Immunity against diphtheria among children aged 5–17 years in India, 2017–18: a cross-sectional, population-based serosurvey

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Summary

Background Diphtheria is re-emerging as a public health problem in several Indian states. Most diphtheria cases are among children older than 5 years. In this study, we aimed to estimate age-specific immunity against diphtheria in children aged 5–17 years in India.

Methods We used residual serum samples from a cross-sectional, population-based serosurvey for dengue infection done between June 19, 2017, and April 12, 2018, to estimate the age-group-specific seroprevalence of antibodies to diphtheria in children aged 5–17 years in India. 8309 serum samples collected from 240 clusters (122 urban and 118 rural) in 60 selected districts of 15 Indian states spread across all five geographical regions (north, northeast, east, west, and south) of India were tested for the presence of IgG antibodies against diphtheria toxoid using an ELISA. We considered children with antibody concentrations of 0·1 IU/mL or greater as immune, those with levels less than 0·01 IU/mL as non-immune (and hence susceptible to diphtheria), and those with levels in the range of 0·01 to less than 0·1 IU/mL as partially immune. We calculated the weighted proportion of children who were immune, partially immune, and non-immune, with 95% CIs, for each geographical region by age group, sex, and area of residence (urban *vs* rural).

Findings 29·7% (95% CI 26·3–33·4) of 8309 children aged 5–17 years were immune to diphtheria, 10·5% (8·6–12·8) were non-immune, and 59·8% (56·3–63·1) were partially immune. The proportion of children aged 5–17 years who were non-immune to diphtheria ranged from 6·0% (4·2–8·3) in the south to 16·8% (11·2–24·4) in the northeast. Overall, 9·9% (7·7–12·5) of children residing in rural areas and 13·1% (10·2–16·6) residing in urban areas were non-immune to diphtheria. A higher proportion of girls than boys were non-immune to diphtheria in the northern (17·7% [12·6–24·2] *vs* 7·1% [4·1–11·9]; p=0·0007) and northeastern regions (20·0% [12·9–29·8] *vs* 12·9% [8·6–19·0]; p=0·0035).

Interpretation The findings of our serosurvey indicate that a substantial proportion of children aged 5–17 years were non-immune or partially immune to diphtheria. Transmission of diphtheria is likely to continue in India until the immunity gap is bridged through adequate coverage of primary and booster doses of diphtheria vaccine.

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Introduction

Diphtheria is an acute infectious disease that is mainly caused by toxin-producing strains of *Corynebacterium diphtheriae* and rarely by toxin-producing strains of *Corynebacterium ulcerans* and *Corynebacterium pseudotuberculosis*.[1] The exotoxin produced by the bacterium leads to formation of a pseudomembrane in the upper respiratory tract, either in the nose, pharynx, or larynx. Absorption of diphtheria toxin into the bloodstream causes toxic damage to organs such as the heart, kidneys, and peripheral nerves.[2] In unvaccinated individuals—particularly if proper treatment is delayed—mortality can occur in up to 10% of clinical cases.[1] Causes of death among patients with diphtheria include acute respiratory obstruction, acute systemic toxicity, myocarditis, and neurological complications.[2]

Globally, diphtheria was a leading cause of childhood morbidity and mortality in the pre-vaccination era.[3] In 1974, WHO established the Expanded Program on Immunization, targeting six vaccine preventable diseases, inclucing diphtheria.[4] Subsequent to the introduction of the diphtheria-pertussis-tetanus (DPT) vaccine, the incidence of diphtheria declined in many countries. The total number of reported diphtheria cases decreased by more than 90% during the period 1980–2000.[1,5,6]

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Research in context

Evidence before this study

Globally, of the 103 138 diphtheria cases reported during the period 2000–17 in the WHO-UNICEF Joint Reporting Form, 79 034 (76·6%) were from India. We searched PubMed up to April 21, 2020, for estimates of immunity against diphtheria in India using the search terms "diphtheria" AND "immunity" AND "India", with no language restrictions. We identified 352 publications, of which eight reported immunity against diphtheria. Five of these studies were among adults, two were among children, and one included children and adults. The largest study, among 2419 school children aged 7–17 years at various government schools in Hyderabad, indicated that 1344 (55·5%) children were seroprotected, with IgG anti-diphtheria titres of 0·1 IU/mL or more, whereas 933 (38·6%) children were partially seroprotected, with antibody titres of 0·01 IU/mL or more and less than 0·1 IU/mL. 142 (5·9%) children were non-immune, with antibody titres of less than 0·01 IU/mL. Among studies in adults from different settings, 19–94% of adults were found to be immune to diphtheria; however, the sample sizes of these studies ranged between 62 and 574. Moreover, these studies were done in small geographical areas.

