

Timeliness of Childhood Vaccination in India: A Systematic Review and Meta-Analysis

Ramesh Dharma Nikam¹, Prashant Bhusari²

¹Assistant Professor, Department of Community Medicine, SMBT Institute of Medical Sciences & Research Centre, Nashik, Maharashtra, India

²Assistant Professor, Department of Community Medicine, SMBT Institute of Medical Sciences & Research Centre, Nashik, Maharashtra, India

Received: 22-06-2021 Revised: 11-07-2021 / Accepted: 15-08-2021

Corresponding author: Dr. Ramesh Dharma Nikam

Conflict of interest: Nil

Abstract

Background: Vaccination coverage does not show whether children receive vaccines at the recommended age, and delayed vaccination leaves children unprotected when risk is greatest. This systematic review and meta-analysis estimated the pooled proportion of children in India who receive childhood vaccines later than recommended under the Universal Immunization Programme.

Methods: PubMed was searched for studies published up to December 2020 that reported the timing of routine childhood vaccines in India, and reference lists and Google Scholar were checked for further PubMed-indexed articles. Quality was assessed with the Joanna Briggs Institute checklist for prevalence studies. Delay was defined as vaccination more than 4 weeks after the recommended age. Proportions were pooled with a random-effects model; heterogeneity was assessed with I^2 and publication bias with Egger's test.

Results: Three studies with 83 640 children with documented vaccination dates were included: two analyses of national surveys and one rural community cohort from Haryana. The pooled proportion of delayed vaccination was 42.5% (95% CI 8.8 to 80.9) for BCG, 38.8 (21.0 to 58.3) for the first dose of DPT or Pentavalent vaccine, 67.6 (42.6 to 88.2) for the third dose and 43.9 (32.5 to 55.6) for the first dose of measles-containing vaccine. No study reported the timing of the hepatitis B birth dose. Heterogeneity was very high (I^2 above 99%). Delay was more common in the rural cohort than in the national surveys for every vaccine. Low maternal education, low household wealth, home delivery, Muslim religion and birth weight below 2000 g were associated with delay.

Conclusion: A large proportion of Indian children receive their vaccines late, and delay increases with each successive dose of DPT. Coverage figures overestimate age-appropriate protection. Timeliness should be monitored as a routine indicator of the Universal Immunization Programme, and interventions should target the later doses and disadvantaged groups.

Keywords: Timeliness; Delayed vaccination; Age-appropriate vaccination; Universal Immunization Programme; India; Meta-analysis.

This is an Open Access article that uses a funding model which does not charge readers or their institutions for access and distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>) and the Budapest Open Access Initiative (<http://www.budapestopenaccessinitiative.org/read>), which permit unrestricted use, distribution, and reproduction in any medium, provided original work is properly credited.

Introduction

India's Universal Immunization Programme is one of the largest public health programmes in the world, targeting about 26 million newborns every year [1]. Its performance has traditionally been judged by coverage, that is, the proportion of children who have received a vaccine by a given age, usually 12 to 23 months. Coverage has improved, but large inequalities by wealth, gender, region and place of residence persist [2-4].

Coverage does not show whether a vaccine was given at the right time. Vaccination schedules are designed to protect children before the age at which they are most likely to be exposed to infection, and a child who receives a vaccine late remains susceptible during this period [5]. Delays also

reduce the fraction of the population that is protected at any given age, even when final coverage is high [6]. Studies from other countries have shown that coverage overestimates age-appropriate vaccination [7,8], and analysis of survey data from 45 low-income and middle-income countries showed that many children were vaccinated weeks or months late [9]. Methods such as survival analysis and the number of days undervaccinated have been developed to measure timeliness [10,11].

In India, analyses of national survey data have found considerable delay in routine vaccines and lower age-appropriate coverage than crude coverage, with differences by gender and region

[12,13]. Individual community-based studies have reported delay rates that vary widely between settings. Factors associated with incomplete or delayed vaccination across countries include low maternal education, low socioeconomic status, home delivery and large family size [14]. There has been no pooled estimate of vaccination delay in India. This systematic review and meta-analysis was conducted to estimate the pooled proportion of children in India who receive routine vaccines late and to summarise the factors associated with delay.

