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Achieving comprehensive childhood immunization: an analysis of obstacles and opportunities in The Gambia

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Introduction Immunization is a vital component in the drive to decrease global childhood mortality, yet challenges remain in ensuring wide coverage of immunization and full immunization, particularly in low- and middle-income countries. This study assessed immunization coverage and the determinants of immunization in a semi-rural area in The Gambia.

Methods Data were drawn from the Farafenni Health and Demographic Surveillance System. Children born within the surveillance area between January 2000 and December 2010 were included. Main outcomes assessed included measles, BCG and DTP vaccination status and full immunization by 12 months of age as reported on child healthcards. Predictor variables were evaluated based on a literature review and included gender, ethnicity, area of residence, household wealth and mother's age.

Results Of the 7363 children included in the study, immunization coverage was 73% (CI 72–74) for measles, 86% (CI 86–87) for BCG, 79% (CI 78–80) for three doses of DTP and 52% (CI 51–53) for full immunization. Coverage was significantly associated with area of residence and ethnicity, with children in urban areas and of Mandinka ethnicity being least likely to be fully immunized.

Conclusions Despite high levels of coverage of many individual vaccines, delivery of vaccinations later in the schedule and achieving high coverage of full immunization remain challenges, even in a country with a committed childhood immunization programme, such as The Gambia. Our data indicate areas for targeted interventions by the national Expanded Programme of Immunization.

Keywords The Gambia, immunization, socio-demographic, determinants, child

KEY MESSAGES

- Despite high levels of coverage of many individual vaccines, full immunization remains a challenge, even in a country with a committed childhood immunization programme, such as The Gambia.
- Some groups of the population are potentially more at risk of defaulting on immunizations and there is discrepancy between urban and rural settings.
- Although some of the barriers to immunization are understood, more evidence is needed as to how these can be overcome in low-income countries.

Introduction

Immunization is recognized as one of the most cost-effective interventions to prevent morbidity and mortality caused by infectious diseases, particularly in a high-endemic setting (The World Bank 1993, 1994; WHO, UNICEF 2005; WHO, UNICEF, World Bank 2009). Vaccines prevent more than 2.5 million child deaths each year and it has been shown that children who receive all appropriate vaccinations by 9 months of age are less likely to die than those who do not (Rutherford *et al.* 2009).

Immunization is therefore a key component of the drive to decrease childhood mortality and to achieve Millennium Development Goal 4—the reduction of under-five mortality rates by two-thirds in 2015 (WHO, UNICEF 2005; WHO, UNICEF, World Bank 2009).

Despite global progress in providing vaccinations, there still remains a challenge in reaching those most vulnerable: the poorest, most disadvantaged and remote communities. Immunization coverage in low-income countries remains significantly below the levels in middle- and high-income countries (WHO, UNICEF, World Bank 2009; WHO 2010a,b). Summarized data from national coverage rates can mask inequalities in regional immunization coverage and even countries with high national coverage rates and demonstrable improvement in coverage continue to show socio-economic disparities in coverage (Jamil *et al.* 1999; Burton *et al.* 2009; Durrheim and Cashman 2010; Uddin *et al.* 2010).

In 1974, the Expanded Programme of Immunization (EPI) was established by the WHO to ensure that all children in all countries benefit from life-saving immunizations. The EPI in The Gambia started in May 1979, covering the core diseases tuberculosis (BCG vaccine), diphtheria, pertussis, tetanus (combined in the DTP vaccine), measles, polio and yellow fever. Hepatitis B (HBV) vaccine was phased in between 1986 and 1990, *Haemophilus influenzae* type B (Hib) vaccine in 1997 and, more recently, the conjugated pneumococcal vaccine (PCV) in 2009.

In contrast to other developing countries, The Gambia has consistently reported high national coverage rates for most routine immunizations. WHO estimates of immunization coverage among 1-year-olds in The Gambia in 2009 indicate that, for many immunizations (measles, yellow fever and third dose of DTP, Hib, HBV and polio), coverage was above 95% (WHO 2011b). The full immunization schedule recommended in The Gambia is summarized in Table 1. The Multiple Indicator Cluster Survey (MICS), a national survey in The Gambia, shows an increase in the percentage of children aged 12–23 months immunized against specific infectious diseases between 2000 and 2006. However, the rate of full immunization (defined as the number of children aged 12–23 months receiving three doses of DTP, three doses of polio, BCG and measles vaccines before their first birthday as a percentage of the total number of children aged 12–23 months surveyed) decreased over this time and in 2006 was only 55% nationally (Government of The Gambia, UNICEF 2002; Government of The Gambia 2007). Completion of the immunization schedule and achievement of the United Nations target of full immunization coverage for 90% of children under 1 year remains a challenge, even in The Gambia.

