# Predictors of Vaccination in India for Children Aged 12–36 Months

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**Introduction:** India has one of the lowest immunization rates worldwide despite a longstanding Universal Immunization Program (UIP) that provides free childhood vaccines. This study characterizes the predictors for under- and non-vaccination among Indian children aged 12–36 months.

**Methods:** This study utilized District Level Household and Facility Survey Data, 2008 (DLHS-3), from India. DLHS3 is a nationally representative sample collected from December 2007 through December 2008; this analysis was conducted during 2014. Children's vaccination status was categorized as fully, under-, and non-vaccinated based on whether children received all, some, or none of the UIP-recommended vaccines (one dose each of bacillus Calmette–Guérin and measles, and three doses of diphtheria–pertussis–tetanus). A multinomial logistic regression model estimated the odds of under-vaccination compared with full vaccination, and odds of non-vaccination compared with full vaccination. Analytic predictors included socioeconomic, cultural, household, maternal, and childhood characteristics.

**Results:** The analysis included 108,057 children; the estimated proportions of fully, under-, and non-vaccinated children were 57%, 31%, and 12%, respectively. After adjusting for state of residence, age, gender, household wealth, and maternal education, additional significant predictors of children's vaccination status were religion, caste, place of delivery, number of antenatal care visits, and maternal tetanus vaccination, all of which demonstrated large effect sizes.

**Conclusions:** India's immunization coverage remained low in 2008, with just slightly more than half of all children aged 12–36 months fully vaccinated with UIP-recommended vaccines. A better understanding of the predictors for vaccination can help shape interventions to reduce disparities in full vaccination among children of differing demographic/cultural groups.
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## Introduction

Approximately one quarter of the 6.6 million deaths among children under age 5 years worldwide in 2012 occurred in India.[1] No other country experiences this level of childhood mortality. The most recent data on vaccine-preventable mortality in India is from a 2008 study,[2] which estimated that of the 826,000 deaths in children aged 1–59 months, almost three quarters or 604,000 deaths were due to vaccine-preventable diseases including diarrhea, pertussis, measles, meningitis, and pneumonia. Collectively, the burden of these diseases highlights the significant human cost of the poor vaccination coverage among infants and children in India.

India has the world's largest annual birth cohort, comprising 26 million newborns, while also reporting one of the lowest immunization rates of any country in the world.[1] WHO estimates that more than 22 million infants worldwide had not received the third dose of the diphtheria–pertussis–tetanus (DPT3) vaccine in 2012, a frequently used proxy for the success of a country's

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immunization program, with 7 million or 30% of those children residing in India.[3]

The Indian Government's Universal Immunization Program (UIP) provides vaccines against six diseases to all infants free of charge: one dose of bacillus Calmette–Guérin (BCG; tuberculosis); three doses of DPT3; three doses of oral polio vaccine (OPV); and one dose of measles-containing vaccine (MCV).[4] All of these vaccine doses should be administered by age 12 months. Indian children who receive all recommended doses of these four UIP vaccines are considered fully vaccinated by WHO; a child lacking any of the recommended doses is considered under-vaccinated, and children who have not received any vaccinations are considered non-vaccinated. The Indian government's nationally representative District Level Household and Facility Survey 2008 (DLHS3) reported that only 54% of children aged 12–23 months were fully vaccinated, 41% were under-vaccinated, and the remaining 5% were non-vaccinated.[5] The challenge of meeting the demands of appropriately and fully immunizing children in India becomes ever more daunting as the country adds a pool of 12.5 million partially immunized children each year.[6]

Against this backdrop of low vaccination coverage, significant variation exists in the estimated coverage for children aged 12–23 months across the 34 Indian states and Union Territories. For example, based on the DLHS3 report, the percentage of fully vaccinated children ranged widely, from a low of 13% in the Indian state of Arunachal Pradesh to a high of 82% in Tamil Nadu.

