Vaccination coverage and factors associated with routine childhood vaccination uptake in rural Vellore, southern India, 2017

Mark Rohit Francis [a], J. Pekka Nuorti [a,b], Rajeev Zachariah Kompithra [c], Heidi Larson [d], Vinohar Balraj [e], Gagandeep Kang [f], Venkata Raghava Mohan [g,*]

[a] Health Sciences Unit, Faculty of Social Sciences, Tampere University, Finland
[b] Infectious Diseases and Vaccines, Department of Health Protection, National Institute for Health and Welfare, Helsinki, Finland
[c] Well Baby Immunization Clinic, Department of Pediatrics Unit – I, Christian Medical College, Vellore, Tamil Nadu, India
[d] Department of Infectious Disease Epidemiology, London School of Hygiene and Tropical Medicine, London, United Kingdom
[e] Society for Applied Studies, Vellore, Tamil Nadu, India
[f] Division of Gastrointestinal Sciences, Christian Medical College, Vellore, Tamil Nadu, India
[g] Department of Community Health, Christian Medical College, Vellore, Tamil Nadu, India

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ABSTRACT

Background: Vellore district in southern India was selected for intensified immunization efforts through India's Mission Indradhanush campaign based on 74% coverage in the National Family Health Survey in 2015. As rural households rely almost entirely on the Universal Immunization Program (UIP), we assessed routine immunization coverage and factors associated with vaccination status of children in rural Vellore.
Methods: We conducted a cross-sectional household survey among parents or primary caretakers of children aged 12–23 months during August–September 2017 using two-stage, EPI cluster sampling. We verified vaccination histories from vaccination cards and collected data on sociodemographic and non-socio-demographic characteristics by using mobile data capture. Associations with vaccination status were examined with univariate and multivariate logistic regression models.
Results: A total of 643 children were included. Coverage of BCG, third dose pentavalent/DPT, measles/MR vaccines and full vaccination (BCG, three doses of polio and pentavalent/DPT and measles/MR vaccines) among children with vaccination cards (n = 606) was 94%, 96%, 93% and 84%, respectively. Of children with vaccination cards, 70.8% had received all recommended doses according to the UIP schedule. No socio-demographic differences were identified, but parents' familiarity with the schedule (Adjusted Prevalence Odds Ratio (aPOR): 2.06, 95%CI = 1.26–3.38) and receiving information on recommended vaccinations during antenatal visits (aPOR: 2.16, 95% CI = 1.13–4.12) were significantly associated with full vaccination status of the children.
Conclusions: We found higher UIP antigen coverage and proportion of fully vaccinated children than previously reported from rural Vellore. However, adherence to the recommended schedule was still not optimal. Our study highlights the potential of improving parental awareness of vaccination schedule and targeting health education interventions at pregnant women during antenatal visits to sustain and improve routine immunization coverage.

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1. Introduction

India's Universal Immunization Program (UIP) is one of the largest public health initiatives in the world in terms of the quantity of vaccines delivered, number of beneficiaries reached and the geographic diversity of regions covered [1]. The UIP provides free vaccines against tuberculosis (BCG), poliomyelitis (OPV and IPV), diphtheria, pertussis, tetanus, *H. influenzae* type b, hepatitis B (pentavalent), measles, Japanese Encephalitis (in endemic districts)

and recently Rubella (MR), rotavirus diarrhea and pneumococcal diseases (PCV) in some Indian states [2,3]. Perhaps the greatest achievement of the Indian UIP is the eradication of polio, with India certified "polio-free" in 2014 [4]. Despite nearly three decades of the UIP, an estimated 500,000 children still die annually of vaccine preventable diseases and only 62% of children receive the full schedule of UIP vaccines during their first year of life according to a report by the National Family and Health Survey (NFHS-4) conducted during 2015–16 [5,6]. The suboptimal coverage of UIP vaccines suggests that nearly 10 million of the 26 million children born every year in India might be partially-vaccinated or completely unvaccinated [7,8].

The Indian government launched the Mission Indradhanush (MI) campaign in 2015 aiming to increase the coverage of recommended UIP vaccines during the first year of life to 90% by 2020 [1,9].The campaign is conducted in four phases and targets districts with the lowest immunization coverage across the country [1,9]. Strategies to improve routine immunization coverage include special immunization sessions, enhanced community engagement and mobilization, intensive training of health workers and increased accountability at all levels of program implementation [9]. Recent administrative reports suggest that full immunization coverage among children aged 12–23 months has increased by 5–7% after the first two phases of Mission Indradhanush [10]. However, aggregated coverage estimates often conceal important regional disparities [11]. For example, NFHS-4 reports full immunization coverage above 80% for states such as Kerala, Punjab, Goa and Sikkim, whereas states like Arunachal Pradesh and Assam have a coverage of 38% and 47% respectively [6]. Even Tamil Nadu, the only Indian state with conditional cash transfer to economically-disadvantaged mothers whose children have completed the primary vaccination series (until the third dose of pentavalent vaccine) has significant district-level differences in immunization coverage [6,12,13].

The district of Vellore in Tamil Nadu was selected as one of 201 "high-focus" districts for intensified routine immunization as part of the MI campaign in 2015 [14]. The NFHS-4, however, reported full immunization coverage of 74% for Vellore, with important urban-rural difference (78% vs. 69% respectively) [6]. Since rural households are almost entirely dependent on immunization services provided by the UIP, it is important to investigate the reasons for the suboptimal coverage and identify potential disparities in the uptake of routine childhood vaccination that may be addressed by targeted interventions [15]. The objective of our study was to assess routine immunization coverage and the factors associated with the vaccination status of children aged 12–23 months in rural Vellore. As a secondary objective, we also describe and evaluate the factors associated with adherence to the UIP schedule, which are generally not reported by administrative and national health surveys in India.

