Neonatal Measles Immunity in Rural Kenya: The Influence of HIV and Placental Malaria Infections on Placental Transfer of Antibodies and Levels of Antibody in Maternal and Cord Serum Samples

Susana Scott,1 Phillippa Cumberland,2 Caroline E. Shulman,3 Simon Cousens,1 Bernard J. Cohen,3 David W. G. Brown,3 Judith N. Bulmer,3 Edgar K. Dorman,4 Ken Kawuondo,4 Kevin Marsh,4 and Felicity Cutts1,7

1Department of Infectious and Tropical Diseases, London School of Hygiene and Tropical Medicine, 2Centre for Paediatric Epidemiology and Biostatistics, Institute of Child Health, 3Enteric, Respiratory and Neurological Virus Laboratory, Specialist and Reference Microbiology Division, Health Protection Agency, Colindale, 4Homerton University Hospital NHS Foundation Trust, London, and 5School of Clinical and Laboratory Sciences (Pathology), University of Newcastle, Royal Victoria Infirmary, Newcastle upon Tyne, United Kingdom; 6Kenyan Medical Research Institute, Centre for Geographical Medicine Research Coast, Kilifi, Kenya; 7Medical Research Council Laboratories, Banjul, The Gambia

Introduction. Young infants are protected from measles infection by maternal measles antibodies. The level of these antibodies at birth depends on the level of antibodies in the mother and the extent of placental transfer. We investigated predictors of levels of measles antibodies in newborns in rural Kenya.

Methods. A total of 747 paired maternal-cord serum samples (91 from human immunodeficiency virus [HIV]-infected and 656 from HIV-uninfected mothers) were tested for measles immunoglobulin G antibodies. Placental malaria infection was determined by biopsy. Data on pregnancy history, gestational age, and anthropometric and socioeconomic status were collected.

Results. Infants born to HIV-infected mothers were more likely (odds ratio, 4.6 [95% confidence interval [CI], 2.2–9.7]) to be seronegative and had 35.1% (95% CI, 9.8%–53.2%) lower levels of measles antibodies than did those born to HIV-uninfected mothers. Preterm delivery, early maternal age, and ethnic group were also associated with reduced levels of measles antibodies. There was little evidence that placental malaria infection was associated with levels of measles antibodies in newborns.

Conclusion. Our results suggest that maternal HIV infection may reduce levels of measles antibodies in newborns. Low levels of measles antibodies at birth render children susceptible to measles infection at an early age. This is of concern in sub-Saharan African countries, where not only is the prevalence of HIV high, but measles is the cause of much morbidity and mortality.

In Kenya, as in many countries in sub-Saharan Africa, measles is among the leading causes of child mortality [1, 2]. Malaria and HIV infections are also common in many of these countries. Understanding the interactions between these infections and measles is important, since they may have major implications for measles control programs.

Young infants are protected from measles infection by maternal measles antibodies of the IgG class, which are actively transported across the placental barrier from ~28 weeks of gestation. The quantity of maternal antibodies in fetal circulation increases until the time of birth [3, 4]. Levels of measles antibodies in newborns are therefore dependent on both the level in their mothers’ serum and the extent of placental transfer.

Maternal infection with other pathogens may affect placental transfer of antibodies. Falciparum malaria can...
cause pathological changes in the placenta, such as basement-membrane thickening [5], that may result in damaged antibody receptors [6]. Some studies have reported reduced placental transfer of tetanus antibodies [6, 7] and measles antibodies [6, 8] in the presence of placental malaria infection.

Children born to HIV-infected mothers may have lower levels of measles antibodies because their mothers have lower levels of measles antibodies [9] and/or because of reduced placental transfer [10]. However, this has not been observed consistently [8, 10–12], and it remains unclear to what extent maternal HIV infection affects protection from measles infection during early infancy.

Other factors associated with low levels of measles antibodies in women include vaccine-induced rather than wild-type (wt) measles virus–induced immunity [13–21], high parity [19], and early gestational age of the fetus, probably due to hemodilution [21, 22]. Low socioeconomic status could be associated with increased levels of measles antibodies in mothers through increased risk of exposure to natural infection in overcrowded housing or with decreased levels of measles antibodies in mothers through poor nutritional status [19, 23]. Reported risk factors for reduced placental transfer include prematurity [21, 22, 24, 25], low birth weight [22, 24, 26], high parity [19], low maternal socioeconomic status, and poor nutritional status [23, 27]. We report a study undertaken in Kenya to assess the effect of maternal HIV and placental malaria infections on levels of measles antibodies in mothers and their newborns.

