SUPPLEMENTARY METHODS

Data source and survey questionnaire

Data for the study were from the Indian District Level Household and facility Survey (DLHS) cross-sectional surveys which are publicly available upon request from the Director of the Indian Institute of Population Sciences (IIPS), Mumbai [1]. The DLHS surveys have been designed and conducted by the IIPS, under supervision of the Ministry of Health, Government of India. The DLHS surveys were designed to periodically monitor and assess reproductive and child health program indicators to reduce infant and maternal mortality through the promotion of newborn care, immunization, antenatal care and institutional delivery in every district of India. Four rounds of the DLHS were completed until the time of this analysis (DLHS-1 in 1998–99, DLHS-2 in 2002–04, DLHS-3 in 2007–08 & DLHS-4 in 2012-13). Data from DLHS-4 were not included in this analysis as the surveys covered only 336 of 640 Indian districts (21 Indian States and Union Territories) and was therefore not representative nationally. On average, the interval between each of the DLHS surveys was 4-5 years. Each DLHS round employed a similar systematic, multi-stage stratified sampling design (see below). The first round of DLHS (DLHS-1) covered a sample of 474,463 currently married women aged 15–44 years, DLHS-2 covered 507,622 currently married women aged 15–44 years and DLHS-3 covered 643,944 ever married women aged 15–49 years [2–5].

The DLHS used two survey tools to capture information from eligible households (Household questionnaire) and eligible women in the reproductive age group (Women's questionnaire). The questionnaires were interviewer-administered and all the questionnaires were bilingual – with questions in both regional and English language. The questionnaires were designed by the IIPS in consultation with the Ministry of Health and Family Welfare and the World Bank, and pre-tested in one Indian State and in each of the different languages by regional agencies. For this study, we only used pre-existing information from the DLHS "Women's questionnaire", covering the following major themes: socio-demographic characteristics such as age, place of birth, educational attainment, number of births, also including accounts of antenatal care and pregnancy related complications and post-partum care. For recent births, immunization status of children was collected from the vaccination card or by asking the mothers to recall the vaccination status of their youngest children. A formal comparison of all the large-scale, national, population-based surveys including the DLHS surveys covering differences in the types of respondents, key questionnaire themes - including proportions of questions covering important maternal, reproductive and child health indicators, along with time frame of availability of data and analytical publications resulting from the DLHS datasets is available elsewhere [6]. In summary, the type and number of questions providing information on household, maternal and child characteristics and immunization histories were generally similar for the DLHS surveys, however, an increase in the number of questions about child and maternal health and non-communicable diseases has been reported from DLHS-1 to DLHS-4 [6].

Survey design and weight calculations

Each of the DLHS surveys used a multi-stage, stratified, systematic sampling design. In each district, up to 50 Primary Sampling Units (PSUs), representing census villages in rural areas and wards in urban areas were selected as the first stage using Probability Proportional to Size (PPS) sampling. The 1991 Census list of India was used as the sampling frames for DLHS-1 and DLHS-2 and 2001 Census list served as the sampling frame for the DLHS-3. All the villages and urban wards in a district were stratified by total number of households in the PSU, female literacy and percentage of Scheduled caste/Scheduled tribe population (only in DLHS-3). The target sample in each district was set to cover a minimum of 1,000 residential households from the selected PSUs. The selection of households in a PSU was done after listing all the households in the PSUs and using either circular systematic random sampling thereafter. This involved mapping and listing of structures and households for each sampled PSU, following which segmentation of smaller areas within villages or wards was carried out systematically and households were selected for sampling from selected segments using PPS sampling. In addition, 10% oversampling of households was done to account for non-response.

District-level sampling weights for households and currently-married (DLHS-1 & DLHS-2) or ever-married women (DLHS-3) were calculated using the selection probabilities at each stage of randomization, i.e. 1) the probability of selection of PSU in a district, 2) the probability of selecting segment from segmented PSU and 3) the probability of selecting households from the total list of households in a PSU or segments of a PSU. State-level weights for households and women were derived as weighted averages of the corresponding district-level weights. Similarly, national-level weights were computed by proportionalization using the all India sample and census totals by states and rural-urban residence. The weighting scheme followed for the DLHS surveys was comparable and additional information on the probability calculations at each level of randomization and for the state and national-level weights are found elsewhere [3,4].