Added value of this study

In 2017–18, the Indian Council of Medical Research did a cross-sectional, population-based serosurvey that covered all five geographical regions of India to estimate the age-specific seroprevalence of dengue infection among individuals aged 5–45 years. Using serum samples obtained during this serosurvey from children aged 5–17 years, we tested for the presence of IgG antibodies against diphtheria in children in India. We found that less than a third of children aged 5–17 years were immune to diphtheria, with most children partially immune and some non-immune. In all regions, the proportion of children immune to diphtheria declined by age. The immunity levels against diphtheria differed by sex in the north and northeastern regions of India, with higher proportions of girls than boys in those regions being non-immune to diphtheria. We also found differences in immunity by caste among children aged 5–8 years.

Implications of all the available evidence

Our study findings have implications for diphtheria vaccination in India. The transmission of diphtheria is likely to continue in the country until the immunity gap is bridged through adequate coverage of primary vaccination and booster doses administered as a part of national immunisation and school health programmes.

India contributes a substantial proportion of the global burden of diphtheria. During 2000–17, almost 77% of diphtheria cases reported to WHO-UNICEF in the Joint Reporting Form were from India.[7] Diphtheria outbreaks have been reported in several Indian states, including Tamil Nadu, Kerala, Karnataka, Jammu Kashmir, Rajasthan, Haryana, Telangana, Gujarat, Assam, Maharashtra, and Andhra Pradesh, in 1994–2015.[8] The DPT vaccine has been in the Indian universal immunisation programme since 1978. A pentavalent vaccine, which provides protection against diphtheria, pertussis, tetanus, hepatitis B, and *Haemophilus influenzae*, was introduced in India in a phased manner in 2011, and covered the entire country by 2015. The schedule for primary vaccination consists of three doses of diphtheria (DPT or pentavalent) vaccine administered at ages 6, 10, and 14 weeks, and is followed by two booster doses, the first given between the ages of 16 and 24 months and the second between the ages of 5 and 6 years. The coverage of the three primary doses of diphtheria vaccines was estimated to be 78·4% during 2015–16, but reliable information about coverage of booster doses is not available in India as it is not routinely collected.[9]

See Online for appendix

A review of 8196 diphtheria cases from India reported during 1997–2016 indicated that 67% of cases were in unvaccinated individuals and that 26% had received at least three DPT doses. 51% of diphtheria cases were in individuals younger than 15 years. Data from case-based surveillance since 2016 for diphtheria in the Indian states of Bihar, Haryana, Kerala, and Uttar Pradesh indicated that 20% of cases were in children younger than 5 years, 39% of cases were in those aged 5–10 years, and 41% of cases were in those older than 10 years.[5] Analysis of published studies indicates that the persistence of diphtheria in India is due to both low coverage of diphtheria vaccines and waning of immunity acquired through vaccination.[5,10] Previous serological surveys helped to identify diphtheria resurgence, determine the duration of immunity after primary and booster vaccination doses, and recommend strategies to reduce immunity gaps. However, serosurveys are underused in low-income and middle-income countries because of resource constraints and restricted access to high-quality laboratories and assays.[11] Very few seroepidemiological studies concerning immunity against diphtheria have been done in India. Existing Indian seroepidemiological studies were mostly done in adults, had small sample sizes, used convenient sampling methods, and were limited to a few cities (appendix p 14).[12–19] In this study, we used serum samples collected from children aged 5–17 years during a cross-sectional, population-based national serosurvey of dengue infection in India to estimate age-specific immunity against diphtheria.