Materials and Methods

Protocol and Reporting: This review was conducted and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [15] and the guidelines for Meta-analysis Of Observational Studies in Epidemiology (MOOSE) [16].

Search Strategy: PubMed was searched for studies published up to 31 December 2020. The search combined terms for timeliness (timeliness, timely, delay, delayed, age-appropriate, on-time), vaccination (vaccination, immunization, immunisation, vaccine, BCG, DPT, Pentavalent, polio, measles, hepatitis B) and children (child, infant, newborn), together with India. The PubMed search string was: (timeliness OR timely OR delay* OR "age-appropriate" OR "on time") AND (vaccin* OR immuni*) AND (child* OR infant* OR newborn*) AND India. Reference lists of included studies and relevant reviews were searched by hand, and Google Scholar was used to trace further articles; only articles indexed in PubMed were retained.

Eligibility Criteria: Studies were included if they were observational studies (cross-sectional, cohort or analysis of survey data) conducted in India; included children aged up to 5 years; reported the number or proportion of children who received at least one routine vaccine of the Universal Immunization Programme later than the recommended age, based on dates recorded on vaccination cards or registers; and were published in English in a PubMed-indexed peer-reviewed journal.

Studies were excluded if they relied only on recall without dates, reported only coverage or a composite measure of schedule adherence without vaccine-specific timing, used a definition of timeliness that could not be matched to the 4-week threshold, estimated age-appropriate coverage among all children rather than delay among vaccinated children, were conducted in special or selected populations such as hospitalised infants or case-control samples, or were reviews, editorials or conference abstracts. When several publications

reported the same population, the most complete report was included.

Outcome and Definitions: The primary outcome was the proportion of children with delayed vaccination for BCG, the birth dose of hepatitis B vaccine, the first and third doses of DPT or Pentavalent vaccine, the third dose of oral polio vaccine, and the first dose of measles-containing vaccine. Delay was defined as vaccination more than 4 weeks (28 days) after the recommended age in the national schedule, or as defined by the study authors when a comparable definition was used. The denominator was the number of children who had received the vaccine with a documented date. When a study reported age at vaccination only in completed months, delay was taken as vaccination at 5 months of age or later for the third dose of DPT (recommended at 14 weeks) and at 10 months or later for measles-containing vaccine (recommended at 9 months). Secondary outcomes were the median delay in days and the factors associated with delay.

Study Selection and data Extraction: Titles and abstracts were screened first, and the full texts of potentially eligible studies were then assessed against the eligibility criteria. Data were extracted with a pre-designed form, recording the first author, year of publication, state, setting (urban, rural or urban slum), study design, sample size, age group, source of vaccination dates, definition of delay, number of children vaccinated late for each vaccine, and the factors associated with delay. When a study reported only the percentage delayed and the number vaccinated, the number delayed was calculated from these figures. All extracted values were checked a second time against the source articles.

Quality assessment: The methodological quality of each study was assessed with the Joanna Briggs Institute critical appraisal checklist for studies reporting prevalence data [17], which covers the sampling frame, sampling method, sample size, description of subjects and setting, coverage of the sample, validity and reliability of measurement, statistical analysis and response rate. The risk of bias tool of Hoy and colleagues was used as a supplementary guide [18]. Studies were classified as of low, moderate or high risk of bias.

Statistical Analysis: The proportion of delayed vaccination was calculated for each study and vaccine with its exact 95% confidence interval. Proportions were stabilised with the Freeman-Tukey double arcsine transformation and pooled with a random-effects model using the DerSimonian and Laird method [19,20]. Heterogeneity was assessed with Cochran's Q test and quantified with the I^2 statistic; I^2 values of

25%, 50% and 75% were taken to indicate low, moderate and high heterogeneity.

Subgroup analyses were planned by setting, region of India, data source (community study or national survey) and risk of bias. Sensitivity analysis was performed by excluding one study at a time.

