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Determinants and Coverage of Vaccination in Children in Western Kenya from a 2003 Cross-Sectional Survey

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Abstract. This study assesses full and timely vaccination coverage and factors associated with full vaccination in children ages 12–23 months in Gem, Nyanza Province, Kenya in 2003. A simple random sample of 1,769 households was selected, and guardians were invited to bring children under 5 years of age to participate in a survey. Full vaccination coverage was 31.1% among 244 children. Only 2.2% received all vaccinations in the target month for each vaccination. In multivariate logistic regression, children of mothers of higher parity (odds ratio [OR] = 0.27, 95% confidence interval [95% CI] = 0.13–0.65, $P \leq 0.01$), children of mothers with lower maternal education (OR = 0.35, 95% CI = 0.13–0.97, $P \leq 0.05$), or children in households with the spouse absent versus present (OR = 0.40, 95% CI = 0.17–0.91, $P \leq 0.05$) were less likely to be fully vaccinated. These data serve as a baseline from which changes in vaccination coverage will be measured as interventions to improve vaccination timeliness are introduced.

INTRODUCTION

Globally, there have been increases in routine childhood vaccination coverage since the 1990s, resulting in large reductions in measles mortality and progress to the attainment of the African regional goal for diphtheria, pertussis, and tetanus (DPT) vaccine coverage.[1] Despite this progress, global trends indicate that the United Nations Millennium Development Goal 4 (MDG4), aimed at reducing child mortality by two-thirds between 1990 and 2015, will not be met without faster progress on reducing preventable diseases[2]; improved coverage of childhood immunizations is essential to meet that goal.

Progress in vaccination coverage has been made, some of which can be attributed to investments by the Global Alliance for Vaccines and Immunization (GAVI), to strengthen immunization services since 2000, thus increasing access and availability to vaccinations. The country of Kenya has shown considerable gains in full vaccination coverage as indicated by the Demographic and Health Surveys (DHS), which have shown that full coverage among children ages 12–23 months increased nationally from about 44.0% in 1989 to 77.4% in 2008.[3,4] In Nyanza Province, located along the shores of Lake Victoria, vaccination coverage reached 64.6% in 2008, although coverage remained lower than the majority of the country with the exception of Northeastern Province.[4]

The Kenya Division of Vaccine and Immunisation (DVI) recommends that, by 12 months of age, children receive bacillus Calmette–Guerin (BCG), three doses of polio vaccine, three doses of a pentavalent vaccine (a combination vaccine comprising five vaccines, namely diphtheria, pertussis, tetanus, *Hemophilus influenzae type b* [*Hib*], and hepatitis B), and one measles vaccine.[5] Before 2001, DPT vaccines were administered rather than pentavalent vaccine. Despite the progress in vaccination coverage seen over the last three decades, vaccine coverage in Kenya remains below the target of 90% fully vaccinated by 2015, and the DVI multiyear plan for 2011–2015 cites both demand- and supply-side challenges for increasing vaccination uptake.[5] Specific barriers cited include accessibility because of distance and poor health-seeking behavior, lack of a government public health communication strategy, missed opportunities at health facilities, inadequate numbers of heath facility staff, stockouts, securing financing for vaccines, and transportation/cold chain issues.[5] Resolving these existing barriers to vaccination is crucial as Kenya expands its routine vaccination schedule; Kenya introduced the pneumococcal vaccine in 2011 and aimed to introduce the rotavirus vaccine in 2013, contingent on GAVI support.[5] Timeliness of rotavirus vaccination will be essential, because the first dose must be administered between 6 and 14 weeks of age; it will be challenging if these existing barriers are not addressed.

Prior studies from Kenya have identified several sociodemographic factors associated with full vaccination, including socioeconomic status, maternal occupation, maternal education, paternal education, maternal age, child's sex, ethnicity, number of siblings/family size, and birth order.[6–11] This existing literature base comes from a range of regions in Kenya, with a number of the studies taking place in urban areas[6,8–10] and others coming from the coastal area of Kilifi.[11,12] Kenya is a diverse country, and regional variation in vaccination coverage or variation between urban or rural populations may exist. More recently, a study undertaken in rural Nyanza Province by Kawakatsu and Honda[13] found that approximately 79.4% of children 12–23 months of age were fully vaccinated. Additionally, the study found that knowledge of the vaccination schedule, longer intervals between births, more children under 5 years old in the household, and high performance of a community health worker were all associated with full vaccination.[13] However, timeliness of vaccination was not assessed.

