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RESEARCH ARTICLE

Crude childhood vaccination coverage in West Africa: Trends and predictors of completeness [version 1; referees: 1 approved, 3 approved with reservations]

Jacob S. Kazungu^{1,2}, Ifedayo M.O. Adetifa ²⁻⁴

¹Department of Public Health, Pwani University, Kilifi, Kenya

²Epidemiology and Demography Department, KEMRI-Wellcome Trust Research Programme, Centre for Geographic Medicine Research (Coast), Kilifi, Kenya

³College of Medicine, University of Lagos, Lagos, Nigeria

⁴Department of Infectious Disease Epidemiology, London School of Hygiene and Tropical Medicine, London, UK

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Abstract

Background: Africa has the lowest childhood vaccination coverage worldwide. If the full benefits of childhood vaccination programmes are to be enjoyed in sub-Saharan Africa, all countries need to improve on vaccine delivery to achieve and sustain high coverage. In this paper, we review trends in vaccination coverage, dropouts between vaccine doses and explored the country-specific predictors of complete vaccination in West Africa. **Methods:** We utilized datasets from the Demographic and Health Surveys Program, available for Benin, Burkina Faso, The Gambia, Ghana, Guinea, Cote d'Ivoire, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo, to obtain coverage for Bacillus Calmette-Guerin, polio, measles, and diphtheria, pertussis and tetanus (DPT) vaccines in children aged 12 – 23 months. We also calculated the DPT1-to-DPT3 and DPT1-to-measles dropouts, and proportions of the fully immunised child (FIC). Factors predictive of FIC were explored using Chi-squared tests and multivariable logistic regression. **Results:** Overall, there was a trend of increasing vaccination coverage. The proportion of FIC varied significantly by country (range 24.1-81.4%, mean 49%). DPT1-to-DPT3 dropout was high (range 5.1% -33.9%, mean 16.3%). Similarly, DPT1-measles dropout exceeded 10% in all but four countries. Although no single risk factor was consistently associated with FIC across these countries, maternal education, delivery in a health facility, possessing a vaccine card and a recent post delivery visit to a health facility were the key predictors of complete vaccination. **Conclusions:** The low numbers of fully immunised children and high dropout between vaccine doses highlights weaknesses and the need to strengthen the healthcare and routine immunization delivery systems in this region. Country-specific correlates of complete vaccination should be explored further to identify interventions required to increase vaccination coverage. Despite the promise of an increasing trend in vaccination coverage in West African countries, more effort is required to attain and maintain global vaccination coverage targets.

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Corresponding author: Ifedayo M.O. Adetifa (IAdetifa@kemri-wellcome.org)

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Background

Over the last half-century or more, vaccination, as one of the most cost effective public health interventions ever, has been key to reducing child morbidity and mortality worldwide¹. Vaccination is essential to preventing target diseases of interest². Consequently, coverage above the minimum thresholds for the target disease or global targets is required to enjoy the full benefits of vaccination^{1,3,4}. Vaccination coverage is a performance indicator of immunisation programmes, which is also used to track global and national progress in the control of vaccine-preventable diseases (VPD). It is also an eligibility criterion for funding in many low and middle-income countries (LMICs)⁵.

With massive global and national investments in vaccination programmes, there have been significant improvements in global childhood vaccination coverage. For example the proportion of children who received the third dose of diphtheria-tetanus-pertussis vaccine (DTP3) by 12 months of age increased from 5% in 1974 to 86% in 2015 (http://www.who.int/immunization/monitoring_surveillance/who-immuniz-2015.pdf?ua=1)⁶. Unfortunately, DTP3 coverage has since stagnated at 85% since 2010 and many LMICs in sub-Saharan Africa (sSA), Eastern Mediterranean and South East Asia Regions of the world have not attained the recommended targets of 90% national vaccination coverage and <10% dropout between vaccine doses. (http://www.who.int/immunization/global_vaccine_action_plan/en/ and http://www.who.int/immunization/monitoring_surveillance/who-immuniz-2015.pdf?ua=1)

These global data masks the widely variable vaccination coverage in LMICs, particularly in sSA countries that only attained 76% DTP3 coverage in 2015⁶. Besides, there are also regional differences in DTP3 coverage of 69% in West and Central compared to 79% in Eastern and Southern Africa (http://data.unicef.org/core-code/uploads/document6/uploaded_pdfs/corecode/Immunization_Summary_2012_Eng_40). When the fully immunised child is considered, less than half of children in its Eastern region are fully immunised⁷. There are also widely varying vaccination coverage in countries within a region, for example overall DTP3 coverage ranges from 56% in Nigeria to 97% in The Gambia ([http://apps.who.int/immunization_monitoring/globalsummary/countries?countrycriteria\[country\]\[\]=GMB](http://apps.who.int/immunization_monitoring/globalsummary/countries?countrycriteria[country][]=GMB)). Yet achieving and maintaining high vaccination coverage could potentially avert millions of VPD-related deaths in children and yield into an estimated \$63 billion in savings during the decade 2011 – 2020⁸. Good quality vaccination data is required to understand inequities in access to vaccines. Most vaccination coverage estimates in LMICs are from administrative reports that tend to overestimate coverage, due to errors in the number of vaccine doses administered and/or invalid assumptions about the size of the target population of children.

DTP3 for children sampled between 12 and 23 months is the principal surrogate measure of vaccination coverage and performance of national immunization programmes. However, the proportions of fully immunised children are often considered better indicators of the full benefits of immunisation compared to DTP3 within countries⁹.

Using datasets from the Demographic and Health Surveys Program (DHS: <https://dhsprogram.com/>), we conducted a comprehensive

review of the trends in vaccination coverage, dropouts between vaccine doses and country-specific predictors of a fully immunised child (FIC) in the West African region.