2. Methods

2.1. Study setting

The study was conducted in Thimiri, a rural administrative block comprising 67 villages in Vellore district in Tamil Nadu, India. Thimiri is one of the larger blocks of the Vellore district with a population of 105,691, with 11,242 children aged six years or younger and literacy of approximately 65% (2011 census). Thimiri was selected as it is easily accessible by road and expected to be representative of the routine immunization services available to the other blocks of the district. Routine immunization is provided in primary health centers, childcare centers (Anganwadis) or the government district hospital at no cost to parents. A Measles-

Rubella (MR) vaccination campaign was held during February-March 2017 to provide a single dose of the vaccine to all children aged 9 months to 15 years before formal introduction into the UIP schedule, replacing the monovalent measles vaccine. Numerous private clinics and hospitals around Thimiri and other parts of Vellore also provide UIP and non-UIP vaccinations for a fee, and generally use the Indian Academy of Pediatrician (IAP) immunization schedule [16].

2.2. Survey procedure and sample size

A household survey of children aged 12–23 months (henceforth called "eligible children") was conducted during August and September 2017, using two-stage cluster sampling based on the Expanded Program on Immunization (EPI) coverage survey methodology [17]. First, 30 clusters were selected with probability proportional to size (PPS), with a cluster defined as a village or a group of congruent villages with a population of ≥2000 individuals (or 400–500 households). At the second stage, from the geographic center of each cluster, a direction for survey and the starting household were selected randomly using EPI guidelines [18]. The next nearest households were based on proximity to the prior household; sampling continued until the required number of children were surveyed in each cluster or until the last household with an eligible child in a given cluster was reached. If multiple children in the eligible age group were present in a household, only the youngest child was included.

The proportion of fully vaccinated children (children who received one dose of BCG and measles and three doses each of DPT & OPV vaccines) according to the NFHS-4 for rural Vellore was 70% [19]. Using this estimate with an absolute precision of ±5%, anticipated design effect (deff) of 2 and inflating the effective sample size by 15% for potential non-response during the surveys, a total sample of 750 children aged 12–23 months or 30 clusters of 25 children each was planned.

2.3. Data collection & management

We used a structured, interviewer-administered questionnaire to collect information from parents or primary caretakers of eligible children from whom written informed consent was obtained. A primary caretaker had to be a relative involved in caring for the child and knowledgeable of their immunization history. The questionnaire was translated to Tamil and programmed using the "KoBo Toolbox", an open-source application for mobile data collection [20]. Both the translated paper and electronic versions of the questionnaire were pre-tested among parents of children aged 12–23 months in a non-study village. Range checks, skip patterns and pictures of children's vaccination cards were programmed into the interface to minimize data-entry errors. All the field staff had a three-day training session prior to survey commencement. 10% validation was independently done for randomly selected children. The study protocol received ethical clearance from the Institutional Review Board (IRB) of the Christian Medical College, Vellore (*IRB no. 10691, dated 21.06.2017*).

2.4. Study variables

The independent variables included socio-demographic characteristics such as parent age, education and occupation and household type, number of members, caste and religion and child characteristics like age at survey, birth order and places of birth and vaccination. Non-socio-demographic characteristics of the parents were outlined using the "5A's taxonomy for determinants of vaccine uptake" [21]. Information on issues of Access – mode of

Table 1
Definitions of vaccination status and schedule-appropriate vaccination status of children aged 12–23 months in rural Vellore, southern India.

Outcome	Definition
Primary: Vaccination status [49]	**Fully vaccinated:** Children who received one dose of BCG, three doses of pentavalent (containing antigens against diphtheria, pertussis, tetanus, hepatitis B and *Haemophilus influenzae* B) or DPT, three doses of OPV (excluding the zero dose) and one dose of measles containing vaccine (monovalent measles or Measles-Rubella), irrespective of age at receipt of individual doses; **Undervaccinated:** Children who missed one or more recommended doses or those who received none of the recommended doses
Secondary: Schedule-appropriate vaccination status [31]	**Schedule-appropriate**: Children who were vaccinated at the right age and interval as per the UIP schedule, i.e. those who received (1) BCG at birth or as early as possible until one year of age, (2) pentavalent/DPT & OPV vaccines - first dose 6 weeks after birth and subsequent doses with at least four week (28 day) intervals and receipt of all three doses before the first birthday (3) Measles containing vaccine (monovalent measles or Measles-Rubella) administered after completion of 9 months of age, but before their first birthday; **Not schedule-appropriate:** Children who either missed one or more recommended doses or did not receive one or more doses at the recommended age and interval as per the UIP schedule during the first year of life (according to the definition above)

Table 2
Socio-demographic characteristics of children aged 12–23 months and their parents in rural Vellore, southern India (N = 643).

Characteristic	Category	Frequency	Percentage (%)
Child characteristics			
Child's age (months)	12–17	308	47.9
	18–23	335	52.1
Child's gender	Female	305	47.4
	Male	338	52.6
Child's birth order	1	275	42.8
	2	279	43.4
	≥3	89	13.8
Place of birth	Public facility	518	80.6
	Private facility	119	18.5
	Home/Others	6	0.9
Place of vaccination	Public facility	605	94.2
	Private facility	38	5.8
Parental characteristics			
Respondent	Mother	611	95.0
	Father	17	2.6
	Others	15	2.4
Age of mother at birth of child (years)	<20	74	11.5
	20–30	526	81.8
	>30	43	6.7
Marital status of respondent	Single	3	0.5
	Married	627	97.5
	Divorced/Widowed	13	2.0
Mother's education	Illiterate	17	2.6
	Up to 12th standard	527	82.0
	Diploma/Degree	99	15.4
Father's education	Illiterate	31	4.8
	Up to 12th standard	522	81.2
	Diploma/Degree	90	14.0
Mothers occupation	Homemaker	561	87.2
	Wage earner	68	10.5
	Salary earner/business	14	2.2
Fathers occupation (n = 638)	Unemployed	16	2.5
	Wage earner	457	71.6
	Salary earner/business	165	25.9
Household characteristics			
Religion	Hindu	623	96.9
	Others	20	3.1
Household size	< 5	217	33.7
	5–10	418	65.0
	> 10	8	1.3
Type of dwelling	Mud	19	2.9
	Semi-cemented	32	5.0
	Cemented	592	92.1
Social group	SC*	164	25.5
	ST	68	10.6
	OBC/general	411	63.9
Ration card ownership	Yes	595	92.5
	No	48	7.5

