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See next page for additional authors

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Risk Factors for Mortality in Children Hospitalized with Severe Malaria in Northern Zambia: A Retrospective Case-Control Study

Matthew M. Ippolito,1,2* Luc K. Kamavu,3 Jean-Bertin Kabuya,4 Catherine Tente,3 Edward Chileshe,5 McBerth Wapachole,6 Philip E. Thuma,2,7 Mbanga Muleba,4 Mike Chaponda,3 Modest Mulenga,4 and William J. Moss2,8 for the Southern and Central Africa International Centers of Excellence for Malaria Research

1Department of Medicine, Johns Hopkins University School of Medicine, Baltimore, Maryland; 2Malaria Research Institute, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland; 3Office of Hospital Administration, Saint Paul’s General Hospital, Nchelenge, Zambia; 4Tropical Diseases Research Centre, Ndola, Zambia; 5Office of Health Management Information Systems, Saint Paul’s General Hospital, Nchelenge, Zambia; 6Ministry of Health, Nchelenge, Zambia; 7Macha Research Trust, Macha, Zambia; 8Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland

Abstract. Malaria remains a public health crisis in areas where it has resisted control efforts. In Nchelenge District, a high-transmission area in northern Zambia, malaria accounts for more than one-third of pediatric hospitalizations and nearly one-half of hospital deaths in children. To identify risk factors for death due to malaria, we conducted a retrospective, time-matched case-control study of 126 children hospitalized with malaria who died (cases) and 126 children who survived (controls). There were no differences in age, gender, hemoglobin concentration, or prevalence of severe anemia between cases and controls. Children who died were more likely to come from villages located at greater distances from the hospital than children who survived (median 13.5 versus 3.2 km). Each additional kilometer of distance from the hospital increased the odds of death by 4% (odds ratio 1.04, 95% confidence interval 1.01–1.07, P < 0.01). Extent of anemia and admission during periods when blood was unavailable for transfusion were associated with early death (P ≤ 0.03). Delays in initiation of treatment of severe malaria contribute to the increased odds of death in children referred from more distant health centers, and might be mitigated by transportation improvements, capacity at rural health posts to administer treatment before transfer, hospital triage systems that minimize time to treatment, and reliable blood product stores at referral hospitals.

INTRODUCTION

Severe malaria, caused by the protozoan Plasmodium, is the leading parasitic cause of mortality worldwide. Plasmodium falciparum, the most lethal among human malaria parasites, predominates in sub-Saharan Africa where it causes a disconcerting 1,200 child deaths per day concentrated in regions where malaria has proven recalcitrant to control measures or where control measures are tenuous or absent.1,2 In Zambia, there were an estimated 3.1 million cases of malaria (severe and uncomplicated) in 2016 among its population of 16.7 million and it was most prevalent in northern Zambia where it persists year round despite the recent scale-up in 2016 and 2017, respectively.3,4 Prevalence by rapid diagnostic tests is estimated to be ∼2% with little decrease in malaria burden has followed.3 Community prevalence by rapid diagnostic tests is estimated to be 50%.5 In 2016, there were 1,128 adult and child hospital admissions for malaria, accounting for 35% of all pediatric hospital admissions and 38% of all pediatric deaths in the hospital. The malaria case fatality rate was 80 and 65 deaths per thousand adult and pediatric hospitalizations for malaria in 2016 and 2017, respectively.

Study site. The study was conducted in Nchelenge District, a high malaria transmission area of northern Zambia. Since 2012, the National Malaria Elimination Program under the Ministry of Health have overseen bed net distributions and indoor residual spray campaigns in the study area, although little decrease in malaria burden has followed. Community prevalence of malaria burden and the relative contribution of malaria to pediatric hospitalizations is ∼50%.6 In 2016, there were 1,128 adult and child hospital admissions for malaria, accounting for 35% of all pediatric hospital admissions and 38% of all pediatric deaths in the hospital. The malaria case fatality rate was 80 and 65 deaths per thousand adult and pediatric hospitalizations for malaria in 2016 and 2017, respectively.

A single 175-bed hospital staffed by three physicians and one midlevel provider serves the district and surrounding
areas. The hospital is a referral center for 11 rural health centers that lie 1.5 to >40 km away, including an island community 30 km away. The rural health centers are neither outfitted with the means to initiate specific therapy for severe malaria, which includes intravenous artesunate, nor are alternatives such as rectal artesunate and intramuscular artemether available.

Children judged by health center providers to require care for severe malaria are transferred to the hospital. Transportation from health centers to the hospital is challenging: patients’ families must arrange transport for a fee, and road conditions are poor.