Methods

Study area and population

This study utilized datasets from DHS conducted in 13 West African countries: Benin, Burkina Faso, Cote d'Ivoire, The Gambia, Ghana, Guinea, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo. DHS methodology encompasses a two-stage cluster sample design that produces unique, consistent, and nationally representative data that are comparable across countries¹⁰. While these DHS datasets are not primarily carried out to collect vaccination data, they incorporate a questionnaire for women of reproductive age (15–49 years) for maternal and child health (including immunisation) in relation to all births within the preceding five years⁵. DHS survey interviewers obtain immunization information from vaccine cards and/or mother's/respondent's recall.

For countries with multiple datasets between 2000 and 2013, we assessed trends in vaccination coverage using their two most recent standard DHS datasets, as follows: Benin (2006 and 2011–12); Burkina Faso (2003 and 2010); Ghana (2003 and 2008); Guinea (2005 and 2012); Liberia (2007 and 2013); Mali (2006 and 2012–13); Niger (2006 and 2012); Nigeria (2008 and 2013); Senegal (2005 and 2010–11) and Sierra Leone (2008 and 2013). The rest of the analyses to calculate dropouts and determine the predictors of a FIC included countries with single datasets (Cote d'Ivoire 2011–12, The Gambia 2013, and Togo 2013–14) and the most recent dataset for those countries with multiple datasets.

Data management and analysis

We followed the widely recommended strategy for measuring complete vaccination status by restricting our datasets to children aged 12–23 months and dropping all children that had passed away by the date of interviews^{7,11,12}.

Our primary outcome was the fully immunised child (FIC). A FIC was defined as having received at birth or first contact, a dose of Bacille Calmette-Guérin vaccine (BCG), a 3-dose course of the diphtheria, pertussis and tetanus combination vaccine (DPT), and oral polio vaccine (OPV; given at 6, 10 and 14 weeks or at least four weeks apart) and a dose of measles-containing vaccine (MCV1; administered at 9 months), as reported by vaccine card or caregiver recall^{9,13}. Other outcomes of interest in this study included access and utilization to immunization services. Good access was defined as having a DPT1 coverage of >80%, whereas a good utilization was defined as a DPT1-to-DPT3 dropout <10%¹⁴.

All statistical analyses were performed using STATA software, version 13.1 (StataCorp, Lakeway Drive, College Station, TX, USA). In descriptive analysis, we reported the proportions of FIC and those who received each vaccine dose by country, as well as the percentage DPT1-to-DPT3 and DPT1-to-MCV1 dropout¹⁵.

Chi-square tests were utilized in univariate analyses to examine associations between FIC and possible risk factors. The risk factors considered were: maternal age, maternal education, gender, religion, place of delivery, marital status, distance from home to

nearest health facility, possession of a vaccine card, number of siblings, birth order, socio-economic status, rural or urban residence, and whether the child received a check-up within two months of birth^{7,13,16–21}. Following this, we constructed multivariable logistic regression models within each country to examine the correlates of FIC. All factors identified at 10% significance (P-value <0.10) in univariate analysis were incorporated into the model. Before fitting the model, we assessed for potential collinearity using the Pearson's R correlation coefficient ($r > =0.8$), and retained strongly correlated variables as suggested in the literature^{22,23}.

To account for the complex DHS survey design, the *svyset* command in STATA was used to apply inverse probability weights (http://www.ats.ucla.edu/stat/stata/faq/svy_introsurvey.htm). Adjusted odds ratios (AORs) and 95% confidence intervals are reported at a 5% significance level.

Ethics statement

Ethical approval was not required for this study because it used anonymised DHS data. DHS surveys are conducted only after approvals have been given by the ICF International Institutional Review Board (IRB) and country IRBs for country-specific DHS survey protocols. In addition, written informed consent is obtained from each survey participant (<http://www.dhsprogram.com/What-We-Do/Protecting-the-Privacy-of-DHS-Survey-Respondents.cfm>). The aggregate data utilised in this study was made freely available by DHS after a simple registration process on their website (<http://www.dhsprogram.com/data/new-user-registration.cfm>), which includes providing an explanation for the need for the datasets and planned analyses.

Results

Coverage by vaccine and proportions of the FIC

As shown in [Table 1](#), coverage for each vaccine also varied by country. For BCG, it ranged from 50.6% in Nigeria to 98.4% in The

Gambia, with only seven countries attaining the 90% Global Vaccine Action Plan target. Similarly, DPT1-to-DPT3 coverage remained low in a number of countries, with DPT3 coverage not reaching the 90% target in all countries. Despite similarly low OPV1-to-OPV3 coverage proportions, a sharp difference in DPT3 and OPV3 was observed in Nigeria – 38.0% and 53.3%, respectively. For measles, the 90% target was only achieved in Ghana (90.2%).

The proportions of the FIC varied across the 13 countries ranging from 24.1% in Nigeria to 81.2% in Burkina Faso ([Table 2](#)). These proportions were significantly different ($p < 0.01$). Burkina Faso also had the lowest numbers of partially vaccinated children. The highest proportions of completely unvaccinated and partially vaccinated children were seen in Nigeria, whereas Ghana had the lowest proportion of unvaccinated children.

Trend in vaccination coverage

Across all 10 countries, there was an overall increase in vaccination coverage for all vaccines, but country-specific coverage actually declined by over 25% in Benin and Mali when their last two DHS datasets are compared (see [Table 3](#)). BCG coverage increased in all countries except in Benin. In particular, Burkina Faso, Liberia, and Niger achieved substantial improvements in coverage of this vaccine.

DPT1 coverage declined in five countries - Benin, Guinea, Mali, Nigeria and Senegal - while DPT2 coverage increased in all countries except Benin, Liberia, and Mali. The biggest gains in DPT3 coverage was seen in Niger, Burkina Faso, Liberia and Sierra Leone. For DPT3, none of the countries attained the 90% target, with three countries recording a decline in coverage (see [Table 1](#) and [Table 3](#)).