*SC: Scheduled castes, ST: Scheduled tribes, OBC: Other Backward classes (for more detail see supplemental material).

travel to the most frequented vaccination center, <u>Affordability</u> – timing of immunization services (a proxy for opportunity costs such as lost earnings or time), <u>Awareness</u> – familiarity with UIP schedule for children and the recently introduced MR vaccine, <u>Acceptance</u> – trust in information provided by health care providers, reported hesitancy about childhood vaccines and <u>Activation</u>

Table 3
Non-socio-demographic characteristics of survey participants in rural Vellore, southern India (N = 643).

Characteristic	Categories	Frequency	Percentage (%)
Access			
Travel to immunization facility (proxy for distance to facility)	Walking	420	65.3
	Private/Public transport	223	34.7
Awareness			
Heard about recently introduced Measles-Rubella vaccine	No	523	81.3
	Yes	120	18.7
I think immunization is important to keep my child healthy	Don't agree (N*)	4	0.7
	Agree (SA,A)	639	99.3
I am familiar with the immunization schedule (individual vaccines & timing of doses)	Don't agree (N,DA, SDA)	180	28.0
	Agree (SA,A)	463	72.0
Affordability			
The timing of immunization sessions was convenient for me	Don't agree (N, DA)	45	7.0
	Agree (SA, A)	598	93.0
Acceptance			
Self-reported hesitancy with one or more childhood vaccines	Hesitant (N,SH,VH**)	365	56.8
	Not hesitant (NH,NTH)	278	43.2
I trust the information provided by the health workers on immunizations	Don't agree (N)	12	1.9
	Agree (SA,A)	631	98.1
Activation			
Health worker home visits	No/Not sure	139	21.6
	Yes	504	78.4
Information about recommended vaccines provided during antenatal visits	No/Not sure	65	10.1
	Yes	578	89.9
Received incentive for completing pentavalent/DPT series (n = 641)	No	208	32.4
	Yes	433	67.6

*SA: Strongly agree, A: Agree, N: Neutral, DA: Disagree, SDA: Strongly disagree.
** SH: Strongly hesitant, VH: Very hesitant, N: Neutral, NH: Not hesitant, NTH: Not too hesitant.

– receipt of monetary incentive for completion of the pentavalent/DPT series, health-worker home visits and provision of information on the UIP schedule during antenatal visits was collected.

Data on routine childhood vaccinations administered during the first year of life were collected from the vaccination cards of eligible children (including doses and dates of vaccination) as well as parental report. If a vaccination card was not available, data were based on parental recall. Children without recorded dates for vaccination were assumed to have missed those doses and were asked for reasons for the missed doses [22,23]. The categorization of the primary and secondary outcomes are found in Table 1.

2.5. Statistical analysis

Data were entered real-time on the KoBo Toolbox interface using Android™ devices. Data were uploaded to the KoBo server and downloaded for cleaning. Data cleaning included reviewing the completeness and validity of the variables collected and verification of the dates of birth and vaccination using the pictures of children's vaccination cards. Data were managed and analyzed using STATA (version 14, StataCorp LP, College Station, TX, USA).

The analyses accounted for the cluster sampling design using a cluster identifier as the primary sampling unit for survey specification in the "svy" package of STATA. Proportions of children aged 12–23 months receiving each of the recommended UIP doses and 95% confidence intervals (CIs) were calculated using information based on (1) vaccination cards or parental recall and (2) vaccination cards alone. We also calculated the sensitivity and specificity of parental recall and vaccination card information to categorize children's vaccination status using the "diagt" package for STATA. The age of children at receipt of individual UIP doses was calculated by subtracting their birthdate from the dates of vaccination. All independent variables were analyzed categorically (see supplemental material). Univariate analysis to examine associations between the socio-demographic and non-socio-demographic variables with vaccination status used logistic regression. All independent variables with a significant univariate association at the $p \leq 0.20$ level were included in the multivariate regression models. The univariate and multivariate analyses were restricted to children with vaccination cards, however supplementary analyses were performed for all the surveyed children, *i.e.* irrespective of the source of vaccination history. Associations between the independent variables and full and schedule-appropriate vaccination status of children are presented as crude and adjusted Prevalence Odds Ratios (aPORs) with 95% CIs derived from design-adjusted standard errors. As sensitivity analysis, we examined the factors associated with full and schedule-appropriate vaccination status after restriction to children exclusively vaccinated at public health facilities.

3. Results

3.1. Participant characteristics

A total of 643 children aged 12–23 months were included (one family declined to participate; survey response proportion = 99.8%) in the survey. Mean (SD) age of children was 18.2 (3.6) months, 52.6% were boys and 42.8% were firstborn. Of the children, 92.1% lived in cemented houses and 623 (96.9%) belonged to Hindu families. Most children (94.2%) received vaccination at public facilities. The characteristics of children and parents are presented in Tables 2 and 3, respectively.