Some patients do not survive transfer from the rural health center to the hospital or from the hospital outpatient department to the ward, and are recorded in ward registers as dead on arrival. Administration of intravenous artesunate, blood transfusion, and other supportive care can only occur once a child has been transferred to the ward.

**Study design.** This was a retrospective, time-matched, case-control study of children with severe malaria admitted to the hospital who died (cases) or survived (controls). Cases were matched 1:1 with controls admitted on or near the same date to account for differences in health-care providers, stockouts of blood products or other hospital resources, and other unmeasured temporal confounders such as road conditions, which vary between the rainy and dry seasons and were hypothesized to impact time to treatment. If more than one control was identified for a given day, the patient admitted closest in time to the case was selected. The study was approved by the Johns Hopkins Bloomberg School of Public Health Institutional Review Board as part of the International Centers of Excellence for Malaria Research study and locally by the Tropical Diseases Research Centre Ethics Review Committee located in Ndola, Zambia.

**Data collection.** Case-control data were collected from hospital registers and laboratory logbooks for children admitted to the hospital between January 2016 and October 2017. Severe malaria was determined by the discharge diagnosis in the register, and the primary outcome of the study (survival or death) was determined by the recorded disposition in the register. All patients admitted to the children’s ward with severe malaria who died were included. Those who did not survive were further stratified by those who died before treatment could be administered (dead on arrival) and those who died after they were admitted and underwent treatment. Patient charts of children who died were frequently unavailable, precluding chart extraction of data.

Hospital epidemiologic data were collected from the hospital Health Management Information Systems database (current to April 2017) and hospital registers. Distances from villages to the hospital were provided by the district office of the Zambian Ministry of Health.

All hemoglobin values were presumed to be pretransfusion values. Hospital practice is to require documented hemoglobin level before transfusion, and patients infrequently undergo more than a single laboratory evaluation. We use the term initial hemoglobin because not all children were subsequently transfused (typical transfusion threshold is ≤5.0 g/dL).

**Statistical analysis.** Matched case-control data were analyzed by conditional logistic regression. Linear and logistic regression models were applied for unmatched adjusted analyses of early death. We hypothesized that the relationship between village-to-hospital distance and survival would be partially mediated by the degree of anemia as patients with delayed presentation are more likely to have low mean hemoglobin concentrations due to disease progression. Mediation analysis was carried out to estimate the percent contribution of hemoglobin concentration to the total indirect effect of distance from the hospital on survival. Sensitivity analyses were performed, one excluding patients from the two most remote villages and their matched controls to account for outlying distances and another introducing a covariate designating admission during a blood stockout period to account for the five study pairs mismatched on that variable. A subgroup analysis of patients who were dead on arrival to the children’s ward was performed to examine risk factors of early death. In a cross-sectional design, these patients were compared with cases who survived the initial admission period but subsequently died. The frequencies of severe malaria hospitalization and death outcomes in relation to blood stockout periods were analyzed using Poisson regression. Statistical significance was prespecified to a threshold $P$ value of 0.05 and two-sided α. Analyses were carried out using Stata 14 (StataCorp, College Station, TX).

**RESULTS**

**Study participants.** We identified 126 children admitted to the children’s ward with a diagnosis of severe malaria who died during the period January 2016 through October 2017. Most (89%) matched control patients were admitted within 1 day of the case patients, and of those, more than half (54%) were admitted the same day. Eleven were admitted within 2 days of the matched control and three within 3 days. Five of the 126 case-control pairs were mismatched on whether there was a blood stockout on the day of admission. One case was missing age and gender, but hemoglobin and village data were available. Data on village distance to the hospital were available for all except nine control and 18 case patients. Hemoglobin concentrations were unavailable for 49 (39%) control and 41 (33%) case children. Missingness was mainly due to hemoglobin measurements done at rural health centers prior to hospital transfer, hence results were not recorded in laboratory logbooks. Children whose hemoglobin measurements were not available were similar in age, gender, and distance from the hospital to those for whom hemoglobin data were available.

**Age, gender, hemoglobin, and severe anemia.** There were no statistically significant differences in age, gender, initial hemoglobin concentration, or prevalence of severe anemia between children who survived and those who died (Table 1). The median age of study children was 1 year 11 months, ranging from 2 months to 18 years. Slightly more than half (53%) were girls. The mean initial hemoglobin concentration of all children was 5.4 g/dL (standard deviation 2.8 g/dL). Prevalence of severe anemia was 61% among cases and 47% among controls, but the difference was not significant after adjustment for age and gender (odds ratio [OR] 2.04, 95% confidence interval [CI] 0.87–4.79, $P = 0.10$).

