Implementing WHO guidance on conducting and analysing vaccination coverage cluster surveys: Two examples from Nigeria

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Abstract

In 2015, the World Health Organization substantially revised its guidance for vaccination coverage cluster surveys (revisions were finalized in 2018) and has since developed a set of accompanying resources, including definitions for standardized coverage indicators and software to calculate them. In addition to tabular presentations of coverage by vaccine and age group, the guidance document and software (named the Vaccination Coverage Quality Indicators - VCQI) – provide insight into crude coverage versus valid doses, vaccination timeliness, missed opportunities for simultaneous vaccination, and vaccination campaign coverage stratified by several parameters, including the number of previous doses received. The VCQI software furnishes several helpful ways to visualize survey results. The current WHO survey guidance was used to design and conduct two nationally representative vaccination coverage surveys in Nigeria – one to assess routine immunization and one to measure post campaign coverage. The primary analysis for both surveys was conducted using VCQI. This paper describes those surveys and highlights some of the analyses that are facilitated by the new resources.

Key Words

survey, vaccination coverage, WHO, Nigeria

Background

Vaccination coverage – the proportion of the target population vaccinated with a given vaccine-dose – of the third dose of DTP-containing vaccines is used as a proxy indicator to monitor progress towards many global initiatives (1–3). Household surveys are frequently conducted aiming to obtain more accurate information on vaccination performance than that derived from routine administrative reports, or to complement such reports (4–7). Furthermore, Gavi-eligible countries are required to have done a nationally representative coverage survey (which may be multi-purpose such as the Demographic and Health Survey (DHS) or a UNICEF Multiple Indicator Cluster Survey (MICS)) within the last 5 years in order to apply for GAVI support as well as to conduct post campaign coverage surveys following any vaccination campaign supported by Gavi (8). In 2015, the World Health Organization (WHO) updated its vaccination coverage survey guidance to promote the use of probability sampling with rigorous quality control, use of appropriate analysis and greater use of results to improve program performance (final version published in 2018) (9,10). The guidance is supported by a set of materials including a list of standard questions and indicators, a tool called Vaccination Coverage Quality Indicators (VCQI) coded to calculate and tabulate most of these indicators (10–12), and intensive training through regional workshops and a large distance-based learning program in English and French, which is reaching several hundred participants around the world (13–16).

Challenges to implementing a high-quality household survey are well-known (4,17,18) but even when surveys are well-implemented, presentation of results may be hampered by a lack of standardized definitions of potential indicators and/or failure to report enough information to define those indicators clearly (10,19–21). WHO and partners therefore recently developed a white paper to help harmonize the collection and analysis of vaccination coverage data across the major survey programs (22).

In this paper, we present results from surveys conducted in Nigeria to illustrate many of the standard measures of vaccination coverage promoted in the White Paper for Routine Immunization (RI) and additional indicators for post campaign coverage surveys (PCCS) done after mass vaccination campaigns. We illustrate how moving beyond a single measure of coverage to an ensemble of quality indicators as produced by VCQI can help highlight priority areas for action.

Materials and Methods

Data Collection

We include data from two recent surveys that followed WHO-recommended procedures: the 2016-17 Multiple Indicator Cluster Survey / Nigeria Immunization Coverage Survey (MICS/NICS) and the 2018 National Post Measles Campaign Coverage Survey (PMCCS).

MICS/NICS

The 2016-17 MICS/NICS was a multi-purpose two-stage cluster sample survey which followed previously described methods (23–25). The 2018 WHO coverage survey guidance (9) recommends that before launching a survey only for vaccination, national immunization

program (NIP) managers should determine whether another high-quality household survey is being planned within the desired time frame and whether that sample would be appropriate for their needs. In 2015, the Government of Nigeria and UNICEF were planning a MICS hence it was decided to incorporate the NICS in the MICS (26). The primary objective of NICS was to assess national and state levels of Routine Immunisation (RI) coverage for the "traditional vaccine doses" – one dose of BCG vaccine, three doses of pentavalent vaccine (containing diphtheria-tetanus-pertussis (DTP), *H. influenzae* type *b* and hepatitis B vaccines), three doses of oral polio vaccine (OPV) and one dose of measles containing vaccine (MCV) – as well as yellow fever, hepatitis B birth dose and vitamin A.

MICS/NICS was stratified by state (Supplementary Figure 1) with census enumeration areas (EAs) as the primary sampling units (PSUs). Sixty EAs were selected in each state (120 in Lagos and Kano) by simple random sample from the National Integrated Survey of Households round 2 (NISH2) master sample, based on a list of EAs prepared for the 2006 Population Census. In each sampled EA, after listing all households, 16 were selected by systematic random sampling. For NICS, to enable estimation of vaccination coverage among the smaller cohort of children aged 12-23 months with precision for the 3rd dose of pentavalent vaccine (Penta3) no wider than +/- 10% in each state, an additional 10-30 EAs were selected in 20 states. Details of sampling are in (24 Appendix A). The overall MICS/NICS duration was about a year and half with about four months for data collection.

Standard MICS questionnaires were administered with an additional set of questions on reasons for no vaccination; data were collected using computer assisted personal interviewing (CAPI). In the supplemental clusters, only the modules on household characteristics and vaccination were administered. Respondents were asked if they had a home-based record (HBR) of vaccination and if this was available, the dates of each vaccination were transcribed. Then, for children not fully vaccinated, an additional question was asked to ascertain and record if any other vaccines had been received that were not shown on the card. If no HBR was seen, caretakers were asked whether the child had received each vaccine-dose in the schedule and their answer was recorded as verbal recall. The availability of HBR in Nigeria has been below 50% in all recent surveys and even though recent guidance recommends that interview teams might visit health facilities to seek documentation for children lacking HBRs (4,9,27), health facility visits were not included in this survey due to logistical and resource constraints.

PMCCS

The PMCCS was conducted between January and April 2018, following measles campaigns targeting children aged 9 to 59 months held from October to December 2017 in northern Nigeria and February to March 2018 for Southern States (28). A forthcoming special supplement to the journal *Vaccine* describes numerous aspects of this particular vaccination campaign. The primary objective of this PMCCS was to estimate the coverage of measles vaccination during the SIA in each state, in the Federal Capital Territory (FCT), and nationally. Some specific Local Government Areas (LGAs) in Borno and Adamawa states were excluded from the sampling frame due to security concerns. Results from those states should be interpreted in light of the exclusions.

The survey methods followed the 2015 draft WHO guidelines (29) (finalised in the 2018 version without substantial change in content) (9,10) and data collection was done using

CAPI. A stratified two-stage cluster sampling design was used, as in MICS/NICS. After household listing, households were selected centrally using simple random sampling without replacement from the list of households with eligible children aged 9 to 59 months. Assuming an expected SIA coverage of 90%, half-width confidence interval around state-level estimates of 8% (i.e., 90% +/- 8% coverage estimate) with an alpha level (type I error) of 5%, the effective sample size (i.e., sample size per stratum under a simple random sampling assumption) was n = 101 (9, Annex B1). This was increased to 210 households with eligible children to account for the cluster survey design effect and expected non-response rate (9, Annex B1). Seven households with eligible children were therefore randomly selected from each of 30 EAs in every state and the FCT. A short questionnaire was administered to record where the child lived during the SIA; knowledge of and source of information about the SIA; vaccination during the SIA according to SIA card, finger-mark or recall; any adverse events following immunization; reasons for not attending the SIA if relevant; and whether the child had received measles vaccination before the SIA according to HBR or recall.

Data Analysis

Weighting and post stratification

The MICS/NICS used a MICS spreadsheet template to calculate cluster-specific survey weights. Base weights were calculated as the inverse of the multi-stage probability of selection. These were adjusted for non-response at the household and child levels. The weights were not post-stratified; that is, the state-level sums of weights were not scaled to match totals or ratios from an administrative list. The weights were scaled to sum to the total nationwide MICS/NICS sample size of children aged 12-23m.

PMCCS weights were computed by adjusting observations with inverse selection probabilities of EAs and households, adjusting for non-response at the EA, household and child levels and finally post stratifying the weights with the estimated number of children aged between 9 and 59 months in each state obtained from the campaign micro plan (30).

For reporting of results, sample weights were applied to outcomes where all respondents are in the denominator and for which results will be generalized to the entire eligible population. Analyses were un-weighted if the denominator included only a subset of respondents.

Indicator definitions and reporting recommendations

Supplementary Tables 1 and 2 summarise the definitions of some of the main indicators calculated by VCQI; details are available in the VCQI documentation (31–33). WHO recommends that RI coverage be tabulated according to the source of information: HBR; health facility-based record (FBR) (if available); caretaker recall only and HBR+FBR+recall (22). Coverage should also be classified as crude (including evidence of vaccination at any age) or valid (children who have documented dates of each vaccine-dose and received each dose according to WHO guidance on minimum ages and intervals between doses) (34).

