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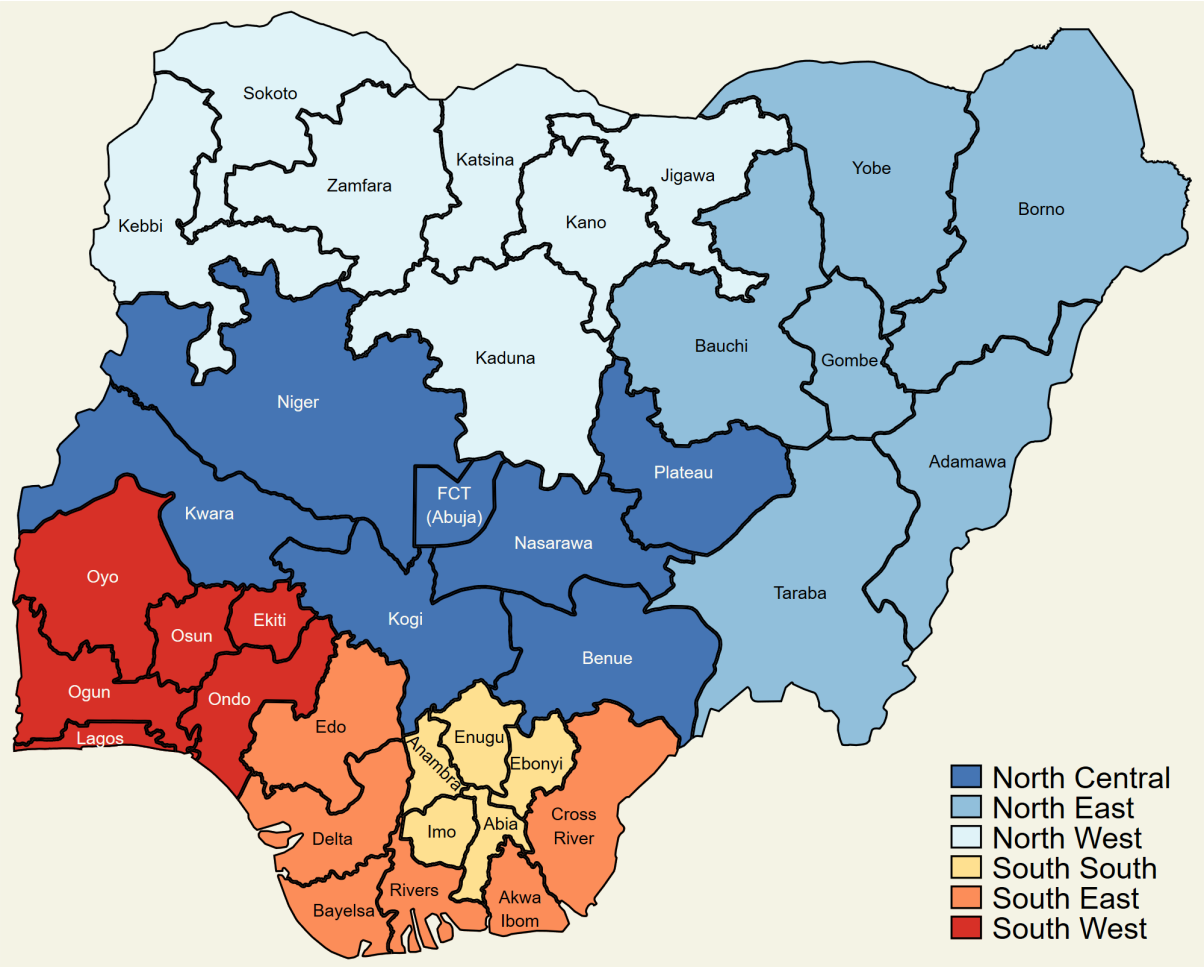
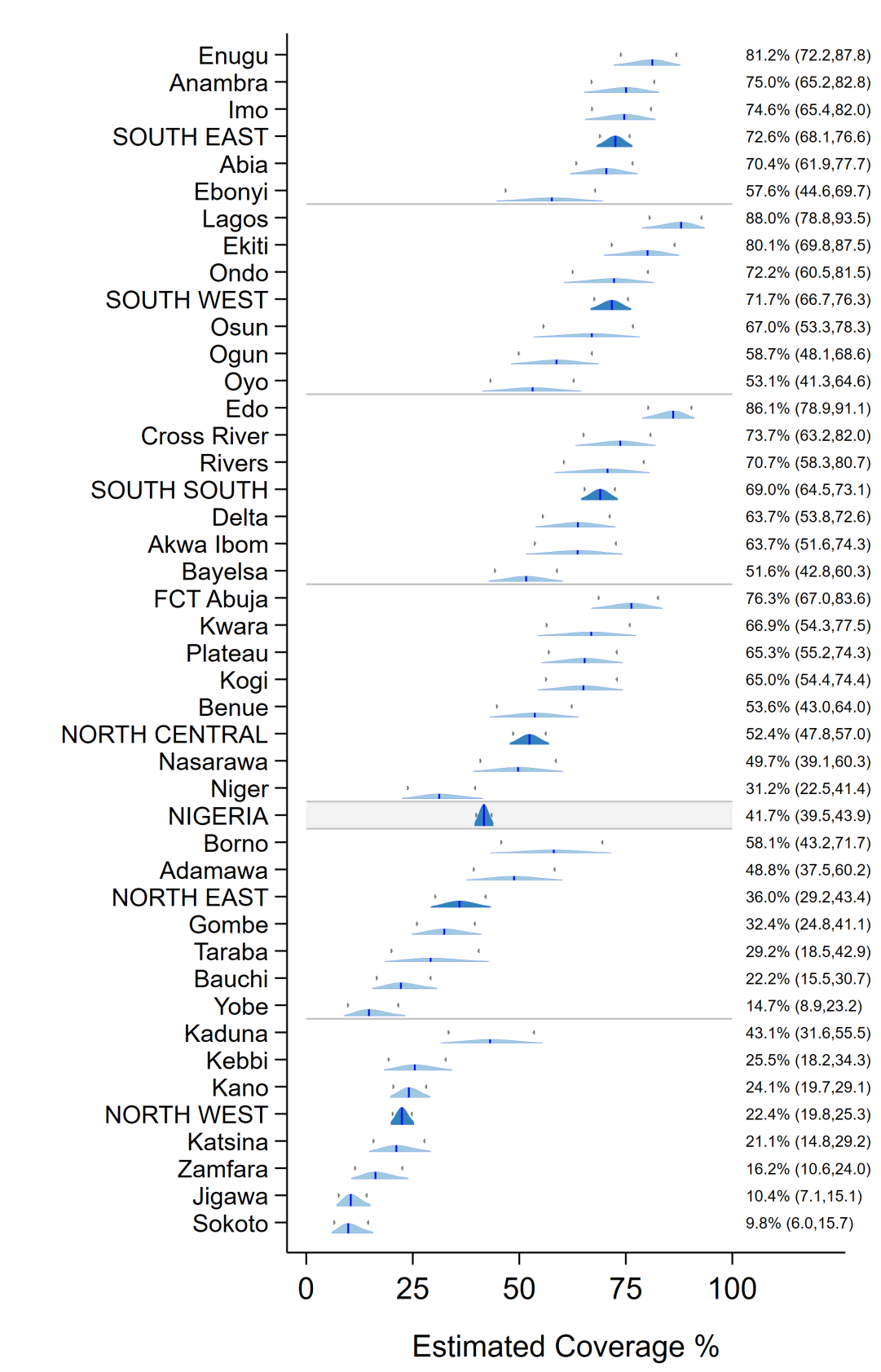
Supplementary Figures

