Routine immunization coverage in Pakistan: a survey of children under 1 year of age in community-based vaccination areas

Meghana Sreevatsava[1], Ashley L. Burman[1], Ashraf Wahdan[1], Rana M. Safdar[2], Aidan O'Leary[3], Raabya Amjad[3], Abdul Salam[1], Mansoor Quershi[1], Rakhshanda Ishaq[1], Jawed Khan[1], Jehangir Khan[1], Edward P. K. Parker[4], Abdirahman Sheikh Mahamud[1], Jamal Ahmed[1]

[1] World Health Organization, Islamabad, Pakistan; [2] Ministry of National Health Services, Islamabad, Pakistan; [3] United Nations Children's Fund, Islamabad, Pakistan; [4] The Vaccine Centre, Department of Clinical Research, Faculty of Infectious and Tropical Diseases, London School of Hygiene and Tropical Medicine, London, UK

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Corresponding author:

Meghana Sreevatsava, World Health Organization, Islamabad, Pakistan

meghana.sreevatsava@gmail.com

Abstract

Pakistan is one of three countries in which poliovirus remains endemic. Considering the high number of children born every year, reaching and vaccinating new birth cohorts by improving routine immunization coverage in children <1 year of age is crucial to halting virus transmission. In 2015, a community-based vaccination (CBV) strategy, using local community members to enhance vaccine access and acceptance and improve routine immunization service delivery, was introduced in areas of Pakistan that have never interrupted poliovirus transmission. In order to assess progress towards improving routine immunization, we performed house-to-house immunization surveys across ten CBV areas in 2017 and 2018. In each household, we determined age-appropriate routine antigen coverage for children <1 year of age based on vaccination card and caregiver recall. We surveyed 5,499 and 5,264 children in 2017 and 2018, respectively. Overall, coverage of inactivated poliovirus vaccine (IPV) at 14 weeks of age was 32% in 2017 and 39% in 2018 based on vaccination card and recall. Across the surveyed areas, coverage ranged from 7% in Killa Abdullah to 61% in Peshawar in 2018. Oral poliovirus vaccination coverage decreased with successive vaccination visits, ranging from 66% for the birth dose to 42% for the 14-week dose in 2018. No area reached the target of 80% coverage for any routine antigen. Our findings highlight the need for concerted efforts to improve routine immunization coverage in these critical areas of wild poliovirus transmission.

Key words: coverage; routine immunization; Pakistan; polio; vaccine

Introduction

Immunization continues to be one of the most successful public health interventions available, saving over 2.5 million lives each year and preventing disabilities and morbidity in many more [1]. Through the delivery of oral and inactivated poliovirus vaccines, the Global Polio Eradication Initiative (GPEI) has brought about a decline in the number of wild poliovirus cases from an estimated 350,000 in 1988 to just 175 in 2019 (as of 05 April 2020). Although supplemented by mass vaccination campaigns in many regions, routine immunization remains a key pillar of the GPEI. Improving routine immunization programs across the globe and specifically in polio-endemic countries (Pakistan and Afghanistan) is crucial if polio eradication is to be achieved.

Until April 2016, routine immunization against polio in Pakistan involved the administration of four doses of trivalent oral poliovirus vaccine (OPV) at 0, 6, 10, and 14 weeks of age. However, trivalent OPV was replaced with bivalent OPV (targeting poliovirus serotypes 1 and 3) as part of the phased global withdrawal of OPV [2]. To provide protection against serotype 2 poliovirus, this switch was preceded by the introduction of a single dose of inactivated poliovirus vaccine (IPV) at 14 weeks of age. IPV was introduced into the routine schedule in August 2015. The sequence of the current schedule ensures infants are primed with at least three doses of bOPV before bOPV and IPV are co-administered at 14 weeks. This single dose of IPV in routine services is now the only safeguard against type 2 virus. Owing to global shortages of IPV, it is currently challenging for countries to do repeated large-scale supplementary campaigns with IPV. Building strong routine immunization programs is therefore crucial for proviing robust immunity to all three poliovirus serotypes. Other vaccines administered as part of the Expanded Program on Immunization (EPI) schedule in Pakistan include, among others, Bacille Calmette-Guérin (BCG) vaccine at birth, pentavalent vaccine

(targeting diphtheria, tetanus, pertussis, hepatitis B and *Haemophilus influenzae* type b) at 6, 10, and 14 weeks, and measles-containing vaccine (MCV) at 9 and 15 months (Table S1).

