Supplementary Appendix

This appendix has been provided by the authors to give readers additional information about their work.

Supplement to: Jenkins HE, Aylward RB, Gasasira A, et al. Effectiveness of immunization against paralytic poliomyelitis in Nigeria. N Engl J Med 2008;359:1666-74.

The effectiveness of immunization against polio in Nigeria – Supplementary Material

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Supplementary Methods

Sensitivity of testing for poliovirus among Acute Flaccid Paralysis cases

A method for evaluating the sensitivity of testing for poliovirus among Acute Flaccid Paralysis (AFP) cases with two stool samples was developed and published by Gary et al. in 1997[1] and is used in this paper. The method assumes that the laboratory test for poliovirus is 100% specific and that the sensitivities of the test for each stool are equal, which is a reasonable assumption provided that the time between collection of each sample is short (in AFP surveillance, the stool samples are typically collected between 24 and 48 hours apart and this was the case for 99% of AFP cases in our dataset). The maximum likelihood estimate of the sensitivity to detect poliovirus from a single stool is given by $S = 2N_{11}/y$ and the prevalence of infection is $y^2/(4N_{11}T)$, where $y = 2N_{11}+N_{10}+N_{01}$ = number of positive specimens, N_{10} = number of people whose first specimen was positive and the second was negative, N_{01} = number of people whose first specimen was negative and the second was positive, N_{11} = number of people with two positive specimens, and T = number of AFP cases. The person sensitivity was defined as the probability that at least one specimen from a child with polio will have a positive test result. As two specimens were collected, person sensitivity was the complement of the probability that both specimens were negative = $1- (1- S)^2$. The probability of misclassifying a case from the AFP database who was paralysed by wild poliovirus as a child without polio was therefore given by prevalence * (1 – person sensitivity).

Conditional logistic regression of 1:1 matched cases and controls

The probability that a child who has received m doses of monovalent oral polio vaccine against serotype 1 (mOPV1) and t doses of trivalent oral polio vaccine (tOPV) is protected against paralysis from type 1 poliovirus is:

$$p=1-(1-v_m)^m(1-v_t)^t \quad \text{(eq. 1)}$$

Where v_m and v_t are the protective efficacies of mOPV1 and tOPV per dose received, respectively. The protective efficacies of mOPV1 and tOPV are estimated in the conditional logistic regression described in the main text which estimates the ln(odds) of paralysis as

$\ln(\text{odds}) = \alpha m + \beta t + E$

where $v_m=1-e^{\alpha}$ and $v_t=1-e^{\beta}$

and α and β are the regression coefficients. Each matched case-control pair has a particular level of exposure to wild poliovirus, E, which is unknown and can be eliminated from the analysis by maximising the conditional likelihood.

To assess the validity of reporting a constant efficacy per dose received of tOPV, the estimated number of tOPV doses received was entered as a continuous and categorical variable in separate models and these models were compared via a likelihood ratio test. The same test was carried out to assess a constant efficacy per dose of mOPV1 although, due to the low numbers of mOPV1 doses received, rounding was to the nearest 0.5 dose (fractions of doses may be inferred when the estimated dose numbers is not equal to the number of immunization rounds to which a child was exposed).

Comparisons of the fit of the models with variable and constant efficacies per dose received showed that the constant efficacy per dose assumption was reasonable for both mOPV1 and tOPV (no significant difference in the goodness of fit assessed by the likelihood ratio, p=0.93 and p=0.085 respectively against type 1 and p=0.36 for tOPV against type 3) (Supplementary Figure 2).

Under the assumption of a constant efficacy per dose of vaccine received, the probability of protection following multiple doses is estimated using (eq. 1). For example, if a child has received 2 doses of mOPV1 and 3 of tOPV then, using the efficacy estimates presented in the main text:

Probability of protection = $p = 1-(1-0.67)^2(1-0.16)^3 = 0.94$

Estimation and analysis of vaccine coverage

All non-polio acute flaccid paralysis (AFP) cases aged under 5 years reported in 2005 were categorised by the number of doses of oral polio vaccine (OPV) received (as reported by parents/carers): 0, 1-3 or >3 doses, state of residence and single years of age. This categorisation was carried out by total doses received to obtain estimates of coverage regardless of vaccine type. This resulted in 185 sets of proportions in each dose category (185 = 37 states x 5 age categories), represented by 185 vectors. The proportion of children in each of the three dose categories was estimated for each of the 6 geographic zones in Nigeria as a

weighted sum over age categories and states to reflect their underlying age distribution and population size[2, 3]. This process was repeated for non-polio AFP cases reported in 2007.

In order to calculate the variance of these weighted estimates, a variance-covariance matrix was calculated for each of the 185 vectors of proportions assuming that the proportions follow a multinomial distribution. From these, a weighted variance-covariance matrix was calculated for each of the 6 zones.

The differences in proportions between 2005 and 2007 in each zone were calculated by subtracting the 2005 vector of proportions from that for 2007 (for each zone in turn). The variance-covariance matrices for these difference vectors were calculated by adding the variance-covariance matrix for 2005 to that for 2007 (since Var(**X**-**Y**)=Var(**X**)+Var(**Y**) assuming that the data from the two years are independent).