The causes of low vaccination coverage in India have recently received more scholarly attention. Numerous studies have focused on individual predictive factors for vaccination including gender, age, and birth order, and others on household factors such as family size, number of children below age 3 years, household wealth, caste, and maternal education.[7–14] However, many of these studies[7,8] did not control for potential confounders such as religion, caste, or state-level effects. Moreover, although it is well documented that the epidemiology of non-vaccination may differ substantially from the epidemiology of under-vaccination,[9,10] most of these studies[7,11,12] dichotomize vaccination status into complete (i.e., full) versus incomplete (i.e., under- or non-vaccinated). The few studies[13] investigating predictors of childhood vaccination in India that utilized three distinct vaccination categories (i.e., full, under-, and non-vaccination) were limited by small sample sizes drawn from narrowly defined geographic areas such as a specific state, city, urban slum(s), or a village(s), potentially impacting the generalizability to the national population.

In this study, we sought to identify individual-level sociodemographic and cultural factors related to vaccination status in Indian children aged 12–36 months using a nationally representative sample from the DLHS3. Based on prior studies in countries other than India,[9,10] we hypothesized that the predictors associated with childhood under- and non-vaccination would be different. To avoid confounding the relationship between vaccination status and individual characteristics by healthcare infrastructure availability, accessibility, and prevailing policy environment in the state, we controlled for state of residence.

## Methods

### Data Source and Sample Design

India's 2008 DLHS3 was used for this study and is the most recent countrywide immunization data set on children available to outside researchers. The DLHS3 is a nationally representative sample collected from December 2007 through December 2008 from 720,320 households located in 601 distinct districts from 34 states. This analysis was conducted in 2014. The DHLS3 sampling featured a multistage, stratified, systematic sample design with two stages in rural and three stages in urban areas. In rural areas, villages served as the primary sampling unit within each state and households were systematically selected within each village. In urban areas, wards served as the primary sampling unit and were selected using probability proportional to size. Within a ward, census blocks were further selected using probability proportional to size and then households were systematically sampled within census blocks. The first stage of the sampling design stratified villages and wards by the total number of households in the primary sampling unit, percentage of scheduled caste and scheduled tribe population, and female literacy. Sampling weights were calculated for each district and permitted unbiased estimation of population characteristics. These design weights incorporated the selection probabilities at each stage of randomization. Additional details regarding the weight calculations and sampling methodology of the DLHS3 are published elsewhere.[5]

The DLHS3 utilized interviewer-administered questionnaires comprising separate surveys for ever-married women within the households, and a second, complementary survey for the entire household. Any adult aged >18 years who lived in the household was permitted to respond for the household. Household questionnaires requested information on all household members, including sociodemographic characteristics and financial assets. Women were only asked about children born on or after January 1, 2004; specific information on their children's immunization status was obtained from the vaccination card for the child. If an immunization card was not available, then reported immunization data were based on maternal recall.

### Measures

The population used for this analysis consisted of the most recently born child per household who was aged 12–36 months at the time of data collection. The primary outcome of vaccination status was classified into three categories: fully vaccinated, under-vaccinated, and non-vaccinated. Using the WHO standards, we defined children who received one dose of BCG, three doses of DPT3, and one dose of MCV as fully vaccinated; children who received one or more but not all of these recommended doses as under-vaccinated; and children who did not receive any vaccinations as non-vaccinated.

The individual-level variables used as predictors of vaccination coverage were broadly classified into four categories: childhood, maternal, household, and sociocultural factors. The three childhood variables were age, gender, and place of birth, all of which have been shown to be associated with vaccination status.[8] Maternal variables were maternal age at childbirth; education level; participation in antenatal care (ANC) services; and mother's receipt of tetanus toxoid (TT) vaccine, which are also known to be associated with their children's immunization status.[14–17] Household characteristics included residence type (rural or urban); household wealth; and household size. The DLHS3 used a standard wealth index based on factor analyses and classified into five quintiles (poorest to wealthiest) based on household amenities, assets, and durables, representing direct and indirect measures of household economic status. In the absence of direct information on income or expenditures, wealth index is considered a robust measure of income at the household level.[18–20]

Religion and caste reflect deeply rooted cultural designations that influence parental beliefs and attitudes toward health-seeking behaviors, including vaccination decisions about their children, and impact access to health care.[21–23] Low caste is also an indicator of social discrimination.[24,25] In this study, caste was used as a four-category variable: scheduled tribe[a] (ST); scheduled caste[a] (SC); less-privileged classes[b] (LPCs); and "others." The "others" category comprises historically privileged groups that are not considered socially disadvantaged by the Indian Government. Conversely, the ST, SC, and LPC categories are historically underprivileged and remain socially disadvantaged, with ST considered to be at the lowest rung of the social caste hierarchy.

