



Poliomyelitis seroprevalence in high risk populations of India before the trivalent to bivalent oral poliovirus vaccine switch in 2016



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ABSTRACT

Introduction: This study assessed the seroprevalence of neutralizing antibodies to all three polioviruses among the last cohort of infants aged 6–11 months who received the trivalent oral polio vaccine (OPV) before the trivalent (tOPV) to bivalent (bOPV) switch and had an opportunity to receive a full dose of inactivated poliovirus vaccine (IPV) introduced in the routine immunization schedule.

Methods: Serum was tested for neutralizing antibodies against polioviruses among infants residing in three different risk-category states for poliovirus transmission in India: Bihar, a historically high-risk state for polio; Madhya Pradesh, a state with low routine immunization coverage; Chhattisgarh, with lower acute flaccid paralysis surveillance indicators.

Results: A total of 1113 serum samples were tested across the three states. The overall seroprevalence was 98.5% (95% confidence interval (CI) 97.7–99.2%), 98.9% (95% CI 98.3–99.5%), and 94.4% (95% CI 93.0–95.8%) for poliovirus types 1, 2, and 3, respectively. The median antibody titres for corresponding serotypes were 575, 362, and 181. Infants who received five doses of tOPV showed respective seroprevalence rates of 98.7%, 98.7%, and 93.7% against types 1, 2, and 3 polioviruses. There was no significant difference in seroprevalence across the groups of IPV recipients. The median reciprocal titre across the groups of IPV recipients was significantly higher for poliovirus 3 ($p = 0.006$).

Conclusions: The seroprevalence rates observed in this study are historically the highest in the series of serosurveys that India has conducted to assess population immunity against polioviruses. Poliovirus 2 seroprevalence was very high at the time of the tOPV to bOPV switch in India effected in April 2016.

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Introduction

India won the war against polio with the last reported case due to wild poliovirus type 1 (WPV1) on January 13, 2011 (Denyer, 2012; World Health Organization, 2012). The country has continued to guard against the risk of wild poliovirus importation from endemic countries and paralysis from circulating vaccine-derived poliovirus (cVDPV) through mass vaccination campaigns, cross-border polio vaccination, travel advisories, and

improvements in routine immunization coverage (Press Trust Of India, 2017; The Global Polio Eradication Initiative, 2014a). As part of the global polio end game strategy, India introduced inactivated poliovirus vaccine (IPV) into the routine immunization schedule and switched from trivalent oral polio vaccine (tOPV) to bivalent oral polio vaccine (bOPV) in April 2016 (The Global Polio Eradication Initiative, 2020; India moves closer to polio end-game, 2013).

The switch from tOPV to bOPV presented an increased risk of emergence of cVDPV type 2 (cVDPV2) due to circulating vaccine virus from previous vaccination with tOPV but no immunity against the type 2 serotype from bOPV in the cohorts born after the switch. The needed type 2 immunity could be obtained by

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introducing IPV into the routine immunization schedule as a risk mitigation strategy (World Health Organization, 2020a). India launched IPV in the routine schedule as one full dose of intramuscular IPV in 2015, starting with high-risk states and subsequently included all states and union territories in a phased manner. The country then moved to nationwide implementation of two fractional (0.1 mL intradermal) doses of IPV, replacing one full dose.

Population immunity in the high-risk areas has been assessed periodically in India since 2007. The previous serosurvey in 2014 showed neutralizing antibody seroprevalence of 98%, 98%, and 91% for poliovirus type 1, type 2, and type 3, respectively, among infants 6–11 months of age, residing in the states at high risk of poliovirus transmission (Ahmad et al., 2016). This serosurvey in 2016 was conducted to assess immunity prior to the switch from tOPV to bOPV. Earlier, the Global Polio Eradication Initiative (GPEI) had set high population immunity against type 2 at the time of the tOPV to bOPV switch as a prerequisite to ward off the risk of emergence of VDPV2 (The Global Polio Eradication Initiative, 2014b).

This study was conducted with the primary objective of assessing the seroprevalence of neutralizing antibodies to polioviruses among infants living in the high-risk categories for polio transmission in India, i.e. historically high-risk states for polio, areas with low routine immunization coverage, and areas with suboptimal acute flaccid paralysis (AFP) surveillance for polio at the time of the vaccine switch.