Timeliness of vaccinations has implications for the child's health and survival, because both initiating vaccination before the recommended schedule and completing vaccination later than recommended can increase the child's risk

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of contracting vaccine-preventable diseases.[14,15] Two studies in Kilifi, Kenya investigated timely immunization; both studies showed low percentages of children receiving the pentavalent vaccine series by the target dates, and one study also showed low timely coverage for the rest of the vaccination schedule.[11,12] Ndiritu and others[12] showed that only 22% of children had received pentavalent dose one by 6 weeks of age, 15% of children had received pentavalent dose two by 10 weeks of age, and 9% of children had received pentavalent dose three by 14 weeks of age, all of which were higher than the timely pentavalent results presented by Moisi and others.[11] In both studies, around 90% of children or greater received each of the pentavalent vaccines by 12 months of age.[11,12] In contrast, a recent study carried out in the Kenya Medical Research Institute (KEMRI)/Centers for Disease Control and Prevention (CDC) Health and Demographic Surveillance System (HDSS) area (site of the present study) involved a small sample of mothers who were enrolled and randomized to receive mobile phone text message reminders to bring their child in for vaccination as well as a conditional cash transfer for timely vaccination.[16] The study found that vaccination coverage with the second dose of the pentavalent vaccine within 4 weeks of the target date reached nearly 95% compared with 60% among children of mothers who did not receive text message reminders.[16]

We used data from a cross-sectional survey conducted in 2003 to examine factors associated with full vaccination in children ages 12–23 months in an HDSS area in Nyanza Province, Kenya. These historical data on full and timely vaccination coverage serve as a baseline to compare changes in vaccination coverage and timeliness after interventions to improve coverage have been introduced. Factors associated with coverage and timeliness may remain relevant and assist in the refinement of interventions to improve timely uptake of vaccination.

The objectives of this study are to (1) determine the vaccination coverage in children ages 12–23 months in this community in western Kenya, (2) determine the proportion of children ages 12–23 months with timely vaccination coverage, and (3) identify factors associated with children ages 12–23 months receiving all DVI-recommended vaccinations.

METHODS

Study site and population. This study took place in Gem (Wagai and Yala Divisions), Nyanza Province, Kenya as part of a cross-sectional survey of children from June to July of 2003. Gem is part of the KEMRI/CDC HDSS, which follows a population of 220,000 in Rarieda, Siaya, and Gem Districts.[17] The KEMRI/CDC HDSS measures mortality, fertility, and migration on a triannual basis. The HDSS also collects data on socioeconomic status and educational levels. The population is culturally homogeneous, with more than 95% being of the Luo ethnic group. Residents live in compounds, which include houses for the household head, his wives (polygyny is practiced), their young children, and unmarried sons. The economy is based on subsistence farming, and young adults often migrate to urban areas for economic opportunities. Mortality in children under 5 years old is high (212 deaths per 1,000 live births in 2008), with malaria, anemia, and pneumonia being major contributors.[18] Human immunodeficiency virus (HIV) prevalence is also high; using 2003–2004 data from this region, prevalence among individuals 13 years of age or older was estimated to be 15.4%.[19] All households within the HDSS are enumerated and mapped using the global positioning system (GPS).

In Gem in 2003, there were six government health facilities where children could receive their routine vaccinations. Vaccines were typically available on specified vaccination days, although a child due for vaccination could receive required vaccinations on any day of presentation according to national guidelines. Vaccinations were provided in a standardized way at all health facilities, with particular antigens administered to specified limbs. Mobile vaccination units were present in the area to supplement routine vaccination efforts.

Design. The study methods have been described previously.[20] Briefly, in Gem, approximately 30% of HDSS households were randomly selected for inclusion. During June and July of 2003, parents/guardians were asked to bring all children under 5 years of age living in selected households to a central point in each village to participate in the survey.

Demographic and vaccination data were collected for all consented children under 2 years of age. Caregivers were asked whether the child received particular vaccinations, the location of the child's last vaccination, and whether the child's vaccination card or health passport was available. If the vaccination card was available, vaccination status was recorded for each vaccination along with the month/year of the vaccination. If the vaccination card was not available, parents/guardians provided verbal reports of the same information.