If there is no difference between two proportions X and Y, then the test statistic $T = (X-Y)^2/(Var(X-Y))$ is asymptotically χ^2 distributed with 1 degree of freedom (under the assumption that the central limit theorem holds and expected values are all greater than 5). In this case we use the multidimensional equivalent $T = \underline{\mathbf{d}}^T \underline{\mathbf{V}}^{-1} \underline{\mathbf{d}}$, where $\underline{\mathbf{d}}$ is the 3x1 vector of the differences in weighted proportions between 2005 and 2007 and $\underline{\mathbf{V}}$ is the 3x3 weighted variance-covariance matrix of the differences. In this case the test statistic is asymptotically χ^2 distributed with 2 degrees of freedom (under the assumption that the central limit theorem holds and expected values are all greater than 5).

Estimation of vaccine-induced population immunity

The fraction of children protected against paralysis by type 1 poliovirus through directly administered OPV was calculated from the estimated coverage with tOPV and mOPV1, and the estimated efficacy of each of these vaccines. The estimated fraction of children unprotected by direct vaccination is given by

$$F = \frac{\sum_i n_i (1-v_t)^{t_i} (1-v_m)^{m_i}}{N} \qquad \text{(eq. 2)}$$

where:

i = an index of unique combinations of doses received, there are a total of 520 different combinations of estimated numbers of mOPV1 and tOPV doses children received in 2007 since the method of estimation can result in fractions of doses (Note: that for years prior to the introduction of mOPV1, i is equal to the number of tOPV doses received)

n_i = the number of children that have received the i^{th} combination of doses

t_i = the estimated number of tOPV doses received in the i^{th} combination

m_i = the estimated number of mOPV1 doses received in the i^{th} combination

$$N = \sum_i n_i$$

α and β are defined as above and the estimates of α and β used are those estimated for the entire country since no evidence was found of regional variation

This quantity, F, is calculated for each of the five age groups within a state and an average of these five numbers is calculated weighting each number by the proportion of children in Nigeria under five that are in that age group, i.e.

Fraction unprotected = $w_1F_1 + w_2F_2 + w_3F_3 + w_4F_4 + w_5F_5$

Where F_1 is the fraction protected in the age group 0-1 years and w_1 is the fraction of the under-five population that are 0-1 years old[2]. The fraction unprotected in a zone then uses the fractions protected in each state and we calculate a weighted average using weights derived from the proportion of the population of the whole zone that are in each state[3].

Vaccine-induced immunity is a function of both reported coverage and estimated efficacy of the monovalent and trivalent oral vaccines (eq. 2). Confidence intervals around the estimates of vaccine-induced immunity were derived using the Delta method. Assuming that the errors around each parameter in F are asymptotically normally distributed with mean 0 and known variance and that the Taylor expansion of F is dominated by the first-order terms, the variance around F is given by:

$$Var(F) = (\nabla F(\alpha, \beta, m_0, .., m_D, t_0, .., t_D, n_0, .., n_D))^T \Sigma (\nabla F(\alpha, \beta, m_0, .., m_D, t_0, .., t_D, n_0, .., n_D))$$

where Σ is the variance-covariance matrix of the parameters, D is the total number of doses reported to have been received and delta F are the partial derivatives of F with respect to each parameter. Var(α), Var(β) and Cov(α, β) are all given directly from the conditional logistic regression. $Var(m_i) = (m_i t_i)/(m_i+t_i)$, $Var(t_i) = (m_i t_i)/(m_i+t_i)$ and $Cov(m_i,t_i) = -(m_i t_i)/(m_i+t_i)$, these variances and covariances assume that the probability that each dose that a child received has a fixed, constant probability of being either mOPV1 or tOPV over time and these probabilities follow a binomial distribution. $Var(n_i) = Np_i(1-p_i)$ where $p_i = n_i/N$ and $Cov(n_i,n_j) = -Np_ip_j$, these variances and covariances assume that the number of children that receive a particular combination of doses follows a multinomial distribution. We assume the covariances $Cov(\alpha,n_i)$, $Cov(\beta,n_i)$, $Cov(m_i,n_i)$ and $Cov(t_i,n_i)$ are zero for all i. The variance of F was calculated for each of the 5 age groups in each of the 37 states and overall variances for each zone were calculated and weighted to match the underlying age distribution and population size[2, 3].

Sensitivity of estimated vaccine efficacy to routine coverage assumptions

To test the assumption that all vaccine doses in our analysis were received from Supplementary Immunisation Activities (SIA) the first three reported doses of vaccine were assumed to be trivalent vaccine received through routine services among a randomly chosen proportion of AFP cases corresponding to reported routine coverage in the corresponding zone (21.4% in the North West, 28.3% in the North East and 36.0% in the North Central zone[4]). The remaining doses were assumed to have been received through SIA and the number of monovalent and trivalent vaccine doses calculated as described in the main text. Vaccine efficacy was calculated using conditional logistic regression as described above. This analysis was repeated 100 times and the percentiles for the estimated efficacy were recorded.