In the early years of the WHO Expanded Programme on Immunization (EPI), only 4 basic vaccines against six diseases (BCG, DTP (3 doses), OPV (3 doses) and MCV) were included in national immunization schedules of low and middle-income countries and a "fully vaccinated" child had received all these doses. The number of vaccines included in

schedules now varies greatly between countries hence a fully vaccinated child can be defined conservatively as a child who has received all doses of the 4 "basic vaccines" (adapting the earlier EPI definition to replace DTP with pentavalent vaccine if used in this combined vaccine) or a child who has received all the vaccines in the country's vaccination schedule in the relevant time period for the cohorts in the study. For simplicity we use only the first definition here.

Missed Opportunities for Vaccination (MOV) due to non-simultaneous vaccination were defined as documented vaccination visits not used to administer all vaccines for which a child was eligible at a visit when at least one vaccine was received. For example, a visit in which an MCV dose was given but OPV or Penta vaccines were not given even though those vaccination series were not completed.

Dropout was defined as the percentage of children 12-23 months who received the first dose in a multi-dose sequence but failed to receive a subsequent or the final dose in the sequence; this is typically calculated between first and third doses of pentavalent vaccines as (penta1-penta3/penta1) expressed in percentage.

Analysis

Both surveys were analysed with WHO's VCQI software using Stata version 15 (11,33,35).

The recent WHO white paper (22) encourages special attention and clear documentation of how the following issues are handled during data cleaning and indicator construction. Supplementary Table 4 details the following:

- Definitions of eligible population and denominators for each indicator
- Handling evidence from tick marks
- Handling imperfect date values
- Handling missing values or 'unsure' or 'do not know'
- Steps to differentiate RI doses from SIA doses
- Definitions of valid doses
- Calculation of confidence intervals
- How many decimal places to report

The analysis plan for each survey aligned well with that described in the WHO white paper (22).

Results

Description of the survey samples

In MICS/NICS, 2,810 EAs were selected into the sample. Interviews were conducted in 2,702 EAs; 108 EAs were excluded for reasons of security and inaccessibility (28 Table HH.3) Interviews were successfully conducted in 40,518 (98.7%) of 42,981 households selected into the sample. In those households, caretakers had responsibility for 6,360 children aged 12-23 months. Interviews were completed for 6,268, yielding a vaccination-specific caretaker-response rate of 98.6%.

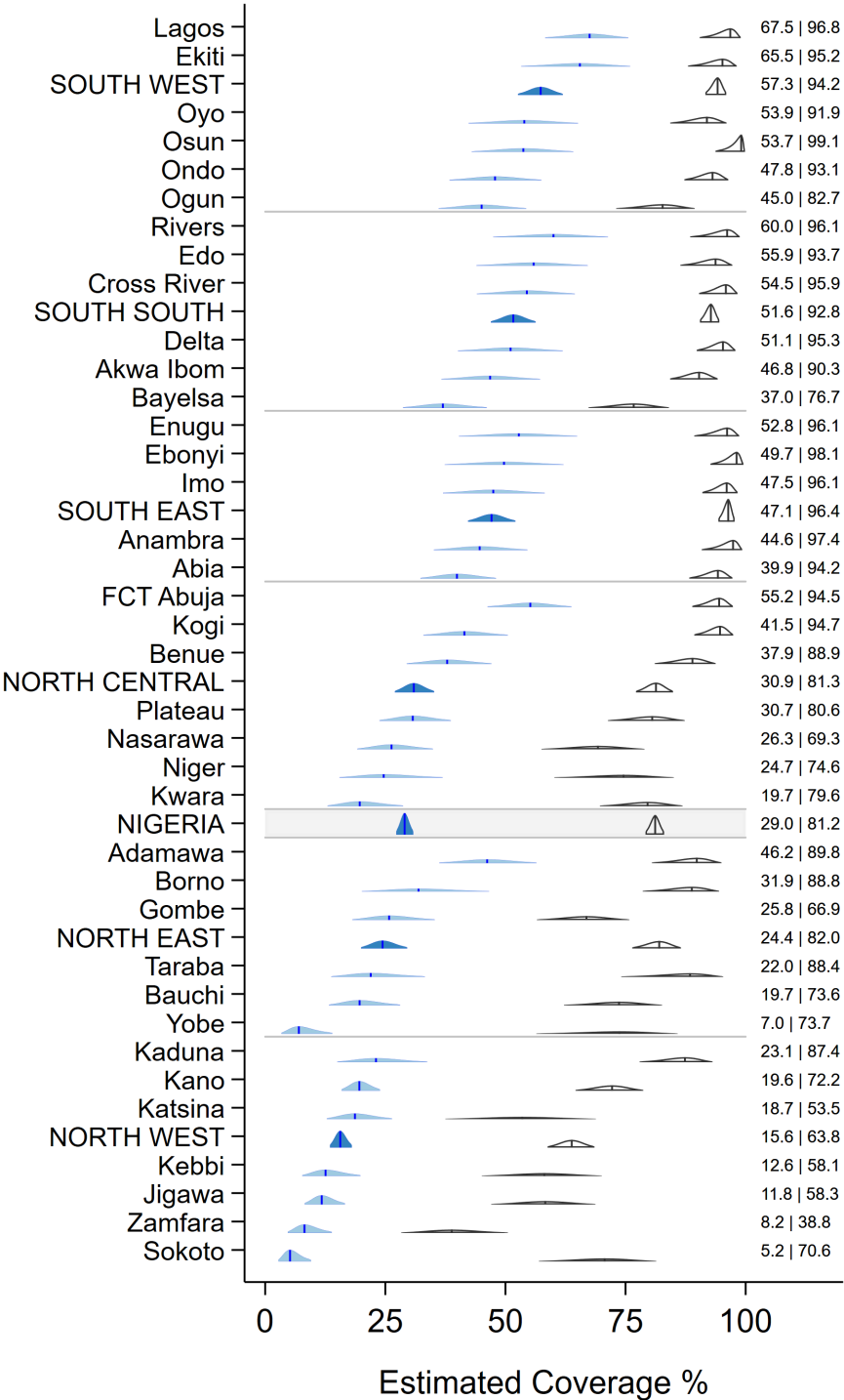
In the PMCCS, 2,239 of 2,340 EAs selected in the first stage of sampling were listed and covered during the fieldwork period while 101 EAs were inaccessible due to insecurity especially in Borno, Yobe and Adamawa states. Of the 7,090 households selected, interviews were successfully conducted in 6,819, a household response rate of 96.2%.

Primary indicators: weighted and applicable to the population

Routine vaccination coverage among children aged 12-23 months, MICS/NICS 2016-17

Although mothers of 51.3% (95% CI 49.0, 53.6) of children reported that their child had ever received an HBR, these were seen for only 29.0% (95% CI 27.3, 30.8) of children, ranging from as low as 5% in Sokoto state to a high of 68% in Lagos (Figure 1). HBRs were seen more frequently in urban than rural areas and in wealthier households (data not tabulated).

Table 1 shows crude vaccination coverage of each vaccine-dose according to source of information, and valid coverage by the time of the survey. At the national level, crude coverage was low for all vaccines (e.g. 48.7% (95% CI: 46.4, 51.1) for first dose of pentavalent vaccine (Penta1) and 41.7% (39.5,43.9) for MCV). Only 22.9% (21.2, 24.6) of children had received all basic vaccines even accepting maternal recall for children without HBR. Remarkably, 40% (37.5, 42.1) of children had received none of the basic vaccinations (Table 1), ranging from 60.5% (57.1, 63.9) in the northwest to only 7.5% (5.1, 11.0) in the southeast.

Figure 1. Weighted percentage of children aged 12-23 months who were reported to have ever received a card and whose card was seen during the survey, Nigeria MICS/NICS 2016-17. The vertical bar in each 2-D distribution represents the survey point estimate. The base of each distribution spans the 2-sided 95% confidence interval. The height of the shape indicates the relative degree of confidence that coverage falls at that value. The shapes consist of scaled stacked confidence intervals with the 95% interval at the base and a 1% interval at the peak. See (9, Annex M).

Text at right: Point Estimate | Point Estimate

Colored shape is card availability; gray hollow shape is card ever received

Table 1. Weighted percentage crude (ignoring age at vaccination or interval between doses) and valid (respecting the schedule) vaccination coverage for the basic EPI vaccines, children aged 12-23 months, MICS/NICS 2016-17.