There have been several recent attempts to estimate EPI coverage in Pakistan. The 2017 WHO/UNICEF estimates for national vaccination coverage were 75% for OPV at 14 weeks (OPV3), 75% for pentavalent vaccine at 14 weeks (Penta3), 67% for IPV, and 76% for MCV at 9 months [3]. The 2017–2018 Demographic Health Survey (DHS) – a nationally representative survey of 12,815 households – reported broadly similar coverage rates of 86% for OPV3, 75% for Penta3, 64% for IPV, and 73% for MCV based on vaccination card and caregiver recall [4]. An estimated 66% of DHS children aged 12–23 months had received all basic vaccines (defined as three doses of OPV, three doses of pentavalent vaccine, BCG, and one dose of MCV), although this rate varied from 29% in the province of Balochistan to 80% in Punjab. Substantial variation in coverage between provinces and also at a sub-provincial level was also evident in the 2010–2011 Multiple Indicator Cluster Surveys (MICS) [5]. Finally, the 2014–2015 Pakistan Social and Living Standards Measurement (PSLM) survey – an independent survey of 78,635 households – reported somewhat higher coverage rates of 97% for OPV3, 88% for Penta3, and 83% for MCV based on vaccination cards and recall (the survey was conducted before the introduction of IPV) for children under 2 years of age [6].

Suboptimal immunization coverage can be attributed to lack of knowledge and awareness regarding the importance of vaccination, vaccine hesitancy, issues of inaccessibility (e.g. due to ongoing conflict), and large population movements [7]. To enhance vaccination coverage in areas with high risk of WPV transmission, the polio program in Pakistan introduced a community-based vaccination (CBV) strategy in 2015, involving local community members to promote vaccination access and acceptance in areas that have never interrupted wild poliovirus

transmission (Khyber, Peshawar, Quetta block [Quetta, Pishin, Killa Adullah], and Karachi). An additional component of CBV is to raise awareness and promote use of routine immunization services for children under 1 year of age. During a cluster randomized controlled trial, this approach improved OPV3 coverage from 75% to 82% [8].

Given the importance of routine immunization among new birth cohorts in high-priority districts, the 2016–2017 National Emergency Action Plan for Polio Eradication (NEAP) – the leading technical document for the Pakistan polio program – set a target of 80% routine immunization coverage among children under 1 year of age in all CBV areas, using age-appropriate pentavalent vaccine and IPV coverage as core indicators [9]. To assess progress towards achieving this target, the Pakistan National Emergency Operations Centre undertook annual assessments of routine immunization in CBV areas in 2017 and 2018.

Materials and Methods

Survey areas

Surveys were performed in March–May 2017 and March–May 2018 by UNICEF, WHO, and National Stop Transmission of Polio (N-STOP) program partners in CBV areas. The CBV strategy is deployed in the highest-risk districts (termed Tier 1 districts) and includes permanent staff hired to ensure high-quality house-to-house supplementary immunization activities (SIAs) are conducted almost monthly to administer an additional dose of OPV to all children under 5 years of age during each campaign. There are some districts that implement a partial CBV strategy; however, these were not included in the present survey. Each CBV district is made up of 35–192 union councils (UCs). Each UC, in turn, comprises 4–5 areas overseen by an area supervisor. Finally, each area supervisor oversees 4–5 community health workers

(CHWs), and each CHW visits 50–60 houses per day during the SIA campaign. SIA campaigns in CBV areas last 5 days with an additional 2 days allocated for catch-up activities.