**SUBJECTS, MATERIALS, AND METHODS**

**Study site.** This substudy was conducted as part of a program of research on malaria and anemia during pregnancy, performed at Kilifi district hospital, on the coast of Kenya [28, 29]. Transmission of Plasmodium falciparum is perennial, with 2 seasonal peaks, during June–August and during November–December. The district hospital assists ∼1200 deliveries each year. All females who gave birth to a child between January 1996 and July 1997 were assessed for eligibility to participate. Females with multiple pregnancies, significant antepartum hemorrhage, or miscarriage (delivery before 24 weeks of gestation or stillbirth of a fetus weighing <500 g) or from whom informed consent was not obtained were excluded. The studies were approved by the Kenyan Medical Research Institute/National Ethical Review Committee and the London School of Hygiene and Tropical Medicine.

After delivery, a standard questionnaire was administered to mothers of live newborns, to collect information on pregnancy history, education level, ethnicity, and socioeconomic indicators (maternal literacy, aspects of housing quality, ownership of a working radio, and presence of a latrine). Maternal height and weight were measured, and body mass index (BMI) was calculated as kilograms per meters squared. Birth weights were measured on digital scales: infants weighing <2500 g were classified as having low birth weight. Primigravidae, who were recruited into an antimalarial intervention study [29], had an ultrasound scan performed during their first antenatal attendance. This was used to determine gestational age. When a scan was not available (n = 383), the Eregie estimate was used. This estimate is based on a postdelivery examination of the newborn to assess posture, scarf sign, skin texture, ear form, breast size, genitalia, and head and mid–upper arm circumference [30].

**Specimen collection and processing.** Five milliliters of venous blood was obtained from the mother on admission to the labor ward and from the cord at delivery, by use of EDTA tubes. Plasma was separated and stored at −70°C. A 1-cm² placental biopsy specimen was obtained from the maternal-facing surface of the placenta. Biopsy specimens were placed in formalin, embedded in paraffin wax, sectioned and stained with Giemsa and hemotoxylin-eosin, and read by 2 of the authors (J.N.B. and E.K.D.). We defined active-acute malaria infection as the presence of parasites in maternal erythrocytes in the intervillous space; active-chronic infection as the presence of malaria pigment in fibrin, in addition to parasites in maternal erythrocytes; past-chronic infection as the presence of pigment only; and no infection as neither parasites nor pigment in the placenta. The HIV status of all women was determined by an IgG antibody-capture particle-adherence test, by use of filter-paper samples collected at the same time that the 5-mL venous blood samples were collected. HIV testing was anonymous, with linkage only after deletion of personal identifiers.

**Laboratory assays for measles antibodies.** Assays for measles antibodies using paired cord-maternal serum samples were performed for all HIV-infected females and for all females with evidence of active-chronic malaria infection. The 1307 females with no active-chronic malaria or HIV infection who participated in the parent study [28, 29] were given a unique number. A random sample of one-third of the females was selected, and available mother-child serum pairs were assayed for measles antibodies if sufficient plasma was available. Levels of measles IgG were measured by ELISA (Enzygnost; Dade Behring) in accordance with the manufacturer’s instructions. The assay was calibrated against the international reference preparation of measles antigen, and results were presented in milli–International Units per milliliter. Levels <150 mIU/mL were classified as negative, levels of 150–335 mIU/mL were classified as equivocal, and levels >335 mIU/mL were classified as positive. On the basis of these recommendations, we defined seropositivity as a level of measles antibodies >335 mIU/mL.