References

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Supplementary Table 1a Annual incidence of paralysis due to type 1 polio in Nigeria by state

Zone	State	Year 2001	2002	2003	2004	2005	2006	2007	2007*	2008*
North West	Jigawa	2	10	12	39	54	102	6	0	22
	Kaduna	1	27	7	78	67	35	5	2	13
	Kano	7	45	31	144	118	304	10	0	55
	Katsina	1	22	7	97	41	157	8	1	21
	Kebbi	8	2	31	37	83	13	17	3	1
	Sokoto	8	0	5	35	37	31	12	1	8
	Zamfara	3	3	4	46	57	29	1	1	25
NORTH WEST		30	109	97	476	457	671	59	8	145
North East	Adamawa	0	0	1	1	2	1	2	0	1
	Bauchi	1	14	25	40	46	82	16	9	15
	Borno	1	8	6	13	11	24	21	5	12
	Gombe	0	9	1	1	8	11	3	2	0
	Taraba	0	0	1	4	3	1	2	1	2
	Yobe	1	9	5	15	15	25	8	2	6
NORTH EAST		3	40	39	74	85	144	52	19	36
North Central	Benue	0	0	8	2	5	0	0	0	2
	FCT	0	1	6	2	2	2	1	1	1
	Kogi	0	2	9	3	2	0	1	1	0
	Kwara	0	0	2	3	1	1	0	0	2
	Nasarawa	0	16	4	1	8	7	0	0	3
	Niger	2	6	3	13	10	17	3	1	6
	Plateau	0	0	3	2	2	4	0	0	2
NORTH CENTRAL		2	25	35	26	30	31	5	3	16
South West	Ekiti	0	0	0	0	0	0	0	0	0
	Lagos	0	0	12	2	1	0	0	0	0
	Ogun	0	0	3	2	0	0	0	0	0
	Ondo	0	0	0	1	0	0	0	0	0
	Osun	0	0	0	2	0	0	0	0	0
	Oyo	0	0	4	6	0	0	0	0	3
SOUTH WEST		0	0	19	13	1	0	0	0	3
South South	Akwa Ibom	0	0	0	0	0	0	0	0	0
	Bayelsa	0	0	0	4	0	0	0	0	0
	Cross River	0	0	0	1	0	0	0	0	0
	Delta	0	0	0	3	0	0	0	0	0
	Edo	0	0	0	0	0	0	0	0	0
	Rivers	0	0	0	0	0	0	0	0	0
SOUTH SOUTH		0	0	0	0	0	0	0	0	0
South East	Abia	0	0	0	0	0	0	0	0	0
	Anambra	0	0	0	1	0	0	0	0	0
	Ebonyi	0	0	0	0	0	0	0	0	0
	Enugu	0	0	0	0	0	0	0	0	0
	Imo	0	0	0	0	0	0	0	0	0
SOUTH EAST		0	0	0	0	0	0	0	0	0
Whole country		**35**	**174**	**190**	**598**	**573**	**846**	**116**	**30**	**200**

*Numbers are as of 18 May of that year

Supplementary Table 1b Annual incidence of paralysis due to type 3 polio in Nigeria by state

Zone	State	Year 2001	2002	2003	2004	2005	2006	2007	2007*	2008*
North West	Jigawa	0	6	17	12	29	30	27	17	1
	Kaduna	0	0	16	15	16	18	2	2	0
	Kano	2	6	57	40	109	51	49	29	2
	Katsina	1	2	32	13	38	22	16	9	1
	Kebbi	0	0	12	17	9	59	10	7	0
	Sokoto	1	3	5	6	16	11	13	9	0
	Zamfara	1	0	1	29	8	20	4	0	2
NORTH WEST		5	17	140	132	225	211	121	73	6
North East	Adamawa	0	0	0	1	1	0	1	0	0
	Bauchi	0	2	11	10	12	18	12	7	1
	Borno	5	5	0	18	1	20	5	2	0
	Gombe	0	1	0	3	1	4	0	0	0
	Taraba	0	0	0	1	0	1	1	0	2
	Yobe	0	0	3	5	5	16	10	3	0
NORTH EAST		5	8	14	38	20	59	29	12	3
North Central	Benue	5	0	1	0	0	0	1	1	0
	FCT	2	1	3	0	3	0	0	0	0
	Kogi	0	0	0	0	1	0	0	0	0
	Kwara	1	0	1	2	0	0	1	0	0
	Nasarawa	1	0	0	1	2	0	3	2	0
	Niger	0	2	1	4	2	5	2	1	1
	Plateau	0	0	2	2	0	1	2	1	1
NORTH CENTRAL		9	3	8	9	8	6	9	5	2
South West	Ekiti	0	0	0	0	0	0	0	0	0
	Lagos	1	0	0	0	0	0	4	0	0
	Ogun	0	0	1	0	0	0	0	0	3
	Ondo	0	0	0	0	0	0	0	0	0
	Osun	0	0	0	0	0	0	0	0	0
	Oyo	0	0	0	1	0	0	6	0	6
SOUTH WEST		1	0	1	1	0	0	10	0	9
South South	Akwa Ibom	1	0	0	0	0	0	0	0	0
	Bayelsa	0	0	0	0	0	0	0	0	0
	Cross River	0	0	0	0	0	0	0	0	0
	Delta	0	0	0	0	0	0	0	0	0
	Edo	0	0	0	0	0	0	0	0	0
	Rivers	0	0	0	0	0	0	1	1	0
SOUTH SOUTH		1	0	0	0	0	0	1	1	0
South East	Abia	0	0	0	0	0	0	0	0	0
	Anambra	0	0	0	0	0	0	0	0	0
	Ebonyi	0	0	0	0	0	0	0	0	0
	Enugu	0	0	0	1	0	0	0	0	0
	Imo	0	0	0	0	0	0	0	0	0
SOUTH EAST		0	0	0	1	0	0	0	0	0
Whole country		**21**	**28**	**163**	**181**	**253**	**276**	**170**	**91**	**20**