Supplementary Figure 1: Map of Nigeria

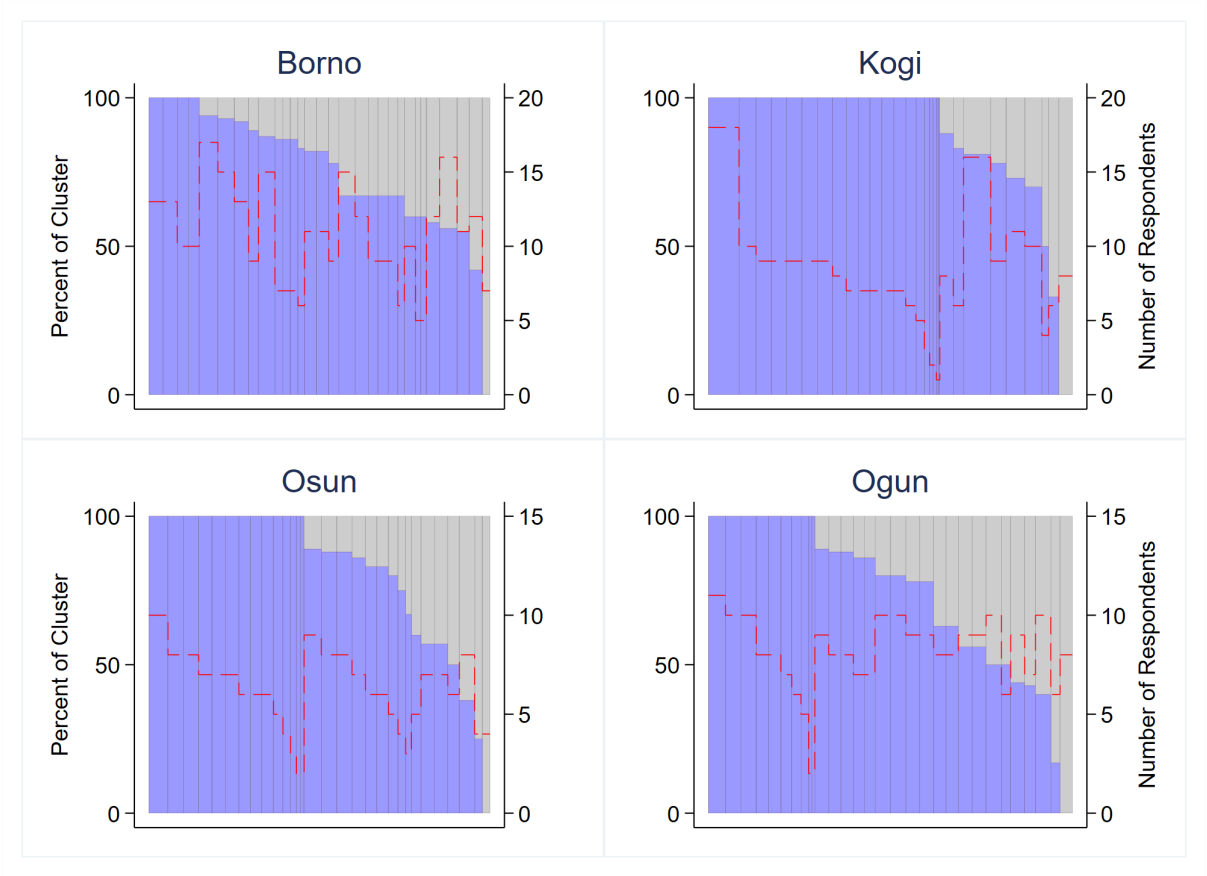


Supplementary Figure 2: Crude MCV coverage, children aged 12-23 months, Nigeria MICS/NICS 2016-17, by state