**Analysis.** Statistical analyses were performed by use of STATA 8.2 (available at: http://www stata.com). Logarithms of maternal and cord levels of measles antibodies were used (values of zero were recoded to 1.0, so that logarithms could be calculated). The ratio of the titers in cord serum samples to the...
titers in maternal serum samples (from respective mothers) (cord:maternal ratio [CMR]) was used as a measure of placental transfer. Geometric mean titers (GMTs) and their 95% confidence intervals (CIs) were calculated. Logistic regression was used to estimate the association of placental malaria infection and maternal HIV infection with measles seronegativity in the mother and the newborn. Linear regression was used to estimate the associations of HIV and placental malaria infection with the log titers in maternal and cord serum samples and the log CMR. The parameters in these models provide estimates of the percentage change in levels of measles antibodies or CMR. Other variables assessed for relationship to measles antibody status were maternal age, parity, postdelivery maternal BMI (as an index of nutritional status), gestational age, infant’s birth weight, ethnic group, and indicators of socioeconomic status (maternal education, maternal literacy, aspects of housing quality, ownership of a working radio, and presence of a latrine). Variables were retained in the model if associations were observed (at the level) and/or if they altered substantially the associations of other effect variables in multivariable analysis. Since birth weight and gestational age were highly correlated and since, we believe, gestational age is more biologically relevant, only gestational age was retained in the multivariable models. Levels of measles antibodies in maternal serum samples were considered to be on the causal pathway in analyses of levels of measles antibodies in cord serum samples and, thus, were excluded from these regression models.

RESULTS

General characteristics. Data on maternal-cord serum samples were available for 747 pairs: 91 women (12%) had HIV infection, and 335 (45%) had placental malaria infection. A total of 51 women (7%) were coinfected with both HIV and placental malaria infection (table 1). The median age of the mothers was 22 years (interquartile range [IQR], 19–26 years), and the mean BMI was 21.7 kg/m² (SD, 3.3), and almost one-half (48.7%) were primigravidae. Women with active-chronic malaria infection tended to be younger (median age, 19 years [IQR, 18–22 years]) than those with no malaria infection (median age, 24 years [IQR, 20–28 years]), and, as expected, placental malaria infection was more common in women of low parity. Placental malaria infection appeared to be associated with low birth weight (odds ratio [OR], 2.4 [95% CI, 1.5–3.9]; \(P < .001\)) but not with prematurity (OR, 1.0 [95% CI, 0.6–1.7]; \(P = .92\)). Of women with placental malaria infection, 40% had a BMI <20 kg/m², compared with 27% of those with no malaria infection (\(P < .001\)). HIV-infected women were slightly older than HIV-negative women (median age, 23.5 vs. 22.0 years). There was no evidence that parity (\(P = .62\)) or BMI (\(P = .24\)) differed between HIV-infected and HIV-uninfected women. Maternal HIV status was not associated with either low birth weight (OR, 1.20; \(P = .61\)) or preterm delivery (OR, 0.92; \(P = .84\)).

Factors associated with measles seronegativity and antibody levels in maternal serum samples. Forty-seven maternal serum samples (6.1%) were found to be negative for measles antibodies. There was little evidence that maternal measles seronegativity or low levels of measles antibodies were associated with HIV infection or postdelivery maternal BMI (tables 2 and 3). Overall, there was little evidence that placental malaria infection was associated with measles seronegativity or levels of measles antibodies. However, high levels of measles antibodies were observed in the small subgroup of mothers with active-acute malaria infection (GMT, 4196) (table 3). Maternal measles seronegativity decreased with increasing maternal age (\(P = .002\)). There was little evidence of an association between measles seronegativity and gestational age of the child at birth (\(P = .28\)), although levels of measles antibodies were 42% lower in mothers with preterm newborns (GMT, 1544 vs. 2552 mIU/mL; \(P < .01\)). Mothers from ethnic groups other than Mijikenda were more likely to be seronegative for measles (adjusted OR, 2.5 [95% CI, 1.3–4.9]; \(P = .01\)), and their mean levels of measles antibodies were 20.1% (95% CI, −0.9% to 36.7%) lower than those of mothers from the Mijikenda ethnic group (\(P = .06\)). There was little evidence that parity, maternal education, maternal literacy, or the other socioeconomic indicators were associated with maternal measles seronegativity or levels of measles antibodies (data not shown).