For the polio vaccines, OPV1, OPV2, and OPV3 coverage increased in all countries except for Benin and Mali, where there was a 27%

Table 1. Percentage coverage for each vaccine in children aged 12–23 months across selected West African countries. BCG, Bacille Calmette-Guérin vaccine; DPT, diphtheria, pertussis and tetanus; OPV, oral polio vaccine; FIC, fully immunised child.

Country	Survey year	BCG	DPT1	DPT2	DPT3	OPV1	OPV2	OPV3	Measles	FIC
Benin	2011–12	86.0	69.0	65.6	58.7	81.1	75.3	53.1	67.8	35.0
Burkina Faso	2010	96.4	94.3	92.7	89.5	97.3	95.5	90.2	87.3	81.2
Cote d'Ivoire	2011–12	83.0	77.4	71.6	63.8	91.1	83.7	69.0	63.9	49.6
Gambia	2013	98.4	94.1	93.3	87.8	96.6	94.3	88.7	87.3	72.5
Ghana	2008	95.7	97.5	95.5	89.3	96.7	94.3	86.8	90.2	78.8
Guinea	2012	82.3	75.5	62.3	49.9	84.2	71.4	51.1	61.4	36.1
Liberia	2013	93.8	91.3	82.0	71.5	95.4	86.8	70.3	74.1	54.6
Mali	2012–13	78.3	74.2	68.8	58.6	77.5	70.3	45.2	66.6	33.9
Niger	2012	83.5	85.2	78.4	68.2	91.2	84.6	75.3	68.0	51.0
Nigeria	2013	50.6	50.0	45.1	38.0	75.8	69.4	53.3	41.4	24.1
Senegal	2010–11	93.8	92.9	89.9	81.8	93.8	89.9	72.1	81.1	60.6
Sierra Leone	2013	95.4	93.0	88.2	78.1	93.5	88.3	77.9	77.9	67.0
Togo	2013–14	95.0	92.9	89.1	82.5	93.7	88.9	73.8	74.1	60.5

Table 2. Proportions of the Fully Immunized Child* in children aged 12–23 months across selected West Africa countries.

	Benin	Burkina Faso	Cote d'Ivoire	Gambia	Ghana	Guinea	Liberia	Mali	Niger	Nigeria	Senegal	Sierra Leone	Togo	P-value ²
	2011–12	2010	2011–12	2013	2008	2012	2013	2012–13	2012	2013	2010–11	2013	2013–14	
	N=2535 ¹	N=2822 ¹	N=1432 ¹	N=1660 ¹	N=552 ¹	N=1296 ¹	N=1272 ¹	N=1846 ¹	N=2275 ¹	N=5900 ¹	N=2169 ¹	N=2169 ¹	N=1395 ¹	
	%	%	%	%	%	%	%	%	%	%	%	%	%	
Fully immunized	35.0	81.2	49.6	72.5	78.8	36.1	54.6	33.9	51.0	24.1	60.6	67.0	60.5	<0.01
Partially immunized	53.3	17.0	45.5	26.3	20.2	53.0	43.8	49.0	44.4	54.9	36.2	29.5	36.0	
Not immunized	11.7	1.8	4.9	1.3	1.0	10.9	1.6	17.1	4.6	21.0	3.2	3.5	3.5	

*Complete vaccination coverage as recommended by World Health Organisation (WHO) (a dose of BCG, 3 doses of polio, 3 doses of DPT and a dose of measles vaccine)

¹Weighted values

²P-values corresponding χ^2 test used to determine statistically significant differences by country in the percentages of children ages 12–23 months, who received complete vaccination according to WHO recommendation.

Table 3. Trends in vaccination coverage in children aged 12–23 months across selected countries in West Africa.

Country	Benin		Burkina Faso		Ghana		Guinea		Liberia		Mali		Niger		Nigeria		Senegal		Sierra Leone		
	2006	2011–12	2003	2010	2003	2008	2005	2012	2007	2013	2006	2012–13	2006	2012	2008	2013	2005	2010–11	2008	2013	
Survey Year	%		%		%		%		%		%		%		%		%		%		
Percentage change																					
BCG	-2.5		21.1		5.7		3.5		22.1		2.8		31.7		2.8		2.5		17.5		
DPT1	-17.6		25.2		7.7		-1.8		22.1		-10.2		47.4		-2.7		-0.3		22.7		
DPT2	-14.8		38.2		8.2		42.5		-4.9		-9.8		62.7		1.3		1.7		27.3		
DPT3	-12.6		58.4		12.3		-2.7		43.9		-14.0		72.7		7.0		4.7		29.3		
OPV1	-7.9		13.8		4.5		2.2		15.9		-8.5		17.7		13.3		0.1		25.3		
OPV2	-5.6		28.9		6.6		2.4		20.9		-8.5		19.7		21.8		4.1		30.0		
OPV3	-17.5		53.9		9.5		1.0		44.4		-27.3		34.0		38.1		-1.1		57.7		
MCV1	11.1		57.0		9.5		22.8		19.5		-2.2		45.6		0.7		11.6		32.3		
Not Vaccinated	69.6		-81.1		-80.0		-22.1		-86.9		35.7		-72.1		-27.6		-15.8		-78.3		
Received all 8 vaccine doses	-25.4		90.2		15.4		-2.4		45.2		-28.3		78.9		9.5		5.0		73.1		

reduction in coverage. OPV3 coverage also declined slightly in Senegal. For OPV3, the biggest gains in coverage were seen in Sierra Leone, Burkina Faso, Liberia, Nigeria and Niger.

Despite a decline in coverage of all other vaccines in Benin, MCV1 coverage actually increased, which was also seen in all other countries except Mali. The biggest gains in MCV1 coverage were seen in Burkina Faso, Niger and Sierra Leone. Recommended MCV1 coverage targets were not met in any of these West African countries, except for Ghana (Table 1).

Across all countries, there were major reductions in the number of unvaccinated children, ranging from 22–81% reduction, except in Benin and Mali where they increased by 70% and 36%, respectively. Similarly, the proportions of the FIC increased in most countries, except Benin, Guinea, and Mali.