Materials and methods

Study design and methods

This was a cross-sectional study of the prevalence of serum neutralizing antibodies against all three poliovirus types among infants 6–11 months of age residing in three different risk category areas for polio transmission. Subjects with reciprocal antibody titres $\geq 1:8$ were considered seropositive for each poliovirus type.

Risk state categories of target populations

Bihar was selected as the historical high-risk state for polio. In Bihar, the central region and the Kosi riverine areas posed seemingly insurmountable challenges to the polio eradication programme before they could be overcome. These areas were the last to halt polio transmission in India (Anon a; Global Polio Eradication Initiative, 2010).

Madhya Pradesh was selected as the low routine immunization coverage state. This state was identified as the state with the lowest fully immunized rates among states with a large population, as per the survey data of the National Family Health Survey (NFHS4, 2015–2016) (National Family Health Survey, India, 2020).

Chhattisgarh was selected for the third risk category, i.e. suboptimal AFP surveillance. This state had the lowest AFP surveillance index – a product of the non-polio AFP rate and stool adequacy rate (World Health Organization, 2020b).

Sample size and study area selection

Keeping in view the primary objective of the study and compensating for the rejection of blood samples (inadequate amount and haemolysis), 360 subjects were proposed to be enrolled in each state with a 95% confidence level and 3% precision (total 1080 subjects in three states).

Five districts were identified in each of the three states. In Bihar, the five districts were selected based on the number of years of poliovirus transmission and the number of poliovirus type 1 cases during 2005–2011. The five districts with the lowest routine

immunization coverage from Madhya Pradesh and the five districts with the least well performing AFP surveillance from Chhattisgarh were included. For operational feasibility, one block (sub-administrative unit) per district was randomly chosen in each district. Thus, a total of 15 blocks were selected across the three study states. In each block, microplans of the polio vaccination campaign teams were used to randomly select sample collection areas. Twelve areas were randomly selected through the probability proportional to size (PPS) method. Thus, a total of 60 polio team areas were randomly chosen in each state. Six infants from each polio team area were selected for the study, giving a total of 360 children in each state.

Screening for age eligible infants and subject enrolment

The field implementation of the study was conducted during July 2016. A few days prior to blood sample collection, the study teams visited households in the study areas to screen infants in the age eligible group of 6–11 months. Screening started from a random first household in the area and then moving consecutively as per the polio microplan. The number of children listed during the screening was about two times the required enrolment in order to account for the loss of participants due to absence, non-participation, sickness, etc. on the day of enrolment. On the day of actual enrolment, a medical officer visited the study area and selected infants for enrolment. Infants 6–11 months of age, residing for >1 month since birth in the study area and whose parents provided written informed consent, were included in the study. Infants with any contraindication to venipuncture and sick children requiring hospitalization or undergoing treatment for a major illness were excluded during the selection process. Six infants (two each from age groups of 6–7, 8–9, and 10–11 months) from each study area were thus selected during the household visits and transported to the nearby health facility set up for blood collection and other study procedures. At 6–11 months of age, it was expected that the infants included in the study would have received all of the routine doses and that maternal antibodies would have waned to undetectable levels. Sampling was distributed equally in the three age subgroups of 6–7, 8–9, and 10–11 months, because every additional 2 months of age could make a difference in terms of exposure to supplementary immunization doses and the resulting seroprevalence.

Study process and laboratory testing

Government health facilities were used as study sites. At each study site, a study physician conducted a physical examination, obtained written consent from the participant's parent, and enrolled the eligible participants. Also, the physician administered a short questionnaire to collect demographic information and vaccination status. An experienced phlebotomist collected 1.0 mL blood by venipuncture.

In addition, as part of the study protocol, testing for haemoglobin was conducted on infants and willing mothers using the HemoCue method and the results were shared immediately. Haemoglobin <11 g/dl in infants and <12 g/dl in mothers was considered as anaemia.

The blood samples for poliovirus antibodies were centrifuged every day, and serum was separated into cryovials and stored below -20°C until shipped in dry ice to the Enterovirus Research Centre, Mumbai on completion of enrolment. The samples were tested to determine neutralizing antibodies against all three poliovirus types using Sabin OPV strains in a modified microneutralization assay following a standard protocol (World Health O, 1993). Serial two-fold dilutions of test serum sample (1:8 to 1:1024) were reacted with 100 CCID₅₀ (50% cell culture infective dose) of each of the three poliovirus

types. HEp-2(C) cells were used to detect virus infectivity. All samples for polio antibodies were tested in triplicate beginning at a 1:8 dilution. Internal reference serum and virus back titration were included in each test run. Antibody titres were determined by Karber method. Positive controls were included in every run, to determine the antibody titres.