The Tier 1 districts include Peshawar district, Quetta division (encompassing Quetta, Killa Abdullah, and Pishin districts), Karachi division, and Khyber agency**.** Peshawar consists of four towns and 103 UCs, and Karachi of 18 towns and 192 UCs. In the present survey, we included 10 survey locations across these Tier 1 districts, with each survey area consisting of 20–40 UCs (Table 1). The survey locations encompass the districts in Pakistan that employ the full CBV strategy. Owing to their large population sizes, Peshawar and Karachi were divided into two and four survey areas, respectively.

The survey areas are frequently visited by CHWs and monitors each month during the vaccination campaigns. As such, the security challenges are well known by both surveyors and the program. Each surveyor was provided with a local police escort as they moved from house to house, which is a standard practice when spending large amounts of time in the field. No areas were deemed inaccessible by the program or surveyors during the course of the study.

The primary objective of the survey was to assess whether pentavalent vaccine (third doses) and IPV had reached a coverage of 80%. Based on the population size of each location, an expected prevalence of 80%, a confidence interval of 95%, a margin for error of 5%, and a design effect of 2 to account for within-cluster correlation inherent in the cluster design [10], we estimated that a minimum sample size of 500 households per CBV location would be required (using the prevalence equation) [11]. To achieve this, 50 clusters of 10 households were selected in each location, wherein a cluster comprised 10 of the 50–60 households visited by a

vaccination team in a given day. For Quetta division, an additional 10 clusters were included to enable variation in coverage at a sub-district level to be explored.

The CBV registration book – a continuously updated registry of households with infants under 5 years of age – served as the sampling frame for this evaluation. The survey was randomized at three stages. First, area supervisors were selected at random from those working in each CBV assessment location. Second, a team and day of campaign work was selected at random from those overseen by the area supervisor during the SIA. Area supervisor and team selection was completed at the federal level based on simple random sampling. Third, a random number generator was used to select 10 households from the 50–60 being visited by the team on the selected day. Questions were asked regarding all children under 1 year of age in each household. Children were eligible for inclusion if they were below 1 year of age and a resident of the selected household, regardless of whether they were physically present at the time of the survey; children who were guests or visitors were not eligible for inclusion. The survey was completed using Open Data Kit (ODK) – a free, open-source tool for mobile data collection. Surveyors included WHO, UNICEF, and N-STOP staff at the federal, provincial, and district levels including Monitoring and Evaluation Officers, Rapid Response Unit Officers, District and Divisional Surveillance Officers, and District Health Communication Support Officers. The survey was conducted only if voluntary informed consent was provided by an adult member of the household.

Training and spot checks

All surveyors received a full day of training before beginning field activities. Surveyors were trained on the objective of the activity and how to select households and children to sample. In addition, orientation was provided on reading EPI cards, CBV registers, and filling out the

survey questionnaire on paper and in the ODK format. Pre- and post-test evaluations were administered to ensure all concepts were understood by surveyors. In the field, surveyors were selected at random for assessment by members of the national Monitoring and Evaluation team. This involved following surveyors for 3–4 houses and ensuring that information provided by households (recall) or EPI cards were correctly entered into the ODK forms. Provincial Monitoring and Evaluation officers served as communication focal points for the surveyors and were available to answer any questions that came up during the study.

Data collection

Information on vaccination status was ascertained through the child's EPI card, which is given to parents when they bring their child to health facilities or outreach sessions to receive routine immunization antigens. The EPI cards are not marked for vaccine doses given during SIAs or outbreak responses; they are only marked when children receive routine immunization doses. For each antigen a child was eligible to receive at the time of the visit to the health centers, surveyors entered the date of the vaccination. If the child did not have an EPI card, vaccination history was provided based on caregiver recall using pictures, administration locations, timing and other identifiers to differentiate between antigens. Demographic variables such as age and gender were also collected. Doses were defined as delayed if administered >28 days late (or 56 days late in the case of the birth dose; see Table S1 for full definitions). In addition, doses were defined as early if given before they were due (either owing to true early administration, error in the recording of the date on the EPI card, or error during entry of the date on the ODK form).

This survey is an annual EPI assessment targeted at the high-risk areas for polio. It is part of a broader range of Monitoring and Evaluation activities that are included in the NEAP. Results

from the Monitoring and Evaluation activities are utilized to guide and improve performance of routine immunization programs in CBV areas.