Immunization coverage, particularly in the developing world, has been shown to be associated with several socio-economic and demographic factors, such as parental education, economic status, region of residence, age of the mother, ethnicity and gender of the child (Hanlon *et al.* 1988; Bhuiya *et al.* 1995; Jamil *et al.* 1999; Bosu *et al.* 2003; Waters *et al.* 2004; Hilber *et al.* 2010; Sullivan *et al.* 2010) and these disparities are not necessarily remedied by increasing the overall percentage of immunization coverage (Jamil *et al.* 1999).

In the Farafenni region of The Gambia, an extensive Demographic Surveillance System has been in place for many years, through which immunization data are collected routinely. This provides a unique opportunity to assess the immunization coverage, in particular full immunization and to determine if variation exists in immunization coverage. This analysis of socio-economic and demographic factors that might influence immunization coverage aims to inform the EPI in The Gambia and other settings.

Scientific and ethical approval was given by the joint MRC/Gambia Government Scientific Co-ordinating Committee and The Gambia Government/MRC Laboratories Joint Ethics Committee (SCC 1244).

Methods

Study area

The Government is the major provider of health care in The Gambia. Primary health care (PHC) is delivered via the PHC strategy, adopted in 1979 to 'make healthcare more accessible and affordable to the majority of Gambians' (Government of The Gambia 2007), with a particular focus on rural settlements with a population of more than 400. As part of the PHC strategy, these rural areas have been served by volunteer village health workers and traditional birth attendants (TBAs) since the 1980s.

Maternal and Child Health (MCH) services have also been a core part of the PHC strategy as it began including outreach

Table 1 The Gambia immunization schedule

Timing	Vaccinations
Birth	BCG, first dose of polio, first dose of HBV
2, 3 and 4 months	DTP/Hib/HBV combined; second, third, fourth dose of polio; PCV
9 months	Measles, yellow fever, fifth dose of polio
16 months	DTP/Hib/HBV combined
18 months	Sixth dose polio
Plus vitamin A every 6 months (from 6 months of age till 59 months)	

Source: WHO vaccine-preventable diseases: monitoring system 2010 global summary (WHO 2010a,b).

services. MCH services are delivered via both static and mobile health clinics with the core objectives to maintain high immunization coverage levels, decrease maternal deaths and improve child nutrition. Before 2009, a 5 Dalasi fee (about US$0.17) was charged for a child healthcard and then all subsequent care was free but now vaccinations, along with all health care for children under five, are free of charge.

This study was carried out in the North Bank East Health Region of The Gambia, within the Farafenni Health and Demographic Surveillance System (FHDSS). The FHDSS was established in 1981, initially including only the rural villages surrounding Farafenni town but has since expanded and the surveillance area now comprises 42 rural villages, the town of Farafenni and the area within a 5-km radius of the town (designated the 'peri-urban' area).

There is one static MCH clinic in the region based in Farafenni town running six MCH sessions per month. There are three mobile clinics held monthly in the surrounding villages. All villages in the region are within 3 km of a mobile clinic and women mostly walk or use donkey carts to reach there (North Bank East Health Region Public Health Officer, personal communication).

The population covered by the FHDSS was ~44 000 as of June 2007, made up of three main ethnic groups: Fula (21%), Mandinka (34%) and Wolof (38%). It is predominantly young, with an average age of 22 years and has a high level of fertility with almost half of all women being in the reproductive age bracket (15–49 years). The study area is relatively poor; most houses are constructed of mud brick and only 3% of the rural and 45% of the urban population have electricity. The study area and population under surveillance are described in more detail elsewhere (MRC 2004).

Data

Data for this study were drawn from the FHDSS. Demographic and immunization data are collected during 4-monthly rounds whereby every household is visited and details of every individual in the household updated, including new members (through birth or entry into the surveillance area). Full details of the FHDSS process and procedures are documented elsewhere (MRC 2004). For this analysis, a snapshot of the FHDSS was taken after update round 62, which occurred between 1 September 2010 and 31 December 2010.

Vaccinations

- BCG
- Measles
- Yellow Fever
- DTP (at least three doses)
- Polio (at least three doses)
- HBV (at least one dose)

Figure 1 Vaccinations selected as measures of immunization coverage.

Data on the immunization status of children under 5 years of age have been collected routinely since 2005 as part of the standard FHDSS process. Data on the immunization status of children born before 2005 were entered retrospectively during a survey in 2005 which covered children aged five or under at the time. All children born after 1 January 2000 who had reached 1 year of age by the final data collection round, and for whom immunization data had been collected, were included in the analysis.

In the analysis, immunization status was interpreted as 'immunized' for all those who had a vaccination date recorded and 'not immunized' for all children who had no vaccination date recorded in the FHDSS. In the majority of cases (98%), immunization data were captured from the child healthcard. If no healthcard was available (2% of children in our analysis), immunization data were based on caregiver's recall.