State of residence was used as an indicator of policy and programs affecting healthcare access, availability, and any other unobserved state-specific factors that might be associated with vaccination status. In addition to 18 individual states, those states that did not have sufficient sample sizes under each vaccination category were collapsed into four clusters of neighboring states: Himachal Pradesh, Punjab, and Chandigarh were one group; Sikkim, Tripura, and Meghalaya another; Andhra Pradesh and Karnataka another; and finally all the islands and smaller states and union territories (Daman and Diu, Dadra Nagar Haveli, Goa, Lakshadweep, Pondicherry, and Andaman Nicobar).

### Statistical Analysis

The analysis focused on ascertaining the predictors for under- and non-vaccination compared with full vaccination. All analyses were performed using the appropriate stratification, clustering, and weighting statements to account for the complex sample design characteristics described above. The Taylor series linearization method was used to calculate the variance of the parameter estimates.

A bivariate analysis was conducted to examine the association of vaccination status with each of the potential predictor variables. The Rao–Scott design-adjusted test statistic for the independence of the two variables was used. Based on these initial tests of association, all of the predictor variables appeared to have significant bivariate associations with vaccination status. To determine if these marginal associations remain significant when controlling for the other predictors and state effects, a multinomial logistic regression model was employed. As the distance between each outcome category was not the same, an ordinal logistic regression was not appropriate. A subpopulation analysis was conducted because the study subjects were a subset (age 12–36 months) of all the children (age 0–5 years) in the data set. The importance of each of these predictors was evaluated using the design-adjusted Wald test. All analyses were conducted using Stata, version 13. This study was deemed exempt from IRB oversight at the University of Michigan, because it was limited to analysis of previously collected data.

## Results

The DLHS3 included information on 268,539 children aged 0–60 months. For this analysis, the most recently born child in each family within the 12–36-month age range at the time of interview was selected, leaving 108,057 children (40% of the total) who met these criteria. Characteristics of the study population are summarized in Table 1. Slightly more than half (53%) of the children were boys. Approximately 72% of the children lived rurally, and three quarters were Hindu, 15% Muslim, 5% Christian, 2% Sikh, and 1.3% from other religions. One quarter of children belonged to privileged classes, with the remainder from historically underprivileged classes; the percentages of SC, ST, and underprivileged classes were 19%, 17%, and 41%, respectively (Table 1). A large proportion (42%) of children had mothers without formal schooling. More than half (55%) of the births were non-institutional, and 24% of births occurred in government institutions including primary health centers, community health centers, and district hospitals.

Vaccination status of children by individual vaccines and series completion was analyzed; the results are shown in Table 2. The overall vaccination coverage was highest for BCG vaccine (86%) and lowest for DPT3 vaccine (62%). The percentages of fully vaccinated children in urban and rural areas were 66% and 54%, respectively. The largest difference (59% vs 70%) between rural and urban vaccine coverage was for DPT3 vaccine. Only 57% children in the study population completed the

[a]Scheduled castes/tribes are identified by the government of India as socially and economically disadvantaged and in need of special protection from social injustice and exploitation.

[b]Officially referred to as "other backward classes" by the Indian Government but referred to in this paper as "less-privileged classes."