Dropout proportions

DPT1-to-DPT3. The proportion of DPT1-to-DPT3 dropouts varied across countries ranging from 5.1% in Burkina Faso to a high of 33.9% in Guinea. All except three countries - Burkina Faso, Gambia, and Ghana - had high DPT-1-to-DPT-3 dropouts (i.e. >10%)^{24,25}, indicating a region-wide problem with utilisation of immunisation services (Table 4). Based on their low DPT1 coverage (<80%), five out of 13 countries also had poor access to immunisation services^{24,25}. Three out of 13 countries reported high DPT1

coverage (>80%), a correlate of good access to immunisation services, and a low DPT1-to-DPT3 dropout (<10%), which is an indication of good utilization of these services.

DPT1-to-MCV1. Given the DPT1-to-MCV1 dropout of <10% in Benin, Burkina Faso, Ghana and The Gambia, children in these countries were more likely to have received all the recommended vaccines by one year of age compared to children from all other countries reviewed (Figure 1).

Predictors of complete vaccination status

In univariate analysis, possession of a vaccine card was associated with increased likelihood of FIC status in all countries. In addition, delivery at a hospital/health facility, and attendance of a well-baby clinic for review/check-up within two months of birth were related to complete vaccination in all countries, except Gambia and Ghana.

Although many countries shared the same predictors or risk factors for complete vaccination in multivariable regression models, the results were still quite variable as shown in the AORs presented in Table 5. Delivery at a health facility remained a significant predictor of a FIC, such that children born at a health facility were 1.5–2.3 times more likely to be fully immunised compared to those born at home in Benin, Burkina Faso, Cote d'Ivoire, Guinea, and Nigeria.

Table 4. Proportion of dropouts between DPT1 and DPT3 in West African children aged 12–23 months by country.

Country	DPT3 vaccinated	DPT1 vaccinated	Drop out	Dropout %	Access	Utilization	Problem Type
Benin	58.7	69.0	10.3	14.9	Poor	Poor	4
Burkina Faso	89.5	94.3	4.8	5.1	Good	Good	1
Cote d'Ivoire	63.8	77.4	13.6	17.6	Poor	Poor	4
Gambia	87.8	94.1	6.3	6.7	Good	Good	1
Ghana	89.3	97.5	8.2	8.4	Good	Good	1
Guinea	49.9	75.5	25.6	33.9	Poor	Poor	4
Liberia	71.5	91.3	19.8	21.7	Good	Poor	2
Mali	58.6	74.2	15.6	21.0	Poor	Poor	4
Niger	68.2	85.2	17.0	20.0	Good	Poor	2
Nigeria	38.0	50.0	12.0	24.0	Poor	Poor	4
Senegal	81.8	92.9	11.1	11.9	Good	Poor	2
Sierra Leone	78.1	93.0	14.9	16.0	Good	Poor	2
Togo	82.5	92.9	10.4	11.2	Good	Poor	2

Dropout = DPT1 – DPT3

Dropout % = (Dropout/DPT1)* 100

1 = Drop-out rates are low (<10%)= good utilization & DPT1 coverage is high (>=80%)= good access

2 = Drop-out rates are high (>=10%)= poor utilization & DPT1 coverage is high (>=80%)= good access

3 = Drop-out rates are low (<10%)= good utilization & DPT1 coverage is low (<80%)= poor access

4 = Drop-out rates are high (>=10%)= poor utilization & DPT1 coverage is low (<80%)= poor access

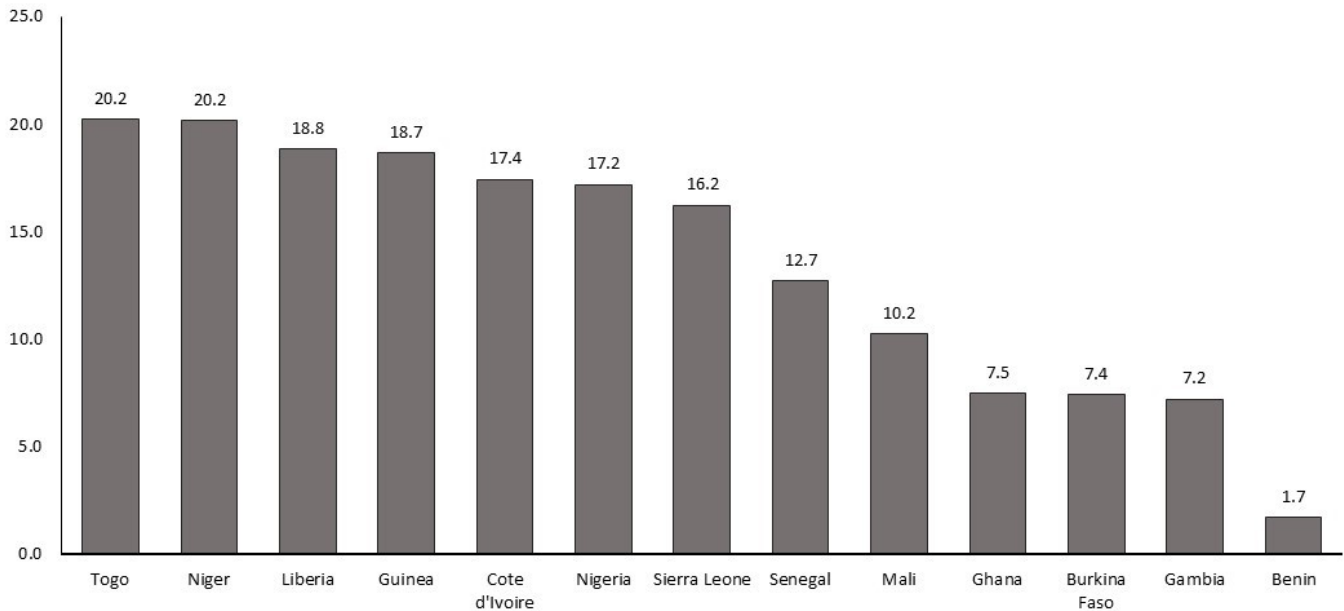


Figure 1. Proportion of DPT1-to-MCV1 dropouts among children aged 12–23 months in selected West African countries.