Data management and analysis of the results

Samples were made anonymous for data analysis by removing participant identifiers. The laboratory test results were merged with the questionnaire database using a common identifier. Children with a reciprocal antibody titre $\geq 1:8$ were considered seropositive for the poliovirus type. State-level estimates and corresponding 95% confidence intervals (CI) for seroprevalence to each type of poliovirus were calculated using the standard binomial proportion methods.

Ethical approval for the study

The Institutional Ethics Committee of the Enterovirus Research Centre, Mumbai and the Ethics Review Committee at the World Health Organization (WHO), Geneva provided approval for the study.

Screening and enrolments

During the screening phase, the field staff visited 63 268 households and identified 2656 age eligible subjects. On the enrolment day, field staff visited the households of all age eligible infants. Of these, 1131 (42.6%) infants were enrolled in the study for blood sample collection. A blood sample could not be drawn from 15 subjects, while three parents refused the blood sample after enrolment, resulting in a total of 1113 samples for laboratory testing. Of these 366 were from Bihar, 370 from Chhattisgarh, and 377 from Madhya Pradesh, and they were uniformly distributed in the age subgroups of 6–7 months ($n = 376$), 8–9 months ($n = 369$), and 10–11 months ($n = 368$). The remaining 1525 (57.4%) age eligible subjects were not enrolled in the study due to various reasons, as listed in Figure 1.

Results

Demographic characteristics of study participants by state

The sex distribution was equal across all three states. However, the religion of the families differed significantly across the states. Furthermore, the literacy level of both parents was significantly better in Chhattisgarh (Table 1).

OPV doses received by subjects

Infants in all three states had the opportunity to receive two tOPV doses during two national polio campaigns (January and February 2016), apart from the tOPVs in the routine schedule. While children from Madhya Pradesh had no additional opportunity, infants from Bihar had the additional opportunity to receive two bOPV (November 2015 and June 2016) and a tOPV (April 2016) during subnational polio campaigns. Children from Raipur District of Chhattisgarh also had an additional opportunity for tOPV (April 2016) during subnational polio campaigns. The median number of OPV doses (routine plus polio campaigns) received by the study infants was eight in Bihar and six in Chhattisgarh and Madhya Pradesh. The median number of tOPV doses received through routine immunization was three in Bihar and four in Chhattisgarh and Madhya Pradesh. The median number of OPV received by the infants was six for all three age subgroups.

State-wise seroprevalence and median titres

The state-wise seroprevalence and median titres against each poliovirus type are depicted in Table 2. Overall, seroprevalence rates across the three states for types 1, 2, and 3 poliovirus were 98.5% (95% CI 97.7–99.2%), 98.9% (95% CI 98.3–99.5%), and 94.4% (95% CI 93.0–95.8%), respectively. A total of 93.4% participants were seropositive against all three poliovirus types. Chhattisgarh had better seroprevalence compared to Madhya Pradesh against type 1 ($p = 0.026$) and type 3 ($p = 0.003$).

The overall median antibody titres were 574.7 (95% CI 574.7–574.7), 362.0 (95% CI 362.0–362.0), and 181.0 (95% CI 181.0–228.1) for poliovirus types 1, 2, and 3, respectively. The median titre was