Statistical analysis

Data were submitted through ODK to a secure server and exported into Microsoft Excel. Data cleaning, merging, and coding were completed using SPSS [12]. Vaccination status was categorized as follows: vaccinated on time based on EPI card, vaccinated but delayed according to current EPI schedule based on EPI card, vaccinated based on recall, not vaccinated, vaccinated early, or not eligible to be vaccinated based on age. Coverage estimates were calculated for each antigen and scheduled visit and corresponding 95% confidence intervals were determined using the Clopper–Pearson exact method [13]. Age-ineligible infants (too young for receipt of the dose in question) were excluded during coverage calculations. All data were analyzed using Microsoft Excel and the programming language R [14].

Results

A total of 5,499 and 5,264 children under 1 year of age were surveyed in 2017 and 2018, respectively. Table 1 shows the distribution of demographic variables across the assessment areas. The mean number of clusters per study area was 47.8 (range 39–58) in 2017 and 46.6 (range 43–50) in 2018. The number of clusters fell below the target of 50 in some areas as surveyors were either unable to reach all allocated clusters within the survey period or did not submit their survey data (e.g. owing to technical errors). The average age of participants was 5.9 months and 6.0 months and 49% and 50% of participants were female in 2017 and 2018, respectively. Age and gender distributions were similar across the assessment areas. A total of 5,900 (55%) participants had an EPI card, although this proportion varied considerably among areas – in 2017, as few as 18% of participants had cards in Killa Abdullah while 79% of

participants in Peshawar 1 had cards. In 2018, 16% of children had cards in Pishin while 80% had cards in Peshawar 1 and 2.

Based on EPI cards, overall age-appropriate coverage of the core indicators of this survey, Penta3 and IPV, was 29% and 24% in 2017 and 33% and 30% in 2018 (Fig 1). When allowing for recall in addition to EPI card status, these estimates increased by approximately 10% (to 37% and 32% in 2017 and 42% and 39% in 2018). Coverage varied considerably by assessment area: in 2017, IPV coverage based on EPI cards and recall ranged from 7% in Killa Abdullah to 57% in Peshawar 1, while Penta3 coverage ranged from 6% in Pishin to 61% in Peshawar 1. Similar trends were evident in 2018 (Fig 1). Although scheduled for administration at 14 weeks of age, IPV and Penta3 were often received later, as emphasized by the higher coverage observed among children >6 months of age than in younger children (Fig 2). For example, in 2018 IPV coverage based on EPI cards and recall was documented in 23% of children aged 3.5–5 months, 33% in children aged 6–8 months, and 33% in children aged 9–11 months.

OPV coverage decreased with each successive vaccination visit, ranging from 64% for the birth dose (OPV0) to 39% for OPV3 in 2017 and 66% for OPV0 to 42% for OPV3 in 2018 based on EPI card status and recall. As observed for IPV and Penta3, coverage varied by assessment area, with lowest coverage rates in Killa Abdullah and Pishin (<10% for OPV3 in 2018 based on EPI card and recall) and highest rates in Peshawar 1 (61% and 65% coverage in 2017 and 2018, respectively). Similar trends were observed for pentavalent vaccine, with coverage decreasing from 57% for the 6-week dose (Penta1) to 37% for Penta3 in 2017, with similar declines apparent in 2018.

The survey also measured age-appropriate coverage of other routine EPI antigens such as BCG, pneumococcal conjugate vaccine, and MCV (Fig 3). BCG and OPV0, both given at birth, had comparable coverage (64% for both antigens in 2017 and 68% and 66%, respectively, in 2018 based on EPI card and recall). BCG scars were present in just over 50% of participants (60% in 2017 and 63% in 2018). Among the 5,499 children surveyed in 2017, 1,705 were >9 months of age and thus eligible to have received MCV. Of these, 20% had received the vaccine in 2017 based on EPI card status and recall. Similarly, 32% of 1,227 eligible infants had received MCV in 2018.