Socio-economic details including household head's occupation, ownership of assets, water supply, toilet facilities, main materials of walls, roof and floor of accommodation, access to electricity and income were elicited through interviewer-administered questionnaires as part of a household survey conducted across the surveillance area between April and June 2007. For this analysis, a wealth index was created using principal components analysis (PCA), based on the ownership of the individual assets included in the household survey (radio; TV; telephone; refrigerator; iron or wooden bed; cart; bicycle; motorbike or scooter; car, truck or tractor) and publicly provided resources, such as electricity, water and toilet facilities. A similar approach in measuring wealth has been used by others (Gwatkin *et al.* 2000).

Outcome measures

For all analyses, the primary outcome of interest was coverage of immunization. Immunization coverage was calculated as:

$$\frac{\text{Number of children who received the immunization}}{\text{All children eligible for immunization who were surveyed regarding immunizations}} \times 100$$

Coverage was calculated for the individual vaccinations listed in Figure 1 and for full immunization at 1 year (defined as receiving BCG, three doses of OPV, three doses of DTP and one dose of measles vaccine by 1 year of age). This is the definition of full immunization used in the national MICS in the Gambia and therefore was used here to enable comparison.

In addition, the proportions of children who received more than half of the 16 recommended vaccine doses in the national schedule, and the proportion who received all 16, were calculated to further assess programme performance.

Predictor Variables

- Area of residence;
- Mother's age at time of child's birth;
- Ethnic group;
- Sex of the child; and
- Household wealth quintile.

Figure 2 Predictor variables selected for regression analysis.

The outcome measures chosen for the analysis of possible factors influencing immunization were:

- BCG immunization as a measure of the system of delivery of vaccines at birth;
- Three doses of DTP vaccine (DTP3) as a measure of consistency of immunization coverage and as an 'indicator' of coverage of other 2/3/4 month vaccines;
- Measles immunization as a measure of consistency of delivery and capacity of the system to ensure follow-up of children above 6 months of age; and
- Full immunization at 1 year (defined as receiving BCG, three doses of OPV, three doses of DTP and one dose of measles vaccine by 1 year of age) as a measure of the proportion of the population of children who have an adequate level of acquired immunity and the capacity of the system to ensure adequate follow-up to achieve this.

Predictor variables

Variables that might affect immunization coverage, therefore of interest in this study, were selected from a review of the relevant literature. These variables are listed in Figure 2.

Statistical analysis

Immunization coverage, with 95% confidence intervals, was calculated for the total population over the whole time period 2000–9 and stratified by area of residence. Multiple logistic regression analysis was carried out on the set of individuals for which observations were available for all predictor variables. Results were adjusted for year of birth to account for any variations in coverage over time. Correlation between predictor variables was also tested for.

Predictor variables for inclusion in the multiple regression models were first tested individually for significance of the relationship with each outcome variable using univariable logistic regression (i.e. unadjusted analyses). Those resulting in P-value <0.25 were included in an adjusted analysis, as recommended by Hosmer and Lemeshow (2000). The variables 'mother's age' and 'sex of the child' did not meet this significance level and were not included in the final model. The Hosmer and Lemeshow goodness-of-fit test was used to check the fit of the final model. The software package STATA 10 (StataCorp 2007) was used for all statistical analysis.

Results

The total number of births in the FHDSS population between 1 January 2000 and 31 December 2009 was 20 514. As of 31 December 2010, 7363 (36%) of these had been surveyed regarding vaccination data. Amongst the surveyed group, a greater proportion were from rural villages (54%) compared with the general population (40%) ($P < 0.001$). There were also small but significant differences in the distribution of ethnic group, household head's occupation, mother's age and wealth quintile (Table 2). These factors have been adjusted for in the analyses.

The variables 'area of residence' and 'wealth' were moderately correlated ($r = 0.519$) but no other variables showed any appreciable correlation and the Hosmer and Lemeshow goodness-of-fit test indicated the model was a good fit.

Immunization coverage

Of the 7363 individuals included in this analysis, 98% (7217) had a child healthcard. Of those children who had a healthcard, 97% (6991) had at least one vaccination recorded. The percentage with no vaccinations was roughly the same in rural and urban areas (3%) and slightly lower in peri-urban areas (2%).

Immunization coverage in this population varied over the study time period. BCG immunization coverage rose steadily till 2005 and then plateaued at >90%. Coverage of measles, DTP3 and full immunization fluctuated.

Of note is the trend that vaccines given at older age, e.g. measles, yellow fever and third dose of HBV, had lower coverage than those given at an earlier age, such as BCG and first dose of HBV. Measles vaccine coverage was only 73% (CI 72–74%) compared with coverage of BCG vaccine of 86% (CI 86–87%) and HBV1 at 92% (CI 92–93%).

In this sample, only 34% (2473) of children received the fourth dose of DTP and of those, less than half received it within 18 months.

A striking feature was the comparatively low coverage of full immunization in this population. Only 52% (3829) of the children surveyed had received BCG, three doses of OPV, three doses of DTP and measles vaccine by 1 year of age.