*Numbers are as of 18 May of that year

Supplementary Table 1c Annual incidence of paralysis due to type 1 polio in Nigeria by age at onset of paralysis

	Year								
Age (years)	2001 N (%)	2002 N (%)	2003 N (%)	2004 N (%)	2005 N (%)	2006 N (%)	2007 N (%)	2007* N (%)	2008* N (%)
0-1	2 (6)	15 (9)	21 (11)	35 (6)	30 (5)	25 (3)	5 (4)	3 (10)	4 (2)
1-2	8 (23)	66 (38)	85 (45)	247 (41)	207 (36)	275 (33)	34 (29)	6 (20)	55 (28)
2-3	11 (31)	47 (27)	46 (24)	162 (27)	181 (32)	279 (33)	29 (25)	9 (30)	64 (32)
3-4	6 (17)	29 (17)	24 (13)	71 (12)	51 (9)	120 (14)	17 (15)	8 (27)	38 (19)
4-5	5 (14)	8 (5)	7 (4)	21 (4)	24 (4)	37 (4)	6 (5)	2 (7)	9 (5)
>5	3 (9)	9 (5)	6 (3)	24 (4)	19 (3)	31 (4)	2 (2)	0 (0)	3 (2)
Missing	0 (0)	0 (0)	1 (1)	38 (6)	61 (11)	79 (9)	23 (20)	2 (7)	27 (14)
Total	35	174	190	598	573	846	116	30	200

*Numbers are as of 18 May of that year

Supplementary Table 1d Annual incidence of paralysis due to type 3 polio in Nigeria by age at onset of paralysis

	Year								
Age (years)	2001 N (%)	2002 N (%)	2003 N (%)	2004 N (%)	2005 N (%)	2006 N (%)	2007 N (%)	2007* N (%)	2008* N (%)
0-1	1 (5)	1 (4)	18 (11)	14 (8)	9 (4)	5 (2)	8 (5)	3 (3)	0 (0)
1-2	11 (52)	9 (32)	56 (34)	51 (28)	85 (34)	76 (28)	51 (30)	27 (30)	6 (30)
2-3	6 (29)	8 (29)	43 (26)	53 (29)	95 (38)	92 (33)	51 (30)	27 (30)	7 (35)
3-4	2 (10)	5 (18)	25 (15)	34 (19)	32 (13)	30 (11)	23 (14)	19 (21)	1 (5)
4-5	0 (0)	2 (7)	9 (6)	12 (7)	9 (4)	16 (6)	11 (7)	5 (5)	0 (0)
>5	1 (5)	3 (11)	12 (7)	8 (4)	12 (5)	14 (5)	10 (6)	5 (5)	3 (15)
Missing	0 (0)	0 (0)	0 (0)	9 (5)	11 (4)	43 (16)	16 (9)	5 (5)	3 (15)
Total	21	28	163	181	253	276	170	91	20

*Numbers are as of 18 May of that year

Supplementary Table 2 Supplementary Immunisation Activities (SIA) by date, vaccine type used and location

Date	Vaccine type	Areas included
January 2001	tOPV	All
April 2001	tOPV	All
June 2001	tOPV	All
November 2001	tOPV	All
January 2002	tOPV	All
June 2002	tOPV	Gombe, Kaduna, Katsina
July 2002	tOPV	Bauchi, Borno, FCT, Gombe, Kaduna, Kano, Katsina, Yobe
October 2002	tOPV	All
November 2002	tOPV	All
January 2003	tOPV	Bauchi, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Yobe
March 2003	tOPV	Kebbi, Niger, Sokoto, Zamfara
April 2003	tOPV	Bauchi, Gombe, Jigawa, Kaduna, Kano, Katsina
June 2003	tOPV	Benue, Kogi, Nasarawa
August 2003	tOPV	Kano
September 2003	tOPV	Bauchi, Benue, Borno, Gombe, Jigawa, Kaduna, Katsina, Kebbi, Kogi, Nasarawa, Niger, Sokoto, Yobe, Zamfara
October 2003	tOPV	All
November 2003	tOPV	All
December 2003	tOPV	FCT, Kano,Lagos, Plateau, Taraba
February 2004	tOPV	All except Kano and Zamfara
March 2004	tOPV	All except Kano
September 2004	tOPV	Bauchi, Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, Zamfara
November 2004	tOPV	All
February 2005	tOPV	All
April 2005	tOPV	All
May 2005	tOPV	All
July 2005	tOPV	Benue, FCT, Kogi, Nasarawa
August 2005	tOPV	Adamawa, Bauchi, Benue, Borno, FCT, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Kogi, Nasarawa, Niger, Sokoto, Taraba, Yobe, Zamfara
September 2005	tOPV	All
November 2005	tOPV	Adamawa, Bauchi, Benue, Borno, FCT, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Kogi, Nasarawa, Niger, Sokoto, Taraba, Yobe, Zamfara
February 2006	tOPV	All except Kebbi, Lagos, Rivers and Taraba
February 2006	mOPV1	Kebbi, Lagos, Rivers, Taraba
March 2006	tOPV	Kebbi, Lagos, Rivers, Taraba
March 2006	mOPV1	All except Kebbi, Lagos, Rivers and Taraba
May 2006	mOPV1	Adamawa, Bauchi, Borno, Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, Yobe, Zamfara
June 2006	mOPV1	Adamawa, Bauchi, Borno, Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, Yobe, Zamfara
August 2006	mOPV1	Taraba
September 2006	mOPV1	Adamawa, Bauchi, Borno, Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, Yobe, Zamfara
September 2006	mOPV1	Taraba
October 2006	mOPV1	Abia, Anambra, Akwa Ibom, Bayelsa, Cross River, Delta,