Table S2 shows overall vaccination coverage and 95% CIs by EPI card and caregiver recall. EPI card coverage estimates are separated based on timely (vaccine given at correct time) or delayed vaccination (vaccine given but at a later time). For IPV and Penta3, more than 50% of administered doses were delayed. Table S2 also shows the number of children who were recorded as receiving an antigen earlier than scheduled (including some before the documented date of birth). These early vaccinations, which depending on the antigen comprised 0.4–2.7% and 0.1–1.1% of children surveyed in 2017 and 2018, respectively, were excluded from coverage estimates.

Drop-out between vaccination visits was high and varied considerably across the CBV areas. In 2017, overall drop-out rates were 18% (range 8–27% across CBV areas) between OPV1 and OPV3, 20% (10–31%) between Penta1 and Penta3, and 44% (7–72%) between BCG and MCV. In 2018, drop-out rates were 18% (7–26%) between OPV1 and OPV3, 19% (range 11–29%) between Penta1 and Penta3, and 36% (10–54%) between BCG and MCV.

Discussion

Our survey recorded vaccination coverage among infants under 1 year of age in CBV areas of Pakistan to be 32–42% by EPI card for Penta3 and IPV in 2017 and 2018. As such, the target of achieving 80% coverage of routine immunization antigens using Penta3 and IPV as core indicators was not met in either year. Moreover, the reported coverage rates fall considerably short of recent estimates of national vaccination coverage in Pakistan [3, 4, 6]; for example, the 2017 DHS estimated coverage to be 64% for IPV, 75% for Penta3, and 86% for OPV3 [4], while our 2018 survey found overall coverage of these antigens to be 39%, 42% and 42%, respectively. We attribute these discrepancies to two key factors: (i) differences in survey methods and (ii) the particular challenges facing vaccination efforts in the CBV areas. In particular, the DHS survey was performed among children aged 12–23 months and included vaccines received any time before the survey date, whereas our survey measured timely vaccination of children in the first year of life. Thus, if children were not age-eligible for a particular antigen, they were not included in the coverage estimates for that antigen in our study. Notably, in spite of their higher overall estimates, the DHS survey and others [7] have reported wide variation in coverage among provinces in Pakistan, with coverage typically lowest for Balochistan. Consistent with these findings, we found coverage of all routine antigens to be lowest in Quetta, Pishin, and Killa Abdullah – all of which are in Balochistan.

The gaps in vaccination coverage reported here also reflect the many difficulties facing routine immunization programs in CBV areas. Historically, the EPI has faced challenges of poor infrastructure, ownership, and accountability in creating demand for routine vaccination services and subsequently delivering on those demands. Other studies conducted in Pakistan have identified reasons for non- or under-immunization to include lack of knowledge on the importance of vaccination and fear of side effects among caregivers [15]. This lack of knowledge in addition to the suboptimal implementation of EPI services results in several missed

opportunities to vaccinate children in their first year of life. One of the mandates of the CBV program is to spend 1 week per month promoting essential immunization and follow up on defaulters; it is likely that challenges in capacity, training, and supervision of frontline workers may have undermined efforts to achieve this mandate.

It is notable that while OPV3, Penta3, and IPV are recommended for concomitant administration as per the current EPI schedule, IPV vaccination coverage was lower (39% in 2018) compared to OPV3 and Penta3 (42% in 2018), potentially reflecting variation in vaccine availability. Consistent with this, a survey of routine immunization centers in the Sindh province of Pakistan documented gaps in vaccine and buffer availability for IPV after its scheduled introduction in 2015 [16]. Additionally, while Penta3 and IPV are meant to be administered at 14 weeks, delays in vaccination were observed which accounts for a higher number of children in older age groups (> 6 months) receiving these antigens.