	Crude coverage						Valid coverage by HBR; denominator is:			
	by HBR†		by Recall		by HBR + Recall		children with HBR‡	all children		
	%	95% CI	%	95% CI	%	95% CI	%	%	95% CI
BCG	28.0	(26.4, 29.7)	25.3	(23.3, 27.3)	53.5	(51.1, 55.9)	87.9	25.6	(24.0, 27.2)
HBV 0	20.5	(19.0, 22.0)	9.7	(8.9, 10.7)	30.2	(28.4, 32.0)	36.2	10.6	(9.5, 11.9)
OPV 0	24.0	(22.4, 25.6)	23.5	(21.7, 25.3)	47.4	(45.4, 49.5)	41.4	12.1	(10.9, 13.3)
OPV 1	27.0	(25.3, 28.7)	22.8	(21.0, 24.7)	49.7	(47.7, 51.7)	85.2	24.1	(22.5, 25.7)
OPV 2	24.3	(22.7, 25.9)	18.3	(16.9, 19.8)	42.5	(40.6, 44.4)	72.9	20.3	(19.0, 21.8)
OPV 3	21.7	(20.2, 23.2)	11.6	(10.3, 13.0)	33.2	(31.5, 35.0)	46.4	12.9	(11.8, 14.0)
Penta 1	27.7	(26.1, 29.4)	21.2	(19.2, 23.3)	48.7	(46.4, 51.1)	88.0	25.1	(23.5, 26.7)
Penta 2	25.2	(23.7, 26.9)	14.7	(12.9, 16.7)	39.9	(37.8, 42.1)	78.2	22.0	(20.5, 23.6)
Penta 3	23.0	(21.4, 24.5)	10.4	(9.0, 11.9)	33.3	(31.4, 35.3)	51.6	14.2	(13.1, 15.4)
MCV	20.5	(19.1, 22.0)	21.2	(19.4, 23.1)	41.7	(39.5, 43.9)	53.2	15.0	(13.8, 16.4)
YF	19.6	(18.2, 21.0)	19.2	(17.6, 20.9)	38.8	(36.7, 40.9)	52.6	14.8	(13.6, 16.1)
Fully vaccinated*					22.9	(21.2, 24.6)	30.8	8.2	(7.4, 9.2)
No vaccinations**					39.8	(37.5, 42.1)	6.1	72.5	(70.8, 74.2)
Unweighted sample size	2,084		4,184		6,268		2,084	6,268	
Weighted sample size	1,883		4,386		6,268		1,883	6,268	

NOTES

Abbreviations: HBR=home-based record (or vaccination card); HBV=hepatitis B vaccine; OPV= oral polio vaccine; penta=pentavalent DTP-HepB-Hib vaccine; MCV=measles-containing vaccine; YF=yellow fever vaccine. The number next to the vaccine indicates the dose, 0 means that is a birth dose.

95 percent confidence intervals reported in parentheses.

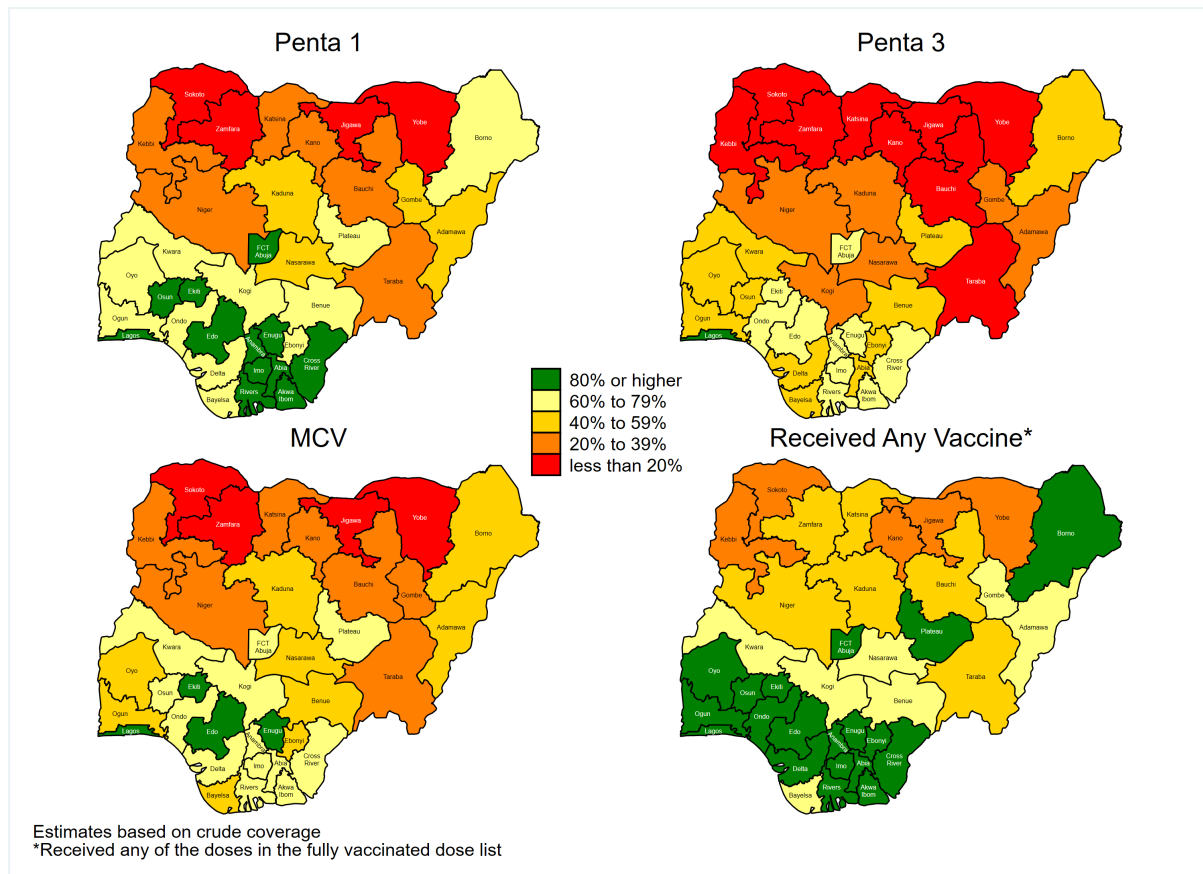
 * Fully vaccinated = the percentage of children aged 12-23 months who received all of the "basic vaccines", i.e. 1 dose of BCG vaccine, 3 doses of DTP-containing vaccine ("penta"), 3 doses of OPV and 1 dose of MCV before the survey.

** No vaccinations = the percentage of children aged 12-23 months who had received none of the "basic vaccines."

† The percentage of children aged 12-23 months for whom a home-based record (HBR) was available and reviewed for evidence of vaccination was 29.0% (95% CI: 27.3,30.8).

‡ By convention, estimates where the denominator is a subset of respondents, are unweighted and presented without a confidence interval.

Coverage varied widely by state (Figure 2 and Supplementary Figure 2). Penta1 coverage, commonly taken as an indicator of access to vaccination services, was over 80% in the three southern zones but very low in northwest and north-eastern zones (Figure 2). For Penta3 and MCV, however, coverage was well below targets even in southern states.

Figure 2. Weighted crude coverage of first and third dose of pentavalent vaccine, of measles vaccine (excluding SIA doses) and of any of the basic vaccines, children aged 12-23 months, by state, Nigeria MICS/NICS 2016-17

Vaccination coverage was virtually identical in boys and girls. More than twice as many children had never been vaccinated in rural (49%) than urban (20%) areas. Coverage was lower among poorer and less educated families and certain ethnic groups (25).