4. Vaccination coverage and adherence to the UIP schedule

The coverage of important UIP doses and children's vaccination status are presented in Table 4. Of the children included, 606 (94.3%) had a vaccination card and the rest reportedly had a vaccination card that could not be produced at the time of survey. There were no significant differences in the socio-demographic characteristics of children with and without vaccination cards (Supplemental Table 1). Vaccination coverage using information from

Table 4
Coverage and vaccination status of children aged 12–23 months in rural Vellore, southern India.

Vaccine antigen	Recommended age	Vaccination status, Card or parental recall (N = 643)		Vaccination status, Card only (N = 606)		Schedule-appropriate vaccination status[*] (N = 606)	
		Number vaccinated	Coverage, % (95% CI)	Number vaccinated	Coverage, % (95% CI)	Number vaccinated	Coverage, % 95% CI
BCG	Birth	642	100.0 (–)	572	94.4 (91.8–96.2)	567	93.5 (91.2–95.9)
Pentavalent/DPT-1	6 weeks	640	99.8 (98.8–99.9)	590	97.4 (95.1–98.6)	572	94.4 (92.2–96.5)
Pentavalent/DPT-2	10 weeks	636	99.5 (97.9–99.8)	590	97.4 (95.3–98.5)	571	94.2 (92.0–95.8)
Pentavalent/DPT-3	14 weeks	632	99.2 (97.1–99.7)	580	95.7 (93.2–97.2)	567	93.6 (91.3–95.3)
OPV-1	6 weeks	641	99.8 (98.8–99.9)	593	97.9 (96.6–98.7)	575	94.9 (93.0–96.7)
OPV-2	10 weeks	636	99.3 (97.9–99.8)	589	97.2 (94.7–98.5)	570	94.0 (91.9–95.7)
OPV-3	14 weeks	635	99.2 (97.1–99.7)	579	95.5 (92.8–97.3)	565	93.2 (90.9–95.0)
Measles or MR	9–12 months	630	98.1 (95.3–99.3)	563	92.9 (89.7–95.2)	517	85.3 (81.7–88.3)
Fully vaccinated children	12–23 months	619	96.4 (93.4–98.1)	509	84.0 (79.0–87.9)	–	–
Schedule-appropriately vaccinated children[**]	By 12 months of age	–	–	–	–	429	70.8 (65.6–75.5)

[*] Children with a vaccination card who received individual doses according to the UIP prescribed ages and before 1 year of age (BCG: Birth to 1 year; Pentavalent/DPT1 & OPV1: After 6 weeks of age, Pentavalent/DPT2 & OPV2: ≥ 28 days after first dose, Pentavalent/DPT3 & OPV3: ≥ 28 days after second dose; Measles: 9–12 months).
[**] Children who received (1) BCG before one year of age (2) Pentavalent/DPT & OPV vaccines - first dose after 6 weeks of birth and two subsequent doses at 28-day intervals, all before the first birthday and (3) Measles after 9 months and before the first birthday

vaccination cards or parental recall (n = 643) was 100% for BCG, and 99.2% and 98.1% for the third dose of pentavalent/DPT and measles/MR vaccination. The coverage of BCG, third dose of pentavalent/DPT and measles/MR vaccine among children with a vaccination card (n = 606) was 94.4%, 95.7%, 92.9% respectively. Coverage of the pentavalent/DPT and OPV doses was similar as these doses were mainly (>98%) co-administered.

The proportion of fully vaccinated children was 96.4% and 84% for information based on parental recall or vaccination cards and vaccination cards alone, respectively. The sensitivity and specificity of parental recall to classify children's vaccination status using vaccination card information as the gold standard for children with a card (n = 606) was 95% and 21% respectively (Supplemental Table 2). Among the children with a vaccination card, 97 (16%) were undervaccinated and only one of these children was completely unvaccinated. A majority (72.2%, n = 70) of the undervaccinated children missed 1–2 recommended UIP doses (Supplemental Table 3). The most frequently missed doses were measles/MR (22.4% of all missed doses), BCG (17.7%) and third dose of OPV or pentavalent/DPT vaccination (14.1% & 13.6% respectively).

Of the 606 children with a vaccination card, 429 (70.8%) had received all the recommended doses at the prescribed age and interval according to the UIP schedule, 80 (13.2%) received all the recommended doses but at least one dose was not given according to schedule and 97 (16%) missed one or more recommended doses. Failure to adhere to the UIP schedule among the 80 children who had received all the recommended doses by their first birthday was mainly due to the first dose of pentavalent/DPT given before 42 days (n = 18 (17.8% of missed doses), mean (SD) age at vaccination = 37.9 (6.1) days) (Supplemental Table 4) or the interval between pentavalent/DPT doses being less than 28 days (n = 32 (31.7%), mean (SD) interval between doses = 24.2 (5.2) days) or measles/MR vaccine given before 9 months of age (n = 32 (31.7%), mean (SD) age at vaccination = 262.5 (6.7) days).

5. Reasons for missed vaccination doses

The most frequent reason for missed UIP doses reported by parents was a failure of health workers to record dates despite the child being vaccinated (n = 137/192 reasons for missed doses, 71%). Other important reasons included travel out of the village on the due date of vaccination (n = 24, 12.4%), misplaced vaccination cards (n = 20, 10.4%) and a lack of awareness of the recommended schedule (n = 5, 2.6%) (Supplemental Table 5).