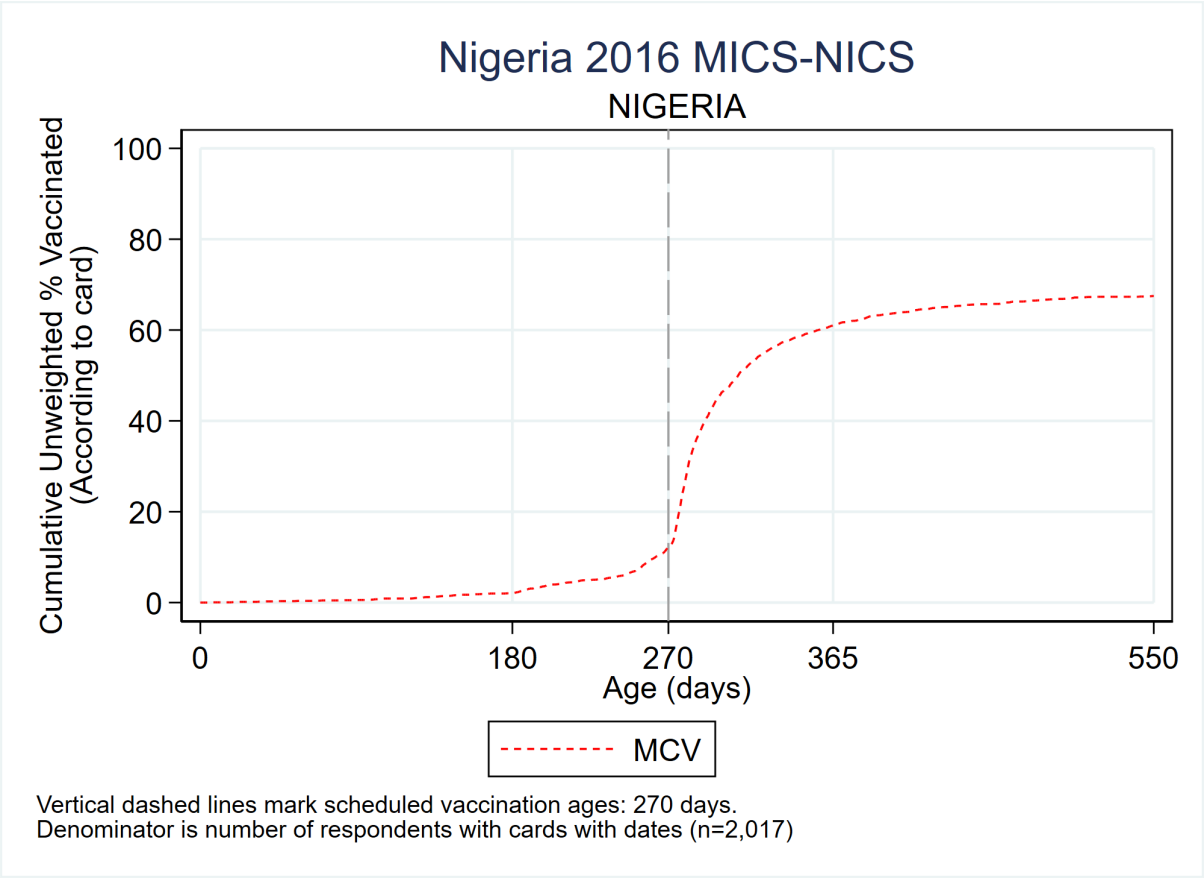


Text at right: Point Estimate (2-sided 95% Confidence Interval)

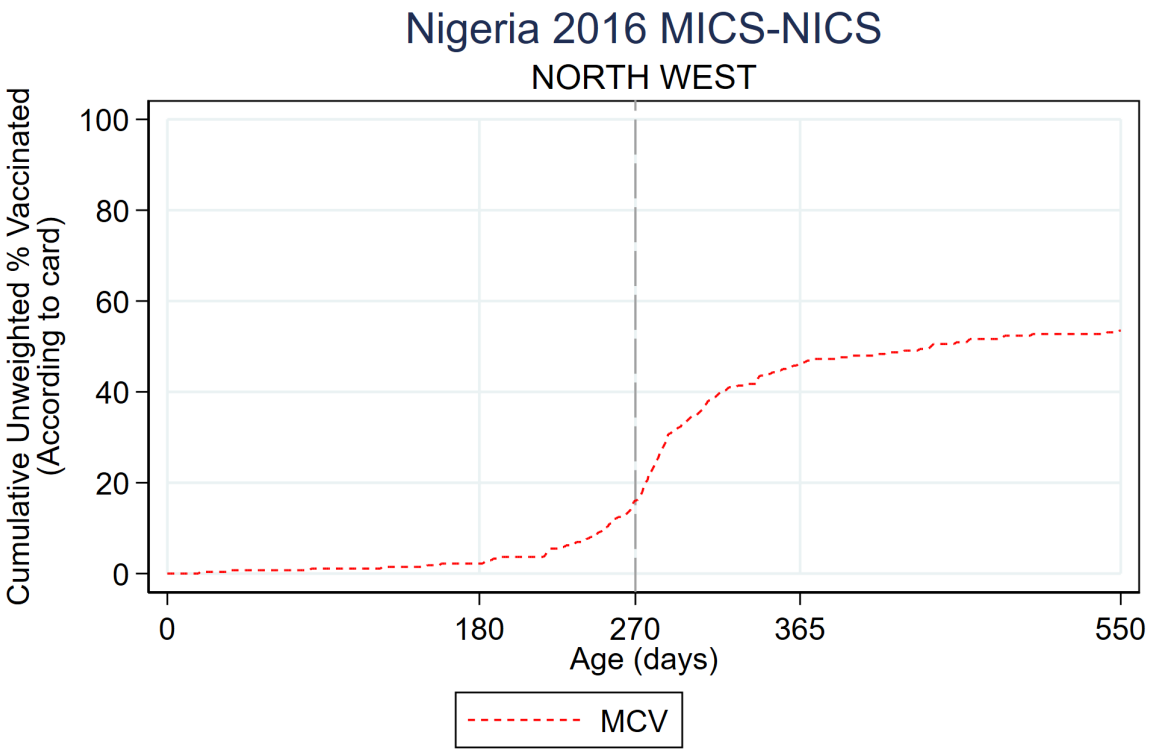
Supplementary Figure 3: PMCCS organ pipe plots for four states, Nigeria PMCCS 2018.