		Ebonyi, Edo, Ekiti, Enugu, Imo, Lagos, Ogun, Ondo, Osun, Oyo, Rivers
November 2006	tOPV	Adamawa, Bauchi, Benue, Borno, Gombe, FCT, Jigawa, Kaduna, Kano, Katsina, Kebbi, Kogi, Kwara, Nasarawa, Niger, Plateau, Sokoto, Taraba, Yobe, Zamfara
January 2007	tOPV	Northern states
January 2007	mOPV1	Southern states
March 2007	tOPV	Bauchi, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Niger, Sokoto, Yobe, Zamfara
March 2007	mOPV1	147 highest risk LGAs in 17 states (Bauchi, Benue, Borno, FCT, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Kogi, Niger, Plateau, Sokoto, Yobe, Zamfara)
June 2007	mOPV1	Bauchi, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Niger, Sokoto, Yobe, Zamfara
July 2007	mOPV3	Bauchi, Borno, FCT, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Niger, Sokoto, Yobe, Zamfara
September 2007	tOPV	Bauchi, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Niger, Sokoto, Yobe, Zamfara
October 2007	mOPV3	Adamawa, Lagos, Taraba
November 2007	mOPV1	Adamawa, Bauchi, Benue, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Kwara, Nasarawa, Niger, Sokoto, Taraba, Yobe, Zamfara
December 2007	mOPV3	Lagos, Ogun, Oyo

Supplementary Table 3a Vaccine efficacy estimates by year of onset of paralysis

	Type 1				Type 3		
Year†	Cases	Case-control matches, n (% of cases)	mOPV1 efficacy (%) (95% CI)	tOPV efficacy (%) (95% CI)	Cases	Case-control matches, n (% of cases)	tOPV efficacy (%) (95% CI)
2001	35	0 (0%)	N/A*	N/A**	21	2 (10%)	N/A**
2002	174	50 (29%)	N/A*	24 (0, 45)	28	9 (32%)	N/A**
2003	190	89 (47%)	N/A*	25 (6, 40)	163	56 (34%)	38 (11, 56)
2004	598	332 (56%)	N/A*	14 (2, 24)	181	109 (60%)	14 (0, 29)
2005	573	275 (48%)	N/A*	18 (7, 27)	253	134 (53%)	15 (0, 31)
2006	846	369 (44%)	80 (53, 92)	9 (0, 20)	276	120 (43%)	13 (0, 30)
2007	116	59 (51%)	34 (0, 77)	30 (0, 58)	170	72 (42%)	15 (0, 36)
Overall	2532	1174 (46%)	67 (39, 82)	16 (10, 21)	1092	502 (46%)	18 (9, 26)

†mid-point between date of onset of paralysis for case and control; *mOPV1 was introduced only in 2006; **Numbers were too small to estimate efficacy

Supplementary Table 3b Vaccine efficacy estimates by age at onset of paralysis

	Type 1				Type 3		
Age (years)†	Cases	Case-control matches, n (% of cases)	mOPV1 efficacy (%) (95% CI)	tOPV efficacy (%) (95% CI)	Cases	Case-control matches, n (% of cases)	tOPV efficacy (%) (95% CI)
<1	133	45 (34%)	64 (0, 96)	0 (0, 26)	56	16 (29%)	16 (0, 53)
1-2	922	520 (56%)	49 (0, 77)	19 (11, 27)	339	184 (54%)	10 (0, 24)
2-3	755	426 (56%)	75 (22, 92)	13 (3, 22)	348	205 (59%)	20 (8, 31)
3-4	318	129 (41%)	99 (55, 100)	13 (0, 28)	151	70 (46%)	29 (2, 49)
4-5	108	34 (31%)	0 (0, 95)	23 (0, 48)	59	20 (34%)	29 (0, 65)
>5	94	20 (21%)	N/A**	16 (0, 48)	60	7 (12%)	13 (0, 69)
Missing age data*	202				79		
Overall	2532	1174 (46%)	67 (39, 82)	16 (10, 21)	1092	502 (46%)	18 (9, 26)

†mid-point between age at onset of paralysis for case and control; *these cases were excluded from the analysis as cases and controls were matched on age; **Numbers were too small to estimate efficacy

Supplementary Table 4 Estimated efficacies of the oral polio vaccines against paralysis from wild poliovirus types 1 and 3 in Nigeria, 2001- 2007. Controls matched to cases based on (a) age at onset of paralysis within 6 months, (b) date of onset of paralysis within 5 months, (c) LGA of residence.

	Type 1				Type 3		
Location	Cases	Case-control matches	mOPV1 efficacy (%) (95% CI)	tOPV efficacy (%) (95% CI)	Cases	Case-control matches	tOPV efficacy (%) (95% CI)
North West	1899	861	56 (9, 79)	14 (7, 20)	851	371	15 (5, 25)
North East	437	147	55 (0, 87)	22 (5, 36)	173	67	18 (0, 40)
North Central	154	65	100 (0, 100)	22 (0, 40)	52	16	24 (0, 56)
South	42	21	N/A*	50 (0, 77)	16	8	12 (0, 54)
Overall	2532	1094	61 (26, 79)	16 (10, 22)	1092	462	16 (7, 25)

*There have been no reported type 1 cases in the South since the introduction of mOPV1

Supplementary Table 5 Estimated efficacy of tOPV and mOPV1 assuming randomly selected cases and controls, or cases only, received 3 doses of tOPV through routine services. The estimated fraction of children receiving 3 doses through routine services was based on the National Immunisation Coverage Survey[4]. See the Supplementary Methods for further details.