5.1. Factors associated with vaccination status and adherence to the UIP schedule

Results of the univariate and multivariate analyses of factors associated with the vaccination status of children aged 12–23 months with a vaccination card at the time of survey are presented in Table 5. In the univariate analysis, children vaccinated in private facilities had a lower odds of full vaccination compared with those receiving vaccination in public facilities (POR: 0.40, 95% CI = 0.17–0.97). Children whose parents agreed (strongly agreed or agreed) that they were familiar with the recommended UIP schedule were more likely to be fully vaccinated compared with those who did not agree (neutral, disagreed or strongly disagreed) to being familiar with the schedule (POR: 2.02, 95% CI = 1.23–3.33). In addition, children whose parents had reported receiving information about the recommended UIP schedule during antenatal visits were more likely to be fully vaccinated than those who reportedly did not receive this information during the visits (POR: 2.53, 95%CI = 1.25–5.11).

In the multivariate analysis, self-reported familiarity with the UIP schedule (aPOR: 2.06, 95%CI = 1.26–3.38), and receipt of information on recommended vaccinations during antenatal visits (aPOR: 2.16, 95%CI = 1.13–4.12) were significantly associated with full vaccination status of children. Familiarity with the UIP schedule and receipt of information on recommended vaccinations during antenatal visits remained associated with full vaccination status in the supplementary analyses including all children regardless of source of vaccination history (n = 643) (Supplemental Table 6). However, children belonging to the other backward classes or the general category were more likely to be fully vaccinated compared with children from the scheduled castes in this analysis (aPOR: 6.02, 95% CI = 1.82–19.90). As sensitivity analysis, we also examined the factors associated with children's vaccination status after recategorizing the doses for which there were missing dates on vaccination cards and for which parents reported a failure in primary recording of the dates as "vaccinated". Familiarity with the UIP schedule and belonging to other backward classes or the general category (vs. scheduled castes) were associated with increased odds of full vaccination (Supplemental Table 7). The positive association between receiving information on the schedule during antenatal visits and full vaccination status remained, but was not statistically significant (aPOR: 2.05, 95% CI = 0.78–5.43). The results of the multivariate analysis restricting the sample to children who were exclusively vaccinated at public

Table 5
Participant characteristics and their association with vaccination status of children aged 12–23 months in rural Vellore, southern India (N = 606).

Characteristic	Categories	Proportions, n (%)		Prevalence Odds Ratio (95% CI)	
		Fully vaccinated	Undervaccinated	Unadjusted	Adjusted
Socio-demographic					
Child's age (months)	12–17	236 (46.4)	56 (57.7)	Ref	Ref
	18–23	273 (53.6)	41 (42.3)	1.58 (0.94–2.65)*	1.64 (0.99–2.70)*
Child's gender	Male	257 (50.5)	62 (63.9)	Ref	Ref
	Female	252 (49.5)	35 (36.1)	1.74 (0.97–3.01)*	1.70 (0.92–3.11)*
Child's birth order	1	210 (41.2)	49 (50.5)	Ref	Ref
	2	230 (45.2)	37 (38.2)	1.45 (1.01–1.95)**	1.24 (0.86–1.79)
	≥3	69 (13.6)	11 (11.3)	1.46 (0.70–3.09)	1.77 (0.77–4.10)
Place of vaccination	Public facility	484 (95.1)	86 (88.7)	Ref	Ref
	Private facility	25 (4.9)	11 (11.3)	0.40 (0.17–0.97)**	0.62 (0.20–1.92)
Mother's age at birth of child (years)	< 20	60 (11.8)	9 (9.3)	Ref	–
	20–30	417 (81.9)	81 (83.5)	0.77 (0.34–1.73)	–
	> 30	32 (6.3)	7 (7.2)	0.69 (0.20–2.39)	–
Mother's education	Illiterate	11 (2.2)	5 (5.2)	Ref	–
	Upto 12th standard	424 (83.3)	73 (75.3)	2.64 (0.54–13.02)	–
	Diploma/Degree	74 (14.5)	19 (19.5)	1.77 (0.34–9.09)	–
Father's education	Illiterate	23 (4.5)	4 (4.1)	Ref	–
	Upto 12th standard	417 (81.9)	76 (78.4)	0.95 (0.16–5.52)	–
	Diploma/Degree	69 (13.6)	17 (17.5)	0.71 (0.11–4.56)	–
Mother's occupation	Homemaker	448 (88.0)	80 (82.5)	Ref	–
	Wage earner	51 (10.0)	14 (14.4)	0.65 (0.32–1.31)	–
	Salary earner/business	10 (2.0)	3 (3.1)	0.60 (0.17–2.06)	–
Father's occupation***	Unemployed	12 (2.4)	4 (4.1)	Ref	Ref
	Wage earner	365 (72.4)	63 (65.0)	1.93 (0.73–5.13)*	1.51 (0.61–3.79)
	Salary earner/business	127 (25.2)	30 (30.9)	1.41 (0.43–4.64)	1.22 (0.42–3.60)
Religion	Hindu	495 (97.3)	94 (96.9)	Ref	–
	Others	14 (2.7)	3 (3.1)	0.89 (0.16–4.81)	–
Household size	< 5	171 (33.6)	34 (35.1)	Ref	–
	5–10	331 (65.0)	62 (63.9)	1.06 (0.71–1.58)	–
	> 10	7 (1.4)	1 (1.0)	1.39 (0.14–13.84)	–
Social group	Scheduled caste	127 (24.9)	23 (23.7)	Ref	Ref
	Scheduled tribe	47 (9.2)	18 (18.6)	0.47 (0.17–1.29)*	0.50 (0.18–1.35)
	Other backward classes/General	335 (65.9)	56 (57.7)	1.08 (0.57–2.04)	1.50 (0.80–2.84)
Type of dwelling	Mud/Semi-cemented	44 (8.6)	3 (3.1)	Ref	–
	Cemented	465 (91.4)	94 (96.9)	0.33 (0.05–2.44)	–
Non-socio-demographic					
Travel to immunization facility	Walking	337 (66.2)	61 (62.9)	Ref	–
	Private/Public transport	172 (33.8)	36 (37.1)	0.86 (0.49–1.53)	–
I think immunization is important to keep my child healthy	Don't agree (N)	2 (0.4)	1 (1.0)	Ref	–
	Agree (SA,A)	507 (99.6)	96 (99.0)	2.64 (0.21–32.81)	–
I am familiar with the immunization schedule (individual vaccines & timing of doses)	Don't agree (N,DA, SDA)****	127 (25.0)	39 (40.2)	Ref	Ref
	Agree (SA,A)	382 (75.0)	58 (59.8)	2.02 (1.23–3.33)**	2.06 (1.26–3.38)**
The timing of immunization sessions was convenient for me	Don't agree (N, DA)	262 (51.5)	58 (59.8)	Ref	–
	Agree (SA,A)	247 (48.5)	39 (40.2)	1.40 (0.80–2.45)	–
Self-reported hesitancy with one or more childhood vaccines	Hesitant (SH, VH, N)*****	302 (59.3)	52 (53.6)	Ref	–
	Not hesitant (NTH, NH)	207 (40.7)	45 (46.4)	0.79 (0.49–1.28)	–
Health-worker home visits	No/Not sure	107 (21.0)	22 (22.7)	Ref	–
	Yes	402 (79.0)	75 (77.3)	1.12 (0.57–2.12)	–
Information about recommended vaccines provided during ANC visits	No/Not sure	42 (8.2)	18 (18.6)	Ref	Ref
	Yes	467 (91.8)	79 (81.4)	2.53 (1.25–5.11)**	2.16 (1.13–4.12)**
Received incentive for completing pentavalent/DPT series	No	157 (30.9)	38 (39.2)	Ref	Ref
	Yes	351 (69.1)	59 (60.8)	1.44 (0.91–2.29)	1.48 (0.83–2.58)