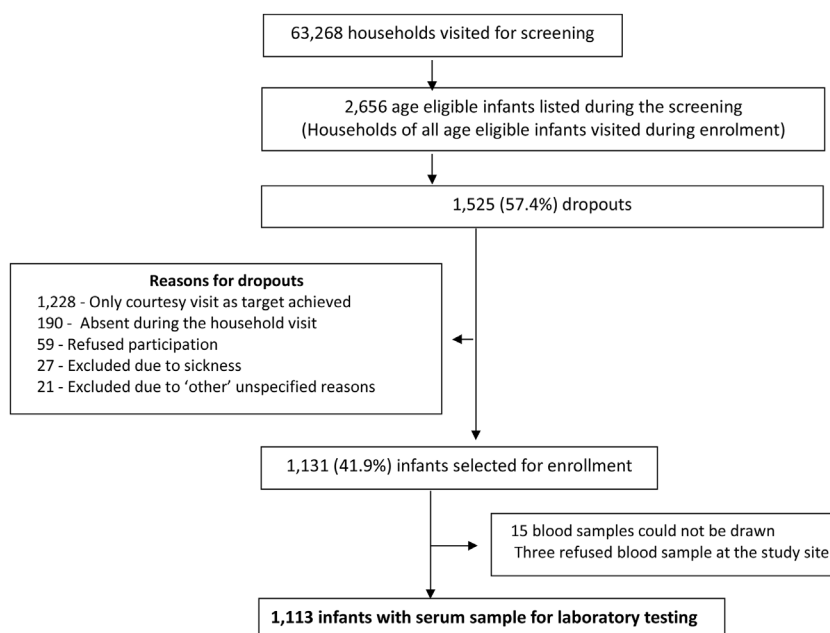


Figure 1. Overview of subject enrolment.

Table 1
Epidemiological characteristics of study participants by state.

		State						p-Value
		Bihar		Chhattisgarh		Madhya Pradesh		
Characteristics		n	%	n	%	n	%	
Sex	Female	169	46.2%	177	47.8%	190	50.4%	0.50
	Male	197	53.8%	193	52.2%	187	49.6%	
Religion	Hindu	303	82.8%	339	91.6%	333	88.3%	<0.001
	Muslim	63	17.2%	19	5.1%	44	11.7%	
	Other	0	0.0%	12	3.2%	0	0.0%	
Mother's education	≥12 years of education	51	13.9%	72	19.5%	78	20.7%	<0.001
	5–10 years of education	133	36.3%	221	59.7%	147	39.0%	
	Illiterate	182	49.7%	76	20.5%	152	40.3%	
Father's education	≥12 years of education	74	20.2%	92	24.9%	95	25.2%	<0.001
	5–10 years of education	181	49.5%	235	63.5%	169	44.8%	
	Illiterate	110	30.1%	43	11.6%	113	30.0%	

Table 2
Seroprevalence and median reciprocal titres against poliovirus types in the study states.

Poliovirus type	Seroprevalence and median titres	Bihar n = 366	Chhattisgarh n = 370	Madhya Pradesh n = 377	Total n = 1113
Type 1	% Seroprevalence (95% CI)	99.2% (98.1–100)	99.2% (98.7–100)	97.1% (94.4–99)	98.5% (97.7–99.2)
	Median titres (95% CI)	574.7 (456.1–574.7)	574.7 (515.4–724.1)	574.7 (456.1–574.7)	574.7 (574.7–574.7)
Type 2	% Seroprevalence (95% CI)	98.9% (96.9–99.6)	99.2% (97.8–100)	98.7% (96.4–100)	98.9% (98.3–99.5)
	Median titres (95% CI)	362.0 (324.7–362.0)	456.1 (362.0–456.1)	362.0 (362.0–456.1)	362.0 (362.0–362.0)
Type 3	% Seroprevalence (95% CI)	93.7% (90.5–96.2)	97.6% (95.2–99.1)	92.0% (86.7–94.4)	94.4% (93.0–95.8)
	Median titres (95% CI)	228.1 (181.1–287.4)	181.0 (181.0–228.1)	181.0 (143.7–181.0)	181.0 (181.0–228.1)

CI, confidence interval.

similar across the states for poliovirus type 1, while it was significantly higher in Chhattisgarh ($p = 0.008$) for poliovirus 2 and in Bihar ($p = 0.046$) for poliovirus 3.

Age-wise seroprevalence

As shown in the Figure 2, the seroprevalence of antibodies against poliovirus type 1 among infants 6–7, 8–9, and 10–11 months old was 97.9% (95% CI 96.3–99.2%), 98.4% (95% CI 96.7–99.5%), and 99.2% (95% CI 98.1–100.0%), respectively. For poliovirus type 2, the corresponding figures were 99.2% (95% CI 98.1–100.0%), 99.2% (95% CI 98.1–100.0%), and 98.4% (95% CI 97.0–99.5%), and for poliovirus type 3, 94.1% (95% CI 91.8–96.3%), 94.9% (95% CI 92.4–96.7%), and 94.3% (95% CI 91.8–96.5%). There was no significant difference within the age groups for any poliovirus type ($p > 0.05$).