Individual information was obtained from the 2003 HDSS database on maternal education, paternal education, household head occupation, occupation of the spouse of the household head, number of children, birth order, economic variables, and GPS coordinates for spatial analysis.

Data analysis. Vaccination data were analyzed on a card plus history basis, which combines information from vaccination cards with information from the guardian's report when cards were not available.[4] Vaccination cards were available for 55.3% of study participants ages 12–23 months ($N = 135$; slightly less than the 62.2% of children with a vaccination card reported in the 2008–2009 Kenya DHS [KDHS]).[4] Full vaccination was defined as having received three polio immunizations, one bacillus Calmette–Guerin (BCG) vaccine, one measles vaccine, and three doses of either DPT or pentavalent vaccine in accordance with the DVI guidelines.[5] The pentavalent vaccine was introduced in Kenya in 2001; some children in the age range of interest (12–23 months), which allows for children to be old enough to have received all vaccinations, received DPT, whereas others received the pentavalent vaccine. Vaccine cards did not specify whether DPT or pentavalent vaccine was administered, and discerning which of the two vaccines the child received was not always possible. When a mother did not know whether their child received a specific vaccine antigen, the child was categorized as having not received the vaccine.

The DVI vaccination schedule recommends that BCG be given within 7 days of birth, polio at 6, 10, and 14 weeks, and pentavalent or DPT at 6, 10, and 14 weeks of age and measles at 9 months.[5] Because only vaccination month and year were available, vaccination was defined as timely for each antigen if the child received each vaccination within the month that

it was due based on the child's birth date. Other studies in Kenya have used survival analysis to investigate timely vaccination, and therefore, they report vaccination coverage at multiple time points from the date of birth until 12 months of age.[11,12] Another study in Kenya defined timely vaccination as no more than 4 weeks between vaccinations.[16] Summary coverage variables were created for children who received all three vaccinations in the polio series (with the exception of birth polio) and the DPT/pentavalent series within the above-mentioned time period; then, an overall summary estimate for both timely and fully vaccinated children was created for the full vaccine series.

Using ArcView Geographic Information Systems (GIS; Esri, Redlands, CA), straight-line distances in kilometers were calculated from a child's mapped household to the closest health facility in the HDSS vicinity.

Mother's age and her number of children were analyzed categorically. Birth order was constructed by looking at the birthdates of all the children of each mother from the 2003 HDSS database and then considered dichotomously (firstborn or not). Two categorical occupation groups were created for the occupation of the spouse of the household head (primary occupation as subsistence farming or not subsistence farming and households where the spouse was absent versus households with a spouse present with an income-generating occupation). A household head is the household's primary decision-maker. The spouse of the household head is married to the household head and not sex-specific. The household head and spouse of the household head are not necessarily the parents of the child included in this study. Education was categorized into two groups (under 8 years or ≥ 8 years). Distance of the residence to the nearest health facility and distance to the health facility where the child received the last vaccination were evaluated as continuous and categorical variables (0–1.99 or ≥ 2 km). An orphan was defined as a child with either parent deceased. We also investigated the following dichotomous variables: whether the mother was alive, whether the father was alive, if a person other than the mother looked after the child, if a person other than the mother accompanied the child to the interview, and child's sex.

We used odds ratios (ORs), χ^2 tests, and 95% confidence intervals (95% CIs) to compare dichotomous variables; *t* tests were used to compare continuous variables. Logistic regression was used to determine the variables that were independently associated with full vaccination at 12–23 months of age. Variables found to be significant in unadjusted models ($P < 0.10$) were included for consideration in the final multivariable logistic regression model. Exposures with a significance level of less than 0.05 were retained in the final multivariable model. All analyses were carried out using Statistical Analysis Software version 9.1 (SAS Institute, Inc., Cary, NC).

This study was reviewed and approved by the institutional review boards of KEMRI (Nairobi, Kenya) and the CDC (Atlanta, GA).

RESULTS

A total of 1,769 households were randomly selected, which was expected to yield an estimated 1,165 children under 5 years of age. In total, 1,197 children under 5 years of age participated in the survey.

Characteristics of 244 participants ages 12–23 months and patterns of vaccination coverage are shown in Tables 1 and 2, respectively. Using card plus history, 31.1% of children were fully vaccinated, with 44.3% of children receiving all vaccinations excluding the measles vaccine. Based on card plus history vaccination coverage estimates, 13.9% of children had not received any vaccinations against childhood illness.