Supplementary Figure 4: Cumulative measles coverage plot by age of child (days) in Nigeria, MICS/NICS 2016-17

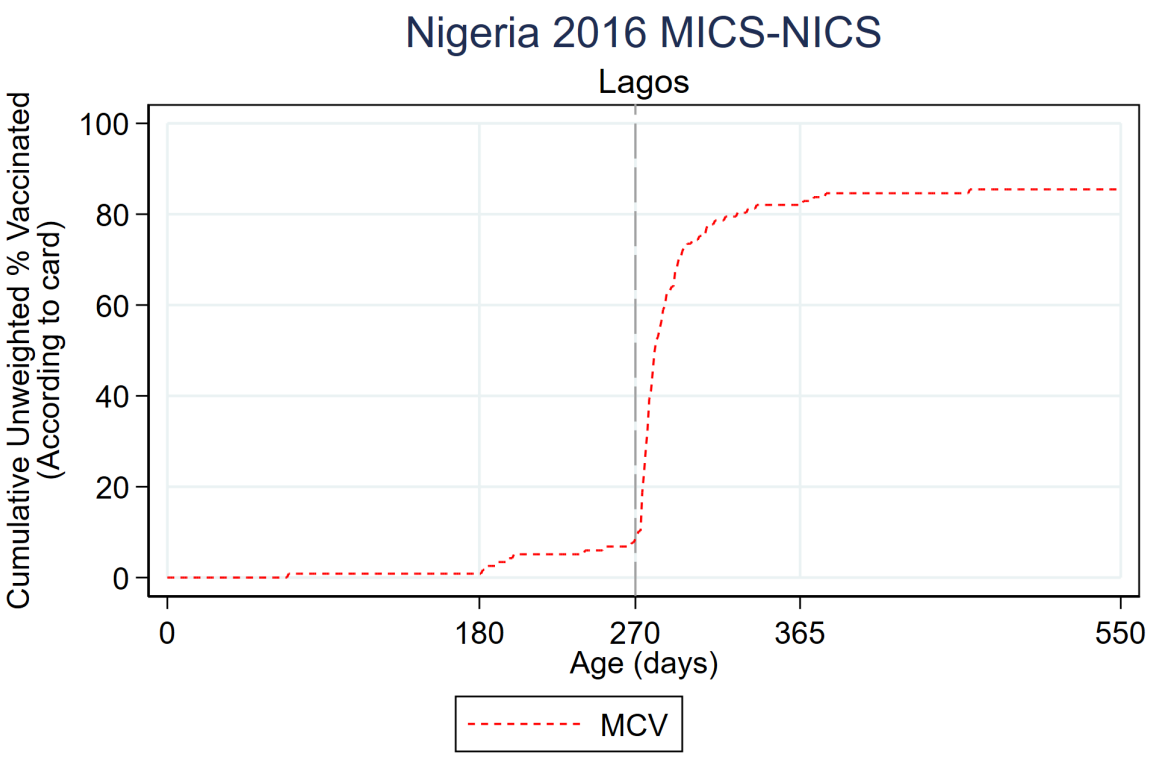


Supplementary Figure 5: Cumulative measles coverage plot by age of child (days) in North West zone, Nigeria MICS/NICS 2016-17



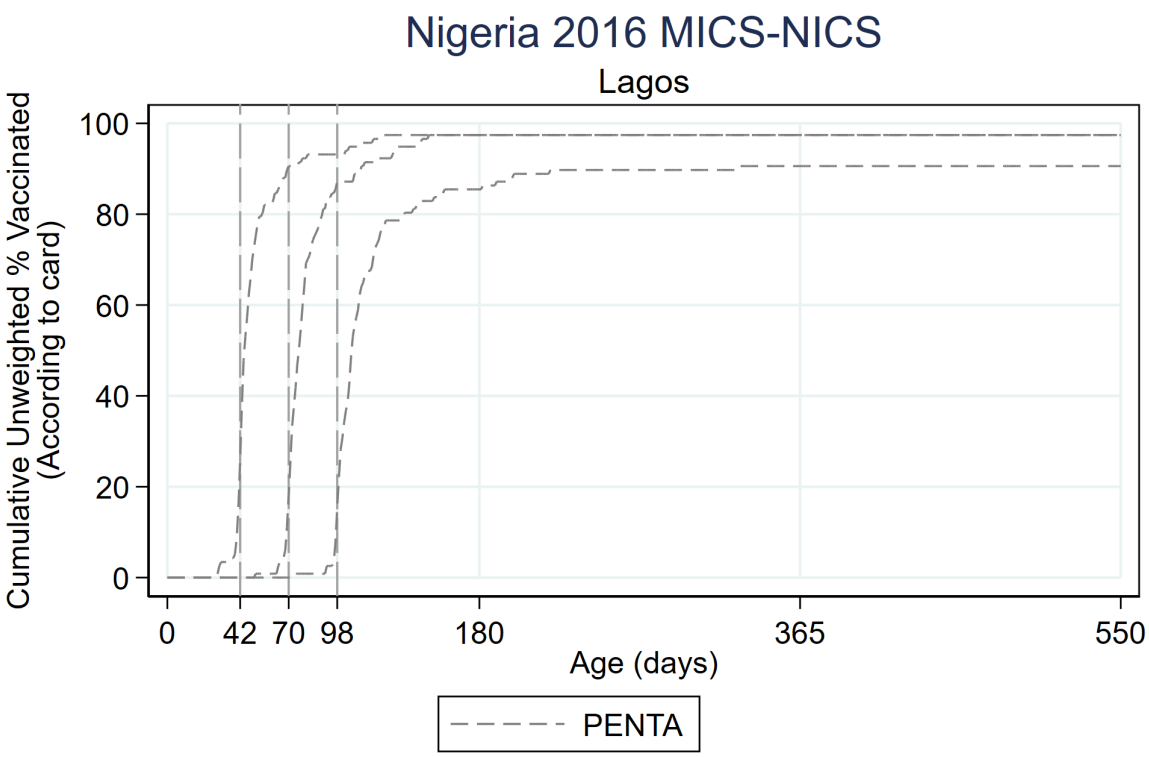
Vertical dashed lines mark scheduled vaccination ages: 270 days.
Denominator is number of respondents with cards with dates (n=295)

Supplementary Figure 6: Cumulative measles coverage plot by age of child (days) in Lagos state, Nigeria MICS/NICS 2016-17