Methods

Study design and participants

The details of the cross-sectional, population-based serosurvey to estimate dengue virus infection in India are

described elsewhere.[20] Briefly, the survey was done in five geographical regions (north, northeast, east, west, and south), covering all 30 states in India. From each region, three states were selected randomly using computer-generated random numbers, and from each selected state, four districts were selected by the probability proportional to population size method.[20] Wards (administrative units) in urban areas and villages in rural areas were considered to be clusters. From each district, four clusters (two from urban areas and two from rural areas) were selected randomly with computer-generated random numbers. From each cluster, one census enumeration block (CEB) was selected randomly with computer-generated random numbers. In India, for decennial censuses (every 10 years), each census enumerator is allotted one CEB area, which contains about 120–150 households. Serosurvey procedures included identification of the CEB using census maps and enumeration of the entire population of the CEB by house-to-house visits, and were the responsibility of survey teams. During enumeration, all houses were numbered and information on all household members, including their age and sex, was collected using an Android application developed specifically for the survey and was sent to a central server. From the enumerated populations, 25 individuals were selected randomly, using computer-generated random numbers, from each of the three age groups (5–8 years, 9–17 years, and 18–45 years). Consenting individuals were interviewed by trained field investigators to collect sociodemographic information, including religion, education, and caste. In India, caste is considered an important social determinant of health, and scheduled castes and scheduled tribes are considered socially disadvantaged groups.[21] The information was uploaded to the central server hosted at the Indian Council of Medical Research National Institute of Epidemiology. The data were downloaded from the server for analysis. 3 mL of blood was collected from each participant for assessment of dengue virus infection. The survey was done between June 19, 2017, and April 12, 2018, and 12 300 samples were collected from 240 clusters (118 rural and 122 urban), in 60 selected districts within 15 states. Serum samples were stored at –20°C at the central laboratory. We used residual sera for estimating diphtheria immunity. For this study, we included only serum samples from children aged 5–17 years.

The Institutional Ethics Committees of the Indian Council of Medical Research National Institute of Epidemiology (Chennai, India) and all participating institutes approved the study protocol. Written informed consent was obtained from the parents of children aged 5–17 years and assent from children aged 7–17 years for their participation in the study, including testing of serum samples for infections other than dengue virus.

Procedures

Serum samples were tested for IgG antibodies against diphtheria toxoid using commercially available ELISA kits (Anti-Diphtheria Toxoid ELISA [IgG]; Euroimmun; Lübeck, Germany). This quantitative assay uses four standard solutions (containing 2·0, 1·0, 0·1, or 0·01 IU/mL anti-diphtheria antibodies) and two control sera (positive and negative). The Euroimmun kit had good agreement in terms of relative sensitivities and specificities with other commercial ELISA kits.[22] Each serological test was done with the positive and negative serological controls provided by the manufacturer. As an additional measure of quality control, we randomly selected 5% of samples for retesting. We calculated the coefficient of variation of IgG antibodies against diphtheria toxoid in initial and retested samples.

Statistical analysis

On the basis of the results of our quantitative assay, we classified children into three categories of immunity against diphtheria according to internationally accepted criteria.[23] We considered children with antibody concentrations of 0·1 IU/mL or greater as immune, those with levels less than 0·01 IU/mL as non-immune (and hence susceptible to diphtheria), and those with levels in the range of 0·01 to less than 0·1 IU/mL as partially immune (basic protection).[23] We calculated weighted proportions of children who were immune, partially immune, and non-immune, along with 95% CIs, for each geographical region by age-group, sex, and area of residence (rural and urban) using appropriate design weights and adjusting for non-response. Design weights are the inverse of the overall compound probability of selection of state, district, village or ward, CEB, and individuals. We adjusted the design weight for non-response by calculating a response rate for a homogeneous group (eg, age, sex, rural and urban areas), then inflated the design weight by dividing it by the response rate for each group. We estimated the proportion of children who were immune, partially immune, and non-immune at the national level using normalised weight (appendix p 2). We compared the weighted proportion of children who were non-immune with those who were partially immune or immune by sex and area of residence (rural or urban) in different geographical regions. We also estimated the unweighted proportion of children who were immune to diphtheria by caste after adjusting for cluster design, and we compared the proportion of children who were non-immune and immune or partially immune to diphtheria among those belonging to general or other backward classes and scheduled caste or scheduled tribe. We plotted the unweighted proportion of children with different levels of immunity against diphtheria by each year of age in each geographical region and fit a linear regression model to estimate the decline in the proportion of children immune to diphtheria by age.

Data analysis was done using the survey data analysis module of STATA SE version 13.0.