The proportion of children receiving all vaccines (and all doses) offered in the national schedule provides an indication of immunization delivery. In this study population, although only 20% of all children received all 16 vaccine doses offered, 86% of children received at least half of the total doses offered and 67% received 12 or more of the 16 doses.

Immunization coverage for the whole sample and by area of residence, alongside national estimates from the MICS report 2006 and WHO 2009, is summarized in Table 3.

Factors affecting immunization coverage

We subsequently analysed the factors potentially affecting immunization coverage. The results of multiple regression analysis of immunization coverage and socio-demographic variables are presented in Table 4.

Area of residence

Among the urban children, the coverage of full immunization was only 47% compared with 56% in rural areas. For all vaccines except HBV, coverage was higher in rural than urban areas. Peri-urban areas also had higher coverage of measles, BCG, DTP3, polio3 and yellow fever immunization than urban areas.

Table 2 Comparison of characteristics of children for whom immunization data were available and the total population of births

	Immunization data %	n	**No immunization data** %	n	**Total population** %	n	**Chi-square *P*-value**
Gender							0.092
Male	50.5	3717	49.0	6479	49.7	10 196	
Female	49.5	3643	51.0	6669	50.3	10 312	
Unknown	0.0	3	0.0	3	0.0	6	
Area							<0.001
Rural	54.2	3989	32.5	4271	40.3	8260	
Urban	33.6	2472	55.6	7316	47.7	9788	
Peri-urban	12.2	902	11.9	1564	12.0	2466	
Unknown	0.0	0	0.0	0	0.0	0	
Ethnic group							<0.001
Fula	21.6	1589	22.0	2864	21.8	4461	
Mandinka	31.8	2339	29.0	3765	29.8	6115	
Wolof	42.9	3157	43.0	5636	43.0	8813	
Other	3.7	276	6.0	637	5.4	1114	
Unknown	0.0	2	0.0	9	0.0	11	
Mother's education level							<0.001
<3 years	17.3	1276	12.2	1606	14.0	2882	
>3 years	6.3	464	3.9	514	4.8	978	
Unknown	76.4	5623	83.9	11 031	81.2	16 654	
Occupation[a]							<0.001
Farmer	48.6	3576	31.7	4165	37.7	7741	
Craftsman	0.3	23	0.3	37	0.3	60	
Tradesman	11.1	819	16.7	2199	14.7	3018	
Retired	6.0	442	4.9	641	5.3	1083	
Other	23.4	1721	25.0	3294	24.5	5015	
Unknown	10.6	782	21.4	2185	17.5	3597	
	Median (25th, 75th)	***n***	**Median (25th, 75th)**	***n***	**Median (25th, 75th)**	***n***	**Rank sum *P*-value**
Wealth quintile	2 (1, 3)	6352	2 (1, 3)[b]	10 036	2 (1, 3)	16 388	<0.001
Mother's age (years)	26 (21, 32)	7126	25 (21, 30)	11 073	26 (21, 31)	18 199	<0.001

[a]Occupation of household head.

[b]Rank sum was higher than expected for those not surveyed indicating that wealth was slightly higher amongst those who were not surveyed.

For all outcome variables except measles immunization, multiple regression indicates that children living in an urban area were less likely to be immunized than those living in rural areas (BCG OR 0.54, 95% CI 0.44–0.66, $P < 0.001$; DTP3 OR 0.74, 95% CI 0.64–0.87, $P < 0.001$; full immunization OR 0.73, 95% CI 0.64–0.84, $P < 0.001$). Those living in peri-urban areas were also less likely to be immunized against BCG or to be fully immunized than in rural areas (BCG OR 0.69, 95% CI 0.54–0.88, $P = 0.003$; full immunization OR 0.72, 95% CI 0.61–0.85, $P < 0.001$).

Ethnicity

Children of Mandinka ethnicity were less likely to be immunized compared with those of Fula or Wolof ethnicity. The results indicate that those of Fula ethnicity were more likely than Mandinka to receive BCG vaccine (OR 1.50, 95% CI 1.21–1.86, $P < 0.001$), Measles vaccine (OR 1.26, 95% CI 1.07–1.49, $P = 0.005$) and full immunization, although non-significant (OR 1.15, 95% CI 1.00–1.32, $P = 0.060$). Children of Wolof ethnicity were more likely than Mandinka to receive BCG vaccine (OR 1.52, 95% CI 1.28–1.81, $P < 0.001$), measles vaccine (OR 1.19, 95% CI 1.04–1.36, $P = 0.012$) or to be fully immunized (OR 1.14, 95% CI 1.01–1.28, $P = 0.032$).

There was no significant association between different ethnic groups and coverage of DTP3.