Publication bias was assessed by Egger's regression test when at least three studies contributed to an estimate [21]. Analyses followed the metaprop approach [22] and were performed in Python 3 with the NumPy and SciPy libraries. A p-value below 0.05 was considered significant.

Results

Study Selection: The PubMed search identified 253 records, and 4 further PubMed-indexed records were found through reference lists and Google Scholar. There were no duplicates, so 257 records were screened. After screening of titles and abstracts, 19 full-text articles were assessed for eligibility, and 3 studies were included in the review and meta-analysis (Figure 1) [23-25].

The main reasons for exclusion were reporting of coverage or a composite measure of schedule adherence only ($n = 5$), a timeliness definition that could not be matched to the 4-week threshold ($n = 4$), estimation of age-appropriate coverage among all children rather than delay among vaccinated children ($n = 3$), case-control or selected samples ($n = 3$) and lack of vaccine-specific data ($n = 1$).

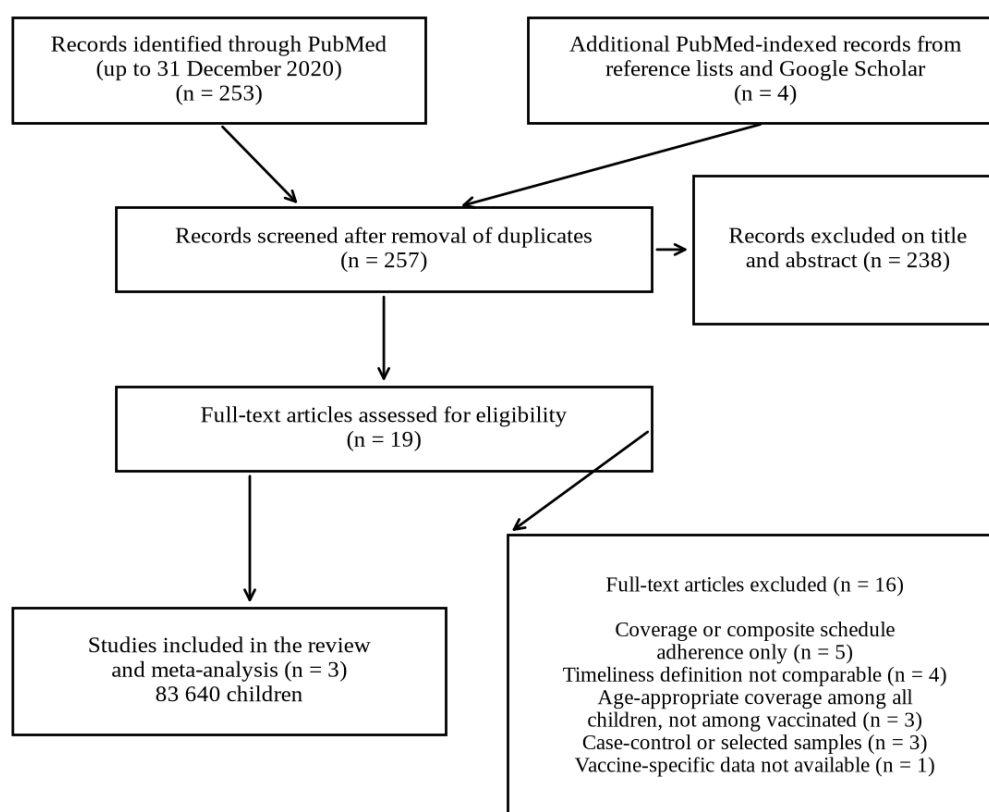


Figure 1: PRISMA flow diagram of study selection

Additional records were identified through reference lists and Google Scholar; only PubMed-indexed articles were retained.

Characteristics of Included Studies: The included studies were published between 2013 and 2019 and contributed 83 640 children with documented vaccination dates (largest vaccine-specific denominator in each study). None was a community-based cross-sectional survey; two were analyses of national survey data, the third round of the District Level Household and Facility Survey (DLHS-3) and the fourth National Family Health

Survey (NFHS-4) [23,24], and one was a community-based birth cohort from rural Haryana [25]. The national surveys covered all states; the cohort was from one state.