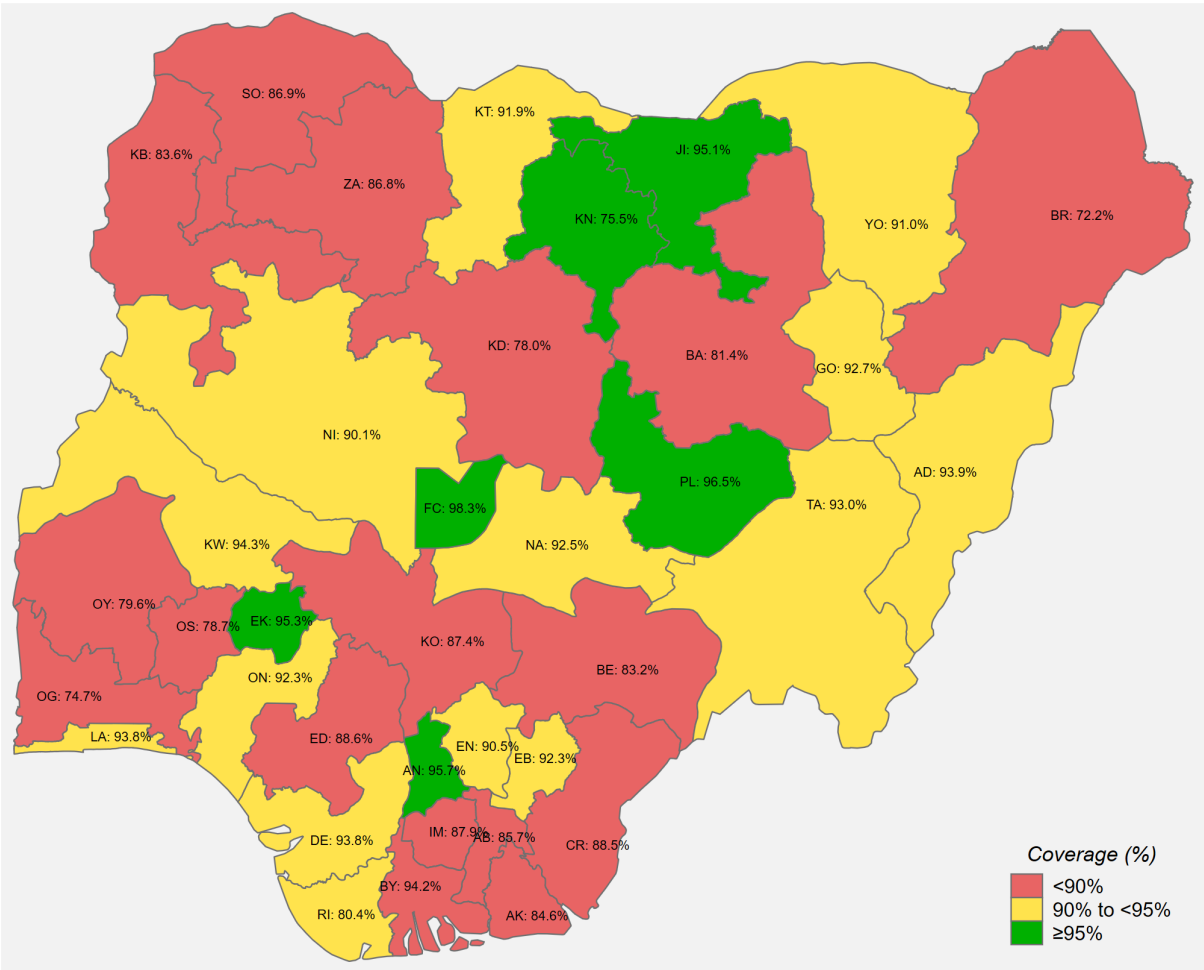
Just over half of caretakers reported obtaining vaccination at government health centres, while only 5% used private facilities (12% in the south-eastern zone and among mothers with higher education) – data not tabulated. Mobile or outreach clinics were mentioned by only 8%, with a high of 12% in north central zone. By contrast, campaigns or SIAs were the reported source of vaccination for 23% of children (higher in the northwest (34%) than southwest (12%)).

Post-campaign measles vaccination coverage among children aged 9-59 months, PMCCS 2018

Only 3% of children were not resident during the time of the SIA (28 Table 2.1a) and only 4% of respondents had not received information about the SIA (though in 2 states, over 10% lacked information) (28 Table 2.2a). Direct communication from community health workers, town criers and community leaders was by far the main source of information (28 Table 2.2a). Overall, 87.5% (95% CI: 86.2, 88.7) of children were estimated to have received MCV during the SIA; approximately half showed the SIA card while 17% had finger-mark evidence, the remainder being verbal recall (28 Table 2.5b). Importantly, the SIA was relatively effective in reaching previously unreached children (82.4%), although coverage was higher (91.6%) among children who had previously received MCV (Table 2). Nationally, 11.2 percent of all children aged between 9 and 59 months remained unvaccinated following the campaign (28 Table 2.8a). Coverage varied by state (Figure 3). In Sokoto, Zamfara and Yobe states where MCV coverage was <17% in MICS/NICS (Supplementary Figure 2), over 85% coverage was reached by the SIA (28 Table 2.5a). Coverage also varied within states – organ pipe plots of the proportion of children vaccinated in each cluster showed which EAs had markedly low numbers of children vaccinated (Supplementary Figure 3) (9 Section 6.1.2) (36–38). There was no sex difference in measles vaccination during the campaign or by urban and rural residence (28 Table 2.5b). Infants aged between 9 and 11 months had lower coverage during the campaign (75.5%, 95% CI: 67.2, 82.3) compared to older children (84-90% in each older year of age) (28 Table 2.5b).

Table 2. Proportion of children aged 9 months to 59 months who received measles vaccine during the measles campaign, Nigeria PMCCS 2018

	Vaccinated during SIA N = 8,884		Not vaccinated during SIA N = 1,269			Weighted
	%	95% CI	%	95% CI	N	N
Nigeria	87.5	(86.2, 88.7)	12.5	(11.3, 13.8)	10,153	35,939,548
Received MCV before the campaign						
Had received ≥1 dose of MCV before the campaign	91.6	(90.2, 92.8)	8.4	(7.2, 9.8)	5,567	19,706,044
Had never received MCV before the campaign	82.4	(80.1, 84.4)	17.6	(15.6, 19.9)	4,586	16,233,504
Abbreviations: CI=Confidence Interval The results in this table are from weighted analysis and the CI calculation considers the sampling design & weights.						

Figure 3. Weighted proportion of children 9 to 59 months vaccinated during the 2017-18 measles SIA, by state.

Note: Coverage includes evidence from SIA card, finger-mark, or caretaker recall

Secondary indicators of vaccination quality from MICS/NICS

Timeliness of vaccination

Among children whose HBR was seen, a high proportion received "non-valid" vaccine doses before the recommended age or with too short an interval between doses. Overall, 13% received Penta1 before age 6 weeks and 8% received subsequent doses of pentavalent vaccine after too short an interval (<28 days), while 17% percent received MCV before the recommended age of 9 months (273 days) (25 Tables IM.15 and IM.16). Zones and states with lower crude coverage also tended to have more early doses – 29% of children with a record of MCV vaccination were vaccinated before 9 months in the North West and 25% in North East zone (Figure 4).

Figure 4. Unweighted percentage of children aged 12-23 months with a date of vaccination for MCV who received the vaccine before age 270 days, by state, Nigeria MICS/NICS 2016-17.

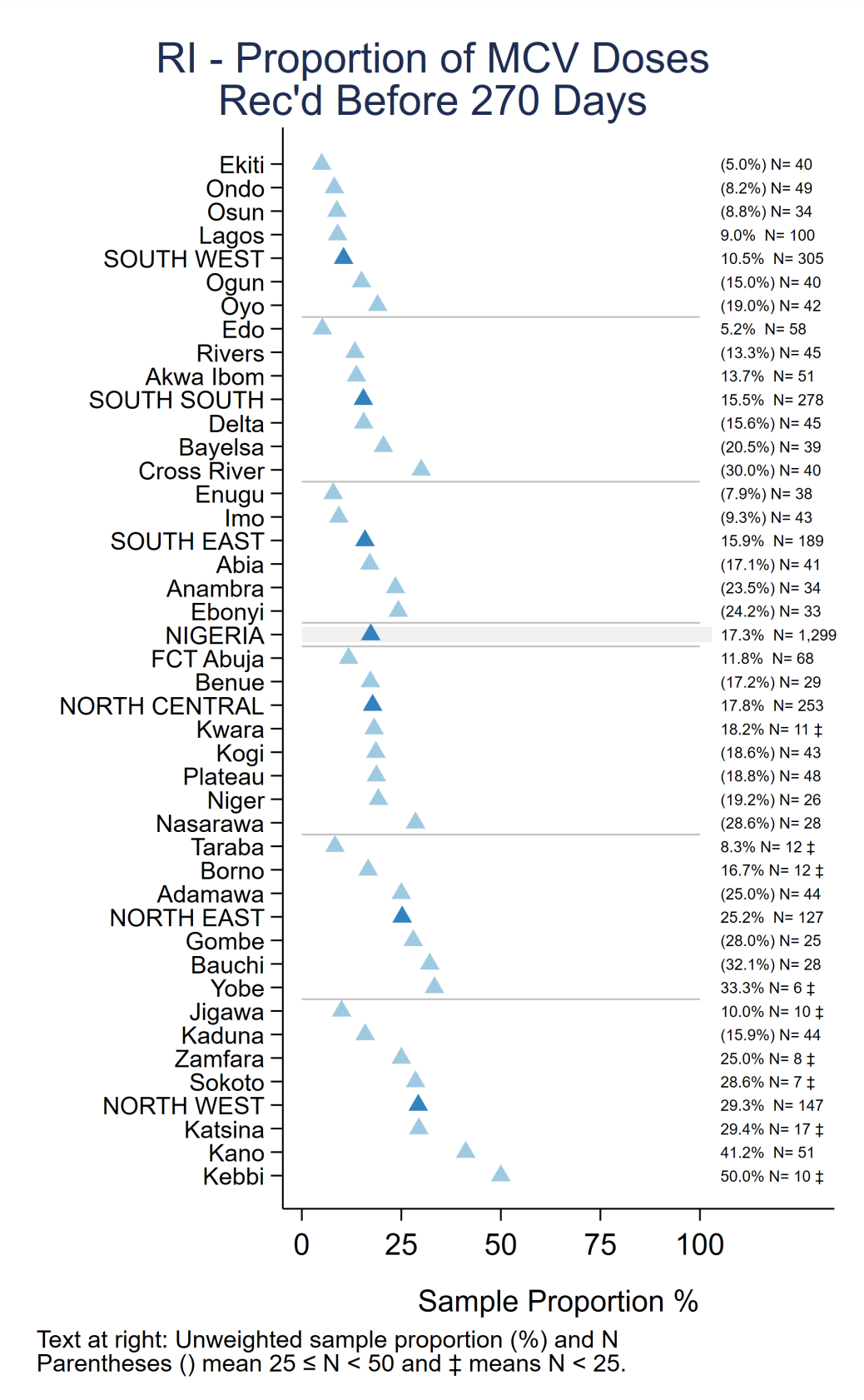
Text at right: Unweighted sample proportion (%) and N
Parentheses () mean 25 ≤ N < 50 and ‡ means N < 25.

