverse birth outcomes based on previous studies were entered into a model;[29] odds ratios and 95% confidence intervals (CI) were calculated from the models. Models were run for each adverse outcome separately, for any of the adverse outcomes, and for LBW, PTD, SGA as a group, adjusting for maternal anemia. Data analysis was performed using SAS software version 9.1 (SAS Institute, Cary, NC).

RESULTS

Participant characteristics. Seven hundred and eighty five (785) women were recruited into the study before delivery; no woman declined participation. Analysis is limited to 746 women for whom we obtained both malaria and intestinal helminth results. Overall, the mean age of the women was 26.8 years (range: 15–48 years); 13.4% were less than 20 years, 23.6% had a weekly income of less than 100,000 cedis (US$10), 30.2% were primigravid (Table 1). A higher proportion of younger, single, low-income women, primigravid, and of women who had not received sulfadoxine pyrimethamine (SP) or started ANC late had more adverse birth outcomes than did their counterparts (Table 1).

Malaria and intestinal helminth infection rates. Overall 407 (54.6%) women had neither *P. falciparum* nor intestinal helminths infection, 271(36.3%) were infected with *P. falciparum*, and 192 (25.7%) were infected with intestinal helminths only (Table 2). *Ascaris lumbricoides* was the most common intestinal helminth, with 12.3% of the women being infected (Table 2).

Pregnancy outcomes. The overall mean ± SD birthweight was 3000 ± 604; 139 (18.6%) infants were LBW. The mean gestational age ± SD was 36.8 weeks ± 2.6; 132 (17.7%) infants were preterm. The mean ± SD hemoglobin level was 11.8 ± 2.0; 193 (26.2%) women had moderate anemia, whereas 33 (4.5%) had severe anemia. In general, the risk factors were similar for LBW, PTD, and SGA (Table 3). Maternal anemia was associated with 80–140% increased odds of each adverse birth outcome, and any use of SP was associated with decreased odds of each (maternal anemia data not shown).

Adjusted Analyses. The non-infectious associations found in bivariate analyses did not change when adjusted for socio-demographics, medical, and obstetric history. Compared with

TABLE 1

Demographic and obstetric characteristics of 746 Ghanaian women, overall and according to whether they had an adverse pregnancy outcome,* 2006

Characteristics	All		Adverse pregnancy outcome*				*P* value
			No (*N* = 413)		Yes (*N* = 333)		
	N	%	N	%	N	%	
Age (years)							
< 20	100	13.4	40	9.7	60	18.0	**< 0.01**
20–24	187	25.1	96	23.2	91	27.3	
25–29	218	29.2	126	30.5	92	27.6	
≥ 30	241	32.3	151	36.6	90	27.0	
Formal education							
None	164	22.1	90	21.7	75	22.6	**0.03**
Primary	97	13.1	45	11.0	52	15.7	
Middle or junior secondary	363	48.9	198	48.3	165	49.7	
≥ Senior secondary	118	15.9	78	19.0	40	12.1	
Weekly income (cedis)							
< 100,000	174	23.6	78	19.1	96	29.1	**< 0.01**
100,000–199,000	49	6.6	22	5.4	27	8.2	
200,000–354,000	295	39.9	161	39.4	134	40.6	
≥ 355,000	221	29.9	148	36.2	73	22.1	
Marital status							
Single	156	21.1	60	14.6	96	29.0	**< 0.01**
Living in union	140	18.9	76	18.5	64	19.3	
Married	445	60.1	274	66.8	171	51.7	
Gravidity							
One	255	30.2	108	26.2	117	35.1	**0.02**
Two	141	18.9	88	21.3	53	15.9	
≥ Three	380	50.9	217	52.5	163	49.0	
Trimester at first antenatal clinic visit							
First	390	52.7	244	59.7	146	44.1	**< 0.01**
Second	324	43.8	157	38.4	167	50.5	
Third/none	26	3.5	8	2.0	18	5.4	
Sulfadoxine pyrimethamine doses							
None	197	26.4	56	13.6	141	42.3	**< 0.01**
One	195	26.1	116	28.1	79	23.7	
Two	255	34.2	169	40.9	86	25.3	
Three	99	13.3	72	17.4	27	8.1	
No deworming	720	97.0	400	97.6	320	96.4	0.35

*Adverse pregnancy outcome = low birth weight or preterm delivery or small for gestational age or anemia.
Frequencies may not equal N because of missing values.
Bold: $P < 0.05$.