None of the studies was limited to urban areas or urban slums. One study was judged to be at low risk of bias and two at moderate risk (Table 1).

Table 1: Characteristics of included studies

First author, year	State	Setting	Design	Sample size	Vaccines assessed	Definition of delay	Risk of bias
Choudhary 2019	All states (NFHS-4)	National, urban and rural	Secondary analysis of national survey (NFHS-4, 2015-16)	Children 10-23 months with card dates (BCG 32 514; DPT1 32 635; MCV 27 017)	BCG, DPT1, MCV1	More than 28 days after recommended age	Low
Awofeso 2013	All states (DLHS-3)	National, rural	Secondary analysis of national survey (DLHS-3, 2007-08)	Children with card dates (DPT3 15 361; MCV 13 511)	DPT3, MCV1	Vaccinated at or after 5 months (DPT3) or 10 months (MCV1) of age	Moderate
Upadhyay 2017	Haryana	Rural	Community cohort (birth cohort of a trial population)	44 779 live births (BCG 35 644; DPT1 34 220; DPT3 21 916; OPV3 19 887; MCV 17 310)	BCG, DPT1, DPT3, OPV3, MCV1	More than 28 days after recommended age	Moderate

DLHS-3: District Level Household and Facility Survey, 2007-08; NFHS-4: National Family Health Survey, 2015-16; DPT1 and DPT3: first and third doses of DPT or Pentavalent vaccine; OPV3: third dose of oral polio vaccine; MCV1: first dose of measles-containing vaccine. Sample sizes are the numbers of children with documented dates for each vaccine. Awofeso and colleagues reported age at vaccination in completed months, so the threshold closest to 4 weeks after the recommended age was used.

Pooled Proportion of Delayed Vaccination: The pooled proportion of delayed vaccination was 42.5% (95% CI 8.8 to 80.9) for BCG, 38.8% for the first dose of DPT or Pentavalent vaccine, 67.6%

for the third dose and 43.9% for the first dose of measles-containing vaccine (Table 2, Figure 2).

No included study reported the timing of the birth dose of hepatitis B vaccine, so this outcome could not be estimated.

Only the Haryana cohort reported the third dose of oral polio vaccine, which was delayed in 78.2% of vaccinated children. Delay increased with each successive dose of DPT: in the Haryana cohort it rose from 48.7% for the first dose to 79.0% for the third, and in the pooled analysis from 38.8% to 67.6%. Only the Haryana cohort reported the median delay, which was 61 days (interquartile range 32 to 105) for the third dose of DPT [25]. Heterogeneity was very high for every vaccine.

Table 2: Pooled proportion of delayed vaccination by vaccine

Vaccine	Studies, n	Children, n	Pooled delay, % (95% CI)	I ² , %	Egger's test p
BCG	2	68 158	42.5 (8.8 to 80.9)	>99.9	NA
Hepatitis B birth dose	0	0	Not estimable	NA	NA
DPT / Pentavalent 1	2	66 855	38.8 (21.0 to 58.3)	>99.9	NA
DPT / Pentavalent 3	2	37 277	67.6 (42.6 to 88.2)	>99.9	NA
Oral polio vaccine 3	1	19 887	78.2 (77.6 to 78.8)	NA	NA
Measles-containing vaccine 1	3	57 838	43.9 (32.5 to 55.6)	99.9	0.19

Random-effects model with Freeman-Tukey double arcsine transformation. The estimate for oral polio vaccine 3 is from a single study, with its exact 95% CI. Egger's test was performed only when at least three studies contributed. CI: confidence interval; NA: not applicable.