**Table 1.** Sociodemographic and Economic Characteristics of Children Aged 12–36 Months, District Level Household and Facility Survey, India, 2008

| Characteristics | Un-weighted sample sizes | Weighted percentages (95% CI) |
|---|---|---|
| Locality | 108,057 | |
| Rural | | 71.70 (63.68, 78.54) |
| Urban | | 28.30 (21.45, 36.32) |
| Religion | 106,430 | |
| Hindu | | 76.06 (75.38, 76.74) |
| Muslim | | 15.49 (14.69, 16.31) |
| Christian | | 5.10 (4.88, 5.33) |
| Sikh | | 2.06 (1.91, 2.23) |
| Other[a] | | 1.29 (1.20, 1.37) |
| Caste | 106,033 | |
| Scheduled caste | | 18.60 (17.85, 19.37) |
| Scheduled tribe | | 16.88 (15.90, 17.92) |
| Less-privileged classes | | 41.38 (40.67, 42.09) |
| Others | | 23.13 (22.31, 23.97) |
| Household size (no. of members) | 108,057 | |
| ≤3 | | 8.01 (7.81, 8.22) |
| 4–5 | | 31.13 (30.81, 31.45) |
| 6–7 | | 28.40 (28.05, 28.78) |
| ≥7 | | 32.44 (32.10, 32.78) |
| Wealth quintile | 108,043 | |
| Poorest (quintile 1) | | 18.44 (16.94, 20.03) |
| Poor (quintile 2) | | 19.37 (18.16, 20.64) |
| Middle (quintile 3) | | 19.46 (18.74, 20.19) |
| Rich (quintile 4) | | 20.82 (20.22, 21.44) |
| Richest (quintile 5) | | 21.90 (19.17, 24.91) |
| Mother's age at child birth (years) | 108,057 | |
| ≤18 | | 7.22 (6.90, 7.55) |
| 19–25 | | 53.48 (53.06, 53.89) |
| 26–35 | | 34.99 (34.44, 35.54) |
| ≥35 | | 4.32 (4.16, 4.49) |
| Maternal education | 107,778 | |
| No school | | 42.58 (40.84, 44.35) |
| 1–5 years school | | 14.44 (14.09, 14.81) |
| 6–12 years school | | 36.53 (35.38, 37.68) |
| ≥13 years School | | 6.45 (5.60, 7.41) |

*(continued on next page)*

three-dose DPT3 series; 31% did not complete the series (under-vaccinated); and 12% were non-vaccinated.

The multinomial logistic regression model was built primarily based on previous literature and the bivariate relationships between sociodemographic and economic characteristics by vaccination status. The results for multinomial logistic regression models estimating the OR of a child being non-vaccinated compared with fully and under-vaccinated compared with fully vaccinated are summarized in Table 3. The fixed effects for states were included in the model; the regression results are not shown (available upon request). Children living in urban areas compared to rural areas had 1.8 times higher odds of non-vaccination compared with full vaccination (OR=1.80, 95% CI=1.67, 1.94), and 1.12 times greater odds of under-vaccination compared with full vaccination (OR=1.12, 95% CI=1.04, 1.20).

When controlling for state of residence, child's age, gender, household wealth, and maternal education, the additional significant predictors of child's vaccination status were religion, caste, number of ANC visits, and maternal TT vaccines, which demonstrated large effect sizes. We found religion highly predictive of a child's vaccination status; relative to Hindus, Muslim children had 2.2 times greater odds of being non-vaccinated versus fully vaccinated and 1.42 times higher odds of being under-vaccinated compared with fully vaccinated. Christian and Sikh children compared with Hindu children were not significantly associated with non-vaccination. Children

**Table 1.** Sociodemographic and Economic Characteristics of Children Aged 12–36 Months, District Level Household and Facility Survey, India, 2008 *(continued)*

| Characteristics | Un-weighted sample sizes | Weighted percentages (95% CI) |
|---|---|---|
| Number of antenatal care visits | 108,057 | |
| None | | 28.54 (27.45, 29.66) |
| 1–2 | | 23.20 (22.71, 23.70) |
| 3–6 | | 35.94 (35.20, 36.69) |
| ≥7 | | 12.32 (11.56, 13.12) |
| Maternal tetanus vaccination | 108,057 | |
| No | | 28.97 (27.86, 30.10) |
| Yes | | 71.03 (69.90, 72.14) |
| Sex of the child | 108,055 | |
| Male | | 52.78 (52.47, 53.08) |
| Female | | 47.22 (46.91, 47.53) |
| Delivery place | 105,871 | |
| Institutional government | | 24.42 (23.67, 25.18) |
| Institutional private | | 20.45 (18.98, 21.99) |
| Non-institutional | | 55.14 (52.95, 57.31) |