As recommended in the WHO White Paper on surveys (22), Figure 5 shows vaccine coverage plots by age of child for select doses for the 2,017 children with an HBR. The curves reveal some doses being administered early and a large portion administered quite late with many children receiving the second and third doses of OPV or Penta after 6 months of age (180 days). Supplementary Figures 4-6 show coverage curves for MCV in Nigeria, the North West zone, and Lagos, respectively. Lagos had the highest proportion of children with HBRs (67.5%) (Figure 1). The North West zone had the highest proportion of early MCV doses among children with HBRs (29.3%) (Figure 4). All three figures reveal an appreciable number of doses given early. Supplementary Figure 7 shows coverage curves by age for Penta1-3 in Lagos and show vaccine administration that is much closer to the recommended age than the national curves in Figure 5.

Figure 5. Cumulative coverage proportions for selected doses, by age of child, among children who showed a vaccination card to the interviewer, Nigeria MICS/NICS 2016-17

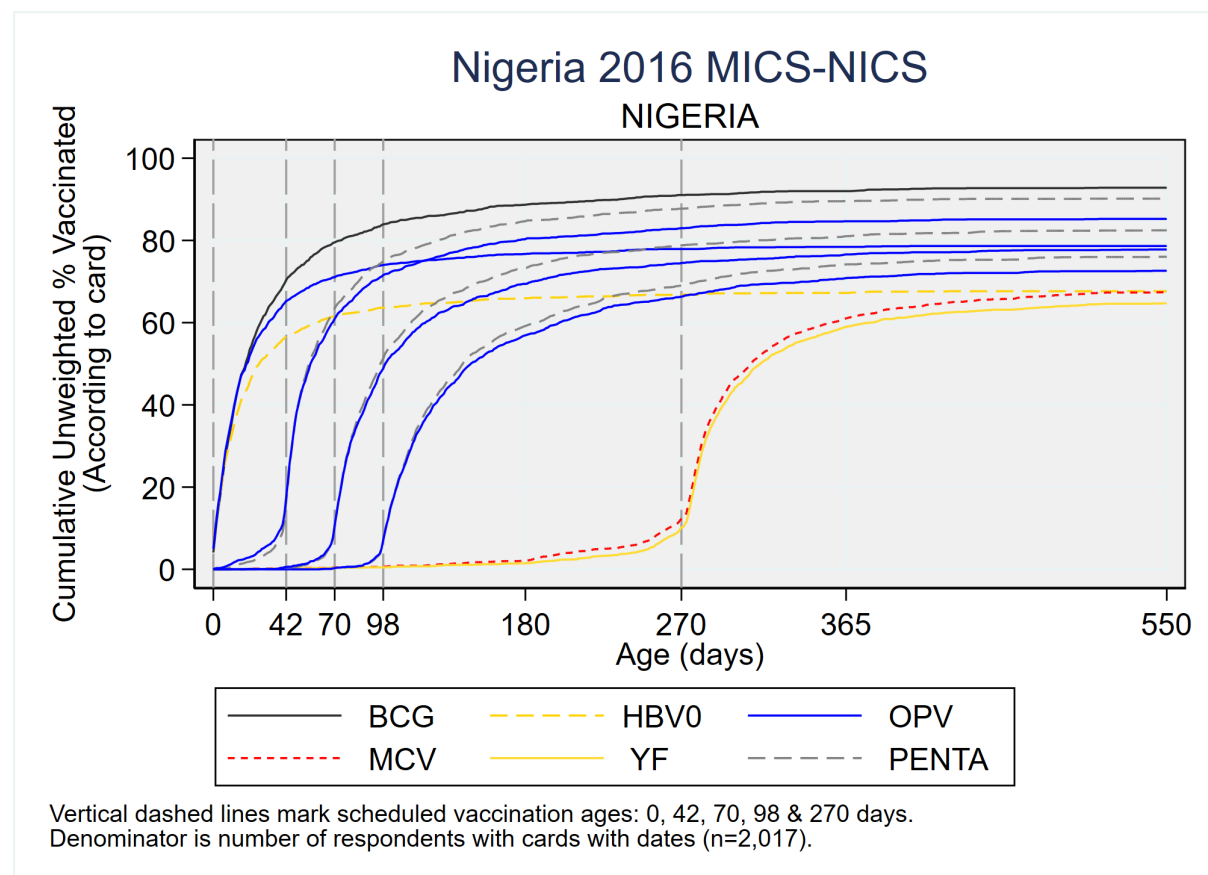
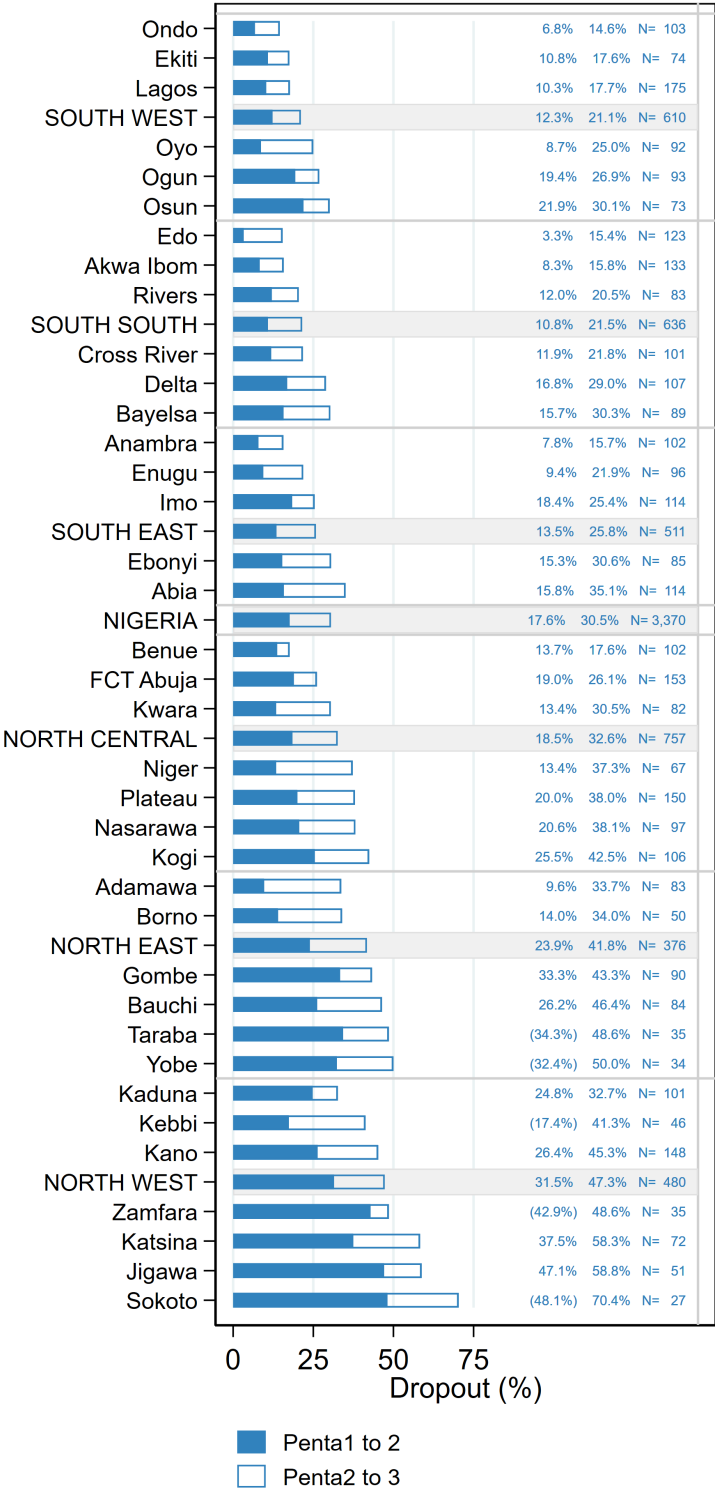
Vertical dashed lines mark scheduled vaccination ages: 0, 42, 70, 98 & 270 days.
Denominator is number of respondents with cards with dates (n=2,017).