The analysis of other routine antigens showed comparable coverage at corresponding time points (e.g. OPV3, Penta3, and PCV3). Drop-out between vaccination visits is a consistent feature of routine immunization [17, 18], and the WHO has specified a rate of >10% to be indicative of high drop-out [19]. Pentavalent vaccine drop-out rates in this survey were substantially higher than 10% in all districts surveyed. MCV, which is given alone at 9 months, had the lowest vaccination coverage of the antigens considered – less than a third of age-eligible children had received this vaccine in 2017 and 2018. This drop-off can be explained in part by the extended duration between MCV administration at 9 months and the previous EPI visit at 14 weeks. Together, these findings highlight the need for closer follow-up and mobilization of drop-outs to ensure they are fully immunized by 12 months of age. Approaches to reduce drop-out include better social mobilization and advocacy at either health facility or vaccination team

level, improvied data management, careful monitoring of drop-outs, and effective reminder systems (e.g. via home visits or phone messages).

To our knowledge, this is the first survey that has used household registration data on children <1 year of age as the source population as opposed to traditional routine immunization surveys, which have used administrative data from health facilities and targeted children less than 2 years of age. Strengths of the survey include the use of household-level data that is regularly updated by CBV teams to identify eligible children, the use of a large number of surveyors not involved in CBV implementation to reduce surveyor bias, and the use of EPI cards as the gold standard measure of vaccination status. However, this survey is not without limitations. Results might not be generalizable within or outside Pakistan as more focus and follow-up on routine immunization has been implemented in CBV areas given their key strategic importance to the polio endgame. Additionally, even though caregiver recall was used as a secondary data source, recall bias cannot be ruled out especially as lower recall was observed with injectable antigens (which is expected given that several different injectable vaccinations are given at the 6, 10, and 14 week visits). As OPV was the only oral vaccine in the schedule in 2017, it would be easier for caregivers to recall their children receiving it, although notably there may have been difficulty in distinguishing between OPV doses administered through routine immunization versus SIA campaigns. The number of clusters fell below the target of 50 in some survey areas, and a formal analysis of the reasons for this was beyond the scope of the present study. However, the mean number of clusters was above 46 per study area in both 2017 and 2018. A final limitation of this survey was the phenomenon of early vaccination. This was an infrequent issue (affecting <3% of doses recorded) that was likely due to errors in entering the dates of vaccination on EPI cards by healthcare workers, errors in entering the dates in ODK by surveyors, and restrictions placed in the ODK form on dates of vaccine entry.

In conclusion, this survey provides an estimate of routine EPI vaccination in CBV areas. While no core reservoir achieved the target of 80% coverage for any routine antigen, certain areas (Karachi and Peshawar) have substantially better coverage than others (Pishin and Killa Abdullah). Concerted efforts must be made to close gaps in coverage in these critical areas of wild poliovirus transmission.

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Author contributions

JA, AM, AB, and RS conceived the idea for the survey. AO and RA provided operational support and the sampling frame. AB and AW designed the statistical methods. AB and MS created the survey tool. AS, MQ, RI, JK, and JK facilitated field implementation. AB cleaned, merged, and coded the datasets. MS coordinated the survey, analyzed the data, and wrote the first draft of the manuscript. EP helped revise the manuscript and prepare the tables and figures. All authors reviewed and revised subsequent drafts.

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We declare no competing interests.

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Table 1. Survey characteristics.

Survey area	Towns	No. children <5 years (1000s)	2017 survey					2018 survey				
			No. clusters	No. infants	% with EPI card	Mean age (m)	% female	No. clusters	No. infants	% with EPI card	Mean age (m)	% fema
Karachi 1	Baldia, Kamari, Orangi	387	43	476	76.5	5.9	44.7	48	481	76.3	6.3	47.4
Karachi 2	Korangi, Landhi, BinQasim	462	53	576	68.2	6.2	49.3	49	508	67.7	6.2	50.0
Karachi 3	Gadap	182	48	537	52.7	6.0	49.2	48	515	57.1	6.3	47.0
Karachi 4	All remaining CBV areas	368	39	543	70.7	6.1	50.3	44	502	75.5	6.3	50.4
Khyber	-	214	50	496	58.7	6.2	47.8	50	578	56.6	5.7	47.8
Killa Abdullah	-	146	44	538	18.0	5.6	51.7	49	535	18.3	6.4	52.1
Peshawar 1	Peshawar towns 1 and 2	372	49	561	79.0	5.2	43.9	43	567	80.4	5.5	48.9
Peshawar 2	Peshawar towns 3 and 4	391	50	559	71.4	5.6	49.4	45	521	79.5	5.8	52.4
Pishin	-	113	46	562	20.8	6.1	50.4	47	527	16.5	5.5	51.0
Quetta	-	258	58	651	31.3	5.8	53.0	50	530	30.8	6.3	54.2
Overall	-		478	5499	54.1	5.9	49.1	466	5264	55.6	6.0	50.1