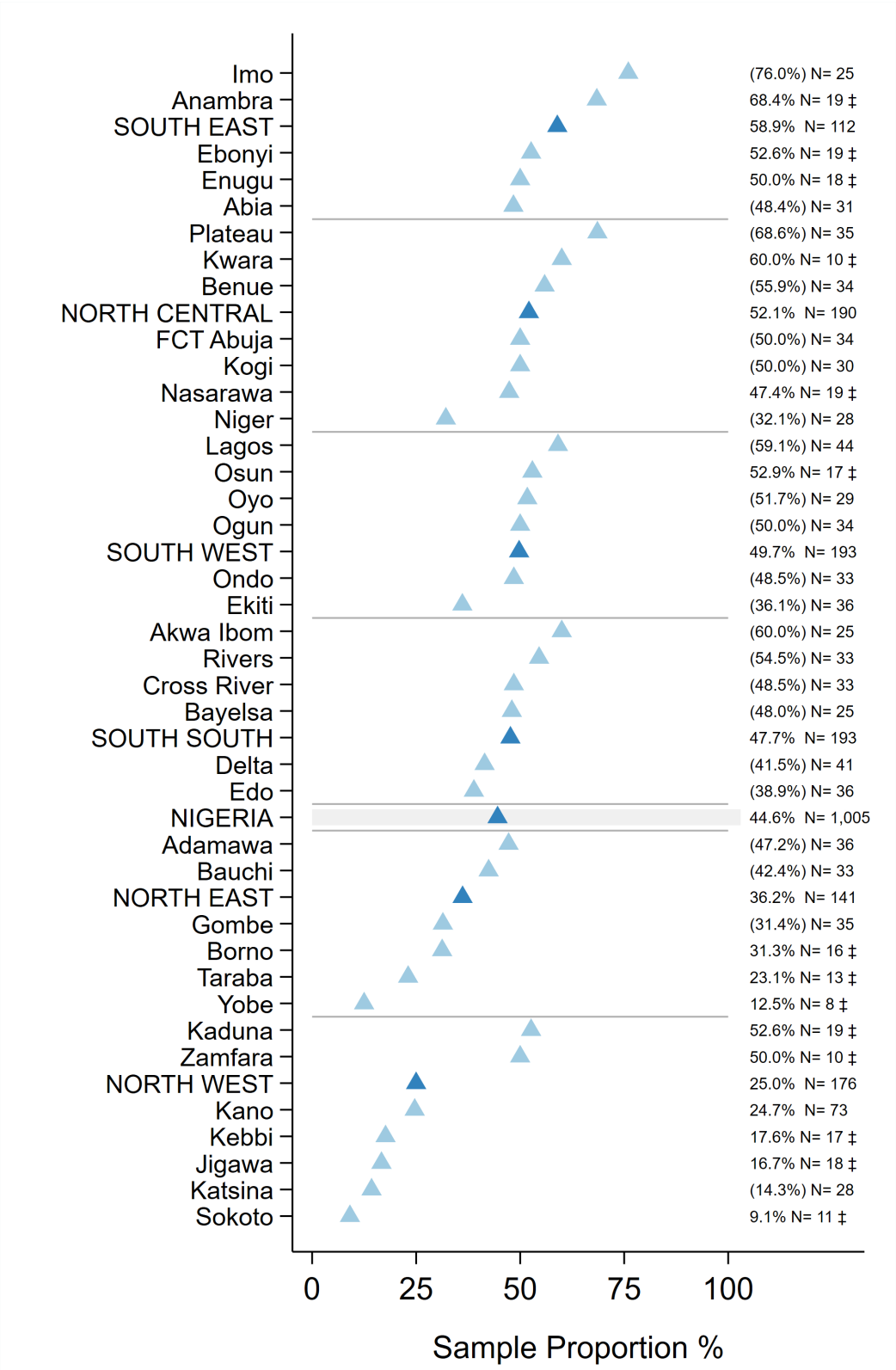
Vertical dashed lines mark scheduled vaccination ages: 270 days.
Denominator is number of respondents with cards with dates (n=121)

Supplementary Figure 7: Cumulative pentavalent coverage plot by age of child (days) in Lagos state, Nigeria MICS/NICS 2016-17