Randomly chosen recipients of routine tOPV	Percentile*	mOPV1 efficacy (%) (95% CI)	tOPV efficacy (%) (95% CI)
Cases and controls	5th	50 (17, 71)	16.1 (10.3, 21.5)
	50th	60 (30, 77)	16.8 (11.1, 22.1)
	95th	70 (46, 83)	17.6 (11.9, 22.9)
Polio cases only	5th	78 (59, 88)	13.9 (8.1, 19.4)
	50th	83 (67, 91)	14.5 (8.6, 19.9)
	95th	88 (75, 94)	14.9 (9.1, 20.4)

*based on rank after the analysis was repeated 100 times

Supplementary Table 6 The estimated percentages of the population (aged under 5 years old) that are protected against paralysis from type 1 polio from direct immunisation by year and state. These figures are presented graphically in Figure 1 of the main text and are calculated using (eq. 2) in the Supplementary Methods assuming vaccine efficacy estimates do not vary across the country.

		Year						
Zone	State	2001	2002	2003	2004	2005	2006	2007
North West	Jigawa	18	27	22	12	13	25	40
	Kaduna	35	30	31	26	24	49	65
	Kano	34	29	24	9	16	28	54
	Katsina	30	31	24	25	22	28	48
	Kebbi	30	35	39	32	40	55	70
	Sokoto	40	27	32	23	26	62	60
	Zamfara	28	37	39	25	13	36	54
NORTH WEST		31	30	29	20	22	38	55
North East	Adamawa	39	43	35	31	40	63	64
	Bauchi	36	28	34	18	20	54	59
	Borno	19	28	26	21	21	43	56
	Gombe	26	34	42	31	43	53	75
	Taraba	24	38	33	39	47	60	58
	Yobe	32	29	32	35	34	45	48
NORTH EAST		30	33	33	27	31	53	60
North Central	Benue	37	37	41	39	54	71	61
	FCT	44	48	52	54	46	69	71
	Kogi	46	41	44	46	46	65	65
	Kwara	44	45	45	43	54	53	59
	Nasarawa	37	44	46	49	53	63	74
	Niger	41	44	44	43	48	62	77
	Plateau	39	36	31	33	41	50	48
NORTH CENTRAL		41	41	42	42	49	62	64
South West	Ekiti	46	55	45	48	50	61	72
	Lagos	45	49	52	59	64	75	85
	Ogun	51	42	53	54	62	82	89
	Ondo	39	48	51	48	48	61	79
	Osun	36	40	48	42	52	58	75
	Oyo	40	46	44	44	49	70	75
SOUTH WEST		43	47	49	51	56	70	81
South South	Akwa Ibom	31	31	45	39	48	68	77
	Bayelsa	27	40	31	35	55	63	78
	Cross River	37	46	50	53	69	69	78
	Delta	43	40	41	42	51	72	73
	Edo	34	52	41	54	59	69	87
	Rivers	45	37	43	42	44	72	81
SOUTH SOUTH		38	40	43	44	53	70	79
South East	Abia	36	48	51	50	57	70	71
	Anambra	46	42	43	48	55	62	68
	Ebonyi	39	44	38	39	40	58	51
	Enugu	49	42	55	40	50	60	67
	Imo	41	40	42	43	44	65	73
SOUTH EAST		43	43	46	44	50	63	67

Supplementary Table 7 Estimated population immunity levels from direct vaccination against paralysis from type 1 polio, 2005-7 calculated assuming that all SIA used tOPV. Also shown are the resulting changes in immunity due to coverage changes, the actual changes seen 2005-7 (from data in Supplementary Table 6) and therefore the fraction of the improvement in vaccine-induced immunity that resulted from the introduction of mOPV1