Timely vaccination for 135 children who received at least one vaccination and had vaccine cards is analyzed in Table 3. Approximately 55% of children received the first of their DPT or pentavalent series late, and 65% of children received the first dose of polio late. The median age at vaccination often exceeded the target age range, although for most vaccines, the median did not exceed the target by more than 1 month (with the exception of the third dose of polio) (Table 3). However, in the most extreme cases, children received individual vaccines over 1 year late. Only 3 of 135 (2.2%) children received all vaccinations within the specific month that was given for timely vaccination. Of 55 children with vaccine cards who were fully vaccinated, 5.5% of children were also timely vaccinated for all antigens.

Twenty-seven children were excluded from the multivariable analysis, because they could not be linked to the 2003 HDSS database. Children missing information on maternal education ($n = 89$) and spouse occupation ($n = 68$) were excluded from the univariable and multivariable analyses. For 137 children in the final analysis, crude analyses show that children who had more than two siblings (OR = 0.30, 95% CI = 0.14–0.66, $P \leq 0.01$), were not firstborn (OR = 0.27, 95% CI = 0.10–0.74, $P \leq 0.05$), and had mothers with < 8 years of education (OR = 0.35, 95% CI = 0.13–0.92, $P \leq 0.05$) were less likely to be fully vaccinated. Households with a working spouse in the home (versus households with spouse absent) were less likely to fully vaccinate their children (OR = 0.45, 95% CI = 0.21–0.99, $P \leq 0.05$) (Table 4). We found no significant difference between orphans and non-orphans with respect to full vaccination (OR = 0.72, 95% CI = 0.18–2.87, $P > 0.05$), but the number of orphaned children was small ($n = 3$) (Table 4).

In our adjusted logistic model, we found that number of children in the family (OR = 0.27, 95% CI = 0.13–0.65, $P \leq 0.01$), maternal education (OR = 0.35, 95% CI = 0.13–0.97, $P \leq 0.05$), and households where the spouse is absent (OR = 0.40, 95% CI= 0.17–0.91, $P \leq 0.05$) were all significantly associated with full vaccination (Table 4).

DISCUSSION

In Gem Division, western Kenya in 2003, only 31.1% of children ages 12–23 months of age had received all DVI recommended vaccinations, 13.9% of children received no vaccinations, and among children with documented vaccination dates, only 2.2% of children were fully and timely vaccinated against childhood illnesses. Data on full vaccination and lack of vaccinations are consistent with 2003 KDHS immunization coverage estimates in Nyanza Province, although recent data from the 2008–2009 KDHS show improvements in full vaccination (64.6% for Nyanza Province).[4,21] The finding that very few children receive vaccinations during the recommended timeframe for optimal protective response is critical information to inform public health policy in this area.

TABLE 1

Characteristics of children ages 12–23 months and their families participating in the KEMRI/CDC HDSS June to July of 2003 cross-sectional survey in Gem, Kenya

Characteristic	Participants ($N = 244$)	
	n	Percent
Mother's age (years)		
15–19	18	7.4
20–24	78	32.0
25–29	53	21.7
30–34	43	17.6
35–40	35	14.3
40+	12	4.9
Missing	5	2.1
Child sex		
Male	119	48.8
Female	125	51.2
Number of children in the household*		
1	27	11.1
2	39	16.0
3	37	15.2
4	34	13.9
5	30	12.3
6+	29	11.9
Missing	48	19.7
Birth order*		
Firstborn	35	14.3
Not firstborn	155	63.5
Missing	54	22.1
Mother alive		
Yes	241	98.8
No	3	1.2
Mother with child at interview		
Yes	233	95.5
No	11	4.5
Mother looks after the child		
Yes	229	93.9
No	15	6.2
Maternal education level* (years)		
< 8	132	54.1
≥ 8 and ≤ 12	21	8.6
> 12	2	0.8
Missing	89	36.5
Spouse occupation*		
Subsistence farming	74	30.3
Skilled labor	13	5.3
Unskilled labor	12	4.9
Small business/business owner	11	4.5
Salaried worker	9	3.7
Other	4	1.6
Housewife	3	1.2
Spouse absent	49	20.1
Missing	68	27.9
Father's education level* (years)		
< 8	88	36.1
≥ 8 and ≤ 12	23	9.4
> 12	6	2.5
Missing	127	52.1
Father's age* (years)		
20–24	5	2.1
25–29	24	9.8
30–34	13	5.3
35–40	23	9.4
40+	35	14.3
Missing	144	59.0
Father alive		
Yes	211	86.5
No	19	7.8
Missing	14	5.7
Household head occupation*		
Subsistence farming	113	46.3
Skilled labor	7	2.9
Unskilled labor	14	5.7
Small business/business owner	32	13.1
Salaried worker	8	3.3
Housewife	2	0.8
Missing	68	27.9
Distance to the clinic where the child received last vaccination (km)		
0–1.99	96	39.3
≥ 2	147	60.2
Missing	1	0.4
Distance to the nearest health facility (km)		
0–1.99	101	41.1
≥ 2	142	58.2
Missing	1	0.4
Child is orphan		
Yes	22	9.0
No	209	85.7
Missing	13	5.3