[a]Other religious group comprises the following religions: Buddhist, Jain, Jewish, Zoroastrian, no religion.

of other religions (Buddhism, Jainism, Zoroastrianism, and Judaism) were less likely to be under- and non-vaccinated than fully vaccinated. Similarly, caste was a strong cultural predictor of vaccination status. Children belonging to LPC groups compared with privileged groups had 33% higher odds of non-vaccination compared with full vaccination and 12% higher odds of under-vaccination relative to non-vaccination. SC and ST children compared with privileged groups children also had significantly higher odds of non- and under-vaccination than full vaccination.

The maternal characteristics exerting the strongest influence were place of delivery, receipt of ANC, and TT; maternal age ($\leq$18 years) also had a statistically significant association with vaccination status. Compared with fully vaccinated children, under-vaccinated (OR=1.18, 95% CI=1.13, 1.24) and non-vaccinated (OR=1, 95% CI=1.09, 1.37) children had greater odds of having a non-institutional delivery as opposed to being born in government institutions. Also, children born in private institutions had greater odds (OR=1.45, 95% CI=1.25, 1.68) of non-vaccination compared with full vaccination, although there was no significant association with under-vaccination. Number of ANC visits and maternal receipt of TT vaccine demonstrated a strong protective effect for non- and under-vaccination of children.

## Discussion

India's immunization coverage remained unacceptably low in 2008, with only slightly more than half of all children

**Table 2.** Probability of Vaccination by Type of Residence

| Variable | Weighted percentages (95% CI) Rural ($n$=87,643) | Urban ($n$=20,414) | Overall ($n$=108,057) |
|---|---|---|---|
| BCG | 84.76 (84.34, 85.19) | 88.91 (88.25, 89.54) | 85.94 (85.50, 86.37) |
| DPT1 | 76.22 (75.69, 76.75) | 83.13 (82.21, 84.02) | 78.18 (77.56, 78.79) |
| DPT2 | 69.45 (68.94, 69.96) | 78.56 (77.35, 79.72) | 72.03 (71.32, 72.72) |
| DPT3 | 58.90 (58.37, 59.44) | 70.33 (68.82, 71.80) | 62.14 (61.31, 62.96) |
| Measles | 68.52 (68.03, 69.00) | 78.07 (76.82, 79.26) | 71.22 (70.51, 71.93) |
| Fully vaccinated | 53.58 (53.05, 54.10) | 65.63 (63.97, 67.25) | 56.99 (56.14, 57.83) |
| Under-vaccinated | 33.07 (32.71, 33.43) | 24.43 (23.16, 25.75) | 30.62 (30.04, 31.21) |
| Non-vaccinated | 13.35 (12.97, 13.75) | 9.94 (9.40, 10.52) | 12.39 (12.01, 12.78) |

BCG, bacillus Calmette–Guérin; DPT, diphtheria–pertussis–tetanus.