Wealth

There was no significant association between wealth and immunization coverage. There was a slight apparent trend in BCG coverage with increasing coverage for higher wealth quintiles but this was not significant except for comparison of the wealthiest to the least wealthy quintiles (OR 1.49, 95% CI 1.09–2.04, $P = 0.011$).

Table 3 Percentage of children who received vaccination by area of residence for each vaccine and national estimate comparators

Vaccine	All areas ($n=7363$)		Rural ($n=3989$)		Urban ($n=2472$)		Peri-urban ($n=902$)		WHO 2009[a]	MICS 3 %[b]	FHDSS 2008[c] ($n=662$)
	% coverage	95% CI	% coverage	95% CI	% coverage	95% CI	% coverage	95% CI			
BCG	86	(86–87)	88	(86–88)	85	(83–86)	86	(84–88)	94	98.7	94
DTP3 (at least three doses)	79	(78–80)	82	(80–83)	76	(74–77)	79	(77–82)	98	86.8	67
Polio (at least three doses)	88	(87–89)	89	(88–90)	86	(84–87)	89	(87–91)	97	87.6	81
Measles	73	(72–74)	75	(73–76)	70	(68–71)	72	(69–75)	96	92.4	67
Yellow fever	72	(71–73)	74	(73–75)	69	(67–71)	72	(69–75)	96	83.5	67
Full immunization[d]	52	(51–53)	56	(54–57)	47	(45–49)	47	(44–51)	–	55.3	48
Vitamin A (at least one dose)	43	(41–44)	39	(37–40)	47	(45–49)	47	(43–50)	–	–	68
Hepatitis B (at least one dose)	92	(92–93)	92	(91–93)	93	(92–94)	92	(90–94)	–	–	95
Hepatitis B (three doses)	69	(68–70)	70	(69–72)	68	(66–69)	68	(65–71)	98	–	51

[a]Data source: WHO Gambia Immunization profile: http://apps.who.int/immunization_monitoring/en/globalsummary/countryprofileresult.cfm?C=gmb, accessed 12 November 2012.
[b]MICS 3 measures percentage of children aged 12–23 months having received specified vaccine at the time of the survey.
[c]FHDSS single year comparator for WHO 2009 data.
[d]Includes three doses of DTP, three doses of OPV, BCG and measles vaccine by 1 year of age.

Table 4 Unadjusted and adjusted analysis of association between vaccination coverage and predictor variables

Variable	Category	Unadjusted OR			Adjusted OR ($n=6350$)		
		OR	CI	*P*-value	OR	CI	*P*-value
Full immunization							
Area	Rural (ref)	1.00			1.00		
	Urban	0.72	0.65–0.79	<0.001	0.73	0.64–0.84	<0.001[a]
	Peri-urban	0.72	0.62–0.83	<0.001	0.72	0.61–0.85	<0.001[a]
Sex	Male (ref)	1.00					
	Female	1.03	0.94–1.13	0.57	–	–	–
Ethnic group	Mandinka(ref)	1.00			1.00		
	Fula	1.14	1.00–1.29	0.046	1.15	1.00–1.32	0.060
	Wolof	1.16	1.04–1.29	0.008	1.14	1.01–1.28	0.032[a]
	Other	0.90	0.70–1.16	0.418	1.10	0.82–1.46	0.537
Wealth[b]	Quintile 1: lowest (ref)	1.00			1.00		
	Quintile 2	0.79	0.68–0.92	0.003	0.82	0.70–0.95	0.010[a]
	Quintile 3	0.89	0.76–1.05	0.164	0.97	0.82–1.14	0.705
	Quintile 4	0.81	0.69–0.94	0.007	0.92	0.78–1.09	0.330
	Quintile 5	0.70	0.59–0.83	<0.001	0.89	0.72–1.09	0.251
Mothers age (years)	–	1.00	0.99–1.01	0.272	–	–	–
BCG							
Area	Rural (ref)	1.00			1.00		
	Urban	0.79	0.68–0.91	0.001	0.54	0.44–0.66	<0.001[a]
	Peri-urban	0.88	0.72–1.09	0.255	0.69	0.54–0.88	0.003[a]
Sex	Male (ref)	1.00					
	Female	1.03	0.90–1.18	0.659	–	–	–
Ethnic group	Mandinka (ref)	1.00			1.00		
	Fula	1.36	1.13–1.63	0.001	1.50	1.21–1.86	<0.001[a]
	Wolof	1.42	1.22–1.65	<0.001	1.52	1.28–1.81	<0.001[a]
	Other	1.05	0.74–1.48	0.790	1.21	0.80–1.82	0.364

(continued)