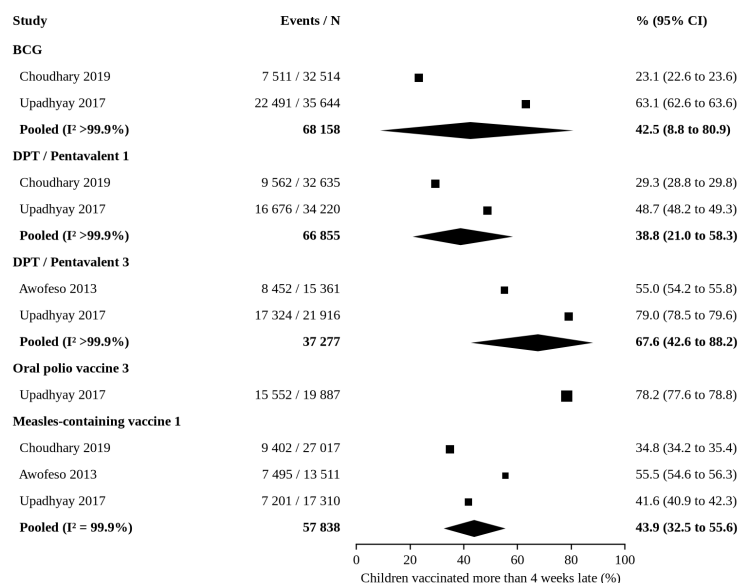


Figure 2: Forest plot of the proportion of delayed vaccination by vaccine

Squares show individual study estimates with exact 95% confidence intervals, sized by the number of vaccinated children; diamonds show pooled random-effects estimates. Delay was defined as vaccination more than 4 weeks after the recommended age.

Subgroup and Sensitivity Analyses: Subgroup analysis by setting and region was limited because the national surveys covered all of India and the only community study was a rural cohort from north India. Delay in the third dose of DPT or Pentavalent vaccine was 79.0% in the rural Haryana cohort and 55.0% in the national DLHS-3 survey (Table 3). For every vaccine, delay was higher in the rural cohort than in the national

surveys: 63.1% against 23.1% for BCG, 48.7% against 29.3% for the first dose of DPT, and 41.6% against 45.0% for measles-containing vaccine (p for difference = 0.81).

No study was at high risk of bias. The only study at low risk of bias, the NFHS-4 analysis, gave lower estimates than the pooled values [23].

With two studies for most vaccines, exclusion of either study changed the pooled estimate substantially; for measles-containing vaccine, exclusion of one study at a time gave estimates between 38.2% and 48.5%, a change of no more than 5.7 percentage points.

Table 3: Subgroup analysis of delayed vaccination by data source

Subgroup	Studies, n	Pooled delay, % (95% CI)	I^2 , %	p for difference
BCG: national survey	1	23.1 (22.6 to 23.6)	NA	Not estimable
BCG: rural community cohort	1	63.1 (62.6 to 63.6)	NA	
DPT / Pentavalent 1: national survey	1	29.3 (28.8 to 29.8)	NA	Not estimable
DPT / Pentavalent 1: rural community cohort	1	48.7 (48.2 to 49.3)	NA	
DPT / Pentavalent 3: national survey	1	55.0 (54.2 to 55.8)	NA	Not estimable
DPT / Pentavalent 3: rural community cohort	1	79.0 (78.5 to 79.6)	NA	
Measles-containing vaccine 1: national survey	2	45.0 (25.6 to 65.3)	>99.9	0.81
Measles-containing vaccine 1: rural community cohort	1	41.6 (40.9 to 42.3)	NA	

National surveys: NFHS-4 and DLHS-3 analyses, which also correspond to the low and moderate risk of bias groups for BCG and DPT 1. Rural community cohort: Haryana, north India. Single-study estimates are shown with exact 95% CIs, and a test for subgroup difference was not estimable when each subgroup had one study. Subgroups by urban or slum setting and by other regions could not be formed because no eligible study was available. NA: not applicable.

Factors Associated with Delay: Two studies examined the factors associated with delay in multivariable analysis [23,25]. The factors most

often associated with delayed vaccination were low maternal education (2 studies), low household wealth (2), home delivery (2), Muslim religion (2)

and birth weight below 2000 g (2). Maternal age below 20 years (1 study) and lack of tetanus toxoid vaccination in pregnancy, a marker of antenatal care (1), were also associated with delay.

The sex of the child, birth order and rural residence were not significantly associated with delay in the studies that examined them (Table 4).