Possession of a vaccine card was also significantly associated with full immunisation in all countries, except in Ghana, and the effect size was particularly significant in Togo where those with a vaccine card were almost 14 times more likely to be fully immunised.

Children who attended a check-up/clinic appointment within two months of birth had significantly greater odds of a FIC status in nine countries: Benin, Burkina Faso, Cote d'Ivoire, Guinea, Mali, Niger, Nigeria, Senegal and Togo.

In Liberia, Nigeria, and Togo, birth order was an important predictor of FIC. Compared to first-born children, second-born or higher birth order children had lower odds of FIC status only in Liberia, Nigeria, and Togo. Maternal education was also an important predictor of FIC in Cote d'Ivoire, Liberia, and Senegal, while the distance from vaccine clinics reduced the odds of FIC in Mali and Niger. The direction of the effects of socio-demographic factors like maternal marital status and rural residence on FIC status were not consistent across these West African countries. For example, rural residence was a predictor of FIC in The Gambia, but contributed to lower odds of full immunisation in Ivoirian children. Similarly, children born to mothers who were married or previously married were 2.2–9.7 times more likely to be fully immunised in Ghana, but this was 0.3–0.5 times lower in Senegal.

Discussion

Despite the promising trend of increasing vaccination coverage observed in the region, the mean prevalence of the fully immunised child (FIC) was only 49%, indicating the poor state of vaccination coverage in this region and its constituent countries. Although there were significant inter-country variations in the prevalence of the FIC (ranging from 24% in Nigeria to 81% in Burkina Faso), the overall picture highlights the need for increased and consistent

interventions to improve vaccination coverage in countries of West Africa. According to our analyses, some of the worst performing countries have made significant progress, but they are still clearly far off track towards achieving global vaccination coverage targets.

Although there was no single risk factor/predictor for FIC across all the West African countries covered in this study, delivery in a health facility and attending a well-baby clinic visit within two months of birth were common to over 50% of these countries. The other risk factors were less prevalent or relevant to fewer countries. In order to identify interventions to increase the proportion of the FIC in these countries, multidisciplinary investigations into the social (culture, religion, behaviour, etc.), health systems, political and economic correlates of childhood vaccination in countries of this region in much finer detail is essential.

In particular, this study highlights the enormous gap in the ability of healthcare service delivery system to minimize dropouts. The proportion of DPT1-to-DPT3 dropouts measure the consistency of a vaccination programme in delivering the same antigen(s) multiple times over a relatively short period. On the other hand, DPT1-to-MCV1 assesses dropouts over an extended period in the life of an infant and is considered a better measure of the overall effectiveness of immunization programs²⁶.

Children in Benin, Cote d'Ivoire, Guinea, Mali, and Nigeria were less likely to complete the schedule for repeated vaccines given DPT1-to-DPT3 dropout levels were higher than the WHO 10% threshold^{27,28}. The reasons for this are not immediately obvious. All five countries are ranked quite low on the Human Development Index (HDI) with Mali and Guinea among the ten countries with the lowest HDI in Africa (http://www.instituto-camoes.pt/images/cooperacao/relatorio_ocde14b.pdf). However, the conditions of

Table 5. Predictors of complete vaccination status according to WHO recommendations for FIC status in West African children aged 12–23 months.

	Benin	Burkina Faso	Cote d'Ivoire	The Gambia	Ghana	Guinea	Liberia	Mali	Niger	Nigeria	Senegal	Sierra Leone	Togo
Visit within 2 months	1.5 (1.2, 1.8)*	1.7 (1.2, 2.3)*	1.6 (1.1, 2.3)*	-	-	1.6 (1.1, 2.3)*	-	1.5 (1.1, 1.9)*	2.1 (1.6, 2.7)*	1.4 (1.2, 1.8)*	1.7 (1.3, 2.3)*	-	1.5 (1.0, 2.1)*
Birth order													
1 st	-	-	-	-	-	-	Ref	-	-	Ref	-	-	Ref
2 nd –3 rd	-	-	-	-	-	-	0.6 (0.4, 0.9)*	-	-	0.8 (0.6, 1.0)*	-	-	0.7 (0.5, 1.1)
≥4 th	-	-	-	-	-	-	0.7 (0.4, 1.1)	-	-	0.7 (0.5, 0.9)*	-	-	0.6 (0.4, 0.8)*
Place of delivery	2.3 (1.6, 3.4)*	2.0 (1.5, 2.7)*	2.0 (1.4, 2.8)*	-	-	1.9 (1.3, 2.6)*	-	-	-	1.5 (1.2, 1.9)*	-	-	-
Has a vaccine card	3.3 (2.6, 4.1)*	7.8 (5.7, 10.5)*	12.8 (7.9, 20.7)*	10.8 (6.2, 18.9)*	-	11.3 (7.5, 17.0)*	7.6 (5.3, 11.0)*	3.2 (2.4, 4.3)*	5.8 (4.5, 7.4)*	9.9 (7.9, 12.4)*	9.1 (7.0, 11.8)*	4.1 (3.0, 5.5)*	13.8 (10.0, 19.0)*
Rural residence	-	-	0.6 (0.4, 0.9)*	2.0 (1.3, 3.1)*	-	-	-	-	-	-	-	-	-
Mother's Education													
None	-	-	Ref	-	-	-	Ref	-	-	-	Ref	-	-
Primary	-	-	1.8 (1.2, 2.7)*	-	-	-	0.9 (0.6, 1.3)	-	-	-	1.1 (0.8, 1.5)	-	-
Secondary/higher	-	-	3.1 (1.8, 5.4)*	-	-	-	2.3 (1.4, 3.7)*	-	-	-	1.9 (1.2, 2.9)*	-	-
Mother's marital status													
Never married	-	-	-	-	Ref	-	-	-	-	-	Ref	-	-
Currently married	-	-	-	-	2.2 (1.0, 4.7)*	-	-	-	-	-	0.5 (0.3, 0.8)*	-	-
Formerly married	-	-	-	-	9.7 (1.1, 82.9)*	-	-	-	-	-	0.3 (0.1, 0.8)*	-	-
Distance to health facility	-	-	-	-	-	-	-	0.6 (0.4, 0.8)*	0.8 (0.6, 1.0)*	-	-	-	-
Mother's age group													
≤24	-	-	-	-	-	-	-	-	-	Ref	-	-	-
25–29	-	-	-	-	-	-	-	-	-	1.6 (1.2, 2.1)*	-	-	-
≥30	-	-	-	-	-	-	-	-	-	1.8 (1.3, 2.4)*	-	-	-