Dropout

Figure 6 shows very high dropout especially in states in the North West and North East zones, where fewer than half the children who received Penta1 completed the three-dose series. Of note, dropout was substantially higher when using information from caretaker recall than among children with a HBR (Table 1 and Supplementary Table 3).

Figure 6. Unweighted dropout for Penta1-to-2 and for Penta1-to-3. Percentage of children who received 1st dose of pentavalent vaccine according to HBR or recall but did not receive the 2nd dose and received the 1st but did not receive the 3rd, by state, Nigeria MICS/NICS 2016-17. Results are sorted from bottom to top by Penta1-3 dropout at the zone level, and within zone, by state level. The national dropout estimates appear near the centre of the figure.

Note: Penta1 to 2 + Penta2 to 3 = Penta1 to 3 dropout.
Shaded rows indicate results aggregated over several states (zones) or all states (NIGERIA).
Text at right: Penta1 to 2 dropout (%); Penta1 to 3 dropout (%); Unweighted sample N.
Parentheses () indicate 25 <= N < 50.

Missed Opportunities for Vaccination (MOVs)

Of 1,912 children aged 12-23 months who had at least one documented age-eligible vaccination visit in their HBR, 1,005 (53%) experienced at least one MOV for any of the 4 basic vaccine/doses or yellow fever (Figure 7). Of these, 45% had all MOVs later corrected (i.e. they received the missed vaccines at a later date) (Supplementary Figure 8) and 17% had some corrected, while 38% never received any of the vaccines that had been missed (not tabulated here). MOVs were high in all zones and states. Among states where more than 50 children showed HBRs, the percent of children with one or more MOVs ranged from 34% in Enugu to 75% in Kano (Figure 7). Even in the South East, which had the highest overall coverage, 41% of children with HBRs had at least one MOV for these vaccines (Figures 7 and 8) (39).

The proportion of MOVs that was later corrected was much higher in southern than northern states (Figure 8 and Supplementary Figure 8). Elapsed time from the first MOV until the dose was later received is represented in Figure 9 using cumulative distributions, in days. Red lines mark the 50th percentile, indicating that in most cells, 50% of the corrections occurred within one or two months of the missed opportunity.

Lagos and Kano were the states with largest MICS/NICS survey samples, 120 clusters each, because of detailed sub-state reporting requirements. MOVs were much more prevalent in Kano than Lagos with the proportion of Kano's children experiencing MOVs ranging from 10% (for Penta2) to 44% (for OPV1) (Figure 10). Kano was the only state with more than 50 children with HBRs who had MOVs; N=73. Of those, only one-fourth had all MOVs corrected before the survey (Figure 10 and Supplementary Figure 8). The supplement shows the prevalence of MOVs for select doses in every state (Supplementary Figures 9-10).

VCQI calculates several other indicators which we do not have room to discuss in detail: proportion of dose intervals that were too short or very long; proportion of children who would have received a valid dose if there had been no MOVs, proportion of vaccination visits that produce 1+ MOVs, and others (32,33).

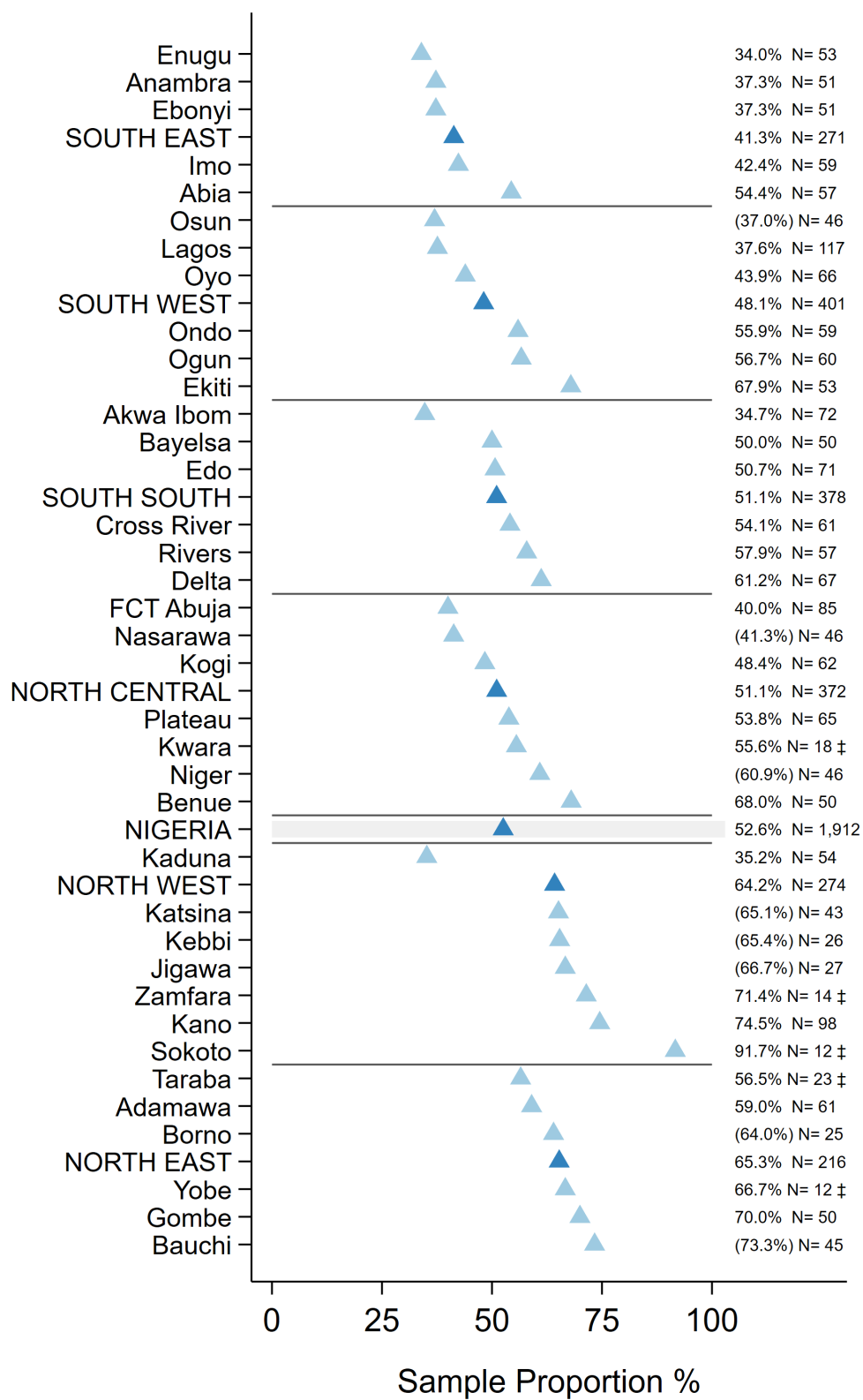
Figure 7. Unweighted percentage of children aged 12-23 months with an HBR who had at least one MOV for BCG, HBV0, OPV0-3, Penta1-3, MCV or YF due to non-simultaneous vaccination, by state, Nigeria MICS/NICS 2016-17.

Text at right: Unweighted sample proportion (%) and N
Parentheses () mean 25 ≤ N < 50 and ‡ means N < 25.

Figure 8. Proportion of children vaccinated at the first eligible opportunity, and proportion who experienced one or more missed opportunities, whether later corrected or not. The numbers in the centre of each cell portray the number of children in that zone (row) who had 1+ vaccination visits when age eligible to receive that dose (column). Nigeria MICS/NICS 2016-17

Crude measures of MOV shown. Figure shows suppressed output for bars where n < 25.

The stratum summary table shows information for the following doses: BCG, HBV0, MCV, OPV0, OPV1, OPV2, OPV3, PENTA1, PENTA2, PENTA3, YF.