Table 4: Factors associated with delayed vaccination in the included studies

Factor	Studies reporting a significant association, n	Direction of association
Low maternal education	2	Higher odds of delay; maternal schooling of 12 years or more was protective
Home delivery	2	Higher odds of delay than birth in a health facility
Higher birth order	0	Not significant in adjusted analysis (1 study examined)
Low socioeconomic status	2	Higher odds of delay in the poorest wealth quintiles
Female child	0	Not significant (1 study examined)
Rural residence	0	Not significant after adjustment (1 study examined)
Inadequate antenatal care	1	No tetanus toxoid in pregnancy associated with delay
Muslim religion	2	Higher odds of delay
Birth weight below 2000 g	2	Higher odds of delay
Maternal age below 20 years	1	Higher odds of delay

Based on multivariable analyses in the NFHS-4 analysis and the Haryana cohort; in the Haryana cohort, factors were analysed among low birth weight infants. The DLHS-3 analysis did not report factors associated with delay.

Publication Bias: Egger's test could be performed only for measles-containing vaccine, the one outcome with three studies, and was not significant ($p = 0.19$). With so few studies, funnel plots could not be interpreted and the test has little power.

Discussion

This systematic review and meta-analysis found that 67.6% of Indian children received the third dose of DPT or Pentavalent vaccine more than 4 weeks late, and that delay increased from the first to the third dose. About two in five children received BCG, the first dose of DPT and measles-containing vaccine late. To our knowledge, this is the first pooled estimate of vaccination timeliness in India. Our findings agree with other analyses of national survey data from India, which showed that age-appropriate coverage was considerably lower than crude coverage and that delay was common for all routine vaccines [12,13]. In DLHS-3, BCG, the third dose of DPT and measles-containing vaccine were given on time to only 31%, 19% and 34% of children, although coverage by 5 years was 87%, 63% and 76% [13]. In a community with very high coverage at Ballabgarh, Haryana, the proportion vaccinated late ranged from 15.9% for the oral polio booster to 83.5% for the third dose of oral polio vaccine [26]. These results are also consistent with the multi-country analysis of Clark

and Sanderson, in which delays were common in South Asia and increased with later doses [9]. Studies from Uganda found that coverage figures overestimated age-appropriate vaccination [7,8]. The accumulation of delay with each dose occurs because a late first dose pushes back every subsequent dose, and because the minimum interval between doses is often exceeded.

Delayed vaccination matters for disease control. Children who receive vaccines late remain susceptible during the first months of life, when pertussis, measles and other infections are most dangerous [5]. Delay reduces the fraction of children protected at each age even when final coverage is high [6], and it may allow outbreaks of measles and diphtheria in communities that appear well covered. Timeliness should therefore be monitored as an indicator of programme quality alongside coverage, using methods such as survival analysis or days undervaccinated [10,11].

The factors associated with delay in the included studies were similar to those associated with incomplete vaccination. Low maternal education and health literacy [27], low household wealth and home delivery [2-4,12] were the most consistent predictors, in line with an international review [14] and with predictors of vaccination identified in national Indian data [28,29]. Muslim religion and low birth weight were also associated with delay. Children living in urban poor settlements face additional barriers [30]. The rural cohort reported more delay than the national surveys, which may reflect its population of mostly low-income rural families and its prospective recording of dates. The

very high heterogeneity between studies reflects differences in setting, period, definition of delay and source of data, and the pooled estimates should be interpreted with this in mind.

These findings have implications for the Universal Immunization Programme. Due-list based tracking of each child, reminders through ASHA workers and mobile phones, and the inclusion of timeliness indicators in programme monitoring could reduce delay. Institutional delivery offers an opportunity to give the birth doses on time, and the antenatal period can be used to inform mothers about the schedule. Special attention is needed for the third doses, where delay is greatest, and for disadvantaged groups.