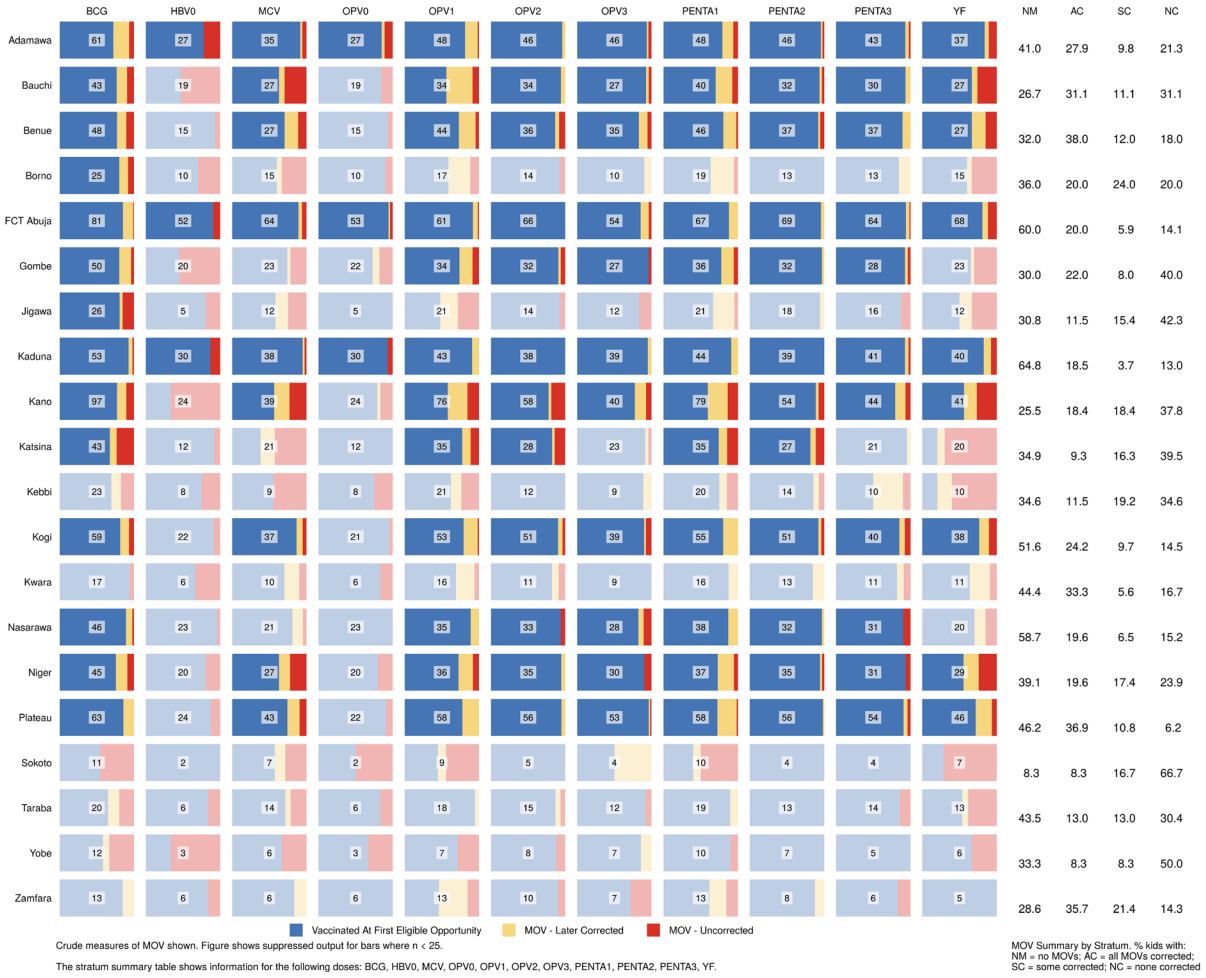
Vertical dashed lines mark scheduled vaccination ages: 42, 70 & 98 days.
Denominator is number of respondents with cards with dates (n=121)

Supplementary Figure 8: Unweighted percentage of children aged 12-23 months with an HBR and at least one MOV for BCG, HBV0, OPV0-3, Penta1-3, MCV or YF who later received all the vaccines that had been missed ("corrected" MOVs), Nigeria MICS/NICS 2016-17



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

Supplementary Figure 9: 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 state (row) who had 1+ vaccination visits when age eligible to receive that dose (column). Northern states, Nigeria MICS/NICS 2016-17



Supplementary Figure 10: 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 state (row) who had 1+ vaccination visits when age eligible to receive that dose (column). Southern states, Nigeria MICS/NICS 2016-17

Supplementary Tables

Supplementary Table 1: Selected definitions used in VCQI for indicators calculated using weighted analyses

Indicator	Definition	Numerator	Denominator
Home-based record (HBR) ever ownership	Percentage of children age 12-23 months whose mother or caretaker says have ever received a HBR, even if the record is not seen on the day of the interview (e.g. because it is locked away and the person with the key is absent)	Sum of weights of children said to have had a vaccination record even if not seen on day of interview	Sum of weights of all children in the sample in the defined target population (12-23 months)
HBR current ownership	Percentage of children age 12-23 months whose home-based record is seen and contains usable information	Sum of weights of children whose vaccination record is seen and has at least one date of vaccination on it	Sum of weights of all children aged 12-23 months in the sample
Crude Coverage of {vaccine-dose} *	Percentage of children age 12-23 months who received {vaccine-dose} at any age by time of survey (sub-categories: according to documentation (HBR)/according to maternal recall)	Sum of weights of all children identified in the denominator who received the specified vaccine dose(s) (by sub-categories: by documented evidence or by recall) by any date prior to the survey	Sum of weights of all children in the sample in the defined target population (12-23 months)
Crude Coverage of fully vaccinated** children	Percentage of children age 12-23 months who received all vaccine-doses recommended in the national schedule by time of survey (sub-categories: according to documentation (HBR)/according to maternal recall)	Sum of weights of all children identified in the denominator who received all vaccine-doses included in the fully vaccinated definition	Sum of weights of all children in the sample in the defined target population (12-23 months)
Valid Coverage of {vaccine-dose} * based on documented evidence	Percentage of children age 12-23 months who received {vaccine-dose} respecting the minimum ages for each dose and the minimum interval between doses as recommended in the national schedule by time of survey. Because documented dates of each vaccine-dose are needed in order to determine if the schedule was followed appropriately, this can only be calculated among children with documented evidence.	Sum of the sample weights for children 12-23 months who are vaccinated where the doses followed the earliest recommended age and minimum interval between doses	Sum of the sample weights for children 12-23 months with documented evidence of their vaccination status (unless otherwise specified – can have a second related indicator that includes all children in denominator)

Indicator	Definition	Numerator	Denominator
Never vaccinated (with any of the basic antigens) coverage	Percentage of children aged 12-23 months who received none of the basic vaccines	Sum of the sample weights for those of children who received none of recommended vaccine doses for the basic six antigens, by the time of the survey, based on the combination of recall and documented evidence	Sum of weights of all children aged 12-23 months in the sample
SIA coverage	Percentage of children aged 9 months to 59 months who received a dose of MCV during the SIA	Sum of weights of children said to have received MCV during the SIA	Sum of weights of all children aged 9-59 months in the sample
Percentage of children not vaccinated against measles before SIA ("zero-dose" children)	Percentage of children aged 9 months to 59 months who had not received a dose of MCV before the SIA	Sum of weights of children with no history or record of receiving MCV before the SIA	Sum of weights of all children aged 9-59 months in the sample
Percentage of children already vaccinated against measles before SIA	Percentage of children aged 9 months to 59 months who had received a dose of MCV before the SIA	Sum of weights of children with a history or record of having received MCV before the SIA	Sum of weights of all children aged 9-59 months in the sample
SIA coverage among zero-dose children	Percentage of children aged 9-59 months at the time of the SIA with NO history of receipt of MCV before the SIA who received a dose of MCV during the SIA (by card, finger-mark or parental recall)	Sum of weights of children with no history or record of receiving MCV before the SIA who received a dose of MCV during the SIA	Sum of weights of children with no history or record of receiving MCV before the SIA
SIA coverage among children vaccinated previously	Percentage of children aged 9-59 months at the time of the SIA with a history of receipt of MCV before the SIA who received a dose of MCV during the SIA (by card, finger-mark or parental recall)	Sum of weights of children with a history or record of having received MCV before the SIA who received a dose of MCV during the SIA	Sum of weights of children with a history or record of having received MCV before the SIA

* {vaccine-dose} is specified in each row, e.g. BCG, pentavalent 1, pentavalent 2, etc.