**Distance from hospital.** Children came from 73 villages situated between 1.5 and 89.6 km from the hospital. One child (control) lived within the hospital compound and one child (case) was from the island community located 30 km away. Those with severe malaria who did not survive were more likely to come from distant villages than those who survived
Presentation during blood product stockout, n (%) 27 (21.4) 22 (17.5) 0.99
Presence of severe anemia, n (%) 52 (61.2) 36 (46.8) 0.10
Hemoglobin concentration (g/dL), mean (SD)* 5.0 (2.9) 5.8 (2.7) 0.16
Distance from home village to hospital (km), median (IQR) 13.5 (2.3–26.0) 3.2 (1.5–14.0) < 0.01
Age, months, median (IQR) 21 (12–36) 24 (13–36) 0.85
Female, n (%) 66 (52.8) 67 (53.2) 0.70
Hemoglobin < 3 g/dL, n (%) 20 (23.5) 10 (13.0) 0.20

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**DISCUSSION**

This case-control study of children hospitalized with malaria in a high-transmission setting of northern Zambia found that the strongest predictor of mortality was distance from the patient’s village to the hospital. Each kilometer of distance from the hospital was accompanied by a 4% increase in the odds of death. Low hemoglobin and hospitalization during blood inventory stockouts were associated with early death, defined as those recorded as dead on arrival to the children’s ward.

Distance to health centers is a well-documented risk factor for child mortality in sub-Saharan Africa, although few studies have examined its influence on malaria fatality. Long distance delays time to the first dose of intravenous artesunate, time to blood transfusion, and time to other supportive care. Living a greater distance from the hospital may be associated with other factors that affect malaria health outcomes, including delayed health-care-seeking behaviors.

The young ages of the patients, and the prevalence and profoundness of anemia, were commensurate with a high malaria transmission environment. In contrast to prior studies of severe malaria conducted elsewhere in sub-Saharan Africa, we did not find an association between age and mortality, perhaps explained by the overall low median age of our study population (<2 years) relative to previously studied populations. Most children (85%) were younger than 5 years and age-related factors (e.g., premunition) may have been attenuated because of the narrow age range of the study children.

Blood stockouts were more common during peaks in hospital admissions for malaria. The number of deaths among hospitalized children with malaria was higher during stockout periods, but modeling showed this to be explained wholly by the increased number of admissions and not the depletion of blood stores.

There were two unexpected findings related to the role of anemia. First, we detected no significant difference in admissions for malaria (OR 7.1, 95% CI 4.5–11.3, P < 0.01).

During stockout periods, the incidence of death among children with malaria was once in 3 days, compared with one death every 6 days during periods when blood was in supply (daily mean number of deaths 0.30 versus 0.18, P = 0.02), but the number of deaths as a proportion of admissions did not differ (0.13 versus 0.13, P = 0.88).

**TABLE 1**

Characteristics of children admitted to the hospital with a diagnosis of severe malaria who died (cases) and survived (controls)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cases (n = 126)</th>
<th>Controls (n = 126)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, n (%)</td>
<td>66 (52.8)</td>
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<td>0.70</td>
</tr>
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<td>Age, months, median (IQR)</td>
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<td>0.85</td>
</tr>
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<td>Hemoglobin concentration (g/dL), mean (SD)*</td>
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<td>Hemoglobin &lt; 3 g/dL, n (%)</td>
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<td>0.20</td>
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</tr>
</tbody>
</table>

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* IQR = interquartile range; SD = standard deviation.

The P values were estimated by conditional logistic regression of matched case-control data.

* Initial values measured on presentation.
hemoglobin concentrations between those who survived and those who died. Sample size limitations imposed by missingness in hemoglobin data and potential instances of misclassification of the cause of death leading to artificial inflation of the mean hemoglobin relative to controls are possible explanations for this finding. Based on data from a pivotal trial of artemisinin versus quinine for severe malaria,\textsuperscript{19} hemoglobin appears to influence survival only at concentrations < 3 g/dL.\textsuperscript{20} Twice as many cases as controls in our sample had such low hemoglobin concentrations, though the difference did not reach the preset significance threshold ($P = 0.20$).