*Identifies the significant factors

-Data omitted from this table because no association was seen in univariate analyses

Ref – Reference for the various categories in each variable with >2 outcomes

literacy, life expectancy and income per capital resulting in a low HDI rank are only a part of the explanation, since Burkina Faso has excellent access and utilization of vaccination services and is also among the 10 lowest HDI ranked countries in Africa. Health system weaknesses caused by security challenges, civil war, insurgency, and political unrest are also very likely contributors. For example, Cote d'Ivoire suffered a second civil war in 2011, Guinea and Mali experienced health system weaknesses driven by political instability and insurgency, which for Guinea in particular, contributed to the country being the epicentre of the 2014 Ebola Epidemic. Mali's predominantly rural population, a significant proportion that is nomadic scattered across a vast landmass that is the seventh largest in Africa, highlights its challenge with access and utilization of immunisation services. That Nigeria is the only country in Africa to have never eradicated polio perhaps underscores the challenges faced in delivery and access to vaccines, especially in the northern part of that country.

Only three countries -Ghana, Gambia and Burkina Faso - had acceptable DPT1-to-DPT3 drop-out levels i.e. <10%. The Gambia and Burkina Faso have good access to and utilization of immunization services despite a HDI rank of 175 and 185, respectively, suggesting other context specific issues contribute to high childhood vaccination coverage. Ghana ranked over 35 places on the HDI than Gambia, which is a country where >60% of the population live within a convenient distance from a health centre, and 80% vaccine coverage was achieved since 1990²⁹. Unsurprisingly, the same countries with low DPT1-to-DPT3 dropout also had the lowest DPT1-to-MCV1 dropout, with the surprise inclusion of Benin.

Our findings here are similar to results found in other studies using dropout between BCG and MCV1^{30,31}. Since all, except the aforementioned countries, had DPT1-to-MCV1 dropout of >10%, there is clearly a region-wide problem with retention of infant cohorts by immunisation services. With the Ebola-hit countries, Liberia, Guinea, and Sierra Leone, which were among those with the highest dropout, poor retention confirms that a weak health system is a predisposing factor to disease outbreaks and significant mortality from VPDs^{32,33}. There are large inter-country differences observed in access (DPT1-to-DPT3 drop-out) and utilization (DPT1-to-MCV1 drop-out) of immunization programmes. In order to identify and implement interventions to increase access and utilization, affected countries need to conduct in-depth investigations of associated risk factors/predictors for poor vaccine coverage and healthcare utilization³⁴.

In all countries, except Ghana, having a vaccine card was a significant predictor of FIC. Vaccine cards are thought to be essential in promoting complete vaccination in children by acting as information resources¹⁶. Similar to our findings, other studies have also shown the importance of vaccine cards in promoting child health and immunization^{13,35}.

Delivery in a hospital or a health facility is associated with higher vaccine coverage because early contact with the healthcare system

during and following parturition ensures prompt delivery of birth vaccines (BCG, OPV0, and Hepatitis B) and provides an opportunity to reinforce the need for immunization to mothers and other caregivers^{7,21}. Similarly, increasing contact time with the healthcare system through post-natal appointments has also been associated with increased vaccination coverage. As shown in this study, receiving a check-up within two months of birth was associated with full immunisation. These kinds of visits achieve this by affording health care workers opportunities to review vaccination histories, and reinforce (and/or clarify) vaccine-related information. It also results in reduced missed opportunities and contributes to higher compliance with the childhood immunisation schedule^{7,36}.

It is not surprising that, along with higher maternal age (one country), maternal education (three countries) was associated with complete vaccination status. Other investigators have reported educated mothers tend to have better health care seeking behaviour, due to a better understanding of the benefits of medical care, including the benefits of spacing their children³⁷.

Our study had some limitations. We used DHS data that is designed to be comparative at national and regional levels, so the findings here do not have the richness of detail for a finer examination of coverage and associated risk factors at the level of districts or settlements. These surveys assess vaccination status by vaccine card record and parental recall. Recall of vaccination history introduces recall bias. In addition, using vaccine cards as a source document from which vaccination histories were obtained alongside recall may have introduced some ascertainment bias. It is possible the varying effect sizes for vaccine cards observed was driven by card retention within countries and the contribution of parental recall to the ascertainment of exposure to vaccination, which may overestimate vaccination coverage.

Even with a probability-based sampling design, underserved populations or those most likely to be unimmunized may be undersampled by vaccination coverage surveys, like DHS. Clusters with a larger population are more likely to be selected compared to less populated clusters, increasing the risk of oversampling high populated areas and making the sample less representative. The net effect of this will be exaggerated vaccination coverage. To counter this, we applied survey weighting in our analyses.

It would have been useful to examine other sources of survey coverage data to validate or triangulate the DHS data used in the study. One likely source is from the results of the UNICEF-led Multiple Indicator Cluster Surveys (MICS, <http://mics.unicef.org/surveys>). However, this was not possible for two key reasons. First, the survey years do not overlap, and secondly, there is a slight difference in methodology as DHS surveys record all vaccines given before the survey, while MICS looks at all vaccines given just before the first birthday in the target population. Nonetheless, the DHS surveys are rigorously designed and utilize well validated methodology.