** May have 2 definitions for fully vaccinated, one focusing only on the original 6 antigens and another including all antigens in the schedule – see results table.

Supplementary Table 2: Selected definitions used in VCQI for indicators calculated using unweighted analyses which represent a subset of the total target population

Indicator	Definition	Numerator	Denominator
Percentage of {vaccine-doses} that were invalid	The percentage of children who had received the relevant {vaccine-dose} while they were either at too young or with too short an interval since the previous dose in the series. E.g. DTP1<42 days; DTP2<70 days or <28 days after DTP1; DTP3<98 days or <28 days since DTP2; MCV1<273 days.	Number of respondents whose {vaccine-dose} was invalid	e.g. Number of respondents who had date of birth data and received {vaccine-dose} with a date
Dropout between vaccine-doses (e.g. Penta1 to Penta3; Penta1 to MCV etc.	The estimated percentage of children 12-23 months who received the specified vaccine-dose given earliest in the schedule but failed to receive the specified subsequent vaccine-dose in the schedule. For example, Penta1 to Penta3 dropout is shown here: dropout = (Penta1-Penta3)/Penta1 This indicator can be sub-categorized according to source of evidence (HBR/recall/either)	Number of respondents who received the first dose but did <u>not</u> receive the later dose (e.g. Penta1-Penta3)	Number of respondents who received the first dose (e.g. Penta1)
Percent of children with missed opportunity for simultaneous vaccination (MOV)	Percent of children who on at least on occasion, did not receive all the vaccines for which they were eligible*. E.g. those with different dates for Penta1 and OPV1. Can sub-categorise according to whether the MOV was later corrected or not (i.e., was the missed vaccine-dose received later at a valid age?) Calculate for each vaccine and dose Calculate over all vaccines and doses	Number of children who experienced 1+ missed opportunities to be vaccinated for the dose in question	Number of children with date of birth data and date of vaccination data indicating that they had 1+ visits for vaccination on days when they were eligible to receive the dose in question
Percent of *visits* with missed opportunity for simultaneous vaccination (MOV)	Percent of visits (i.e. considering all visits by all children with documentation) where at least one vaccine-dose was not administered despite the child being eligible* Calculate for each vaccine and dose Calculate over all vaccines and doses	Number of vaccination visit dates where a respondent did not receive all vaccinations for which they were eligible	Number of vaccination visit dates where a respondent was eligible to receive 1+ vaccinations

*Eligibility is based on age of child and, where relevant, interval since the previous dose in the sequence. Information on any potential contraindications on the visit is not available hence all children are assumed to have no contraindications.

Supplementary Table 3: Dropout rates between different vaccine-dose combinations in the vaccination series, by source of information, Nigeria MICS/NICS 2016-17.

		Children with HBR having received at least Penta1		Children without HBR having received at least Penta1 by recall		All children who had documented or recall evidence of having received Penta1	
		Penta1 to Penta3	Penta1 to measles	Penta1 to Penta3	Penta1 to measles	Penta1 to Penta3	Penta1 to measles
		% (weighted N)	% (weighted N)	% (weighted N)	% (weighted N)	% (weighted N)	% (weighted N)
	National	16.9 (1737)	26.9 (1737)	51.6 (1326)	14.8 (1326)	31.7 (3055)	21.1 (3055)
	Urban	12.2 (797)	18.7 (797)	48.3 (571)	9.3 (571)	26.9 (1366)	14.0 (1366)
	Rural	20.9 (940)	33.9 (940)	54.2 (755)	18.9 (755)	35.6 (1689)	26.9 (1689)
Zone	North West	28.8 (356)	36.7 (356)	69.5 (271)	17.4 (271)	46.1 (625)	28.2 (625)
	North East	24.2 (288)	36.7 (288)	51.9 (343)	17.4 (343)	39.6 (629)	26.3 (629)
	North Central	16.8 (276)	26.9 (276)	52.0 (253)	10.4 (253)	33.4 (528)	18.2 (528)
	South West	7.2 (394)	16.7 (394)	45.6 (177)	14.3 (177)	18.7 (570)	15.1 (570)
	South East	11.0 (164)	23.1 (164)	39.0 (138)	15.6 (138)	23.3 (301)	19.1 (301)
	South South	11.1 (259)	20.8 (259)	36.4 (144)	11.4 (144)	19.3 (401)	16.1 (401)
Caregiver's education	Non-formal	36.1 (114)	56.6 (114)	66.0 (150)	11.4 (150)	53.7 (260)	31.3 (260)
	Primary	16.2 (283)	33.0 (283)	49.4 (211)	15.8 (211)	30.1 (493)	24.5 (493)
	Secondary / Secondary-technical	13.3 (803)	22.6 (803)	46.2 (520)	13.8 (520)	25.5 (1322)	18.3 (1322)
	Higher	3.3 (260)	7.1 (260)	42.8 (193)	4.8 (193)	20.1 (452)	5.7 (452)
	Missing	33.2 (276)	39.8 (276)	63.0 (252)	25.6 (252)	47.8 (527)	33.4 (527)
Wealth index	Poorest	31.6 (157)	47.4 (157)	67.5 (129)	24.5 (129)	47.7 (285)	36.8 (285)
	Second	24.4 (243)	39.0 (243)	59.0 (231)	22.0 (231)	41.6 (470)	30.7 (470)
	Middle	23.2 (348)	32.7 (348)	50.4 (244)	11.6 (244)	33.6 (591)	23.3 (591)
	Fourth	14.1 (423)	26.2 (423)	44.2 (392)	11.9 (392)	28.4 (813)	18.8 (813)
	Richest	7.8 (565)	13.0 (565)	50.1 (331)	11.8 (331)	23.1 (896)	11.8 (896)
	Median (range) by state*	14.7 (3.0,45.5)	26.9 (8.8,59.9)	53.1 (19.6,94.4)	11.8 (0,55.9)	31.8 (13.4,69.0)	20.6 (7.2,57.1)

*The median, min. & max. percentages of the 37 states are provided, not the mean or weighted N.