women with neither malaria nor helminth infection, those with malaria alone (adjusted odds ratio [AOR] = 2.0; 95% CI: 1.2–3.6), helminth alone (AOR = 1.4; 95% CI: 1.1–4.3), or coinfected (AOR = 2.8; 95% CI: 1.7–4.8) were each significantly more likely to have maternal anemia at delivery (maternal anemia data not shown). For LBW, PTD, and SGA, adjusted analyses were stratified by, but not adjusted for, maternal anemia. Among women with anemia, women who were infected with both malaria and intestinal helminths had 3.0-, 2.6-, and 3.5-fold increased odds of LWB, PTD, and SGA, respectively, compared with uninfected women (Table 4). In contrast, among women without anemia, the only significant association was a 60% increased odds of LBW with coinfection (Table 4). Compared with women infected with intestinal helminths only, those who were also infected with malaria had more than 2-fold increased odds of LBW, SGA, and maternal anemia; all were statistically significant (maternal anemia data not shown). For LBW and SGA, this was only true for women with anemia.

DISCUSSION

This study demonstrated that the prevalence of adverse pregnancy outcomes was high in the study population (44%). Compared with uninfected women, coinfection was associated with 3-fold increased odds of LBW. Coinfected women with anemia were 2.6 times as likely to have PTD and 3.5 times as likely to have SGA infants as uninfected women. The odds of anemia were increased almost 3-fold.

Women living in malaria-endemic areas have an increased risk of *Plasmodium falciparum* infection during pregnancy.[30] *P. falciparum* is the most common *Plasmodium* species (> 95% of malaria infections) in Ghana.[31] However, although parasite prevalence and density are higher among pregnant women compared with non-pregnant women, infection with *P. falciparum* is usually asymptomatic.[32] Malarial parasites accumulate within the intervillous spaces of the placenta, leading to placental malaria. Women enrolled in this study during labor were asymptomatic for malaria but a fairly high percentage were positive for malaria antigen. As expected, maternal malaria at delivery was associated with an increased risk of LBW, an observation that has been made in previous studies.[18,33,34] Women who had malaria infection alone also had an increased risk of anemia. This is consistent with findings from sub-Saharan Africa.[33,35] Because *Plasmodium falciparum* infection during pregnancy rarely results in fever in endemic areas, infected women remain untreated, leading to increased risk for maternal anemia, LBW, SGA, and subsequently, perinatal mortality.[36] Malaria infection alone was not associated with PTD in our study. It has been demonstrated that in areas

TABLE 2

Malaria and Intestinal Helminth infection rates of 746 Ghanaian women, overall and according to whether they had an adverse pregnancy outcome,* 2006

	All		Adverse pregnancy outcome*				
			No (N = 413)		Yes (N = 333)		
Characteristics	N	%	N	%	N	%	P value
Malaria:							
No	475	63.7	292	70.7	183	55.0	**< 0.01**
Yes	271	36.3	121	29.3	150	45.0	
Intestinal helminths							
No	554	74.3	317	76.8	237	71.2	0.07
Yes	192	25.7	96	23.2	96	28.8	
Hookworms							
No	687	92.1	390	94.4	297	89.2	**< 0.01**
Yes	59	7.9	23	5.6	36	10.8	
Ascaris lumbricoides							
No	654	87.7	366	88.6	288	86.5	0.37
Yes	92	12.3	47	11.4	45	13.5	
Trichuris trichura							
No	704	94.4	392	94.9	312	94.6	0.56
Yes	42	5.6	21	5.1	21	5.4	
Strongyloides stercoralis							
No	717	96.1	402	97.3	315	94.6	0.05
Yes	29	3.9	11	2.7	18	5.4	
Enterobius vermicularis							
No	731	98.0	405	98.1	326	97.9	0.87
Yes	15	2.0	8	1.9	7	2.1	

*Adverse pregnancy outcome = low birth weight or preterm delivery or small for gestational age or anemia.
Frequencies may not equal N because of missing values.
Bold: $P < 0.05$.

of high malaria transmission like Ghana, women may get exposed to a greater number of malaria infections, and may have acquired immunity to prevent severe malaria that causes PTD.[36]