Strengths and Limitations: The strengths of this review are a predefined search, a standard definition of delay, formal quality assessment and the use of large national and community datasets with documented vaccination dates. It has limitations. Only three studies met the eligibility criteria, and most pooled estimates rest on two studies, so the confidence intervals are wide and subgroup analyses by setting and region were not possible. No eligible study reported the timing of the hepatitis B birth dose. Only PubMed-indexed studies published in English were included, and grey literature was not searched. Study selection and data extraction were done by a single reviewer, and some counts were calculated from reported percentages. For the DLHS-3 data, delay was approximated from age in completed months. Delay could be assessed only in children with documented vaccination dates, and children without cards may differ from those with cards. The factors associated with delay come from cross-sectional and observational analyses and cannot be interpreted as causal.

Conclusion

A large proportion of children in India receive routine vaccines late, and delay increases with each successive dose of DPT. Coverage alone overestimates the protection of Indian children. Timeliness should be monitored as a routine indicator of the Universal Immunization Programme, and interventions to promote on-time vaccination should focus on the later doses, on mothers with low education and on disadvantaged communities. Further community studies from different regions, reporting vaccine-specific timing with a standard definition, are needed.

Declarations

Acknowledgement: The author thanks the faculty and residents of the Department of Community Medicine, SMBT Institute of Medical Sciences & Research Centre, Nashik, for their support.

Funding: None.

Conflict of Interest: The author declares no conflict of interest.

Author Contribution: Dr. Ramesh Dharma Nikam conceived the review, performed the literature search, study selection, data extraction, quality assessment and analysis, wrote the manuscript and approved the final version.

Data Availability: All data analysed in this review are from published studies cited in the article.

References

1. Lahariya C. A brief history of vaccines & vaccination in India. *Indian J Med Res.* 2014;139(4):491-511. PMID: 24927336.
2. Pande RP, Yazbeck AS. What's in a country average? Wealth, gender, and regional inequalities in immunization in India. *Soc Sci Med.* 2003;57(11):2075-88. PMID: 14512239.
3. Prusty RK, Kumar A. Socioeconomic dynamics of gender disparity in childhood immunization in India, 1992-2006. *PLoS One.* 2014;9(8):e104598. PMID: 25127396.
4. Singh A. Gender based within-household inequality in childhood immunization in India: changes over time and across regions. *PLoS One.* 2012;7(4):e35045. PMID: 22509379.
5. Guerra FA. Delays in immunization have potentially serious health consequences. *Paediatr Drugs.* 2007;9(3):143-8. PMID: 17523694.
6. Akmatov MK, Kretzschmar M, Krämer A, Mikolajczyk RT. Timeliness of vaccination and its effects on fraction of vaccinated population. *Vaccine.* 2008;26(31):3805-11. PMID: 18565626.
7. Fadnes LT, Nankabirwa V, Sommerfelt H, Tylleskär T, Tumwine JK, Engebretsen IM. Is vaccination coverage a good indicator of age-appropriate vaccination? A prospective study from Uganda. *Vaccine.* 2011;29(19):3564-70. PMID: 21402043.
8. Babirye JN, Engebretsen IM, Makumbi F, Fadnes LT, Wamani H, Tylleskär T, et al. Timeliness of childhood vaccinations in Kampala Uganda: a community-based cross-sectional study. *PLoS One.* 2012;7(4):e35432. PMID: 22539972.
9. Clark A, Sanderson C. Timing of children's vaccinations in 45 low-income and middle-income countries: an analysis of survey data. *Lancet.* 2009;373(9674):1543-9. PMID: 19303633.
10. Dayan GH, Shaw KM, Baughman AL, Orellana LC, Forlenza R, Ellis A, et al. Assessment of delay in age-appropriate vaccination using survival analysis. *Am J*