	Children aged 5–17 years (n=8324*)
Region	
North	1620 (19·5%)
Northeast	1527 (18·3%)
East	1689 (20·3%)
West	1592 (19·1%)
South	1896 (22·8%)
Age, years	
5–8	4059 (48·8%)
9–17	4265 (51·2%)
Median (IQR)	9 (7–13)
Sex	
Male	4278 (51·4%)
Female	4046 (48·6%)
Religion	
Hindu	6343 (76·2%)
Muslim	844 (10·1%)
Christian	439 (5·3%)
Sikh	421 (5·1%)
Other	81 (1·0%)
No data	196 (2·3%)
Caste	
General class	2697 (32·4%)
Other backward class	2798 (33·6%)
Scheduled caste	1632 (19·6%)
Scheduled tribe	1001 (12·0%)
No data	196 (2·3%)
Education	
No education	428 (5·1%)
≤5 years (primary school)	4534 (54·5%)
6–8 years (middle school)	1758 (21·1%)
9–10 years (secondary school)	943 (11·3%)
11–12 years (higher secondary)	548 (6·6%)
Diploma or degree	70 (0·8%)
Unknown	12 (0·1%)
No data	31 (0·4%)
Area of residence	
Rural	4258 (51·2%)
Urban	4066 (48·8%)
Having Below Poverty Line card	3645 (43·8%)

Data are n (%), unless otherwise indicated. *Includes 15 children for whom the quantity of serum was inadequate.

Table: **Sociodemographic characteristics of the population surveyed**

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Of the 11 930 children aged 5–17 years who were randomly selected for inclusion in the original survey on dengue virus infection, 8324 (69·8%) provided a blood sample (4059 [68·4%] of 5930 children aged 5–8 years and 4265 [71·1%] of 6000 children aged 9–17 years; reasons for not providing a blood sample are in the appendix p 3). The sociodemographic characteristics of the 8324 children are shown in the table.

We tested serum from 8309 (99·8%) of the 8324 children for IgG antibodies against diphtheria toxoid; the quantity of serum for 15 children was inadequate for the ELISA assay. 450 serum samples were retested, and the coefficient of variation of diphtheria antibody titres in the initial test was 1·645% and in the subsequent retest was 1·652%.

10·5% (95% CI 8·6–12·8) of 8309 children aged 5–17 years were non-immune, 59·8% (56·3–63·1) were partially immune, and 29·7% (26·3–33·4) were immune to diphtheria (figure 1; appendix p 4). In both age groups, most children were partially immune or immune, with 13·7% (95% CI 10·1–18·3) of children aged 5–8 years and 8·9% (7·0–11·3) of children aged 9–17 years non-immune (figure 1; appendix p 4). The weighted proportion of children aged 5–17 years who were non-immune to diphtheria ranged from 6·0% (95% CI 4·2–8·3) in the south to 16·8% (11·2–24·4) in the northeast (figure 1; appendix p 3). The unweighted proportions of children immune, partially immune, and non-immune to diphtheria by state are in the appendix (p 5).

The proportions of boys and girls aged 5–17 years who were non-immune, partially immune, and immune to diphtheria were similar (figure 2; appendix p 6). In the north and northeastern regions, a significantly higher proportion of girls were non-immune to diphtheria than were immune or partially immune to diphtheria (appendix p 7).

Overall, among children aged 5–17 years, 9·9% (95% CI 7·7–12·5) of children residing in rural areas and 13·1% (10·2–16·6) residing in urban areas were non-immune to diphtheria (figure 3; appendix p 8). The majority of children in both areas were partially immune (figure 3; appendix p 8). In all regions except the northeast, immunity levels did not differ between urban and rural areas (appendix p 9). In the northeastern region, a significantly higher proportion of children from rural areas were non-immune to diphtheria than from urban areas (17·3% [95% CI 11·6–25·2] *vs* 8·8% [5·6–13·6]; p=0·0238; appendix p 9).

The proportion of children aged 5–17 years who were non-immune was significantly higher among children belonging to a scheduled caste or a scheduled tribe than among children belonging to general or other backward classes (11·3% [9·9–13·0; 491 of 5488] *vs* 8·9% [8·0–9·9; 298 of 2625]). By age group, this difference was significant only in children aged 5–8 years (p=0·0046; appendix p 10).