Factors associated with placental transfer of measles antibodies (table 3). The mean CMR was 0.98 (95% CI, 0.95–1.01) and was lower in HIV-infected mothers than in HIV-

<table>
<thead>
<tr>
<th>Table 1. Distribution of mother-child pairs according to maternal HIV status and placental malaria status.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maternal HIV status</strong></td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>Negative*</td>
</tr>
<tr>
<td>Positive</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

*One HIV-uninfected mother had missing data on placental malaria.
uninfected mothers (0.83 vs. 1.00, respectively; \( P < .001 \)) (table 3). In multivariable analysis, maternal HIV infection was associated with a 15.5% (95% CI, 6.5%–23.7%) reduction in the CMR. Overall, placental malaria infection was not associated with CMR (\( P = .15 \)). However, a reduction of 10.0% (95% CI, 1.3%–17.9%) was observed in the subset of women with active-chronic malaria infection. The CMR was 17.8% (95% CI, 9.4%–25.5%; \( P < .001 \)) lower in those born preterm than in those born after 37 weeks of gestation and was 10.5% (95% CI, 3.5%–16.9%; \( P = .004 \)) lower in those with a maternal BMI <20 kg/m\(^2\) than in those with a maternal BMI \( \geq 20 \) kg/m\(^2\). Increasing levels of measles antibodies in maternal serum samples were associated with a small decrease in the CMR (6.4% [95% CI, 0.8%–11.7%] decrease for a 10-fold increase in measles antibodies in maternal serum samples; \( P = .03 \)). Maternal age, parity, birth weight, ethnic group, socioeconomic factors, and maternal education were not associated with CMR (data not shown).

**Factors affecting measles seronegativity and antibody levels in cord serum samples.** Measles antibody titers in maternal and cord serum samples were strongly correlated (\( r = 0.95 \), for both HIV-infected and HIV-uninfected groups). Of all cord serum samples, 8.3% were found to be negative for measles antibodies. Seven of the 47 newborns born to measles-seronegative mothers were found to be seropositive for measles (15%). The levels of measles antibodies in serum samples from the mothers of these 7 newborns were just below the seropositive cutoff point (range, 229–331 mIU/mL). Of newborns born to HIV-infected mothers, 17.6% (95% CI, 9.6%–25.6%) were seronegative for measles, compared with 7% of those born to HIV-uninfected mothers (adjusted OR, 4.6 [95% CI, 2.2–9.7]; \( P < .001 \)) (table 2). The former also had 35% (95% CI, 9.8%–53.2%) lower levels of measles antibodies (table 3). There was little evidence of an association between placental malaria infection and measles seronegativity or antibody levels in cord serum samples. Preterm newborns were nearly twice as likely to be seronegative for measles than were those born after 37 weeks of gestation, and their antibody levels were approximately half of those of full-term infants. Infants born to young mothers and non-Mijikenda mothers were more likely to be seronegative for measles and to have lower levels of measles antibodies. Measles seronegativity of and levels of measles antibodies in cord serum samples were not associated with the BMI of the mother.
Table 3. Measles antibody titers in maternal and cord serum samples and cord:maternal ratio (CMR), by maternal HIV status, placental malaria status, and other factors.