- Epidemiol. 2006;163(6):561-70. PMID: 16421238.
11. Luman ET, Barker LE, Shaw KM, McCauley MM, Buehler JW, Pickering LK. Timeliness of childhood vaccinations in the United States: days undervaccinated and number of vaccines delayed. *JAMA*. 2005;293(10):1204-11. PMID: 15755943.
 12. Corsi DJ, Bassani DG, Kumar R, Awasthi S, Jotkar R, Kaur N, et al. Gender inequity and age-appropriate immunization coverage in India from 1992 to 2006. *BMC Int Health Hum Rights*. 2009;9 Suppl 1(Suppl 1):S3. PMID: 19828061.
 13. Shrivastwa N, Gillespie BW, Lepkowski JM, Boulton ML. Vaccination Timeliness in Children Under India's Universal Immunization Program. *Pediatr Infect Dis J*. 2016;35(9):955-60. PMID: 27195601.
 14. Tauil Mde C, Sato AP, Waldman EA. Factors associated with incomplete or delayed vaccination across countries: A systematic review. *Vaccine*. 2016;34(24):2635-43. PMID: 27109562.
 15. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6(7):e1000097. PMID: 19621072.
 16. Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, et al. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. *JAMA*. 2000;283(15):2008-12. PMID: 10789670.
 17. Munn Z, Moola S, Riitano D, Lisy K. The development of a critical appraisal tool for use in systematic reviews addressing questions of prevalence. *Int J Health Policy Manag*. 2014;3(3):123-8. PMID: 25197676.
 18. Hoy D, Brooks P, Woolf A, Blyth F, March L, Bain C, et al. Assessing risk of bias in prevalence studies: modification of an existing tool and evidence of interrater agreement. *J Clin Epidemiol*. 2012;65(9):934-9. PMID: 22742910.
 19. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials*. 1986;7(3):177-88. PMID: 3802833.
 20. Barendregt JJ, Doi SA, Lee YY, Norman RE, Vos T. Meta-analysis of prevalence. *J Epidemiol Community Health*. 2013;67(11):974-8. PMID: 23963506.
 21. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 1997;315(7109):629-34. PMID: 9310563.
 22. Nyaga VN, Arbyn M, Aerts M. Metaprop: a Stata command to perform meta-analysis of binomial data. *Arch Public Health*. 2014;72(1):39. PMID: 25810908.
 23. Choudhary TS, Reddy NS, Apte A, Sinha B, Roy S, Nair NP, et al. Delayed vaccination and its predictors among children under 2 years in India: Insights from the national family health survey-4. *Vaccine*. 2019;37(17):2331-2339. PMID: 30914221.
 24. Awofeso N, Rammohan A, Iqbal K. Age-appropriate vaccination against measles and DPT-3 in India - closing the gaps. *BMC Public Health*. 2013;13:358. PMID: 23594400.
 25. Upadhyay RP, Chowdhury R, Mazumder S, Taneja S, Sinha B, Martinez J, et al. Immunization practices in low-birth-weight infants from rural Haryana, India: Findings from secondary data analysis. *J Glob Health*. 2017;7(2):020415. PMID: 29423177.
 26. Yadav K, Srivastava R, Kumar R, Chinnakal P, Rai SK, Krishnan A. Significant vaccination delay can occur even in a community with very high vaccination coverage: evidence from Ballabgarh, India. *J Trop Pediatr*. 2012;58(2):133-8. PMID: 21742766.
 27. Johri M, Subramanian SV, Sylvestre MP, Dudeja S, Chandra D, Koné GK, et al. Association between maternal health literacy and child vaccination in India: a cross-sectional study. *J Epidemiol Community Health*. 2015;69(9):849-57. PMID: 25827469.
 28. Shrivastwa N, Gillespie BW, Kolenic GE, Lepkowski JM, Boulton ML. Predictors of Vaccination in India for Children Aged 12-36 Months. *Am J Prev Med*. 2015;49(6 Suppl 4):S435-44. PMID: 26297449.
 29. Francis MR, Nohynek H, Larson H, Balraj V, Mohan VR, Kang G, et al. Factors associated with routine childhood vaccine uptake and reasons for non-vaccination in India: 1998-2008. *Vaccine*. 2018;36(44):6559-6566. PMID: 28844636.
 30. Devasenapathy N, Ghosh Jerath S, Sharma S, Allen E, Shankar AH, Zodpey S. Determinants of childhood immunisation coverage in urban poor settlements of Delhi, India: a cross-sectional study. *BMJ Open*. 2016;6(8):e013015. PMID: 27566644.