Table 4 Continued

Variable	Category	Unadjusted OR			Adjusted OR ($n = 6350$)		
		OR	CI	*P*-value	OR	CI	*P*-value
Wealth[b]	Quintile 1: lowest (ref)	1.00			1.00		
	Quintile 2	0.78	0.63–0.97	0.028	0.80	0.63–1.00	0.053
	Quintile 3	1.05	0.83–1.34	0.663	1.19	0.92–1.54	0.185
	Quintile 4	1.01	0.80–1.26	0.953	1.21	0.94–1.56	0.129
	Quintile 5	1.05	0.82–1.35	0.697	1.49	1.09–2.04	0.011[a]
Mother's age (years)	–	1.00	0.99–1.01	0.572	–	–	–
Measles							
Area	Rural (ref)	1.00			1.00		
	Urban	0.78	0.70–0.87	<0.001	0.90	0.77–1.05	0.174
	Peri-urban	0.88	0.75–1.04	0.127	0.91	0.75–1.09	0.301
Sex	Male (ref)	1.00					
	Female	0.97	0.87–1.07	0.543	–	–	–
Ethnic group	Mandinka(ref)	1.00			1.00		
	Fula	1.18	1.02–1.36	0.025	1.26	1.07–1.49	0.005[a]
	Wolof	1.14	1.01–1.29	0.028	1.19	1.04–1.36	0.012[a]
	Other	0.88	0.67–1.15	0.355	0.98	0.72–1.35	0.921
Wealth[b]	Quintile 1: lowest (ref)				1.00		
	Quintile 2	0.82	0.69–0.97	0.023	0.86	0.72–1.03	0.274
	Quintile 3	0.83	0.69–1.00	0.047	0.92	0.76–1.12	0.481
	Quintile 4	0.83	0.70–0.99	0.042	0.95	0.78–1.15	0.646
	Quintile 5	0.77	0.63–0.93	0.006	0.97	0.77–1.23	0.718
Mother's age (years)	–	1.00	0.99–1.01	0.694	–	–	–
DTP3							
Area	Rural (ref)	1.00			1.00		
	Urban	0.72	0.65–0.81	<0.001	0.74	0.64–0.87	<0.001[a]
	Peri-urban	0.87	0.74–1.03	0.098	0.85	0.71–1.02	0.083
Sex	Male (ref)	1.00					
	Female	1.00	0.90–1.11	0.986	–	–	–
Ethnic group	Mandinka(ref)	1.00			1.00		
	Fula	1.02	0.88–1.18	0.801	1.03	0.88–1.21	0.707
	Wolof	1.11	0.99–1.26	0.082	1.12	0.98–1.28	0.1
	Other	0.79	0.61–1.04	0.088	0.93	0.68–1.27	0.651
Wealth[b]	Quintile 1: lowest (ref)	1.00			1.00		
	Quintile 2	0.93	0.78–1.11	0.397	0.95	0.79–1.14	0.565
	Quintile 3	0.91	0.76–1.10	0.33	0.97	0.80–1.17	0.727
	Quintile 4	0.80	0.67–0.96	0.013	0.89	0.74–1.07	0.214
	Quintile 5	0.79	0.65–0.95	0.014	1.00	0.79–1.26	0.982
Mother's age (years)	–	1.00	0.99–1.01	0.627	–	–	–

(ref) denotes baseline category of the variable used for regression.

Variables selected for inclusion in multivariable regression if unadjusted *P*-value for any category of the variable <0.25.

[a]Significant adjusted OR, $P < 0.05$.

[b]Wealth quintile calculated using PCA including ownership of: radio; tv; telephone; refrigerator; iron or wooden bed; cart; bicycle; motorbike or scooter; car, truck or tractor; and if dwelling has electricity, water piped into compound or dwelling; flush toilet.

Discussion

This study highlights that despite high coverage for some immunizations, serious gaps exist even in The Gambia, and reaching the United Nations target of 90% of children being fully immunized by 1 year of age (and the Government of The Gambia target of 100% by 2015) remains a challenge. Only 52% of children achieved full immunization by 1 year of age over the study period, with the proportion even lower (47%) among children living in the urban area, indicating that a large proportion of children in this population are not benefiting from the protection against common childhood infections that the immunization schedule aims to provide.

Our data are in accordance with the Gambia MICS 2006 report, where national coverage of full immunization is similarly reported to be only 55.3% (Government of The Gambia 2007). Rates of full immunization in other developing countries vary, with low rates reported in India (less than one-third of rural children and one-half of urban children) and Ethiopia (49%) (Pande and Yazbeck 2003; Tadesse *et al.* 2009). In Bangladesh, high national coverage (75%) conceals low coverage of full immunization in rural areas (42%) suggesting that full immunization remains a challenge for developing countries (Uddin *et al.* 2010).

Despite the fact that The Gambia has reported consistently high national immunization coverage for many years, this study highlights room for improvement, both with overall immunization coverage in some parts of the country and the distribution of this coverage. The proportion of children receiving no vaccines at all is very low (3%) and the coverage of BCG immunization is high, indicating that the system of delivering immunizations at or close to birth works well. However, coverage of later immunizations, such as measles, given at 9 months, is much lower indicating that challenges still exist in follow-up of children throughout the immunization schedule.