		Assuming no mOPV1				Estimated	Improvement due
			Year		Change from 2005	total change	to use of mOPV1
Zone	State	2005	2006	2007	to 2007 due to coverage changes	from 2005 to 2007	(% of total change)
North West	Jigawa	13	16	21	8	27	19 (70)
	Kaduna	24	32	41	17	41	24 (59)
	Kano	16	20	34	18	38	20 (53)
	Katsina	22	19	26	4	26	22 (85)
	Kebbi	40	41	42	2	30	28 (93)
	Sokoto	26	37	33	7	34	27 (79)
	Zamfara	13	25	29	16	41	25 (61)
NORTH WEST		22	25	33	11	33	22 (67)
North East	Adamawa	40	42	41	1	24	23 (96)
	Bauchi	20	36	35	15	39	24 (62)
	Borno	21	31	32	11	35	24 (69)
	Gombe	43	43	55	12	32	20 (63)
	Taraba	47	47	40	-7	11	18 (100)
	Yobe	34	30	27	-7	14	21 (100)
NORTH EAST		31	37	37	6	29	23 (79)
North Central	Benue	54	60	52	-2	7	9 (100)
	FCT	46	58	50	4	25	21 (84)
	Kogi	46	54	54	8	19	11 (58)
	Kwara	54	39	47	-7	5	12 (100)
	Nasarawa	53	54	56	3	21	18 (86)
	Niger	48	52	53	5	29	24(83)
	Plateau	41	38	35	-6	7	13 (100)
NORTH CENTRAL		49	51	49	0	15	15 (100)
South West	Ekiti	50	46	50	0	22	22 (100)
	Lagos	64	64	63	-1	21	22 (100)
	Ogun	62	68	69	7	27	20 (74)
	Ondo	48	49	51	3	31	28 (90)
	Osun	52	49	52	0	23	23 (100)
	Oyo	49	55	48	-1	26	27 (100)
SOUTH WEST		56	57	56	0	25	25 (100)
South South	Akwa Ibom	48	53	46	-2	29	31 (100)
	Bayelsa	55	51	49	-6	23	29 (100)
	Cross River	69	57	51	-18	9	27 (100)
	Delta	51	57	47	-4	22	26 (100)
	Edo	59	58	59	0	28	28 (100)
	Rivers	44	51	49	5	37	32 (86)
SOUTH SOUTH		53	55	50	-3	26	29 (100)
South East	Abia	57	56	43	-14	14	28 (100)
	Anambra	55	46	43	-12	13	25 (100)
	Ebonyi	40	41	33	-7	11	18 (100)
	Enugu	50	47	38	-12	17	29 (100)
	Imo	44	51	45	1	29	28 (97)
SOUTH EAST		50	48	41	-9	17	26 (100)

Supplementary Table 8 Spearman's rank correlation coefficient, by year, measuring correlation between the proportions of the population (under 5 years) protected by vaccination and incidence of reported type 1 cases. Data are grouped by state of residence.

Year	Spearman's rank correlation coefficient (95% CI)	P-value	Spearman's rank correlation coefficient (95% CI)
2001	0.43 (0.12, 0.66)	0.007	2001-3 combined: 0.38 (0.21, 0.53)*
2002	0.51 (0.22, 0.71)	0.001	
2003	0.39 (0.07, 0.63)	0.016	
2004	0.62 (0.36, 0.78)	<0.001	
2005	0.71 (0.50, 0.84)	<0.001	2004-7 combined: 0.61 (0.49, 0.70)*
2006	0.75 (0.55, 0.86)	<0.001	
2007	0.54 (0.26, 0.73)	<0.001	

*Correlation post-2003 significantly higher than in earlier years ($p = 0.023$).

Supplementary Table 9a Characteristics of all and matched type 1 polio cases

	Cases* n (%) (n=2469)	Cases with necessary data** n (%) (n=2171)	Case-control matches n (%) (n=1174)
Age (years)			
<1	128 (5%)	116 (5%)	58 (5%)
1-2	890 (39%)	858 (40%)	536 (46%)
2-3	744 (33%)	721 (33%)	406 (35%)
3-4	308 (14%)	294 (14%)	123 (10%)
4-5	107 (5%)	97 (4%)	31 (3%)
5+	92 (4%)	85 (4%)	20 (2%)
Missing	200 (8%)		
Location			
North West	1861 (75%)	1663 (77%)	925 (79%)
North East	421 (17%)	340 (16%)	158 (13%)
North Central	147 (6%)	134 (6%)	68 (6%)
South	40 (1%)	34 (2%)	23 (2%)
Period			
2001-2003	379 (15%)	320 (15%)	148 (13%)
2004-2007	2090 (86%)	1851 (85%)	1026 (87%)
Exposed to mOPV1	488 (20%)	469 (22%)	237 (20%)

*These case numbers exclude those excreting vaccine virus since these were excluded from our case-control studies