Seroprevalence according to certain epidemiological variables

There was no significant difference in seroprevalence between the sexes or the different religions, or according to the child's anaemia status. However, the infants of illiterate mothers had a lower seroprevalence of all three poliovirus types compared to infants who had educated mothers, and this was significant for

types 1 and 3. Similarly, infants of illiterate fathers had lower seroprevalence to all poliovirus types, but significantly so for type 3 (Table 3).

Seroprevalence according to the number of OPV doses

As can be observed in Figure 3, after three doses of OPV (tOPV and/or bOPV), the seroprevalence reached 96.2% (95% CI 86.2–100%), 100% (95% CI 100–100%), and 76.9% (95% CI 59.3–92%) for poliovirus types 1, 2, and 3, respectively. After five OPV doses, the corresponding seroprevalence rates were 98.7% (95% CI 96.6–100%), 98.7% (95% CI 96.9–100%), and 93.7% (95% CI 89.5–97.1%).

Seroprevalence according to additional IPV dose received

A total of 476 (42.8%) infants received additional intramuscular dose(s) of IPV in the routine immunization schedule (471 infants received one dose and five infants received three doses; apparently additional IPV doses from the private sector). Those infants who did not receive any IPV dose had seroprevalence of 97.8%, 98.4%, and 93.4% for poliovirus types 1, 2, and 3, respectively. The corresponding figures for the infants who received one dose of IPV were 99.4%, 99.6%, and 95.8%. All infants who received three additional IPV doses were found to be seropositive. There was no significant difference in seroprevalence across the groups of IPV recipients. However, the median reciprocal titre across the groups of IPV recipients was significantly higher ($p = 0.006$) for poliovirus 3, but insignificant for poliovirus types 1 and 2 (Table 4).

Discussion

In 1988, India committed itself to the global aim of polio eradication (New initiatives help India achieve improved coverage and quality of immunization, 2020). Booth-based polio immunization campaigns covering children up to 3 years of age were started in Delhi in 1994 and extended to the whole country in 1995. From 1996 to 1997, children up to 5 years of age were immunized in

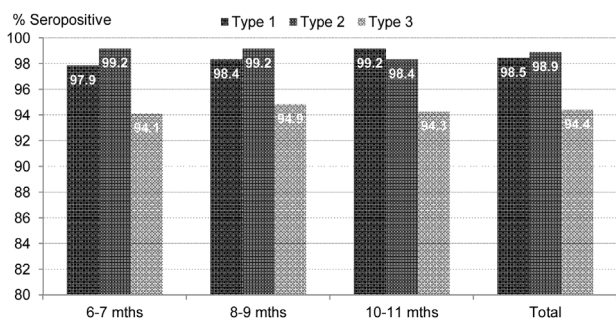


Figure 2. Age-wise seroprevalence among study infants.

Table 3
Seroprevalence according to certain epidemiological variables.

Variables		Poliovirus type								
		Type 1			Type 2			Type 3		
		n	% Seropositive	p-Value	n	% Seropositive	p-Value	n	% Seropositive	p-Value
Sex	Female	527	98.3%	0.69	531	99.1%	0.65	511	95.3%	0.20
	Male	569	98.6%		570	98.8%		540	93.6%	
Religion	Hindu	959	98.4%	0.70	965	99.0%	0.79	919	94.3%	0.63
	Muslim	125	99.2%		124	98.4%		120	95.2%	
	Other	12	100.0%		12	100.0%		12	100.0%	
Mother's education	≥12 years of education	201	100.0%	0.02	200	99.5%	0.20	197	98.0%	0.00
	5–10 years of education	496	99.0%		498	99.4%		479	95.6%	
	Illiterate	398	97.1%		402	98.0%		374	91.2%	
Father's education	≥12 years of education	258	98.9%	0.16	259	99.2%	0.87	254	97.3%	0.03
	5–10 years of education	579	99.0%		579	99.0%		553	94.5%	
	Illiterate	258	97.0%		262	98.5%		243	91.4%	
Haemoglobin	Anaemic	777	98.6%	0.605	777	98.60%	0.121	777	94.0%	0.322
	Normal	336	98.2%		336	99.70%		336	95.5%	