**Table 3.** AORs of Vaccination from a Design-Based Weighted Multinomial Logistic Regression Model[a,b,c]

| | AOR (95% CI) | |
|---|---|---|
| **Covariates** | **Non- versus fully vaccinated** | **Under- versus fully vaccinated** |
| Locality | | |
| Rural | ref | ref |
| Urban | 1.80 (1.67, 1.94) | 1.12 (1.04, 1.20) |
| Religion | | |
| Hindu | | |
| Muslim | 2.22 (2.03, 2.44) | 1.42 (1.33, 1.52) |
| Christian | 0.86 (0.69, 1.08) | 1.06 (0.93, 1.21) |
| Sikh | 0.85 (0.65, 1.10) | 0.82 (0.69, 0.97) |
| Other | 0.55 (0.40, 0.76) | 0.67 (0.56, 0.79) |
| Caste | | |
| Others | ref | ref |
| Scheduled caste | 1.30 (1.17, 1.44) | 1.16 (1.08, 1.24) |
| Scheduled tribe | 1.27 (1.13, 1.43) | 1.15 (1.07, 1.23) |
| Less privileged classes | 1.33 (1.23, 1.44) | 1.12 (1.06, 1.19) |
| Wealth quintile | | |
| Poorest | ref | ref |
| Poor | 0.76 (0.70, 0.82) | 0.86 (0.81, 0.91) |
| Middle | 0.60 (0.55, 0.66) | 0.81 (0.77, 0.86) |
| Rich | 0.46 (0.40, 0.52) | 0.71 (0.66, 0.76) |
| Richest | 0.32 (0.27, 0.37) | 0.59 (0.54, 0.65) |
| Household size (no. of members) | | |
| ≤3 | ref | ref |
| 4–5 | 0.98 (0.88, 1.11) | 1.01 (0.95, 1.08) |
| 6–7 | 0.99 (0.87, 1.12) | 1.00 (0.94, 1.07) |
| ≥7 | 1.07 (0.94, 1.22) | 1.04 (0.97, 1.11) |
| Maternal age | | |
| ≤18 | 1.11 (1.01, 1.22) | 1.10 (1.03, 1.18) |
| 19–25 | ref | ref |
| 26–35 | 0.97 (0.92, 1.03) | 0.92 (0.90, 0.95) |
| ≥35 | 1.10 (0.98, 1.23) | 1.00 (0.91, 1.09) |
| Sex of the child | | |
| Male | ref | ref |
| Female | 1.20 (1.15, 1.26) | 1.05 (1.01, 1.08) |
| Maternal education | | |

*(continued on next page)*

aged 12–36 months fully vaccinated with the UIP-recommended vaccines, and the remainder either under-vaccinated or not vaccinated at all. Based on India's large birth cohort, this translates into approximately 22 million children aged 12–36 months at elevated risk for vaccine-preventable diseases, which partially explains the continued high burden of morbidity and mortality from such diseases in Indian children.

The Indian Government launched the National Rural Health Mission in 2005, which resulted in substantial improvements in immunization service delivery.[26] Additionally, a web-based Mother and Child Tracking System that collects childhood immunization data was introduced by the government in 2009; however, it has relatively low enrollment and other data capture–related problems. More recently, the Indian Government declared in 2012 that a renewed focus on strengthening routine immunization services was needed, which was followed by the establishment of an Immunization Technical Support Unit at the Public Health Foundation of India in collaboration with other partners to revamp the ongoing efforts to improve vaccination coverage.[27] The impact of these major governmental initiatives aimed at improving vaccination coverage is difficult to ascertain without newer data sources of population-level data on immunizations. Although the DLHS4, conducted in

Table 3. AORs of Vaccination from a Design-Based Weighted Multinomial Logistic Regression Model[a,b,c] *(continued)*

| Covariates | AOR (95% CI) Non- versus fully vaccinated | AOR (95% CI) Under- versus fully vaccinated |
|---|---|---|
| No school | ref | ref |
| 1–5 years | 0.64 (0.60, 0.69) | 0.85 (0.80, 0.89) |
| 6–12 years | 0.41 (0.38, 0.45) | 0.69 (0.66, 0.73) |
| ≥13 years | 0.27 (0.19, 0.37) | 0.54 (0.48, 0.61) |
| Delivery place | | |
| Government institution | ref | ref |
| Private institution | 1.45 (1.25, 1.68) | 1.03 (0.97, 1.10) |
| Non-institutional | 1.81 (1.63, 2.00) | 1.18 (1.13, 1.24) |
| Number of antenatal care visits | | |
| None | ref | ref |
| 1–2 | 0.99 (0.83, 1.17) | 0.95 (0.85, 1.06) |
| 3–6 | 0.67 (0.56, 0.81) | 0.73 (0.65, 0.83) |
| ≥7 | 0.92 (0.73, 1.18) | 0.68 (0.60, 0.76) |
| Maternal tetanus toxoid | | |
| No | ref | ref |
| Yes | 0.25 (0.21, 0.29) | 0.68 (0.61, 0.75) |
| Vaccination card | | |
| No | ref | ref |
| Yes | 0.03 (0.03, 0.04) | 0.19 (0.18, 0.19) |

[a]Coefficients are estimated controlling within state variation and child's age in months. State effects were added to the model to control for unobserved state-specific factors that might be associated with vaccination status that were not included in the model.
[b]Using the District Level Household and Facility data, 2007–2008, from India for children aged 12–36 months.
[c]Sample size: 102,039.