*This variable comes from the HDSS database, and the missing data are a result of incomplete HDSS records.

MDG4, which aims to reduce child mortality, emphasizes the need to increase measles and pentavalent vaccination coverage to reduce mortality. We found that only 41.0% of children surveyed received the measles vaccine and that less than one-fifth of children received timely measles vaccination. Low coverage and late administration of measles vaccination are both harmful, because maternal antibodies fail to provide protection for children as they reach 1 year of age. Early vaccination is also suboptimal, because children who receive the measles vaccination too early are at increased risk for vaccine failure.[22] Low measles vaccination coverage in a community can also have a deleterious effect on children who have been adequately vaccinated, putting them at elevated risk for contracting measles.[23]

TABLE 2

Vaccination coverage by reporting method for children ages 12–23 months for selected antigens from June to July of 2003 in Gem, Kenya

Antigen	Card or recall evidence combined in all children ($N = 244$)*	
	Number vaccinated	Vaccinated (%)
BCG	185	75.8
Birth polio	145	59.4
Polio 1	171	70.1
Polio 2	148	60.7
Polio 3	122	50.0
All polio†	118	48.4
DPT/pentavalent 1	178	73.0
DPT/pentavalent 2	152	62.3
DPT/pentavalent 3	133	54.5
All DPT/pentavalent	130	53.3
Measles	100	41.0
Received no vaccinations	34	13.9
Fully vaccinated‡	76	31.1

*Includes 34 (14% of total) children who reported receiving no vaccinations.
†A child fully immunized for polio does not need to include the vaccination given at birth.
‡BCG, measles, three doses of polio (excluding polio at birth), and three doses of DPT or pentavalent are considered to have received all World Health Organization recommended immunizations.

TABLE 3

Percentage of children ages 12–23 months who received timely vaccination among those children who received at least one vaccination from June to July of 2003 in Gem, Kenya

Antigen	DVI target age (months)	Card evidence in children with cards ($N = 135$)		Timely vaccination*			Age at vaccination (months)	
		Number vaccinated	Vaccinated (%)	Number†	Children with cards (%; $N = 135$)	All vaccinated children‡ (%)	Median	Range
BCG	Birth	133	98.5	93	68.9	69.9	1	0, 14
Birth polio	Birth	98	72.6	71	52.6	72.5	1	0, 14
Polio 1	1.5	121	89.6	47	34.8	38.8	2	0, 13
Polio 2	2.5	101	74.8	37	27.4	36.6	3	0, 13
Polio 3	3.5	81	60	25	18.5	30.9	5	2, 16
All polio§		79	58.5	17	12.6	14.4	–	–
DPT/pentavalent 1	1.5	128	94.8	60	44.4	46.9	2	0, 15
DPT/pentavalent 2	2.5	107	79.3	47	34.8	43.9	3	2, 13
DPT/pentavalent 3	3.5	93	68.9	37	27.4	39.8	4	3, 16
All DPT/pentavalent		92	68.1	31	23	25.4	–	–
Measles	9	67	49.6	24	17.8	35.8	10	5, 21
Fully vaccinated	12–23	55	40.7	–	–	–	–	–
Timely/fully vaccinated¶	12–23	–	–	3	2.2	5.5	–	–

*Vaccination in the scheduled month based on child's birth date.
†Child receiving vaccination during target month for vaccination based on child's date of birth.
‡Calculated as timely vaccination for each specific vaccine antigen, with the total number of children that received the vaccination for each antigen as the sample size (i.e., the percent of timely vaccination among children that received the vaccination).
§A child fully immunized for polio does not need to include the vaccination given at birth.
¶Children who received the eight-vaccination series within the target age range listed for each individual vaccine in the series.