Supplementary Table 4: Data cleaning details for Nigeria MICS/NICS 2016-17 and PMCCS 2018

Issue	Resolution
Eligible population and indicator definitions	Vaccination coverage for the MICS/NICS focused on children aged 12-23m. The denominator for crude and valid coverage and fully-immunised and proportion showing cards is all eligible children in the survey. The denominator for indicators concerning timeliness and missed opportunities for vaccination (MOVs) is all eligible children whose date of birth was known and showed a card with vaccination dates on it. The eligible population for the PMCCS is all children aged 9-59m and the denominator for coverage indicators is all eligible children in the PMCCS.
Steps to differentiate RI from SIA doses	The MICS/NICS asked not only about doses delivered through routine immunization but also, for children with a HBR that does not show a date of MCV, whether additional vaccines had been received in a campaign. For children without a HBR, mothers are asked if the child ever received each vaccine but without specifying if it was in RI or a campaign. For analysis purposes, if the HBR is blank for measles but the caretaker says the child participated in an SIA, the child could be given coverage credit based on the caretaker's recall. This requires careful coding of the input data and tracking of provenance if the analysis plan calls for tables that document the sources of vaccination.
How valid doses are defined	A dose is *valid* if the child has reached the minimum age to receive the antigen and, for multi-dose antigens, if the appropriate interval has passed since the most recent dose. To assess age and interval duration, the software requires vaccination dates, so children who do not furnish HBRs and for whom FBRs are not found must be excluded from calculations about valid doses. There is a tradition in WHO EPI surveys to include all eligible children in the denominator of valid coverage, even though the numerator can only include children who show cards with dates. For example, if 40% of children showed an HBR and 90% of children with HBRs showed evidence of receiving a valid dose of measles, the valid coverage estimate would be 36% (or 90% of 40%). Including all children in the denominator puts the valid coverage estimate on the same scale as crude coverage, but if HBR availability is low, it suppresses the maximum possible value for valid coverage. If only a small portion of children have or show HBRs, then we can only confirm the validity of doses for a small portion of respondents. The White Paper recommends that valid coverage include all eligible children in the denominator but that it only be presented when at least 80% of children have an HBR.
Evidence from tick marks	In the best case, doses are documented on HBRs and FBRs with a legible date of vaccination. In some cases, the date is missing and the HBR includes only a check mark or a signature from the vaccinator. In other case the date is present, but incomplete or impossible to read. These children receive credit for a crude dose of the vaccine, but because we cannot know the age at which they received it, they are excluded from indicators that assess age or eligibility at the time of vaccination.

Issue	Resolution
Imperfect date values	In some cases, the dates of birth or vaccination may be incorrect on the source document, the survey questionnaire or the survey dataset. One important step during data cleaning is to identify impossible or unlikely vaccination dates and, if paper forms were used, send them back to the data entry team to confirm or correct. The MICS/NICS and PMCCS interviewers entered responses directly into tablets via computer-assisted personal interviewing (CAPI) so there was no possibility of correcting nonsensical dates. In VCQI analyses of RI surveys, imperfect dates are handled thus: – The analyst provides input parameters listing the earliest and latest possible dates of vaccination for a child in the dataset – Any vaccination date that falls a) before the child's date of birth, or b) outside the earliest-to-latest window is analysed as if it were a tick mark instead of a date; that is, the child is given credit for crude coverage but is not included in date-based analyses for that dose – Any vaccination dates in a dose series that is out-of-chronological order is also analysed as if it were a tick mark – If the HBR or FBR includes dates for later doses in a series (e.g., OPV2) but is missing evidence for the earlier dose (OPV1) then VCQI analyses the earlier dose as if it had been recorded with a tick mark – Finally, any date that is partially recorded (i.e., includes month and year but missing day) or illegibly recorded, and any date that is legible but nonsensical, like February 30 or September 31 is analysed as if it had been recorded with a tick mark
Missing values, 'unsure', and 'do not know' responses	The VCQI Results Quick Interpretation Guide lists how missing/unsure/do not know responses are handled for each indicator [27]. For coverage outcomes, the child is assumed to be unvaccinated if the caretaker is not sure. In cases where the caretaker is confident that the child received the antigen but are unsure how many doses they received, VCQI gives credit for only a single dose, which is a conservative approach.

Issue	Resolution
Confidence interval calculations	Symmetric Wald-type confidence intervals can yield absurd lower or upper bounds that fall outside the 0-100% range when the estimated coverage is very low or very high. Several alternative formulae have nice properties: – Their bounds always fall between 0-100% (inclusive) – If the survey is unbiased, the confidence intervals contain the true population proportion nearly 95% of the time – The intervals are narrow (precise) when compared to alternatives A coverage survey report should document which formula was used. VCQI can calculate logit, Wilson, Jeffreys, or Clopper-Pearson intervals, and it adjusts the degrees of freedom to account for the complex sample design. The analyses reported here used Wilson confidence intervals when coverage was between 0 and 100% and Clopper-Pearson intervals when coverage was exactly 0% or 100%.
How many decimal places to report	It is common to report coverage percentages with a single digit after the decimal place (e.g., 53.4%). But to keep tables from being too wide to fit on a standard page, some reports omit that final digit, rounding to the nearest percent, reasoning that the decimal digit is usually not critical for policymakers. The MICS report and PMCCS reports included the final digit and the NICS report omitted it.