2012, reassesses national coverage and updates the DLHS3, it is not yet available to outside researchers.

The reasons for under- and non-vaccination are multifactorial and complex. On the basis of literature from other developing countries, we hypothesized that the reasons for non-vaccination would be different from those for under-vaccination.[10] However, we found that the predictors were similar for both, although the effect sizes of the predictors differed between the two outcomes.

In this sample, coverage for the BCG vaccine was very high, indicating a certain level of healthcare services access. The gradual decrease in the vaccination coverage from the birth-administered BCG to DPT3 given at age 6 months could be secondary to difficulty accessing immunization services, lack of understanding for the need for vaccination, loss in motivation or perceived need for child vaccination, or a combination of all these factors. Difficulty in accessing health services could be explained, at least in part, by institutional and societal discrimination directed at parents belonging to lower castes and poorer households, and physical barriers such as unavailability of services due to long distances to health centers, scarcity of vaccines at the health center, or unavailability of health workers.

Children from urban areas have been reported to have better vaccination outcomes relative to children residing in rural areas.[8,11,14] By contrast, we found that children from rural areas had a lower risk of non- and under-vaccination compared with children from urban areas after controlling for the effects of other potential risk factors, whereas most previous studies[7,8] reporting the reverse relationship did not control for those effects. In general, when urban and rural averages are compared for most development indicators, the former tend to be better. However, the concentration of wealth in urban areas likely masks the depth of urban poverty. Although the proportion of fully vaccinated children was higher in urban areas compared with rural areas, we found just the opposite when controlling for other factors. This may be attributable to the fact that urban areas in India have both middle-class neighborhoods but also large, pervasive slum areas with high concentrations of poor and uneducated families (of lower caste), who largely lack access to healthcare facilities. Unfortunately, the data did not permit us to distinguish between the urban areas of higher SES and the slums with which they are often directly intertwined. Although the DLHS3 lacked specific information as to whether families lived in a slum, it seems reasonable to assume that urban slum children live in extreme poverty, are more isolated from mainstream society, and are at higher risk of nonand under-vaccination than children living in middle-class neighborhoods. Conversely, there is an extensive network of primary health centers, subcenters, and community health workers (Anganwadi workers) in poor rural areas of India, and their task is to mobilize children and pregnant women to receive healthcare center services; a comparable network may not exist in urban areas. This could partially account for our finding that urban children with the same level of poverty, education, religion, and caste as rural children still have lower chances of being fully vaccinated, with significant implications for targeted immunization intervention programs and related policies.

Researchers have noted that existing health inequities in India are related to a lack of attention to social determinants of health, including education, employment, and the failure of the healthcare system to deliver to those in need.[28] We found significant disparities in vaccination coverage between the richest and poorest children, and between the children of mothers with high education and low education, confirming findings in previous literature.[8,14–17,29] Inequities in vaccination coverage among social and religious groups in India were also clearly evident. Children from Muslim families had significantly poor vaccination outcomes, and Christian children were also at an elevated risk for under-vaccination. Children of Sikh and other religious affiliations, such as Buddhist, Jain, Jewish, and Zoroastrian, had better vaccination coverage than all the other religious groups. Previous vaccination studies[11,14] that investigated effects of religion on vaccination coverage dichotomized religion as Hindu and non-Hindu and concluded that non-Hindu religions have poor vaccination outcomes, whereas in this study we further categorized the non-Hindu religions and found that Sikhs and "others" have significantly better vaccination outcomes than Hindu children.