<table>
<thead>
<tr>
<th>Factor</th>
<th>No.</th>
<th>Maternal serum samples</th>
<th>Cord serum samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GMTa (95% CI)</td>
<td>CMR</td>
</tr>
<tr>
<td>Overall unadjusted</td>
<td>747</td>
<td>2413 (2194–2654)</td>
<td>0.98 (0.95–1.01)</td>
</tr>
<tr>
<td>Maternal HIV status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td>656</td>
<td>2456 (2219–2718)</td>
<td>1.00 (0.97–1.04)</td>
</tr>
<tr>
<td>Positive</td>
<td>91</td>
<td>2126 (1616–2798)</td>
<td>0.83 (0.76–0.91)</td>
</tr>
<tr>
<td>Placental malaria status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>411</td>
<td>2458 (2192–2757)</td>
<td>1.01 (0.97–1.05)</td>
</tr>
<tr>
<td>Active acute</td>
<td>28</td>
<td>4196 (2672–6589)</td>
<td>1.01 (0.84–1.21)</td>
</tr>
<tr>
<td>Active chronic</td>
<td>154</td>
<td>1971 (1548–2510)</td>
<td>0.91 (0.84–0.98)</td>
</tr>
<tr>
<td>Past infection</td>
<td>153</td>
<td>2535 (2004–3207)</td>
<td>0.98 (0.92–1.04)</td>
</tr>
<tr>
<td>Age group, years</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14–19</td>
<td>186</td>
<td>1781 (1403–1380)</td>
<td>0.99 (0.92–1.06)</td>
</tr>
<tr>
<td>20–24</td>
<td>236</td>
<td>2575 (2176–3046)</td>
<td>0.99 (0.93–1.04)</td>
</tr>
<tr>
<td>25–29</td>
<td>149</td>
<td>3036 (2549–3616)</td>
<td>0.98 (0.92–1.05)</td>
</tr>
<tr>
<td>&gt;30</td>
<td>81</td>
<td>2709 (2252–3259)</td>
<td>0.98 (0.89–1.08)</td>
</tr>
<tr>
<td>Gestational age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;37 weeks</td>
<td>600</td>
<td>2552 (2303–2835)</td>
<td>1.04 (1.00–1.07)</td>
</tr>
<tr>
<td>&lt;27 weeks</td>
<td>102</td>
<td>1544 (1151–2072)</td>
<td>0.84 (0.76–0.93)</td>
</tr>
<tr>
<td>Ethnic group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mijikenda</td>
<td>544</td>
<td>2504 (2252–2786)</td>
<td>0.98 (0.95–1.02)</td>
</tr>
<tr>
<td>Other</td>
<td>203</td>
<td>2184 (1782–2627)</td>
<td>0.97 (0.91–1.04)</td>
</tr>
<tr>
<td>Body mass index</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;20 kg/m&lt;sup&gt;2&lt;/sup&gt;</td>
<td>497</td>
<td>2502 (2228–2811)</td>
<td>1.02 (0.99–1.06)</td>
</tr>
<tr>
<td>&lt;20 kg/m&lt;sup&gt;2&lt;/sup&gt;</td>
<td>241</td>
<td>2170 (1832–2570)</td>
<td>0.99 (0.85–0.96)</td>
</tr>
</tbody>
</table>

NOTE. CI, confidence interval; GMT, geometric mean titer.

a Zero values were included in the analysis.

b Adjusted for all other factors in the table.

c P value given for adjusted percentage difference in GMT.

d Overall P value.

number of previous pregnancies, socioeconomic factors, or maternal education.

DISCUSSION

The present study was designed to assess the influence of maternal HIV and placental malaria infections on levels of measles antibodies in newborns. It is likely that the present study was biased toward women who were not greatly immunocompromised, since BMIs of HIV-infected and HIV-uninfected women were not very different. Nonetheless, maternal HIV infection was associated with a 4-fold increase in risk of the newborn being seronegative for measles and a 35% reduction in antibody levels in cord serum samples. This finding is consistent with the findings of 2 studies in Brazil and 1 study in Malawi [8, 10, 11], although only 1 of those studies found evidence of an association at the P<.05 significance level. A further study in Rwanda [12], however, did not find any differences between levels of measles antibodies in newborns born to HIV-infected mothers and those in newborns born to HIV-uninfected mothers. In the present study, the reduction in levels of measles antibodies in newborns arose from a combination of lower levels of measles antibodies in HIV-infected mothers (although the CI around this difference was wide) and reduced placental transfer. In rural Kenya, most women would have acquired measles immunity from wt measles infection that occurred before HIV infection, since measles vaccination only began in the mid-1980s in Kenya [31]. In this situation, HIV infection appears to have little influence on maternal humoral immunity to measles [8, 10, 11]. Possible explanations for inefficient transfer of maternal antibodies include the following: immune complex formation in HIV infection, which may impair transplacental IgG passage; the production of defective IgG, which may impair the binding of its Fc portion to the receptor in the trophoblast; or HIV infection, which may lead to decreased levels of the Fc receptor [11]. However, further study is required to establish the mechanism.

Malaria damages the placenta, and 2 previous studies have reported reduced placental transfer of measles antibodies [6, 8]. We observed no evidence of an association between placental malaria infection and measles seronegativity or levels of measles antibodies in cord serum samples. The CMR was decreased in
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the subgroup with active-chronic malaria infection, which, as this is an indicator of persistent or frequent malaria infection, could represent the group with the greatest placental damage. However, this did not result in lower mean antibody levels in newborns.