**Necessary data = reported doses and age at onset of paralysis

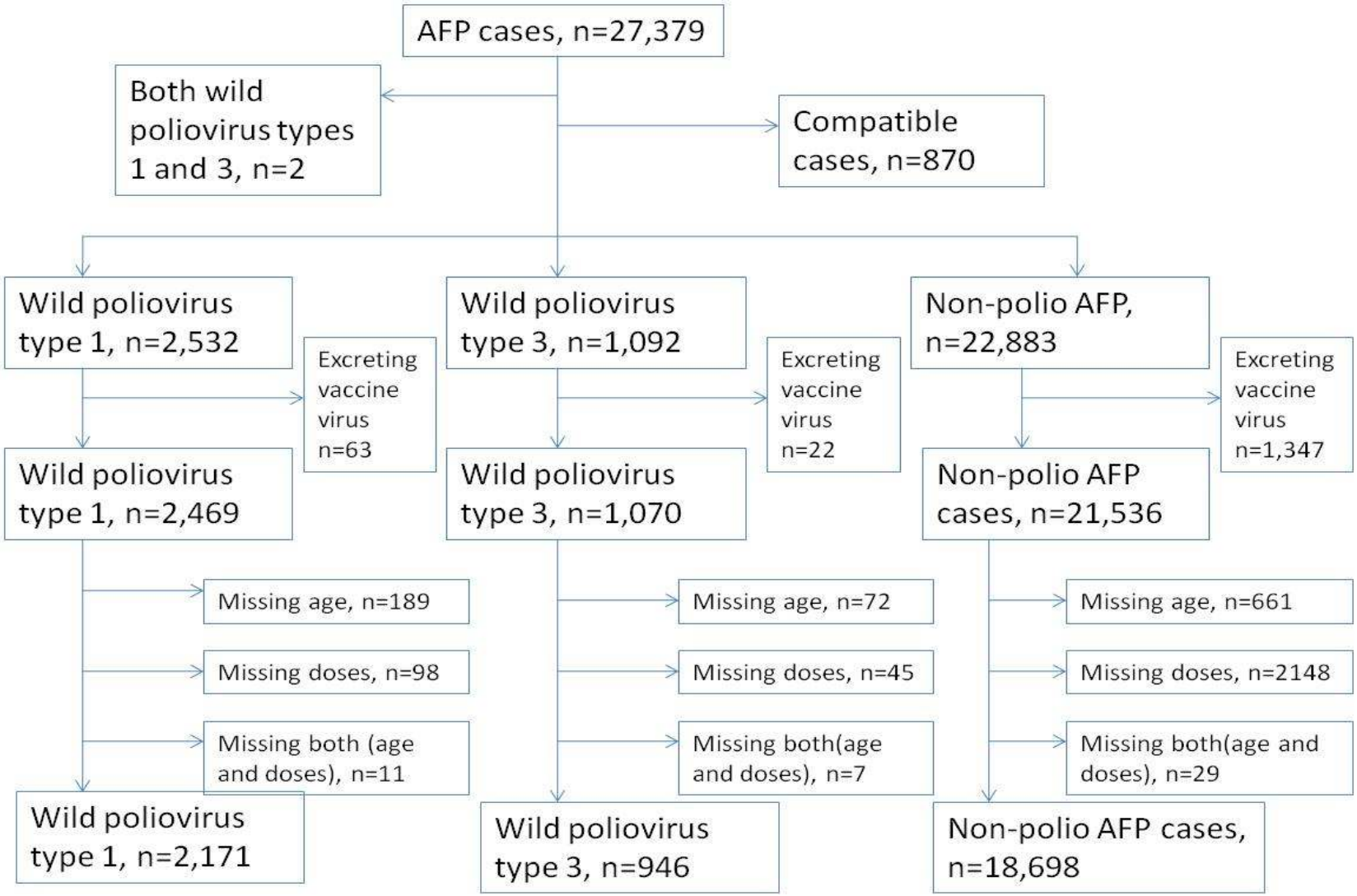
Supplementary Table 9b Characteristics of all and matched type 3 polio cases

	Cases* n (%) (n=1070)	Cases with necessary data** n (%) (n=946)	Case-control matches n (%) (n=502)
Age (years)			
<1	54 (5%)	53 (6%)	22 (4%)
1-2	327 (33%)	315 (33%)	191 (38%)
2-3	342 (35%)	326 (34%)	198 (39%)
3-4	149 (15%)	143 (15%)	64 (13%)
4-5	59 (6%)	56 (6%)	20 (4%)
5+	60 (6%)	53 (6%)	7 (1%)
Missing	79 (7%)		
Location			
North West	835 (78%)	743 (79%)	402 (80%)
North East	170 (16%)	148 (16%)	74 (15%)
North Central	50 (5%)	41 (4%)	18 (4%)
South	15 (1%)	14 (1%)	8 (1%)
Period			
2001-2003	205 (19%)	180 (19%)	74 (15%)
2004-2007	865 (81%)	766 (81%)	428 (85%)
Exposed to mOPV1	331 (31%)	322 (34%)	171 (35%)

*These case numbers exclude those excreting vaccine virus since these were excluded from our case-control studies

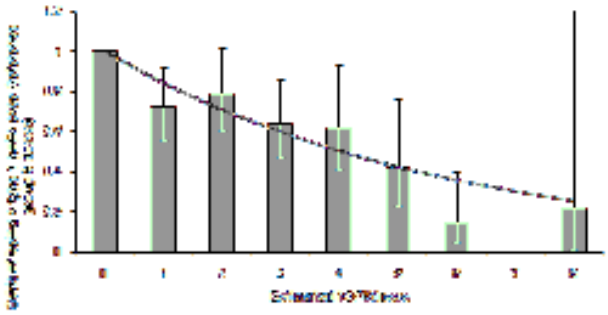
**Necessary data = reported doses and age at onset of paralysis

Supplementary Figure 1 Flow chart illustrating the total number of Acute Flaccid Paralysis (AFP) cases in the surveillance database (2001-7)

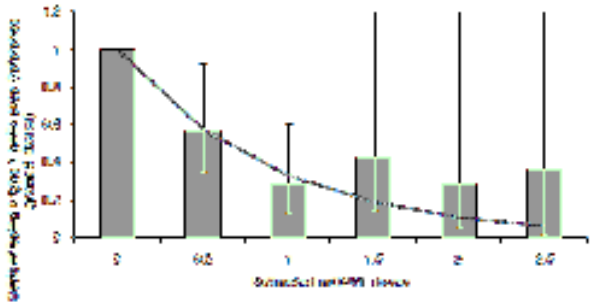


Supplementary Figure 2 Odds of being a type 1 paralytic polio case by estimated number of doses received of: (a) trivalent oral polio vaccine (only up to 8 doses shown), (b) monovalent oral polio vaccine (only up to 2.5 doses shown). Odds of being a type 3 paralytic polio case number of doses received of: (c) trivalent oral polio vaccine (only up to 6 doses shown). Error bars indicate 95% confidence intervals. The curved line represents the relationship between odds of being a case and doses when a log linear relationship is assumed.

(a)



(b)



(c)