* p < 0.10; ** p < 0.05, *** n = 5 missing observations for father's occupation, N = 601 for multivariate model, **** SA: Strongly agree, A: Agree, N: Neutral, DA: Disagree, SDA: Strongly disagree, ***** SH: Strongly Hesitant, VH: Very hesitant, N: Neutral, NTH: Not too hesitant, NH: Not hesitant

health facilities (n = 570) were similar to the unrestricted sample (Supplemental Table 8). Birth order, social group, self-reported familiarity with and receipt of information on the UIP schedule during antenatal visits and receiving an incentive for completing the pentavalent/DPT series had a univariate association with the schedule-appropriate vaccination status of children at the p ≤ 0.20 level (Table 6). In the multivariate analysis, children belonging to families of the other backward classes or the general category were more likely to be vaccinated according to schedule compared to those belonging to the scheduled castes (aPOR: 1.69, 95% CI = 1.04–2.73). The findings of the multivariate analysis restricted to children receiving only public facility vaccination were similar to the model with all children included (Supplemental Table 9).

6. Discussion

The proportion of children aged 12–23 months who were fully vaccinated in rural Vellore was 96.4% and 84% using information from vaccination cards or parental recall and vaccination cards alone, respectively. The coverage estimate based on vaccination card information may be more reliable since the specificity of parental recall (to classify children's vaccination status) in our survey was low (21%). The low specificity indicates that the use of parental recall possibly overestimates vaccination coverage, concurring with previous reports from India and elsewhere [24,25]. Full vaccination coverage in our survey however, differs considerably from the NFHS-4 estimates of 69.7% for children aged 12–23 months in rural Vellore and 74% for the Vellore district overall, which are

Table 6
Participant characteristics and their association with schedule-appropriate vaccination status of children aged 12–23 months in rural Vellore, southern India (N = 606).