As expected, measles antibody titers in cord serum samples were strongly correlated with measles antibody titers in maternal serum samples. The overall mean CMR was 0.98 (95% CI, 0.95–1.01), which is consistent with those in other studies from developing countries [23, 24, 32] but lower than those in studies from developed countries [19–21, 23, 32, 33]. We found some evidence of a small decrease in CMR with increasing levels of measles antibodies in maternal serum samples, as reported elsewhere [19, 26, 34].

Preterm delivery was associated with lower levels of measles antibodies in maternal serum samples, as reported elsewhere [21, 22]. This may be related to the temporary decrease in total IgG during the second trimester of pregnancy that is due to hemodilution [21]. The present study has also provided further evidence of lower levels of measles antibodies in preterm neonates [13, 19, 21, 22, 24]. Since the quantity of maternal antibodies in fetal circulation increases until the time of birth [3, 4], it seems reasonable to assume that this quantity will be reduced as gestational age decreases. Also, the placenta of infants born before 37 weeks of gestation may have fewer mature Fc receptors than those of full-term infants, resulting in lower levels of IgG being transported across the placental barrier [22].

Ten percent of females 14–19 years old and 14.5% of newborns born to these mothers were found to be seronegative for measles antibodies. This age group encompasses the first persons to have had the opportunity for measles vaccination. Vaccinated mothers and their newborns have lower measles antibodies than those who acquire measles immunity through natural infection [13, 17–19]. In the youngest age group, some of the females, classified as seronegative by our ELISA, could have had low levels of neutralizing antibody arising from waning immunity after vaccination. It is possible that some of these mothers may have had measles-specific T cell memory and, therefore, were protected from illness after exposure. However, it is also possible that measles infection may occur in these women, as well as in the 4.7% of older women who were seronegative; thus, there is potential for ongoing transmission of measles among women of childbearing age. Our sample was not representative of the general population, since it contained only pregnant women who underwent delivery in a hospital, and it would be useful to conduct further studies of measles immunity in males and females 14–30 years old. Recent measles vaccination campaigns in Kenya have targeted children <15 years old [35, 36], but if substantial numbers of older persons remain susceptible, outbreaks could occur in the adult population, as has recently been seen in Mexico [37].

Ethnic group was associated with maternal measles seronegativity, with the Mijikenda ethnic group having lower rates of seronegativity than the other ethnic groups. The Mijikenda tend to be subsistence farmers and are generally poorer than the other ethnic groups in the present study. It is therefore possible that they have higher levels of exposure to measles infection, though we have no direct evidence of this. Other socioeconomic factors were not associated with levels of measles antibodies in either the mother or the newborn. Like other investigators, we found no evidence of associations between CMR or levels of measles antibodies in cord serum samples and parity [6, 8, 22, 24, 26].

In conclusion, maternal HIV infection was associated with reduced placental transfer of measles antibodies, a greater risk of the newborn being seronegative for measles, and lower levels of measles antibodies in cord serum samples. Placental malaria infection, however, was not associated with reduced mean levels of measles antibodies in newborns. This is of concern in sub-Saharan African countries, where up to 40% of women of childbearing age may be HIV infected [38] and measles still causes much preventable mortality. Our data suggest that almost one-fifth (17.6% [95% CI, 9.6%–25.6%]) of children born to HIV-infected mothers are seronegative for measles antibodies at birth. Although the present study did not assess levels of maternal measles antibodies during infancy, previous studies have reported that infants born with low levels of maternal measles antibodies continue to have lower levels over time, compared with those who are born with higher levels [39, 40]. Furthermore, a proportion of adults in this rural area are seronegative for measles antibodies. Mass measles vaccination campaigns targeting children <15 years old are being conducted throughout Africa with the support of a consortium of donors, including the American Red Cross, Centers for Disease Control and Prevention, the World Health Organization, United Nations Children’s Fund, United Nations Foundation, and the International Federation of Red Cross and Red Crescent Societies (available at: http://www.measlesinitiative.org). The reduction in transmission of measles effected through these campaigns will provide indirect protection to young infants in the short term, but further study is needed to determine the optimum age range for campaigns for long-term measles reduction and the optimum age for routine vaccination, especially in areas of high HIV and malaria prevalence.

Acknowledgments

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