Timely vaccination coverage, as broadly defined in this study, was low, although many countries, including developed nations, also experience delayed or incomplete vaccination.[24–26] Few children in our study received the recommended schedule of vaccinations in a timely fashion, indicating that many children in this area of Kenya were at risk of vaccine-preventable diseases because of poor adherence to the recommended vaccine schedule. These findings show lower timely vaccination than elsewhere in Kenya; two studies from coastal Kenya reported fewer delays in vaccination.[11,26] The recent study by Wakadha and others[16] in the same HDSS area as our study found high timely coverage with the first two doses of the pentavalent vaccine using a conditional cash transfer program and short message services (SMS) reminders for vaccination. Of note, among mothers in the study who did not receive an SMS reminder, timely vaccination for pentavalent dose two was only 60%. Our study of 2003 data found that about 35% of children were vaccinated on schedule with dose two among children with cards, indicating that some progress has been made to timely vaccination coverage.[16] By the nature of the vaccine schedule, children who received a late first immunization had their entire vaccination schedule delayed. Efforts to improve timeliness of the first vaccination visit are critical.

Another study from this region showed that higher performance of community health workers, measured by frequency of educational visits and mothers' satisfaction with the visits, was associated with full vaccination coverage, but it did not explore the timeliness of vaccinations.[13] Community health workers or traditional birth attendants could be further engaged to mobilize parents to bring their young children in for vaccination and also, ensure that parents adhere to vaccination schedules. Conditional cash transfer programs, which were shown to increase immunization coverage in multiple Latin American countries,[27] need additional assessment in Kenya. A small pilot study in the same HDSS area of our study used a conditional cash transfer program as well as mobile phone SMS reminders to improve timely vaccination for the pentavalent vaccine series.[16] The results were promising and showed that these interventions may be useful tools for increasing timely vaccination coverage, but they require additional investigation to draw conclusions about effectiveness.

As observed elsewhere, having fewer children was strongly associated with full vaccination.[6,10,12] Women with fewer children may have more time to commit to the care of an individual child and may not need to organize child care for other siblings or travel to the health facility with all of the children, thus making vaccine visits easier to prioritize. Alternatively, women with multiple children may synchronize health visits for her children, which could influence whether each child adheres to the recommended schedule. For example, a child may receive their vaccination in conjunction with a sick visit for a sibling rather than on a scheduled visit for vaccination. Children of more educated mothers were more likely to be fully vaccinated, which is consistent with previous studies in Kenya.[6,7,9,10] We were surprised to find that households with the household head's spouse present and household head having an income-generating occupation were less likely to have fully vaccinated children. Based on our data, few households had a deceased parent of the child, suggesting that households have no working spouse because of outmigration rather than death of the spouse. Perhaps children in families with a spouse absent were more likely to be vaccinated, because the absent spouse could be engaged in employment in a city, providing income and knowledge from outside the rural area of Gem.

We were not able to show the distance decay effect, measured elsewhere in Kenya and East Africa, where vaccination decreases with increasing distance from the vaccination clinic.[12,28] It may be because 81% of the population in Nyanza Province lives within 5 km of a public health facility, suggesting that access may be less of a barrier to vaccination uptake than in areas where health facilities may be farther away.[29] Additionally, mothers may go to multiple facilities for vaccination depending on the perceived availability of vaccinations and quality of care at the facilities. Distance to the nearest clinic and distance to the clinic where the child received their last vaccination were not based on walking or travel distance from the child's home, meaning that this estimate of distance fails to take into account geographical boundaries and obstacles (e.g., rivers or mountains), which

TABLE 4

Unadjusted and adjusted ORs from logistic regression analysis for factors associated with fully vaccinated children ages 12–23 months from June to July of 2003 in Gem, Kenya (N = 137)