Characteristic	Categories	Proportions, n (%)		Prevalence odds ratio (95% CI)	
		Schedule-appropriate	Not schedule-appropriate	Unadjusted	Adjusted
Socio-demographic					
Child's age (months)	12–17	206 (48.0)	86 (48.6)	**Ref**	**–**
	18–23	223 (52.0)	91 (51.4)	1.02 (0.74–1.43)	–
Child's gender	Male	217 (50.6)	102 (57.6)	**Ref**	**–**
	Female	212 (49.4)	75 (42.4)	1.32 (0.83–2.14)	–
Child's birth order	1	174 (40.6)	85 (48.0)	**Ref**	**Ref**
	2	198 (46.2)	69 (39.0)	1.40 (1.04–1.88)[**]	1.36 (0.98–1.88)
	≥3	57 (13.2)	23 (13.0)	1.21 (0.75–1.95)	1.64 (0.84–3.19)
Place of vaccination	Public facility	407 (94.9)	163 (92.1)	**Ref**	**–**
	Private facility	22 (5.1)	14 (7.9)	0.62 (0.30–1.30)	–
Mother's age at birth of child (years)	< 20	46 (10.7)	23 (13.0)	**Ref**	–
	20–30	354 (82.5)	144 (81.4)	1.22 (0.69–2.19)	–
	> 30	29 (6.8)	10 (5.6)	1.45 (0.58–3.64)	–
Mother's education	Illiterate	10 (2.3)	6 (3.4)	**Ref**	–
	Upto 12th standard	357 (83.2)	140 (79.1)	1.53 (0.36–6.58)	–
	Diploma/Degree	62 (14.5)	31 (17.5)	1.20 (0.29–4.99)	–
Father's education[***]	Illiterate	19 (4.4)	8 (4.5)	**Ref**	–
	Upto 12th standard	353 (82.3)	140 (79.1)	1.06 (0.37–3.08)	–
	Diploma/Degree	57 (13.3)	29 (16.4)	0.83 (0.27–2.49)	–
Mother's occupation	Homemaker	378 (88.1)	150 (84.8)	**Ref**	–
	Wage earner	42 (9.8)	23 (13.0)	0.72 (0.33–1.49)	–
	Salary earner/business	9 (2.1)	4 (2.2)	0.89 (0.28–2.82)	–
Father's occupation	Unemployed	10 (2.4)	6 (3.4)	**Ref**	–
	Wage earner	311 (73.3)	117 (66.1)	1.59 (0.58–4.38)	–
	Salary earner/business	103 (24.3)	54 (30.5)	1.14 (0.39–3.33)	–
Religion	Hindu	419 (97.7)	170 (96.0)	**Ref**	–
	Others	10 (2.3)	7 (4.0)	0.58 (0.17–1.92)	–
Household size	< 5	147 (34.3)	58 (32.8)	**Ref**	–
	5–10	276 (64.3)	117 (66.1)	0.93 (0.65–1.33)	–
	> 10	6 (1.4)	2 (1.1)	1.18 (0.21–6.62)	–
Social group	Scheduled caste	101 (23.5)	49 (27.7)	**Ref**	**Ref**
	Scheduled tribe	39 (9.1)	26 (14.7)	0.73 (0.34–1.54)	0.73 (0.34–1.57)
	Other backward classes/General	289 (67.4)	102 (57.6)	1.37 (0.84–2.24)	1.69 (1.04–2.73)[**]
Type of dwelling	Mud/Semi-cemented	36 (8.4)	11 (6.2)	**Ref**	**–**
	Cemented	393 (91.6)	166 (93.8)	0.72 (0.25–2.09)	–
Non-socio-demographic					
Travel to immunization facility	Walking	285 (66.4)	113 (63.8)	**Ref**	–
	Private/Public transport	144 (33.6)	64 (36.2)	0.89 (0.55–1.44)	–
I think immunization is important to keep my child healthy	Don't agree (N)	2 (0.5)	1 (0.6)	**Ref**	–
	Agree (SA,A)[****]	427 (99.5)	176 (99.4)	1.21 (0.1–15.1)	–
I am familiar with the immunization schedule (individual vaccines & timing of doses)	Don't agree (N,DA, SDA)	108 (25.2)	58 (32.8)	**Ref**	**Ref**
	Agree (SA,A)	321 (74.8)	119 (67.2)	1.44 (0.91–2.30)	1.42 (0.90–2.22)
The timing of immunization sessions was convenient for me	Don't agree (N, DA)	31 (7.2)	12 (6.8)	**Ref**	–
	Agree (SA,A)	398 (92.8)	165 (93.2)	0.93 (0.44–1.99)	–
Self-reported hesitancy with one or more childhood vaccines	Hesitant (SH, VH, N)[*****]	259 (60.4)	95 (53.7)	**Ref**	–
	Not hesitant (NTH, NH)	170 (39.6)	82 (46.3)	0.76 (0.54–1.07)	–
Health-worker home visits	No/Not sure	88 (20.5)	41 (23.2)	**Ref**	–
	Yes	341 (79.5)	136 (76.8)	1.16 (0.68–2.00)	–
Information about recommended vaccines provided during ANC visits	No/Not sure	36 (8.4)	24 (13.6)	**Ref**	**Ref**
	Yes	393 (91.6)	153 (86.4)	1.71 (0.97–3.01)[*]	1.42 (0.90–2.22)
Received incentive for completing pentavalent/DPT series	No	130 (30.3)	65 (36.9)	**Ref**	**Ref**
	Yes	299 (69.7)	111 (63.1)	1.35 (0.98–1.86)[*]	1.55 (0.82–2.94)

[*] p < 0.10; [**] p < 0.05, [***] n = 5 missing observations for father's occupation, N = 605 for multivariate model, [****] SA: Strongly agree, A: Agree, N: Neutral, DA: Disagree, SDA: Strongly disagree, [*****] SH: Strongly Hesitant, VH: Very hesitant, N: Neutral, NTH: Not too hesitant, NH: Not hesitant.

based on information from vaccination cards or parental recall [19]. One possible reason for the different estimates may be that immunization coverage was estimated for different birth cohorts in the NFHS-4 (2013–14) and our survey (2015–16). Since Vellore was selected as a high-focus district in 2015, the coverage of individual UIP antigens and fully vaccinated children may have increased between the two surveys. Another potential explanation from an independent audit of the NFHS-3 data is the significant difference in full vaccination coverage between children whose vaccination card was seen and those whose card was not seen during the survey [25]. The proportions of fully vaccinated children for these two categories was similar in our study (data not shown).

Many (∼40%) undervaccinated children had missed doses of BCG or Measles. The UIP recommends that BCG is administered at birth or as early as possible until one year of age [2]. Nearly 73% (n = 25) of children with missed BCG doses were born in public facilities and since children may potentially have up to four immunization visits (at 6, 10, 14 weeks & 9–12 months) between birth and one year of age, the missed doses represent missed opportunities for routine immunization at birth or during later visits. If the opportunities to vaccinate these children were utilized, the coverage of BCG would have increased from 94.5% to 99.5%. The first dose of measles is recommended during 9–12 months of age, children who are not vaccinated during the first year only have

opportunity to catch up when returning for the booster doses of OPV and DPT at 16–24 months, when the second dose of measles is due [2]. Timely reminders to parents through health worker home visits or mobile-phone reminders may help improve uptake of measles vaccination during the first year of life [26,27].