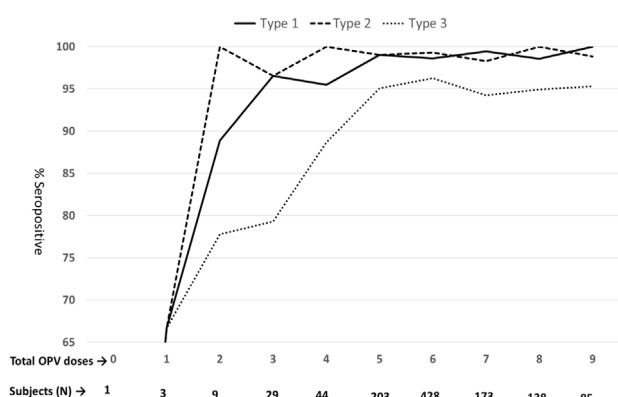


Figure 3. Seroprevalence with the number of OPV doses taken.

the polio vaccination campaigns. A house to house component was added in 2000–2001 as a part of an intensification of polio campaigns. Although the programme initially relied exclusively on the use of tOPVs, monovalent OPVs (mOPV1 and mOPV3) and later bivalent OPVs (against poliovirus types 1 and 3) were introduced into the programme (anon, b). Most parts of the country were covered with the two national rounds of polio campaigns with tOPV (National Immunization Days, NID), but there were additional rounds of sub-national immunization days (SNID) in the high-risk areas for poliovirus transmission. bOPV was used in these SNIDs from 2010 onwards.

In alignment with the globally synchronized switch from tOPV to bOPV, India switched to bOPV on April 25, 2016. Before this, IPV was launched in the country in November 2015 as part of the Expanded Programme on Immunization (EPI) schedule. Bihar and

Madhya Pradesh introduced a single dose of IPV into the routine immunization schedule on November 30, 2015, while Chhattisgarh did so on January 4, 2016. Starting with one full intramuscular dose at 14 weeks of age, the whole country introduced two fractional (intradermal) doses of IPV at 6 weeks and 14 weeks around the time of the OPV switch. The OPV switch was a well-planned process preceded by training programmes across the country and appropriate communication strategies. Independent observers monitored the switch process (World Health Organization, 2020c).

This study represented an opportunity to assess the population immunity against polio in the last cohort of infants (6–11 months of age) who received tOPV before the tOPV to bOPV switch was implemented on April 25, 2016. This was the first polio seroprevalence study in India after the introduction of a full dose IPV at OPV3/Penta3 contact (14 weeks of age) in the routine schedule in November 2015. The purpose of IPV was to maintain poliovirus type 2 population immunity and minimize the risk of emergence of cVDPV2 following the tOPV to bOPV switch (World Health Organization, 2016). The overriding objective of the study, therefore, was to assess immunity against poliovirus type 2. However, due to the risk of importation of WPV1 from endemic countries, it remains critical to maintain immunity against poliovirus types 1 and 3 as well.

The infants in this study had a maximum opportunity to receive four tOPVs from routine immunization and two tOPVs from the two national polio campaigns. Bihar had three additional bOPV sub-national campaigns. The median number of tOPV doses received by study infants through routine immunization was four. Infants in the high-risk states of India increasingly received more tOPVs through the routine immunization schedule until just before the tOPV to bOPV switch. The median number of routine immunization tOPV doses received during 2010 was three in Bihar and one in Uttar Pradesh (Sunil et al., 2014a). The median

Table 4
Seroprevalence with additional doses of IPV.

Additional IPV doses		Type 1	Type 2	Type 3
0	% Seropositive(95% CI)	97.8% (96.5–98.9)	98.4% (97.5–99.4)	93.4% (91.7–95.3)
1		99.4% (98.5–100)	99.6% (98.9–100.0)	95.8% (93.6–97.5)
3		100% (100.0–100.0)	100% (100.0–100.0)	100% (100.0–100.0)
	p-Value across the IPV group	0.10	0.18	0.21
0	Median titres (95% CI)	574.7 (456.1–574.7)	362.0 (362.0–456.1)	181.0 (181.0–181.0)
1		574.7 (474.7–724.0)	362.0 (362.0–362.0)	228.1 (205.1–287.4)
3		1149.4 (287.4–1448.2)	724.1 (287.4–912.3)	456.1 (114.0–1448.2)
	p-Value across the IPV group	0.653	0.328	0.006

CI, confidence interval; IPV, inactivated polio vaccine.

number of doses improved further in 2014 to three tOPVs among children in Bihar, Madhya Pradesh, and Mumbai (Ahmad et al., 2016). The improved routine immunization coverage in the study reiterates India's focus on strengthening routine immunization as a part of the polio endgame strategy and polio legacy transitioning.