In all regions, the proportion of children immune to diphtheria peaked at age 6 years and thereafter showed a declining trend with increase in age (figure 4; appendix p 11). The proportion of children immune to diphtheria in

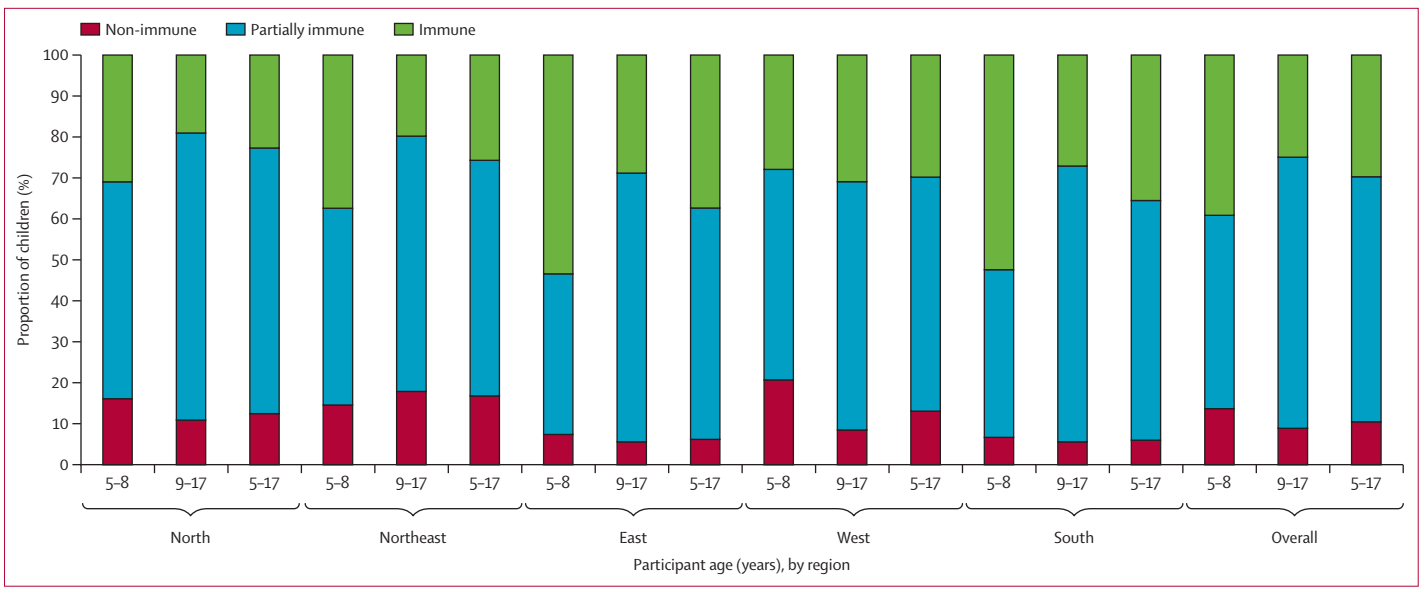

Figure 1: **Diphtheria immunity among children aged 5–17 years in India in 2017–18, by age group and geographical region**
We considered children with antibody concentrations of 0·1 IU/mL or greater as immune, those with levels less than 0·01 IU/mL as non-immune (and hence susceptible to diphtheria), and those with levels in the range of 0·01 to less than 0·1 IU/mL as partially immune.