Over 24% of the women in this study were infected with intestinal helminths and intestinal helminths infection alone increased the risk of maternal anemia and LBW. Previous studies have shown that maternal anemia is a risk factor for LBW.[37,38] Helminth infections have been recognized as major contributors to anemia in endemic countries.[39,40] In fact, hookworm infection is said to be the most important cause of pathological blood and iron loss in the tropics.[41] Even though there have been conflicting findings on the effect of intestinal helminths on birth weight, a study conducted in Nepal showed that birth weights of infants of women who had received two doses of albendazole rose by 59 g and infant mortality at 6 months fell by 41%.[18]

When compared with uninfected women, coinfection was associated with a 3-fold, 2.6-fold, and 3.5-fold increased risk of LBW, PTD, and SGA, respectively in women with anemia, and was associated with an almost 3-fold increased risk of anemia. A comparison of coinfected women with women infected with intestinal helminths only showed that risks of LBW, SGA, and anemia were exacerbated by co-existent helminths. Similarly, when compared with women infected with malaria only, coinfection substantially increased the risk of anemia. A Nigerian study reported that women infected with both malaria and helminths had neonates of lower birth weights than those presenting with malaria alone.[19] Malaria contributes to anemia by various mechanisms, including hemolysis or the direct destruction of parasitized red blood cells, defective red cell production, and shortened red cell survival,[3,4] whereas intestinal helminths, especially hookworms and *Trichuris,* cause anemia through blood loss, impaired nutrient absorption, and damage

TABLE 3

Non-infectious risk factors associated with adverse pregnancy outcomes, Ghana, 2006

	Low birth weight		Preterm delivery		Small for gestational age	
Outcome N (%)	139	(18.6)	132	(17.7)	100	(13.4)
Characteristics	OR	95% CI	OR	95% CI	OR	95% CI
Age (referent 30 + years)						
< 20	1.8	0.7–3.2	1.5	0.4–2.6	1.1	0.6–2.3
20–24	1.0	0.5–2.1	0.7	0.2–1.4	0.8	0.4–1.7
25–29	0.9	0.4–1.6	0.8	0.4–1.5	0.7	0.3–1.8
No formal education	1.0	0.6–1.7	1.6	0.8–6.3	1.2	0.7–2.1
Weekly income < 200,000 cedis	**1.5**	**1.2–2.5**	**1.7**	**1.1–2.7**	1.2	0.6–2.0
Single	1.6	0.9–2.9	1.6	0.9–2.8	2.0	0.9–4.6
Primigravid	**2.0**	**1.1–2.7**	1.3	0.7–2.1	**1.4**	**1.1–2.3**
Any sulfadoxine pyrimethamine	**0.1**	**0.0–0.2**	**0.2**	**0.1–0.3**	**0.1**	**0.0–0.2**
1st antenatal clinic visit in 2nd or 3rd trimester	**2.0**	**1.2–3.2**	1.1	0.7–1.7	**2.4**	**1.4–4.1**

OR = adjusted odds ratio: adjusted for serum folate, HIV status, sickle cell trait and disease, iron and folic acid supplementation, infection status, weight, height, and baby's sex and characteristics listed. CI = confidence interval.
Bold: $P < 0.05$.

TABLE 4
The effect of malaria alone, intestinal helminths alone, and coinfection on LBW, PTD, and SGA, Ghana, 2006