Previous serosurveys in India showed poliovirus type 2 antibody prevalence rates of 70% in 2007 and 36.7% in 2008–2009, which increased steadily to 98% in 2014 (Ahmad et al., 2016; Jagadish et al., 2014; Sunil et al., 2014b). The increasing seroprevalence of antibodies to type 2 could be ascribed to the improving coverage with tOPV, as discussed in the preceding paragraph. During 2008–2009, the priority to eradicate poliovirus type 1 and use of mOPV1 in western Uttar Pradesh led to low seroprevalence of antibodies to poliovirus type 2 during this period. This resulted in outbreaks of cVDPV2 in western Uttar Pradesh in 2009 (Centers for Disease Control and Prevention, 2011). The seroprevalence of antibodies to poliovirus type 2 was observed to be the highest ever in the present study (98.9%), when compared to all previous serosurveys conducted in India. The neutralizing antibody titre against type 2 was also high.

Like poliovirus type 2, the seroprevalence rates of antibodies against poliovirus type 1 and poliovirus type 3 were also the highest ever in 2016 in India (98.5% for type 1 and 94.4% for type 3 in 2016 compared to 98.3% and 91.1% in 2014) (Ahmad et al., 2016; Jagadish et al., 2014; Sunil et al., 2014b). All three states separately were found to have >97% seroprevalence of antibodies against poliovirus 1 and >92% against poliovirus 3. These two serotypes also had high median antibody titres. Chhattisgarh, which was included as a poor polio surveillance indicator state, showed high seroprevalence against all three poliovirus serotypes, for the first time in any polio seroprevalence study in India. The study also demonstrated that infants as young as 6–7 months of age were well protected against all three poliovirus serotypes, similar to older infants.

This study demonstrated that five doses of OPV in the pre-OPV switch period (tOPV in routine immunization schedule and national polio campaigns and bOPV in the sub-national campaigns) provided >95% population immunity against types 1 and 3. Five doses of bOPV (three routine bOPV plus two in polio campaigns) in the post-OPV switch period could provide still better protection against types 1 and 3, by superiority of bOPV over tOPV (Sutter et al., 2010; Tara et al., 2014). However, the median titres against poliovirus type 3 differed significantly across the groups of IPV recipients in the study. Indian infants presently receive two intradermal fractional doses of IPV in the routine immunization schedule at 6 and 14 weeks of age. The study infants in the present study would have been born between September 11, 2015 and January 11, 2016, just around the time they could benefit from the IPV launched in the country. Despite initial operational challenges in rolling out IPV across the country, about 43% of this initial cohort received the single dose of IPV at 14 weeks of age in the routine immunization schedule. However, unless coverage with IPV is escalated rapidly, low type 2 immunity will continue to carry the risk of circulation of the type 2 Sabin virus strain. A high coverage with fractional doses of IPV in the routine immunization schedule is, however, expected to provide good seroprotection against type 2 as well (Abhijeet et al., 2015; Resik et al., 2013).

Due to the high type 2 seroprevalence in the study, the independent effect of IPV in the routine immunization schedule on type 2 immunity could not be analysed.

In conclusion, the findings of this study confirm that India has not only sustained the high seroprevalence achieved during the years prior to 2016, but has also improved the immunity against all three poliovirus serotypes in the subsequent years in its high-risk populations. Type 2 seroprevalence was found to be the highest ever, just prior to the tOPV to bOPV switch. There is no evidence of

any cVDPVs in India after the tOPV to bOPV switch. The high seroprevalence accompanied by high mean titres as observed in the present study has probably helped India to minimize the risk of emergence of cVDPV2 in the immediate period following the tOPV to bOPV switch. As the study suggests, bOPV doses to infants through strengthened routine immunization and a couple of national campaigns could sustain the high levels of seroprotection against serotypes 1 and 3. While it is expected that good coverage with two fractional doses of IPV in the routine immunization schedule could provide a good immunity base against the type 2 serotype, further studies focusing on type 2 population immunity would be useful to assess the impact of these fractional doses of IPV in the cohort of children born after the tOPV to bOPV switch.

Disclaimer

The authors alone are responsible for the views expressed in this article and they do not necessarily represent the views, decisions, or policies of the institutions with which they are affiliated.

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Ethical approval

The Institutional Ethics Committee of the Enterovirus Research Centre, Mumbai and the Ethics Review Committee at the World Health Organization, Geneva provided approval for the study.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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