Conclusions

Most West African countries lag significantly behind the global targets of 90% national vaccination coverage and < 10% dropout between vaccine doses. Although there has been some progress in increasing vaccination coverage in the region, global and regional vaccination coverage targets will not be achieved without improving on and maintaining the uptake of vaccines in these countries. Health system weaknesses and inefficiencies responsible for the unacceptably high dropout rates between vaccine doses needs to be tackled urgently. Given the importance of the correlates of complete vaccination in the region, as highlighted in this study, countries should implement interventions to address locally relevant predictors of complete vaccination to achieve and sustain higher vaccination coverage, leading towards the end of preventable deaths of newborns and children less than five years of age by 2030.

Data availability

The datasets and variable codebooks are freely and publicly available on request from the DHS Program website, <http://dhsprogram.com/What-We-Do/Survey-Types/DHS.cfm> (searching by country is the easiest way to access the datasets used in the current study: <http://dhsprogram.com/What-We-Do/survey-search.cfm?pgtype=main&SrvyTp=country>). We have therefore only made available the data cleaning and analysis code used in generating the findings reported in our publication on the Invasive Bacterial Disease Research Group Dataverse: doi, [10.7910/DVN/YQYES938](https://doi.org/10.7910/DVN/YQYES938).

Author contributions

JSK performed the analyses, interpreted the results and drafted the manuscript. IA conceived the study, obtained the datasets, contributed to the analyses, interpretation of results and drafting the manuscript. All authors read and approved the final manuscript.

Competing interests

No competing interests were disclosed.

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Open Peer Review

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Referee Report 18 April 2017

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Birger C. Forsberg

Department of Public Health Sciences, Karolinska Institute, Solna, Sweden

A well written article with interesting results, though mostly known already, that are most important for policy making. Some comments for further improvements:

1. "explored" in the Abstract is in past tense while the first verb ("review") is in present tense. Chose either.
2. In the "Background" section it is stated that "Most vaccination coverage estimates in LMICs are from administrative reports that tend to overestimate coverage, due to errors in the number of vaccine doses administered and/or invalid assumptions about the size of the target population of children." This statement should by preference be supported by a reference. I would say that most estimates are based on surveys while vaccine coverage reports may be based on administrative reports, i.e. data from routine reporting in the health system.
3. Under "Methods" the risk factors considered are listed. However, the factors listed should rather be called "determinants". For instance, maternal education is not a risk factor in itself but a determinant. Low maternal education carries a risk for lower participation in vaccine programmes. The opposite goes for high education.
4. As pointed out by other referees, it is questionable if "possession of vaccine card" can be put in the logistic regression model if outcome (children vaccinated) is measured with vaccine card. Clearly, there is a risk that possession of vaccine card increases your chance of being included in the sample.
5. Under "Ethic statement" it is said that "...written informed consent is obtained from each survey participant" and a reference to DHS is given. I would soften this fact and make it clearer that it is coming from the DHS report. It could for instance be formulated "The DHS programme reports that....".
6. There are two "after" after each other in the sentence following the one quoted under (5).
7. On page 7 in the second paragraph in the section titled "Predictors of complete vaccination status" the term risk factor is again used in an inaccurate way, I believe. A "risk factor" is related to a negative outcome (in order for it to be a "risk"). Hence, there cannot be "risk factors for complete vaccination". They should be called "determinants" of "predictors".

8. The article is based on an analysis between countries under the standard assumption that countries form relatively coherent entities suitable for comparison. However, intra-country variation may be as important as inter-country variation when it comes to primary care services. Hard to reach regions may be more or less represented in the countries compared. It would be useful if the authors could comment on this somewhere in the article, preferably in the discussion section.
9. Under "Discussion" the first sentence states "...the mean prevalence of the fully immunized child (FIC) was only 49%, indicating the poor state.....". No numbers on aggregated "means" for all countries are given anywhere in the Results section. It is therefore surprising that it appears in the Discussion section. It is not described how the authors calculated this mean prevalence. I suggest the sentence is taken out as it opens up to a different data analysis than the one used in the article (where data from each country are presented separately and compared.)
10. On top of page "capital" should be "capita".
11. In the second column, it is said in the fourth paragraph (starting "Even with a probability...") that "Clusters with a larger population are more likely to be selected compared to less populated clusters..." This is not correct. The cluster sampling is not a method in which you select your sample from clusters. It is a method through which you select clusters from a population enumeration based on an estimate or census data. All persons in the population have the same chance of being included in a cluster, irrespective of where they live. In EPI coverage surveys a cluster typically consists of 7 children.
12. In the "Conclusions" section it is said that "Health system weaknesses and inefficiencies responsible for the unacceptably high dropout rates between vaccine doses need to be tackled urgently." However true this may be, there is in fact little to no evidence in the article that health system weaknesses and inefficiencies are responsible for the drop out rates documented in the surveys. The reason is that this variable is not included in the regression model. It would be possible, but not easy and uncontroversial, to include a proxy for such system weaknesses in the model but rather than redoing their analysis, I suggest the authors move the quoted sentence to the "Discussion" section and then qualify their statement. The "Conclusion" section should focus on the actual results from the study and their policy implications.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

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M Carolina Danovaro-Holliday

Expanded Programme on Immunization, Department of Immunization, Vaccines and Biologicals, World Health Organization, Geneva, Switzerland

Crude childhood vaccination coverage in West Africa: Trends and predictors of completeness

This manuscript presents analyses of DSH from 13 West African countries in terms of fully immunized child or FIC (defined as having received basic vaccines) and drop-out, along with trends between two DHS surveys for 10 of these countries. It is well-written and presents a useful picture of the situation of a group of countries and highlights that there is much work to do in terms of improving coverage and reducing drop-outs. It also shows that the factors associated with FIC differ among countries.