MOV Summary by Stratum. % kids with:
NM = no MOVs; AC = all MOVs corrected;
SC = some corrected; NC = none corrected

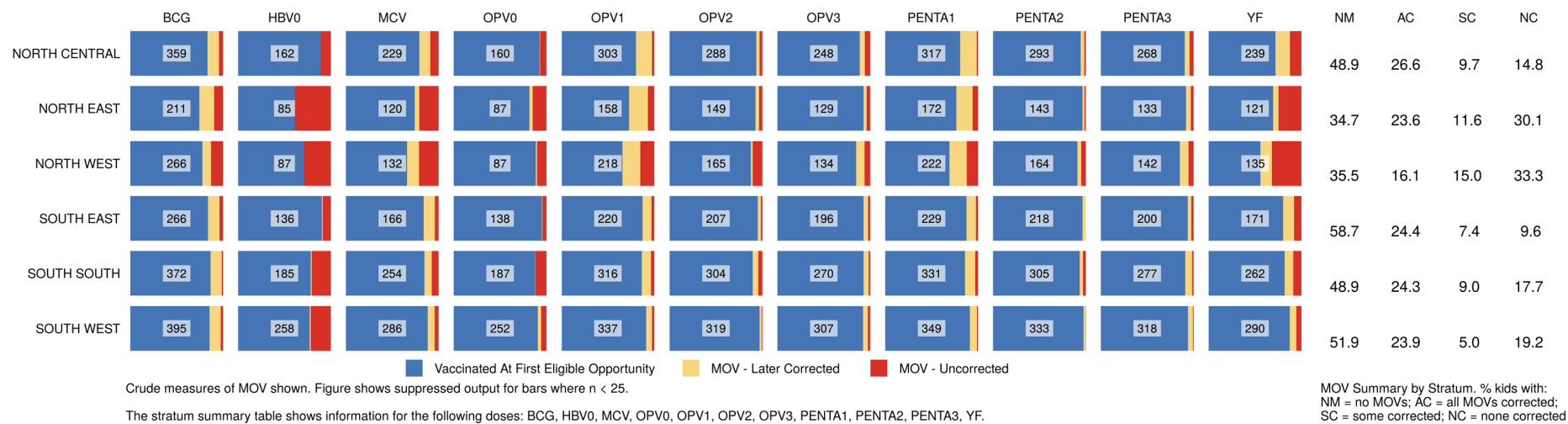



Figure 9. Cumulative distributions of time to correction, in days, for missed opportunities for vaccination, by dose and zone, Nigeria MICS/NICS 2016-17

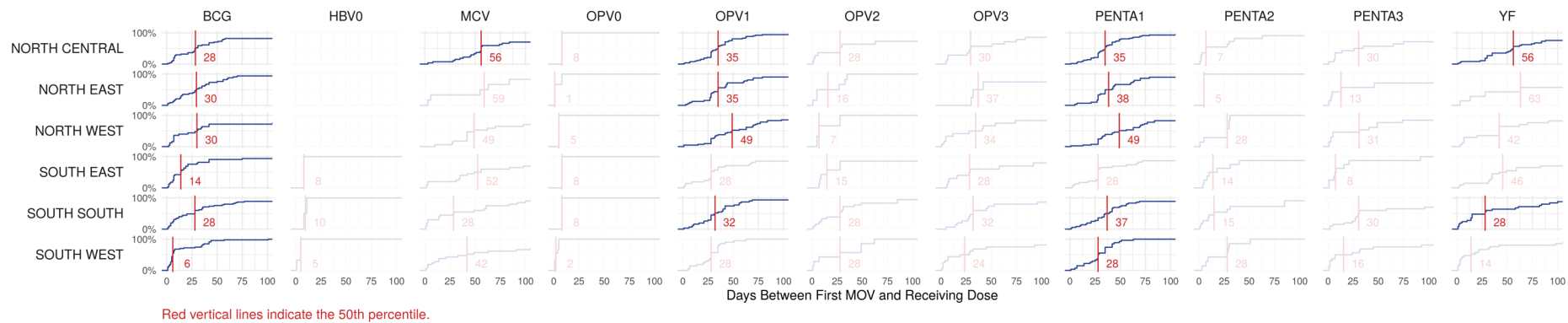
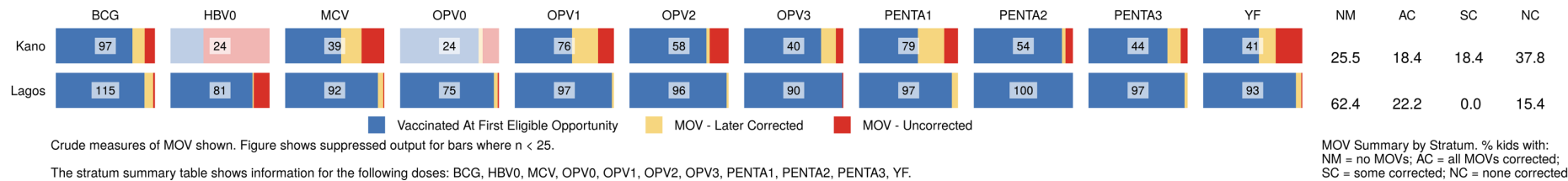
Red vertical lines indicate the 50th percentile.

Crude measures of MOV shown. Figure shows suppressed output for bars where n < 25. Red vertical line indicates the 50th Percentile.

Figure 10. Missed opportunities for vaccination in Kano and Lagos, Nigeria MICS/NICS 2016-17

Crude measures of MOV shown. Figure shows suppressed output for bars where n < 25.

The stratum summary table shows information for the following doses: BCG, HBV0, MCV, OPV0, OPV1, OPV2, OPV3, PENTA1, PENTA2, PENTA3, YF.

MOV Summary by Stratum. % kids with:
NM = no MOVs; AC = all MOVs corrected;
SC = some corrected; NC = none corrected

Discussion

Since the early years of the EPI, household surveys have been promoted to monitor vaccination coverage (40). With the aim of obtaining results that are as accurate, precise, and reliable as possible, countries are currently encouraged to commission institutions or partners with statistical and survey expertise to conduct high-quality and statistically sound independently implemented vaccination coverage surveys. The reasons for this include the increasing complexity and cost of EPI with the addition of new vaccines targeting different age groups; increasing coverage levels in most countries, which calls for more precise coverage estimates; improved survey and statistical methods as well as tools to manage large databases; and a world where accountability is key for governments, partners supporting EPI and for the beneficiaries of the immunization programme (9). During the development and rollout of updated survey guidance, WHO and partners noted the need to improve the standardization of coverage indicator definitions, survey questionnaires and the analysis and presentation of results (4,10,21,41). In this paper we have illustrated the use of a standardized, freely available tool to analyse coverage surveys and the presentation of results on indicators that are harmonized across the major survey programs which monitor vaccination coverage (22). The suite of indicators presented here, along with others detailed in VCQI documentation provides managers with information to guide improvements to their programs (11).

The 2016-17 MICS/NICS showed several findings of importance to the Nigeria vaccination program. Coverage of all vaccines was low even when using the most liberal definition of crude coverage by the time of the survey including maternal recall. Only just over half of respondents said the child had ever received a card, and only 29% could show a card to interviewers. Survey results for crude coverage therefore rely heavily on caretaker recall, which reduces data reliability (42–44) especially for the number of doses received in a multi-dose series – studies suggest that in some settings caretakers tend to under-report the number of doses received (42,44).

Coverage varied greatly between states and, though not presented here, according to background factors including education and wealth (25). Low coverage of Penta1 is often taken to indicate low access to vaccination services (9) and many northern states had crude coverage for Penta1 below 40%, contrasting starkly with the African regional average for 2016 of 84% (45). There was a gradient of coverage for all vaccines from lowest in the north, especially those in the North West and North East zones, to higher in the south but only one state (Lagos) achieved over 80% crude coverage of Penta3. To compound the problem of low average coverage, Nigeria was recently ranked highest among 45 GAVI-supported countries for inequity in coverage (46,47)

Crude coverage of MCV was higher than that of Penta3, and four states achieved over 80% coverage for measles. This probably reflects the inclusion of campaign doses in the measure of measles vaccination coverage (27), as about half the age cohort included in MICS-NICS would have been eligible for the 2015-16 measles SIA. This conclusion is supported by the finding that MCV coverage was slightly lower than Penta3 coverage among children with cards (where documented doses reflect RI) whereas it was about twice as high as Penta3 by recall (Table 1) and the low availability of HBR meant that most information was obtained by verbal recall, though some missed-opportunities to give Penta when a child present late for vaccination cannot be excluded. Since MCV is administered via many of the same fixed

facilities and outreach posts in campaigns as in routine services, it would be difficult for respondents to differentiate between RI and campaign doses several months or years after a campaign took place. The WHO white paper encourages further operational research on how to frame questions to elicit this type of information (22).