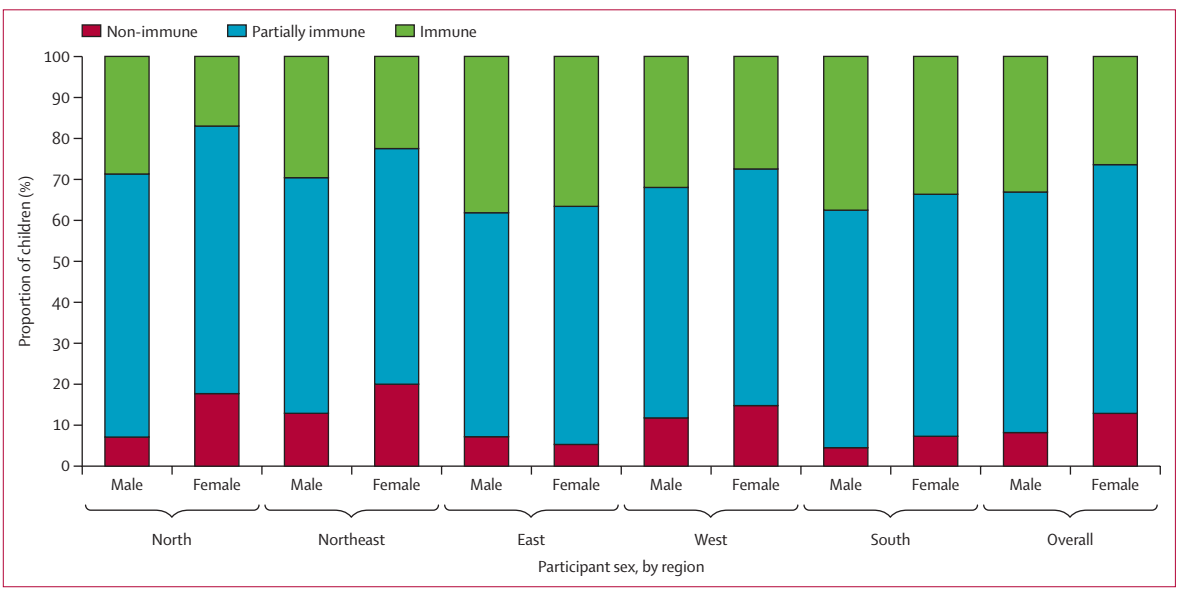

Figure 2: **Diphtheria immunity among children aged 5–17 years in India in 2017–18, by sex and geographical region**
We considered children with antibody concentrations of 0·1 IU/mL or greater as immune, those with levels less than 0·01 IU/mL as non-immune (and hence susceptible to diphtheria), and those with levels in the range of 0·01 to less than 0·1 IU/mL as partially immune.

successive age years decreased by 2·53% (regression coefficient –2·53, 95% CI –3·24 to –1·82), with reductions per age year ranging from 1·10% (95% CI 0·29 to 1·91) in the west to 3·85% (2·97 to 4·73) in the south (appendix p 12).

The geometric mean titre of IgG antibodies against diphtheria toxoid was 0·074 IU/mL (95% CI 0·071–0·076) in all children, 0·102 IU/mL (0·096–0·108) in children aged 5–8 years, and 0·054 IU/mL (0·052–0·057) in children aged 9–17 years (appendix p 13).

Discussion

This national serosurvey provides data on immunity against diphtheria among children aged 5–17 years from different geographical regions in India. The findings indicate that less than a third of children in this age group were immune to diphtheria at the time of the survey, with most children partially immune and some non-immune. We found that immunity against diphtheria varied by caste among children aged