Several other studies in developing country settings have found a similar pattern with a drop-off in both measles vaccine coverage and full immunization despite high BCG coverage, indicating that drop-out is a common challenge (PATH 2002; Odusanya *et al.* 2008; Mutua *et al.* 2011).

Coverage of measles immunization of only 73% is of concern and poses a risk to both individual protection and to herd immunity within the community. Cutts (1993) suggests that coverage of at least 90% is required to achieve a marked reduction in measles incidence in Africa; and as high as 98% for elimination. Measles is still a contributor to under-five mortality in The Gambia, accounting for 1% of all under-five mortality in 2008 (WHO 2011a).

DTP vaccine is recommended as multiple doses at 2, 3 and 4 months and a booster at 16 months. The proportion of children receiving the first three doses of DTP is commonly used as measure of how well immunization programmes are functioning (WHO, UNICEF, World Bank 2009). Though even one dose of a vaccine will usually provide some degree of immunity, the full vaccine schedule is recommended to achieve long-lasting, full immunity. In this study, only 79% of children received three or more doses of DTP. Given that other recommended vaccinations, such as Hib and PCV, are delivered at the same point in the schedule as DTP, the low coverage of DTP3 could be a predictor of low coverage of Hib and PCV as well.

The high proportion of children receiving at least one vaccine dose, high coverage of BCG immunization and 67% receiving most of the recommended vaccine doses (12/16) suggest that some of the logistical or infrastructure related barriers to vaccination reported in other developing countries are not an obstacle in The Gambia. TBAs and PHC workers, an integral part of the MCH outreach programme, also play a role in encouraging women to attend MCH clinics. In the surveillance area the regular fieldworker visits every 4 months, and as part of the FHDSS rounds these visits also act as a reminder and communication route with every household regarding immunization services. Capacity issues and insufficient health workers are however recognized issues in The Gambia. This can lead to long queues at immunization clinics, especially in the urban areas; which have previously been reported by women as a deterrent from attending immunization clinics (Cassell *et al.* 2006).

Non-uptake of immunization can be a consequence of either lack of acceptance or willingness but inability to access immunization services, e.g. due to associated costs. Even in a system where immunization is free, the indirect costs such as transport and opportunity costs may be a deterrent for some mothers to get their children immunized, despite general acceptance and robust provision of immunization services (Jamil *et al.* 1999; Canavati *et al.* 2011). Cassell *et al.* (2006) found that non-uptake in The Gambia was usually related to inability to take children to immunization clinics or mothers mistakenly believing their children are fully immunized when they are not, rather than resistance to immunization per se.

The factors determining receipt of immunization are complex and interlinked. In this population, immunization coverage varied by area of residence. In contrast to what has been found in other developing countries (Pande and Yazbeck 2003; Uddin *et al.* 2010), immunization coverage was higher in rural areas than urban townships, as also confirmed by Cassell (2006) and the MICS 2006 (Government of The Gambia 2007).

These differences are small in magnitude but strongly significant and consistent across all outcomes. Few qualitative studies of vaccine coverage (or default) in low- to middle-income countries exist so evidence for the reasons for default among certain groups is limited. The work pattern of the mother or primary caregiver is a possible explanation for higher immunization coverage in rural areas (Canavati *et al.* 2011). Local EPI staff report anecdotally that mother's in urban areas are more likely to be in formal work than their rural counterparts which might interfere with their ability to attend immunization clinics, where they are often required to wait most of the day (EPI Officer, Personal communication). Data on mother's occupation were not captured for this analysis so this hypothesis was not tested. Although clinics are often closer and more accessible in urban areas, Cassell (2006) reported that urban mothers experience more problems with crowding and long waits at the clinics than mothers from rural villages and that cohesive family and social networks in rural villages play a role in facilitating mothers' ability to attend the clinic through 'social orchestration', which is less common in urban areas.

Furthermore, in rural areas, the TBA and PHC workers both play a role in encouraging mothers to attend the MCH clinics. These roles do not formally exist in urban areas and it has been shown in other low-income settings that household visits by health workers positively influence immunization coverage (Jamil *et al.* 1999).

We found that children of Mandinka ethnicity were less likely to be immunized than those of either Fula or Wolof ethnicity. There is minimal literature on ethnic differences in healthcare utilization in The Gambia with which to compare these results.

Anecdotally, local health officers in the North Bank East Region report lower engagement of Mandinka communities with MCH services in general (North Bank East Health Region Public Health Officer, personal communication). The consistency of the ethnicity association across all outcomes in this study suggests that further investigation of the potential ethno-cultural differences in access to, or acceptance of, immunization is warranted.