These observed differences across social and religious groups may be secondary to beliefs and practices that influence the receptivity and uptake of medical practices like vaccination. Detailed variables related to religious beliefs and attitudes were not available in the DLHS3, which may have permitted a more nuanced understanding of religion-associated differences in vaccine acceptance. Given the magnitude of these disparities, a qualitative study on vaccination attitudes, especially maternal attitudes, among different religious groups could be informative. Similarly, we also found that the historically disadvantaged groups (at the lower rung of the social strata, ST, SC, and LPCs), not surprisingly, were associated with both under- and non-vaccinations. Again, this could be reflective of prevailing practices and beliefs among these groups, which act as impediments to vaccination access or uptake and to encountered social barriers, making it more difficult to use healthcare services. Past studies on caste have examined inequality in terms of economic opportunities,[30] education,[31] occupation,[32] and income.[33] The few studies[34–36] that have examined health in the context of caste membership have specifically looked at the prevalence of anemia, treatment of diarrhea, infant mortality, and childhood vaccination, noting children belonging to underprivileged classes are more vulnerable to poor health outcomes. The findings of these studies suggest that people belonging to castes in the lower hierarchical strata may face systematic social discrimination, including that from the medical establishment, which impedes their access to critical healthcare services like vaccination.

Our finding that children born in private institutions were at greater risk of non-vaccination than those who were born in government institutions has major policy implications. Private hospitals in India do not benefit from the government's healthcare funding for the poor, nor do private institutions operate under any government mandate to deliver immunizations or increase immunization coverage, whereas government institutions do. Consequently, there is little or no financial or policy incentive for private facilities to ensure that children are appropriately immunized.

Interventions such as enrolling women in ANC programs and encouraging institutional deliveries, as well as the implementation of mandates for private hospitals/healthcare facilities to immunize children covered under the UIP program, might reasonably be assumed to be helpful based on the associations we observed, although the cross-sectional study design prevents us from establishing causal inference. Further studies are needed to more clearly establish the roles of these predictors for vaccine receipt.

## Limitations

This study has several limitations. The vaccination information on children was based on mothers' recall in cases where vaccination cards were not available. However, previous studies have reported that in countries lacking immunization records, maternal recall provides accurate population-level estimates of vaccination coverage.[37] We were unable to include OPV, a recommended UIP vaccine, in our analysis because of a systematic data recording error in the DLHS3 regarding OPV. This error was discussed with immunization program staff from the Immunization Technical Support Unit and village health workers during a project assessing the immunization program performance in two districts of Gujarat (oral communication, April, 2013). The sustained and intensive national campaign for polio vaccination has resulted in estimated immunization coverage close to 100% for OPV in all Indian states and territories. However, based on the DLHS data, the OPV coverage for the three dosages of OPV was reported artificially low, at 48%, 46%, and 42%, respectively. This discrepancy is attributable to OPV administered as oral drops, which are not registered as vaccinations like injectable vaccines. Furthermore, this analysis did not control for a number of important variables because they were not included in the data set. For example, previous literature reported that under-vaccination was associated with immunization system factors and access to services, such as training of health workers to reduce missed opportunities, communication of benefits of vaccination, lack of adequate vaccine supply, and inconsistent scheduling of vaccination supply; none of these variables were available for this analysis. DLHS3 is a cross-sectional survey; thus, no causal inference can be made, only statistical associations. Finally, because of insufficient sample size from a few states, they were grouped together, which may have masked the true effects in some of those states.

### Strengths

This study also has several strengths. We used a national data set, which provided a very large sample size, permitting us to test many associations with sufficient statistical power. Appropriate survey methods were used to account for the complex sample design of the data, which provides unbiased population estimates. Finally, this is the first study to characterize the differences between the risks of under- and non-vaccination among Indian children using a national data set.

### Conclusions

Using a large, nationally representative sample, we found that immunization uptake in Indian children was low, with many children under- and non-vaccinated. Highly predictive social determinants of vaccination include religion, caste, wealth, and education, which will require multifaceted public health programs to successfully address. The Indian government may wish to consider encouraging pregnant women to enroll in ANC programs and ensuring institutional births in order to improve childhood vaccination levels.

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