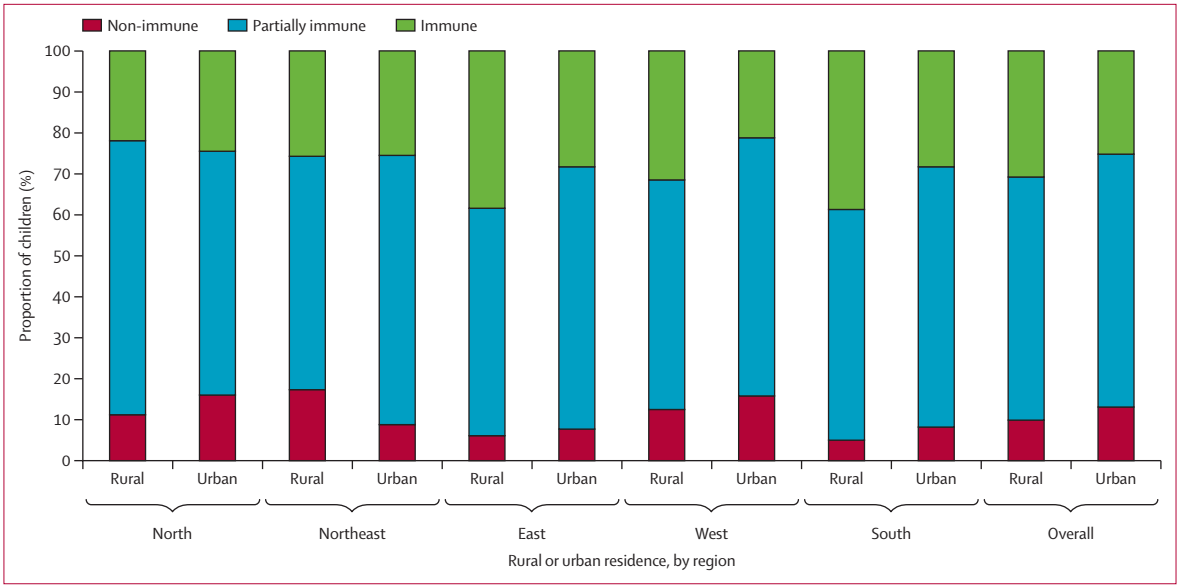

Figure 3: **Diphtheria immunity among children aged 5–17 years in India in 2017–18, by area of residence and geographical region**
We considered children with antibody concentrations of 0·1 IU/mL or greater as immune, those with levels less than 0·01 IU/mL as non-immune (and hence susceptible to diphtheria), and those with levels in the range of 0·01 to less than 0·1 IU/mL as partially immune.

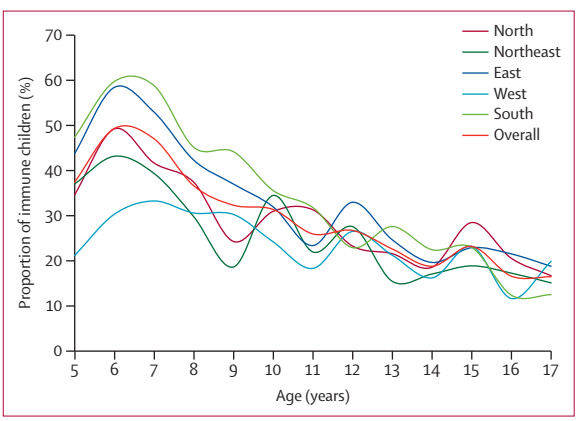

Figure 4: **Unweighted proportion of children immune to diphtheria by age in different geographical regions in India, 2017–18**
We considered children with antibody concentrations of 0·1 IU/mL or greater as immune.

5–8 years and by sex in the north and northeastern regions.

It is recommended that at least 90% of children should be immune to diphtheria to achieve sufficient herd immunity.[24] However, the proportion of children immune to diphtheria in India was substantially lower in our study, and around 60% of children were found to be partially immune. Although children with partial immunity are protected against clinical disease, the duration of protection is generally considered to be short-term, and these children are at risk of infection once immunity levels decline.[23] Low immunity against diphtheria among children could be the reason for continued transmission of diphtheria in India.

Around 13–17% of children from the northern, northeastern, and western regions of India were non-immune to diphtheria. This low population-level immunity possibly reflects incomplete coverage of diphtheria vaccination, especially booster doses, and a decline in acquired immunity by primary and booster vaccination. The coverage of three doses of DPT or pentavalent vaccine among children aged 5–17 years (born during 2000–12) in India was 58·2% during 2002–04,[25] 55·3% during 2005–06,[26] and 63·5% during 2007–08.[27] Coverage varied across states. For example, coverage as per the District Level Household Survey-4 or Annual Health Survey during 2012–13 among the states where the serosurvey was done ranged from 63·2% in Uttar Pradesh to 91·5% in West Bengal (appendix p 15).[28,29] The coverage in these surveys was higher in urban areas than in rural areas (appendix p 15). Furthermore, the dropout rate from DPT dose one to DPT dose three was around 12% during the National Family Health Survey (NFHS)-4 done in 2015–16.[9] Although information about coverage of booster doses is not routinely collected during national-level family health surveys, it is expected that the coverage of first and second boosters will be lower than the coverage of primary vaccination. Low population immunity against diphtheria could also be due to disruption of the vaccine cold chain, especially freezing of diphtheria vaccine.[30]

In the north and northeastern regions, we found lower immunity among girls than among boys. This difference could due to lower coverage of diphtheria vaccine (primary and booster) in girls than boys. Analysis of NFHS data indicated that, during 1992–2006, the proportion of children who received three doses of primary diphtheria vaccine increased from 37% to 45% among boys and

from 34% to 42% among girls, suggesting gender disparity. Furthermore, the gender disparity ratio in 2006 (defined as the ratio of boys fully immunised to girls fully immunised×100) was found to be higher in northern states, such as Punjab and Uttar Pradesh, and northeastern states, such as Arunachal Pradesh and Mizoram.[31]