	LBW						PTD						SGA					
	Anemia no			Anemia yes			Anemia no			Anemia yes			Anemia no			Anemia yes		
Models*	N (%)	OR	95% CI	N (%)	OR	95% CI	N (%)	OR	95% CI	N (%)	OR	95% CI	N (%)	OR	95% CI	N (%)	OR	95% CI
All women																		
Uninfected	46 (58.2)	Ref		15 (25.0)	Ref		40 (55.6)	Ref		20 (33.3)	Ref		31 (58.5)	Ref		10 (21.3)	Ref	
Malaria only	10 (12.7)	1.3	0.6–1.6	18 (30.0)	**2.5**	1.1–5.5	14 (19.4)	1.5	0.7–2.9	16 (26.7)	1.3	0.6–2.5	10 (18.9)	1.0	0.1–1.2	15 (31.9)	**2.7**	1.5–5.9
Helminths only	8 (10.1)	0.7	0.3–1.6	9 (15.0)	1.1	0.8–1.9	7 (9.7)	1.7	0.8–3.8	8 (13.3)	1.9	0.8–7.3	3 (5.7)	1.2	0.4–2.6	7 (14.9)	**2.2**	1.4-3.8
Coinfected	15 (19.0)	**1.6**	1.1–2.7	18 (30.0)	**3.0**	1.2–8.3	11 (15.3)	1.7	0.9–3.2	16 (26.7)	**2.6**	1.2–7.5	9 (16..9)	1.4	0.5–2.3	15 (31.9)	**3.5**	1.4-8.6
Malaria infected																		
Malaria only	8 (34.8)	Ref		14 (45.2)	Ref		12 (50.0)	Ref		4 (26.7)	Ref		17 (53.1)	Ref		12 (48.0)	Ref	
Coinfected	15 (65.2)	1.1	0.4–2.6	17 (54.8)	1.8	0.7–2.6	12 (50.0)	1.0	0.3–3.0	11 (73.3)	1.1	0.4–2.5	15 (47.9)	1.7	0.6–2.9	13 (52.0)	2.1	0.6–7.6
Helminth infected																		
Helminths only	10 (40.0)	Ref		9 (34.6)	Ref		9 (42.9)	Ref		8 (34.8)	Ref		6 (35.3)	Ref		4 (23.5)	Ref	
Coinfected	15 (60.0)	2.0	0.8–5.0	17 (65.4)	**2.7**	1.1–6.4	12 (57.1)	1.2	0.5–2.7	15 (65.2)	1.4	0.6–3.3	11 (64.7)	2.6	0.8–8.6	13 (76.5)	**2.9**	1.2–7.6

*All models for LBW, PTD, and SGA adjusted for age, income, mother's weight and height, previous birth outcomes, gravidity, baby's sex, serum folate, HIV status, malaria and helminth prophylaxis, sickle cell trait and disease, and iron and folic acid supplementations.
OR = odds ratio; CI = confidence interval.
Bold: $P < 0.05$.

to the mucosal lining.[14,15] Because the mechanisms by which malaria and intestinal helminth infections cause anemia differ, it is possible that their impact on anemia are additive[22] and could exacerbate adverse birth outcomes. Our study observed lower mean hemoglobin level for coinfected women compared with women infected with malaria alone, intestinal helminths alone, or women with neither infection.

Because many factors can contribute to LBW, PTD, and SGA, their risk factors were assessed. We observed that anemia was associated with a 2-fold increased risk of LBW. The model was adjusted for infection status of the women. First pregnancy was also a risk factor for LBW. Similar findings have been observed previously.[33] Women who began antenatal care in their second or third trimester had an increased risk of having a low birth weight infant compared with women who began antenatal care in their first trimester, confirming observations made in Ethiopia.[42] In this study only 18 women began ANC in the third trimester. In the Ethiopian study, it was noted that women who began ANC early tended to have more visits and therefore more medical evaluations. Women who had taken one or more doses of SP had a reduced risk of LBW, confirming results from a study done in Southern Ghana.[42]

Anemia increased the risk of PTD, and one or more doses of SP reduced the risk of PTD. Similar findings were observed in previous studies.[7,8] Although resistance has emerged in some places, SP is currently the most effective single-dose antimalarial drug for prevention of malaria during pregnancy. It has been found to be safe in pregnancy, efficacious in reproductive-age women in most areas, and feasible for use by control programs because it can be given as a single dose treatment under observation by a health worker.[42] At least two doses of SP are recommended during pregnancy, the first dose being given after quickening (first noted movement of the fetus).[43]

Anemia and second trimester at first ANC visit increased the risk of SGA. A study in India demonstrated that maternal anemia increased the risk of SGA.[44] ANC utilization, including number and gestational age at first visit were found to be associated with SGA in a Swedish study.[45]

The strengths of the study include the relatively large sample size and the fact that the hospitals in which the study was conducted cater to large numbers of women of all socioeconomic status from Kumasi and surrounding regions. However, not all women in Kumasi deliver in the hospital and our results are probably not representative of all pregnant women in the area. Another limitation of the study is that uncontrolled confounding cannot be excluded. There is potential confounding by uncontrolled poverty-related factors. A methodological limitation of the study lies in the fact that we used only one stool sample from each woman for investigation of intestinal helminths. Thus, a proportion of women with low intensity hookworm infections could have been misclassified as uninfected because hookworms shed eggs intermittently, and the prevalence of intestinal helminth infections is therefore likely to be under-estimated in this study. However, this study demonstrates that women with malaria and intestinal helminth coinfection are at a particular risk for adverse birth outcomes. In places where both infections are prevalent, all pregnant women should be the focus of malaria, intestinal helminth, and anemia control programs to improve birth outcomes.

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