The 2018 PMCCS confirmed that SIAs reach much higher coverage than routine in much of Nigeria and importantly, SIA coverage among previously MCV zero-dose children was high (27), suggesting that lack of acceptance of vaccination is not a major barrier. A mixed-methods study in two Nigerian states found that receipt of MCV was related to awareness of vaccination, parental education, maternal participation in decision-making, presence of a government vaccination facility, and lack of barriers such as having to pay for vaccination (48). The intensive information campaigns leading up to SIAs combined with making vaccination sites more accessible likely both contribute to the SIA's success (49). Nonetheless, SIA coverage was below that required for measles elimination and in some survey clusters fewer than 25% of children in the coverage survey had received the SIA dose, hence SIA implementation needs further improvement (28).

Indicators of the quality of vaccination services highlight multiple problems in all states. Although low card availability in MICS/NICS limits the generalisability of measures of vaccination quality, there is no reason to expect *better* performance among the children whose HBR were not seen. Many doses were given before the recommended age or with too short an interval between doses. Valid coverage was therefore even lower than crude coverage by HBR, the difference being most marked for OPV3, Penta3, MCV and YF (Table 1). For MCV, although 225 (17.3%) of 1,299 children whose age at vaccination could be calculated received the dose before age 9 months, most of the early doses were received between 6-8 months of age (and over half in their 8th month) when immunogenicity is only moderately reduced (50). In Nigeria, the frequent conduct of SIAs should mean that most children have an opportunity for additional doses to ensure protection.

Dropout between vaccine doses in the primary series was high, especially in states with low coverage of Penta1. Under the 4th strategic objective of GVAP Monitoring and Evaluation/Accountability Framework, measuring of the dropout rates between first dose (DTP1) and third dose (DTP3) of diphtheria-tetanus-pertussis-containing vaccines is a key component of tracking the functionality of the health system. Incomplete vaccination in Nigeria has been linked to parental belief that the series was complete; inconvenient vaccination sites; lack of awareness and absence of vaccinators or of vaccine (51,52). Further health-facility-based studies would be useful to determine how to address problems of health worker absence, health worker attitudes, and other potential barriers to completion of the series (41). Given the big difference in dropout measured by card versus recall in MICS/NICS, health facility-based studies would also have the advantage of enabling the use of register data to obtain more accurate information on dropout at the health facility level.

MOVs due to non-simultaneous vaccination were common. This is particularly worrisome where access is poor – when a mother does bring a child for vaccination it is especially important to ensure that all indicated vaccines are administered. In the North East and North West zones, most children with an MOV never received the missed vaccine, and no zone compensated for more than 60% of the missed opportunities, hence the overall effect on coverage was large (Figure 8 and Supplemental Figures 8-10). As noted in the WHO

coverage survey reference manual, it is possible that some children had a valid contraindication to receipt of a vaccine, but these are likely to be a small minority given the rarity of true contraindications (53,54). Health-facility based surveys of MOVs, which can investigate causes of MOV and also assess MOVs among children attending primarily for reasons other than vaccination, have been done in Nigeria and a national plan of action to reduce MOVs needs to be developed and acted on (55). A review of MOV literature from 1992-2014 concluded that lack of standardized analyses was a barrier to assessing MOV trends over time (56). The updated WHO survey guidelines and VCQI address this issue with clear MOV-related indicators that may be used to examine prevalence and incidence of MOVs in both past and current coverage survey datasets (9,33).

Few countries have lower routine vaccination coverage or greater geographical inequity than Nigeria (57). Since 2000, coverage gains in Nigeria have mainly been limited to the south, with most of the northwest and northeast stagnating or deteriorating (57). In summer of 2017 the National Primary Healthcare Development Agency declared a state of emergency on routine immunization in Nigeria (58,59). A national coordination centre was established to provide guidance and resources to states (60,61), several of which have signed memoranda of understanding with national and international partners to strengthen routine immunization programs (62,63). Improving access to routine vaccination e.g. by increasing the frequency and reliability of fixed and outreach services is likely to be an important strategy to increase coverage. In addition to improving access, much can be achieved by improving the standard of services offered at existing facilities and information given to parents, so that children who do access vaccination complete the vaccination series on time. Future facility-based surveys should complement household surveys for the needed improvement of health worker performance.

Our results are subject to many limitations, mainly related to the surveys themselves. Sampling frame, areas that could not be visited, limited and heterogeneous availability of HBRs, no visits of health facilities. However, the main findings stand: coverage is low, dropouts are high, campaigns reached many people who were previously measles-zero dose, but not at the same level as for those who had already a previous MCV dose, and VCQI can help rapidly run these analysis and visuals.

Household surveys are done regularly in Nigeria, as in many low-income countries, and standardising their analysis and reporting of results will help to increase their use for programmatic action. WHO is rolling out training on the conduct of high-quality immunization surveys and how to use VCQI for analysis. Immunization program managers and their partners should become familiar with new guidelines and available tools and support for high quality surveys, definitions and outputs of a broad array of indicators, and consider other indicators that they may wish to have calculated (e.g. factors associated with receipt of vaccination). A useful starting point is to request secondary analyses of earlier household surveys that included vaccination coverage in their country, to identify possible strengths and shortcomings and to provide information to help plan the design and analysis of upcoming surveys. Lastly, those commissioning and conducting surveys should ensure that microdata are made publicly available, so the most can be made of survey results to plan improvements to their program.

Acknowledgements

The MICS/NICS survey was commissioned by the National Primary Healthcare Development Agency (NPHCDA) and implemented by the National Bureau of Statistics (NBS) with technical support and funding from WHO, UNICEF and the Bill and Melinda Gates Foundation (BMGF) and technical support from Biostat Global Consulting.

The PMCCS was commissioned by the NPHCDA and implemented by the NBS between January and April 2018 with funding from BMGF, Gavi (The Vaccine Alliance), and the Government of Nigeria and with technical assistance from WHO, the Centre for Disease Control and Prevention - National Stop Transmission of Polio (CDC-NSTOP) programme, and the United Nations Children's Fund (UNICEF).

Specific mention goes to Dr Faisal Shuaib, Dr Eric Nwaze, Dr Joseph Oteri, Ms Ijeoma Onuoha of NPHCDA; Dr Isiaka Olarewaju, Mr Biyi Fafunmi, Mr Salihu Isaac, Mr Kola Ogundiya, Mr Bolakale Kareem, Mr Shamsudeen Lawal, Ms Abiola Adeleke of NBS; Dr Tove Ryman, Jenny Sequeira and Yusuf Yusufari of BMGF; Dr David Brown of Brown Consulting Group International, Dr Wenfeng Gong, Dr Kyla Hayford of the International Vaccine Access Center, Johns Hopkins Bloomberg School of Public Health; Dr Modibo Kassogue, Denis Jobin, Denis Businge of UNICEF Nigeria Country Office; Bo Robert Beshanski-Pedersen of UNICEF Headquarters; Dr Fiona Braka, Dr Rachael Seruwange, Dr Anne Jean Baptiste, Dr Daniel Ali of WHO, Nigeria Country Office for their contributions to the planning, coordination, implementation and dissemination of the MICS/NICS and PMCCS surveys.

Additional Supporting Materials

The 2018 Vaccination Coverage Cluster Survey Reference Manual is available in English and French (9,64) and is supported not only by the Vaccination Coverage Quality Indicators (VCQI) Stata programs (11) and the white paper (22) mentioned in this manuscript, but also by a freely-available sample size calculator (65) and a so-called *cookbook* consisting of 1-2 page summaries of the steps to conduct a coverage survey (66). Figures 8-10 and Supplementary Figures 9-10 were made with an interactive R Shiny tool that any VCQI user may use to browse their own output; the tool can export images or tables or datasets to document the prevalence of missed opportunities for vaccination (39). WHO welcomes feedback on all of these materials; address correspondence to Carolina Danovaro at danovaroc@who.int and Dale.Rhoda@biostatglobal.com.

Funding

DAR and MLP and MKT were funded via BMGF Investment ID 29065. FTC received consultancy fees from BMGF. CBC is funded on BMGF Investment ID 53009. MCDH is a WHO staff member. JNW was funded as the primary WHO consultant on the MICS/NICS and on the PMCCS.

The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding agencies. M. Carolina Danovaro[-Holliday] works for the World Health Organization. The author alone is responsible for the views expressed in this publication and they do not necessarily represent the decisions, policy or views of the World Health Organization. The funders did not play any role in the collection, analysis, interpretation, writing of final reports, or decision to submit this research.

Author contributions

JNW was the primary WHO consultant on the MICS/NICS and PMCCS participating in survey design, organization and supervision of field work with JO, BO and AA. DAR provided support to the design of MICS/NICS and PMCCS. JNW, DAR, MLP, MKT and CBC conducted data analyses with input from MCD-H and FTC. FTC wrote the first draft of the manuscript. All authors contributed to writing and editing of the manuscript.

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