While many studies from India have reported socio-demographic disparities in vaccination coverage among young children, we found none in our study, suggesting a uniform delivery and uptake of routine immunization services in rural Vellore [28–33]. The observed disparity in full vaccination coverage by social group in the supplementary and sensitivity analyses may represent differences in parental beliefs and practices regarding childhood immunization or access to routine immunization services, which needs further investigation [28]. Of the non-socio-demographic factors assessed, parents' familiarity with the recommended UIP schedule and receiving information on the UIP schedule during antenatal visits were associated with increased odds of full vaccination. Nearly one-third of parents in our survey reported not being familiar with the UIP schedule for their children and a majority (>80%) had not heard of the recently introduced Measles-Rubella vaccine. With the recent addition of the rotavirus and pneumococcal conjugate vaccines to the UIP in some Indian states and planned nationwide introduction, health education interventions must aim to improve parental awareness of currently available and newly introduced UIP vaccines. The positive association between the reported receipt of information on the UIP schedule during antenatal visits and children's vaccination status highlights the importance of nudging parents towards vaccine uptake [21]. This finding is compatible with previous research from India which suggests that a higher number of antenatal visits (three or more) is associated with an increased likelihood of children completing the recommended immunization schedule [34]. Pregnant women are an important group for targeted educational intervention to sustain and improve uptake of routine childhood vaccination.

We also analyzed children based on if they had received all the recommended vaccine doses during the first year of life according to the UIP schedule or not [31]. Many previous studies have reported the need to measure adherence to immunization schedules in addition to the traditionally used coverage metrics to evaluate the performance of routine immunization programs [35–38]. Despite the high proportion (84%) of fully vaccinated children in our study, 13% of these children had one or more doses not given according to schedule (mainly due to less than optimal spacing of the multiple dose vaccines or early measles vaccination). Improper spacing of the pentavalent, DPT or OPV doses may lead to suboptimal immune response and according to current UIP guidelines, measles doses administered before 9 months of age are considered invalid and must be repeated [2,39]. These findings concur with various national, state and community-level evaluations which recommend the need for periodic assessment and improvement of age-appropriate immunization coverage among young children in India [31,33,40–42].

Our study had some limitations that should be considered when interpreting the findings: First, the exclusion of children without a vaccination card could have introduced a selection bias; however, we found no significant differences in the socio-demographic characteristics of children with and without vaccination cards (Supplemental Table 1). The results of the multivariate analysis were also similar whether restricted to children with a vaccination card or including all children irrespective of the source of vaccination history. Second, most parents (>70%) reported a failure of the health worker to record vaccination dates as the main reason for missed UIP doses and we were unable to verify these inconsistencies with provider-maintained records due to logistic constraints. It is possible that children received the doses for which the dates were not recorded and since the accuracy of coverage estimates largely depend on the quality of vaccination documentation, there is a need to improve primary data recording [43]. However, it is also likely that there was a degree of "social desirability" in parents' reasons for missed vaccinations for their children as the questionnaires were interviewer-administered [43]. In addition, some overlapping of the reasons for missed vaccination may have occurred; for example, the reported failure in primary data recording could have been due to misplaced cards during vaccination sessions. Third, we were unable to validate parents' knowledge of the vaccination schedule, which may have helped identify knowledge gaps to be addressed by government educational interventions. Fourth, it was also not possible to verify if the participating women had actually received information on the UIP schedule during antenatal visits. The observed association between receiving information on the schedule during antenatal visits with children's vaccination status may in part be due to a recall bias. We did not find any differences in reporting by place of delivery (public vs. private facility). Fifth, a degree of bias in the recording of study exposures may have occurred since the interviewers were not blinded to the children's vaccination records. However, information bias is expected to be minimal as the interviewers were unaware of the study outcomes during data collection. And lastly, as self-reported measures of household income are generally considered unreliable, we used the "type of dwelling" of eligible children as a relative measure of household wealth as previously reported [29,44].

The limitations notwithstanding, this survey is the most recent independent assessment of routine immunization coverage among young children in Vellore, a Mission Indradhanush high-focus district. Our study was characterized by high vaccination card availability (>94%), improving the accuracy of the coverage estimates reported. In contrast, other independent household surveys from India have reported a vaccination card availability of 60–80% [30,31,45,46]. We used standard EPI coverage survey methodology and recorded information using KoBo Toolbox, a free, open-source application for field data collection [20]. Mobile data collection is known to improve real-time supervision of data collectors, reduce the duration and cost of interviewing participants and decrease the possibility of data-entry errors at the point of collection [47,48]. In addition, the "5As taxonomy" aided identification of the possible role of "awareness" regarding the UIP schedule and "activation" through health education to pregnant women in the uptake of routine childhood vaccinations in rural Vellore and can be used for similar evaluations in other parts of India.

7. Conclusions

Periodic, region-specific evaluations of childhood immunization coverage are important to monitor progress and identify barriers to the achievement of national immunization program targets. We found higher coverage of the individual UIP antigens and full vaccination among children in rural Vellore than previously reported. Despite the high coverage, however, adherence to recommended schedule was not optimal. Self-reported familiarity with the UIP recommended schedule and receipt of information regarding childhood vaccinations during antenatal visits were associated with increased odds of full vaccination. Our study highlights the need to improve parental awareness of the currently available and newly introduced UIP vaccines. Health education interventions to improve coverage of routine vaccinations may benefit if targeted at pregnant women during antenatal visits.

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Authors' contributions

Study concept and design: MRF, JPN, GK, VB, VRM; Analysis and interpretation of data: MRF, JPN, GK, VRM; Drafting of the manuscript: MRF; Critical revision of the manuscript for important intellectual content: All authors; Statistical analysis: MRF; Obtained funding: JPN, GK; Study supervision: JPN, GK, VRM; Final approval: All authors.

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Conflict of interest

HL's research group has received funds from GSK and Merck to convene research symposium and holds a grant from GSK to support research on maternal vaccination. HL has served on the Merck Vaccines Strategic Advisory Board 2014-2016. None of the other authors have conflicts of interest to declare.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2019.04.058.

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