Variables

Outcome

We combined data recorded from children's vaccination card and maternal recall into a three-level categorical variable capturing if children were fully-vaccinated, partially-vaccinated or unvaccinated by 12 months of age using World Health Organization recommendations. Previous reports have highlighted potential differences in the predictors and reasons for partial-vaccination and non-vaccination among young children [7,8]. A recent study using data from the DLHS-3 survey reported that the predictors of partial- and non-vaccination were generally similar [9], however our study intended to examine the factors associated with suboptimal vaccination uptake across three consecutive DLHS surveys conducted from 1998 to 2008. We hypothesized that any differences in the factors associated with suboptimal childhood vaccination would be more pronounced when combining information for the three DLHS surveys. Also, to investigate potential differences in the factors associated with the vaccination status of "partially-vaccinated" children based on whether the children had very few vaccines or nearly all, but were missing only one or two, we recategorized these children as those who received 1) "very few" recommended doses (1 – 2 doses), 2) "some" recommended doses (3 – 5 doses) or 3) "almost all" recommended doses (6 – 7 doses).

Selection of socio-demographic variables

The primary analysis of the study aimed to examine socio-demographic disparities in children's vaccination status, as social determinants are known to have a significant impact on routine immunization programs in countries regardless of their income level [10]. Research using demographic and health survey (DHS) data worldwide tend to focus on examining socio-demographic disparities for different human health indicators [11]. Socio-demographic variables are also important indicators of inequalities in access to or uptake of immunization and other health services among different populations [8,10]. We used individual, household and regional variables known to have a well-documented association with children's vaccination status in India. Of the individual variables, child-specific variables such as gender and age of the child in months were selected for the analysis. Gender disparities in children’s vaccination status in India have been reported for decades now, with a recent study reporting regional, religious and other socio-economic factors that compound this disparity [11–13]. Further, maternal characteristics such as mother’s age at childbirth, educational attainment, antenatal participation, place of delivery and maternal tetanus vaccination were selected for analysis. Children of adolescent mothers (aged 15 – 19 years) are known to be more likely to be partially vaccinated and unvaccinated in India and elsewhere [14,15]. Also, while the association between higher maternal education and complete vaccination has been extensively reported, it is important to examine the influence of lower educational attainment (primary or lesser schooling) on childhood vaccination status [12,16]. Traditionally, antenatal participation has represented mother’s access to and regular use of government health care services and an increasing number antenatal visits are known to be associated with a higher probability of complete childhood vaccination [17]. Place of delivery, specifically home deliveries are known to be associated with lower full immunization coverage in India, and a recent analysis of the DLHS-3 data found increased odds of non-vaccination among children born in private institutions, we therefore considered place of delivery as an important factor determining vaccination coverage. In addition, social group and religious preference were selected as they may represent potential disparities in access to health services and are also known to represent parental beliefs and attitudes toward healthcare and vaccination decisions [9,18]. To adjust for household wealth, we used the type of dwelling as a proxy measure, categorized as “cemented” construction, “thatched” construction or a “mix” of cement and thatch construction. Type of dwelling was used more as an “absolute” measure of household wealth to help quantify the level of poverty of survey households as opposed to “wealth indices”, which are relative measures of wealth generally created using Demographic and Health Survey data [19]. As regional variables, we adjusted for urban and rural location of residence and used a categorization like one previously used for India to account for wider geographic region of residence [20].

Statistical analyses

To account for the complex DLHS survey design, we set the pooled datasets using the “svyset” set of commands in STATA 12. For survey setting the data, we used the “psu” or primary sampling unit along with the supplied national-level weights provided as part of the DLHS datasets. The use of these weights enabled calculation of unbiased population-level estimates of vaccination coverage for children aged 12-23 months and for the regression estimates. Univariate regression modelling was performed for each of the socio-demographic variables to examine their association with children’s vaccination status. Since the outcome of children’s vaccination status had three levels, multinomial logistic regression was used to examine associations between the socio-demographic variables and the odds of partial-vaccination and non-vaccination versus full-vaccination among children aged 12-23 months. We used the Wald test p-values, which tests associations across all categories of the exposure and outcome variables as likelihood-ratio tests are not recommended for survey data where individual observations are no longer independent. All the socio-demographic variables were significantly associated with children’s vaccination status at $p \leq 0.05$ level and were included in the multivariate regression model. The multivariate model adjusted for age of the child in months, type of dwelling and geographical region. The importance of each socio-demographic variable in the multivariate model (or model fit) was assessed using the Wald test statistic p-values derived using the “mlogtest”, post-estimation command in STATA 12. All categories of the socio-demographic variables were significantly associated at the $p \leq 0.05$ level across the different levels of the outcome. For the secondary analyses, we categorized the partially vaccinated children to explore differences in the factors associated with vaccination status based on whether children received “very few” vaccines (1 – 2 doses), “some” vaccines (3 – 5 doses) or “almost all” vaccines (6 – 7 doses). We used multinomial logistic regression, to handle the three-level outcome, examining the factors associated with having “very few” or “some” of the recommended vaccines compared to having “almost all” vaccines by 12 months of age. We repeated the modeling strategy and adjustment for confounding used in the primary analysis and the results of the secondary analysis is presented in Supplementary Table 2.

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