The main issue I have with the study is that it only presents coverage point estimates. It fails to show the % of cards seen and confidence intervals around estimates. This limits data interpretation. Also, at least to me, it is not clear if the authors were able to replicate the results included in the respective DHS report. If it was a re-analysis, it is frequent that estimates are a bit different due to non-explicit decisions on record or data point exclusion, or how to treat “don’t know” responses, for example. This is not mentioned.

Also, by calling the drop-out DTP1-DTP3 an “access” issue and the drop-out DTP1-MCV1 a “utilization” issue, it creates confusion, as often DTP1 coverage is used to denote access and drop-out (any) to denote utilization. See: Immunization in Practice. Module 6. Monitoring and Surveillance

http://apps.who.int/iris/bitstream/10665/193412/1/9789241549097_eng.pdf

Regarding the exclusion of MICS surveys, at least the most recent MICS do include vaccination history not limited to those received before their first birthday. See: <http://mics.unicef.org/tools> and Cutts *et al.*, 2013.

Finally, though the results illustrate a group of countries in a sub-region, generalizing to “West Africa” seems an unneeded stretch.

Specific comments:

Abstract

- Provide a timeframe, e.g., from 2003 DHS in Burkina Faso and Ghana to 2013.

Introduction

- Review the references for the statement about drop-out. While the webpages cited do include a recommendation on attaining coverage $\geq 90\%$ at the national level, they do not include a target for drop-out. The 10% is commonly used, but the reference needs to be added. It could be Immunization in Practice. Module 6. Monitoring and Surveillance

http://apps.who.int/iris/bitstream/10665/193412/1/9789241549097_eng.pdf

- Add a reference for the statement about admin reports most frequently overestimating coverage
- Consider Lim *et al.*, in addition to, or instead of, reference 11
- You may want to add here why you didn't include MICS

Methods

- Consider changing to univariate to bivariate

Results

- Present uncertainty data
- Include the % with cards seen
- Table 3 is confusing. It could add coverage “before” and “after” to better understand what the % presented is about
- Remove data interpretation when presenting drop-out results, as the definitions were included in the methods

Discussion

- Avoid presenting a summary figure
- Again, revise the references used when presenting a threshold of 10% for drop-out
- Discuss the potential use of cards as an explanatory variable, given that vaccination ascertainment may be affected by this
- Revise the use of access and utilization when referring to drop-outs
- Consider adding the limitation that surveys do not directly obtain data on barriers to vaccination
- Consider adding the limitation that untimely vaccination may occur. See a recent review “Factors associated with incomplete or delayed vaccination across countries: A systematic review” by Taui *et al.*, Vaccine 2016.

Conclusions

- I don't think the data presented allows determining the cause of the mostly low coverage and high-drop outs found. Thus, I suggest removing or rewording “Health system weaknesses....to be tackled urgently”. It may be true, but it is not a conclusion based on the data presented.

References

- Consider further references by Brown *et al.* on home-based records, more on timeliness and references on the Global Vaccine Action Plan (GVAP), see:
http://www.who.int/immunization/global_vaccine_action_plan/GVAP_doc_2011_2020/en/

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Referee Report 03 March 2017

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Charles S. Wiysonge , Abdu Adamu 

Cochrane South Africa, South African Medical Research Council, Cape Town, South Africa

General comments

We commend the authors for choosing a very topical issue for the manuscript. However, we have concerns with the amalgamation of data from different years in different countries. For example, the authors combine 2008 data from Ghana and 2014 data from Togo, to give an overall estimate of

vaccination coverage in West Africa. To which year did the authors assign the 49% mean vaccination coverage for West Africa? In the same vein, if the authors were asked to assess whether West Africa achieved the GVAP coverage target for 2015 (using the two countries mentioned above as examples), would they be comfortable combining 2009 data for Ghana and 2015 coverage data for Togo to give 2015 figures for the region?

Specific comments

- In the abstract, the authors should mention the years for the coverage data.
- We do not think that the average coverage reported for West Africa is informative, for the reason stated above.
- For the average coverage data, the median and range would be more informative than mean and range.
- The authors refer to "...a trend of increasing vaccination coverage..." in the abstract. If this trend is over time, would it not be helpful to indicate the years of interest?
- We found it difficult to understand the concept of "risk factor for full immunization coverage" in this study. Could there be a more informative phrase than "risk factor" in this context? Is maternal education a risk factor for vaccination in a similar sense to smoking being a risk for lung cancer?
- Given that vaccination coverage was assessed from records in vaccination cards, we doubt whether it is appropriate to put "possession of a vaccination card" in the multivariate logistic regression model.
- It would be helpful in the abstract, to provide the effect estimates and their 95% confidence intervals for the respective effects on vaccination coverage of maternal education, delivery in a health facility, etc.
- The authors report "Chi-square tests were utilized in univariate analyses to examine associations between FIC and possible risk factors". Should the analyses be referred to as "bivariate", given that the authors examined the relationship between two variables?

Overall, we read the manuscript with great interest and appreciate the efforts of the authors.

Competing Interests: No competing interests were disclosed.

We have read this submission. We believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have significant reservations, as outlined above.

Referee Report 27 February 2017

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Lars T. Fadnes

Department of Global Public Health and Primary Care, University of Bergen, Bergen, Norway

I think the study is generally well written and well presented. The analyses are generally appropriate; however there are a few details that need to be checked and clarified.

Major revision:

When vaccination cards were used to obtain immunization information, can they then be assessed as a factor in a multivariable regression analysis on whether they were fully vaccinated (particularly as parent recall of individual vaccines is challenging)?

Nevertheless, for the point of the discussion and independent of this paper, there are good reasons to believe vaccination cards are of importance for obtaining appropriate and timely immunization.

Minor revisions:

Timeliness of vaccination can also impact on vaccine efficacy. Please add a section on timeliness of vaccination in the discussion.

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