In all five regions of India, the unweighted proportion of children who were immune to diphtheria peaked at 6 years and thereafter declined with increase in age. The peak in immunity at 6 years could be due to the second DPT booster given between ages 5 and 6 years. A diphtheria serosurvey in Poland showed that antibody levels increased with each booster dose.[32] In India, the decline in immunity with age was greatest in the southern region, with the proportion of immune children declining from 47·4% at age 5 years to 12·6% at age 17 years. Higher levels of immunity in the southern region in younger age groups reflects higher coverage of primary (as well as booster doses) immunisation. The subsequent decline in immunity in the southern region (and all regions) could be due to inadequate boosting of immunity. The decline in immunity observed in all regions indicates inadequate boosting of immunity from booster doses and through natural environmental exposure.[5] In the Indian national immunisation programme, two booster doses of diphtheria are recommended, first between the ages of 16 and 24 months and second between the ages of 5 and 6 years. However, this vaccination schedule is not enough to boost waning immunity. In view of diphtheria cases in older children, the National Technical Advisory Group on Immunization has recommended two additional doses of diphtheria vaccine for children aged 10 years and 16 years, by replacing the tetanus toxoid vaccine given in the school health programme with the adult tetanus-diphtheria vaccine.[33] A study in Hyderabad showed that a single dose of adult tetanus-diphtheria vaccine was highly immunogenic in children who were non-immune or partially immune to diphtheria.[34]

Our study showed that a higher proportion of children aged 5–8 years belonging to scheduled castes or scheduled tribes than to general or other backwards classes were non-immune. Data from national health and vaccination coverage surveys have shown lower coverage of primary vaccination among children from scheduled castes or scheduled tribes compared with those belonging to general or other backward classes.[35] During the first three rounds of national family health surveys between 1992 and 2006, compared with children belonging to general castes the coverage of three doses of DPT vaccine was lower by 7·7–13·5% among children belonging to scheduled castes and by 18·5–24·5% among children belonging to scheduled tribes. This gap reduced to 1·2% among scheduled castes and 7% among scheduled tribes during NFHS-4 done in 2015–16 (appendix p 16), possibly due to strengthening of health systems and improvements in vaccination coverage.[36]

Our study has limitations. First, as declining immunity by age was observed in all regions, it is likely that a substantial proportion of adults would also be non-immune or partially immune to diphtheria. Previous surveys in India have documented gaps in immunity against diphtheria among adults, with declining antibody levels with increasing age.[12,16,18] However, because of resource constraints, our study considered only children aged 5–17 years, and not older individuals. We also did not collect samples from children younger than 5 years. Second, we did not document the vaccination status of study participants, on account of the possible limitation in recalling this information. Moreover, immunity acquired through childhood vaccination is expected to wane with age. Third, the sample size for the serosurvey was calculated assuming a dengue seroprevalence of 60% in various geographical regions and age groups.[20] This sample size was adequate to capture a proportion of children immune to diphtheria of 20%, with an absolute precision of 5%, design effect of 2, and a confidence level of 95%.

In conclusion, the findings of our serosurvey indicate that a substantial proportion of children aged 5–17 years residing in different geographical regions of India were non-immune or partially immune to diphtheria. Transmission of diphtheria is likely to continue in India until the immunity gap is bridged through adequate coverage of primary vaccination and booster doses administered as a part of universal immunisation and school health programmes. This survey could serve as a baseline of population immunity for assessing the effect of introduction of tetanus-diphtheria vaccine in India.

Contributors

MVM was the principal investigator of the survey. MVM, PK, MSK, NG, and SMM conceived and designed the study. MVM, PK, MSK, SAK, RRA, PVB, BD, SK, UM, SSM, SR, VS, DS, BVT, RKT, SB, GSG, PVML, CMM, PS, PKS, SKS, CPY, RK, SD, and GST coordinated the field operations. CPGK oversaw all laboratory procedures with the support of RS, PK, and MSK, and MVM managed and analysed the data. MVM drafted the first version of the manuscript and all authors contributed, reviewed, and approved this article. MVM, PK, MSK and RS had access to all the data in the study and accept responsibility to submit for publication. MVM, PK, MSK, and RS have verified the data.

ICMR Serosurvey group

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Declaration of interests

We declare no competing interests.

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