Variable	Fully vaccinated no. (%)	Unadjusted OR	95% CI	Adjusted OR	95% CI
Mother's age (years)					
15–19	1 (33.3)	1.10	0.09–12.85		
20–24	12 (31.6)	1.02	0.43–2.41		
24–29	13 (40.6)	1.51	0.62–3.63		
30+	20 (31.3)	Reference			
Child's sex					
Male	27 (38.6)	Reference			
Female	19 (28.4)	0.63	0.31–1.29		
Children in the family					
1–2	20 (54.1)	Reference		Reference	
3+	26 (26.0)	0.30	0.14–0.66*	0.27	0.13–0.65*
Birth order					
Firstborn	11 (61.1)	Reference			
Not firstborn	35 (29.4)	0.27	0.10–0.74†		
Mother alive					
Yes	46 (33.6)	–	–		
No	0	–	–		
Mother looks after the child					
Yes	43 (32.6)	Reference			
No	3 (60.0)	3.1	0.50–19.27		
Mother with the child at interview					
Yes	45 (33.6)	Reference			
No	1 (33.3)	0.99	0.09–11.20		
Mother's education level (years)					
< 8	35 (29.9)	0.35	0.13–0.92†	0.35	0.13–0.97†
≥ 8	11 (55.0)	Reference		Reference	
Child is orphan					
Yes	3 (27.3)	0.72	0.18–2.87		
No	43 (34.1)				
Working spouse in the home					
No	29 (28.7)	Reference		Reference	
Yes	17 (47.2)	0.45	0.21–0.99†	0.40	0.17–0.91†
Distance to the clinic where the child received last vaccination (km)					
0–1.99	22 (36.1)	Reference			
≥ 2	24 (31.6)	0.82	0.40–1.67		
Distance to the nearest health facility (km)					
0–1.99	22 (34.9)	Reference	0.44–1.82		
≥ 2	24 (32.4)	0.89			

* $P \leq 0.01$.
† $P \leq 0.05$.

would impact the ease of travel to a health facility more so than solely the number of kilometers. Future analyses should take into account actual travel time to the clinics, which was done in the study by Moisi and others[11] in Kilifi, Kenya, but no significant relationship was found between travel time and vaccination coverage in their study.[11]

The subset of children with vaccination status determined by maternal recall had lower vaccination coverage than the children who had vaccination status determined by examination of their vaccination cards. Mothers who are more adherent to health worker instructions to retain vaccine cards may also be more adherent to vaccination schedules. Alternatively, maternal recall may underestimate vaccination coverage, and thus, our card plus estimates that incorporate maternal recall may underestimate true vaccination coverage, which was seen elsewhere in Kenya.[12]

Our analysis had several limitations. Participating households were more likely to have a household head with secondary education, which could bias to higher reported full vaccination. Children with vaccination cards included in the timely vaccination analysis were younger, more likely to be looked after by their mother, and fully vaccinated. We would expect higher timely vaccination in this group than children without a vaccination card, but timeliness of vaccination remained low (at about 2%). Exact dates of vaccination were not available, meaning that timeliness of vaccination was based on an estimation of the date of vaccination. Because of this estimation, intervals between multidose vaccine series were not calculated. Therefore, this analysis does not capture timely vaccination for children who started a multidose vaccine series late but adhered to the recommended interval between doses. Additionally, defining time of vaccination by month, without knowing the day, may underestimate timeliness. Children due for vaccination at the end of the month who received the vaccination early in the next month were not classified as receiving timely vaccination, although they may have been within a clinically appropriate window for vaccination. Supply-side factors related to service provision, including vaccine shortages, clinic staffing shortages, ability to maintain the cold chain, and limited vaccination days per week, were not available from the 2003 HDSS dataset; future studies should investigate these supply-side barriers to vaccination service provision.

Our analysis shows that young children remained at risk for vaccine-preventable diseases in this area of western Kenya, where vaccination coverage was modest and timeliness was

very poor. Reducing dropoff between completing multidose vaccine series should be a focus for programs working to improve vaccination coverage. Maternal education and family planning may have an indirect effect on vaccination uptake. Our analysis also shows that measuring vaccination coverage without considering timeliness of vaccination may result in an overly optimistic assessment of successful prevention of vaccine-preventable diseases. Improving timeliness of the first vaccinations will be essential as new vaccinations are adopted by DVI, such as the rotavirus vaccine, the first dose of which must be administered between 6 and 14 weeks of age. Data from this survey serve as a useful baseline measurement from this region of low vaccination coverage as Kenya strives to meet MDG4. Efforts to improve full, timely vaccinations should focus on areas of low vaccination coverage, such as Nyanza Province, where the greatest improvements can be achieved.

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