Family wealth has repeatedly been shown to influence immunization coverage in many developing countries, usually with the poorest being least likely to be immunized. The underlying hypothesis is that the poorest are most disadvantaged by the time, logistics and opportunity costs involved in accessing immunization services (Jamil *et al.* 1999; Tadesse *et al.* 2009; Mutua *et al.* 2011). The lack of association between immunization and family wealth in this study could be expected in a setting where immunizations are free at the point of care and robust outreach services are in place to ensure accessibility in rural areas. Household wealth was measured using a one-off household asset survey carried out in 2007. Comparative data for earlier years were not available. It is possible that relative changes in household wealth over the study time period could have occurred, influencing the lack of association between vaccine coverage and wealth found here.

The strengths of this study include a rigorous and frequent data collection process, a reasonably stable population; and few significant changes to the delivery of the immunization programme over the time span of the study.

However our study also has some limitations. Some potential confounding variables of interest were not available for analysis such as use of antenatal care and mother's education which has often been found to be associated with immunization coverage in low- to middle-income countries (Bosu *et al.* 2003; Hilber *et al.* 2010; Sullivan *et al.* 2010). It is unclear whether these variables would have influenced the associations found here. In addition, supply side factors, such as vaccine availability, adverse events or environmental catastrophe have potential to impact immunization coverage but the authors found no evidence of these factors affecting the FHDSS area.

Despite consistent data collection processes across the FHDSS and fieldworkers being encouraged to ask about immunizations for all households, immunization data have been collected only for a subset of the population with a higher proportion of rural children surveyed with respect to immunizations. Although the sample for which immunization data were collected was shown to be similar, in terms of a number of demographic characteristics, to the general population, it is possible that there are additional factors that differ in distribution between these groups which were not adjusted for. Regression analysis was limited to the subset of children for whom data on all predictor variables were available ($n = 6350$, 86%); however, this subset was representative of the whole sample in terms of demographic characteristics.

All children born during the study period, for which immunization data were available, were included in the analyses. It is reported that ~5% of children born in this area die during their first year (Jasseh *et al.* 2011). Given that children do not always receive immunizations exactly according to the schedule it is impossible to quantify exactly how many of these children would have been immunized had they survived longer. However, assuming some would have gone on to receive further immunizations, coverage rates for the vaccines received later in the first year are likely to be slight underestimates in our results.

Immunization data on children born before 2005 were collected retrospectively. Given immunization data were taken from the child's healthcard for 98% of children, retrospective data entry is unlikely to have lead to any serious bias.

A key question of course remains: what is the impact of the immunization coverage levels on disease and mortality? Some recent research reports declines in child mortality in The Gambia, against a backdrop of fairly consistent national immunization rates, suggesting that this improvement might be due to factors such as a reduction in malaria mortality, improved oral rehydration for diarrhoea and better sanitation (Hill *et al.* 2000; Jasseh *et al.* 2011). However, the importance of the protective effect of immunization against child mortality should not to be overlooked due to the high attributable risk of mortality from lack of immunization (Rutherford *et al.* 2009). Given the role that measles still plays in under-five mortality in The Gambia, the immunization coverage rate of 73% indicates there is further scope for decreasing mortality by improved immunization. Equally, with pneumonia still a significant cause of childhood mortality and recent introduction of the PCV, improved coverage rates of immunizations delivered at 2, 3 and 4 months, which now include PCV, have potential to further decrease mortality.

Given the low coverage of full immunization, it would be valuable to gauge the impact of lack of full immunization on levels of protective antibody, in particular through to adulthood—often secured through delivery of booster vaccine doses. This is especially pertinent in women of child-bearing age as immunity in adulthood influences the immunity provided to infants through maternal antibodies (Jones *et al.* 2011).

Initiatives to improve rates of full immunization need to respond to the barriers to immunization. While this analysis is useful for determining the gaps in immunization coverage and the socio-demographic factors associated with coverage, further qualitative research is needed to better understand why differences exist in different groups of the population and what barriers prevent full immunization. Evidence of effective interventions in response to these barriers is also required. Current evidence indicates that patient reminders help to increase immunization rates; however, most studies using reminders and patient recall have been carried out in developed countries and such systems usually require technologies that may be lacking in low-income countries (Szilagyi *et al.* 2002; Oyo-Ita *et al.* 2011). Evidence also suggests that interventions such as facility-based health education, evidence-based discussions and targeted information campaigns can improve immunization coverage (Oyo-Ita *et al.* 2011). Such interventions are feasible in low-income countries.

Conclusions

Immunization remains an important tool to reduce childhood mortality with additional vaccines now available and ready to be taken up. This study highlights that, despite high levels of coverage of many individual vaccines, full immunization remains a challenge, even in a country with a committed childhood immunization programme, such as The Gambia. We identified groups of the population who are potentially more at risk of defaulting on immunizations. The results of this study can be used to target the groups with lower immunization coverage and to encourage further research into how barriers to full immunization can be overcome. Interventions such as information campaigns and catch up campaigns, targeted specifically to those with lower immunization coverage such as Mandinka ethnic groups and focused on immunizations late in the schedule, should be explored by the Gambia EPI.

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