The second unexpected finding was that hemoglobin concentration explained only a small portion (4%) of the effect of distance on malaria death. We hypothesized that greater distance from the hospital would correspond with delay in presentation and thereby more profound anemia, and ultimately a higher risk of death, as the illness progressed unchecked. Although we did not observe this in the overall sample, the association was observed among children brought in dead to the ward. In these children, hemoglobin concentration accounted for > 25% of the estimated effect of distance on death, consistent with the additional finding of an association between children who were dead on arrival to the ward and admission during a blood stockout period. Hemoglobin testing and subsequent blood transfusion, if indicated and possible, are often done between the time the child arrives to the hospital and is registered on the ward. Our findings suggest that those who did not survive the interval between presentation to the hospital and registration on the ward often died for lack of transfusion. These represent children who never had the opportunity to receive treatment and supportive care. Had they survived long enough to undergo treatment, it is likely that some would

\begin{table}
\centering
\caption{Characteristics of children with severe malaria who were dead on arrival to the ward and those who died after arrival to the ward.}
\begin{tabular}{lccc}
\hline
\textbf{Characteristic} & \textbf{Dead on arrival} & \textbf{Died after arrival} & $P$ Value \\
\hline
Female, n (%) & 26 (55.3) & 40 (51.3) & 0.42 \\
Age, months, median (IQR) & 21 (12–36) & 22 (12–36) & 0.09 \\
Hemoglobin concentration (g/dL), mean (SD)* & 3.8 (1.6) & 5.6 (3.1) & 0.01 \\
Presence of severe anemia, n (%) & 19 (73.1) & 33 (55.9) & 0.06 \\
Hemoglobin < 3 g/dL, n (%) & 7 (26.9) & 13 (22.0) & 0.20 \\
Distance from home village to hospital (km), median (IQR) & 14.0 (2.3–26.6) & 11.0 (3.2–15.5) & 0.05 \\
Presentation during blood product stockout, n (%) & 14 (31.1) & 13 (16.5) & 0.03 \\
\hline
\end{tabular}
\footnotesize{IQR = interquartile range; SD = standard deviation. $P$ values were estimated by logistic regression of cross-sectional (cases only) data. *Initial values measured on presentation.}
\end{table}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{blood_product_stockout.png}
\caption{Outcomes of hospitalization among children with severe malaria admitted to the pediatric ward showing periods of blood product stockouts.}
\end{figure}
have recovered and survived to discharge, implying that ensuring reliable blood inventories would improve malaria survival.

There are limitations to this study. Reliance on hospital registries precluded a rigorous case definition of severe malaria and death due to malaria, introducing potential misclassification bias. However, given the high background prevalence of malaria in the catchment area, ready availability of malaria diagnostics, and experienced hospital staff, we believe this is unlikely to have significantly influenced the study’s results. Furthermore, there is precedent for our case definition; for example, the Severe Malaria in African Children network enrolled any child with malaria sick enough to be hospitalized.51 Similarly, we were unable to ascertain clinical syndromes (e.g., cerebral malaria, lactic acidosis) nor could we account for children with coinfections or incidental parasitemia unrelated to their illness. A hospital-based study such as this is unable to account for children who die at home from complications of malaria, die at rural health centers or healers, or die en route to the hospital, who constitute most severe malaria deaths in some settings.22,23 There are potential unmeasured confounders and mediators of the effect of distance on malaria death, including factors related to delays in care such as health-seeking behavior and knowledge, attitudes and practices around malaria, time to first dose of artemesunate, and time to blood transfusion.

A precept of malaria control is prompt diagnosis and treatment to reduce deaths from severe malaria and to diminish the infectious reservoir. National and local malaria control programs prioritize surveillance of and response to severe malaria morbidity and mortality, but these priorities are often detrimentally overlooked by the research community where clinical trials of interventions for severe malaria are sparse and progress thereby slow.24 In the meantime, investments in transportation infrastructure (e.g., road improvements) to reduce transfer times to the hospital, hospital triage systems that expedite treatment on arrival for patients with severe malaria, and maintenance of responsive supply chains for blood inventories to avert stockouts during periods of high malaria incidence would temper case fatality. Stationing ambulances at remote health posts and furnishing them with the capacity to initiate pre-transfer treatment of severe malaria, such as intramuscular or rectal artemesunate, would be lifesaving.

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Authors’ addresses: Matthew M. Ippolito, Department of Medicine, Johns Hopkins University School of Medicine, Baltimore, MD, E-mail: miappolito@jh.edu. Luc K. Kamavu, Catherine Tente, and Edward Chileshe, St. Paul’s General Hospital, Nchelenge District, Luapula Province, Zambia, E-mails: nespluckam@yahoo.fr, catherine.tente@gmail.com, and chileshechifuuba@outlook.com. Jean-Bertin Kabuya, Mbangu Muleba, Mike Chaponda, and Modest Mulenga, Tropical Diseases Research Centre, Ndola, Zambia, E-mails: kabuya@tdrc.org.zm, mulebam@tdrc.org.zm, and mulengam@tdrc.org.zm. McBerth Wapachole, Ministry of Health, Nchelenge District, Luapula Province, Zambia, E-mail: mcbethwapachole@yahoo.com. William J. Moss, Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, E-mail: wmoss1@jhu.edu.

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