Population size estimates are based on 2017–2018 Pakistan polio program microcensus data. Abbreviations: CBV, community-based vaccination; EPI, Expanded Program Immunization; m, months.

Figure legends

Figure 1: Vaccine dose coverage by assessment area. Age-ineligible infants are excluded. EPI, Expanded Program on Immunization; KAB, Killa Abdullah; IPV, inactivated poliovirus vaccine; Penta3, pentavalent vaccine at 14 weeks of age.

Figure 2: Vaccine dose coverage by age group. EPI, Expanded Program on Immunization; IPV, inactivated poliovirus vaccine; Penta3, pentavalent vaccine at 14 weeks of age.

Figure 3: Overall vaccination coverage by assessment area. Results are displayed for (a) polio-specific antigens and (b) other antigens. Age-ineligible infants are excluded. BCG, Bacille Calmette-Guérin; EPI, Expanded Program on Immunization; KAB, Killa Abdullah; IPV, inactivated poliovirus vaccine; MCV, measles-containing vaccine; Penta, pentavalent vaccine; PCV, pneumococcal conjugate vaccine.

Supporting information

Table S1. Routine immunization schedule in Pakistan during 2017 and 2018 surveys.

Table S2. Routine immunization coverage by vaccination card and caregiver recall.

Figures

Figure 1

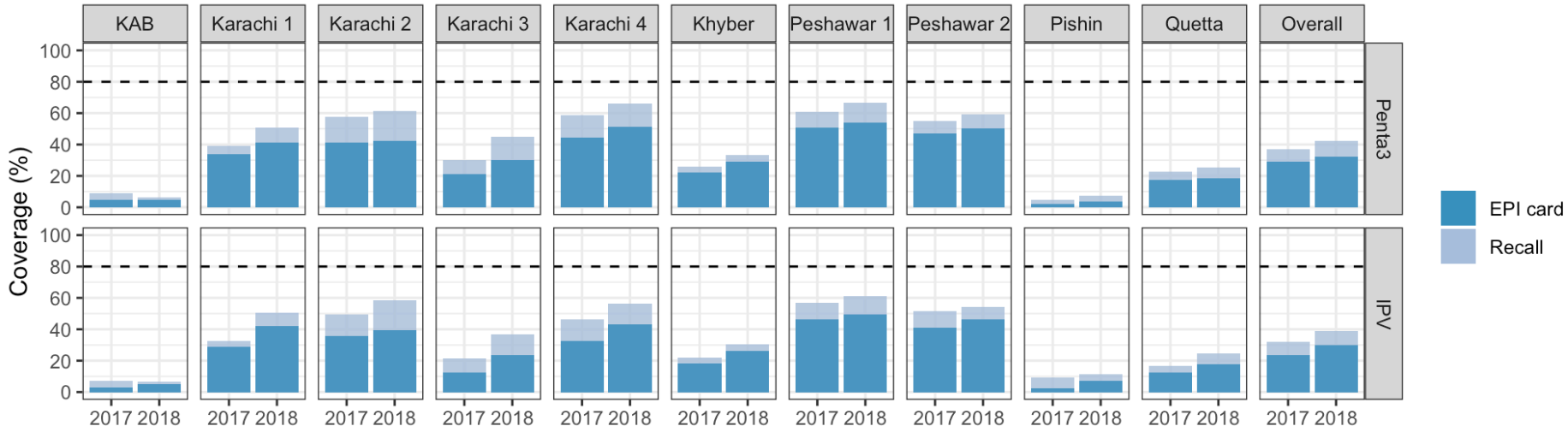


Figure 2

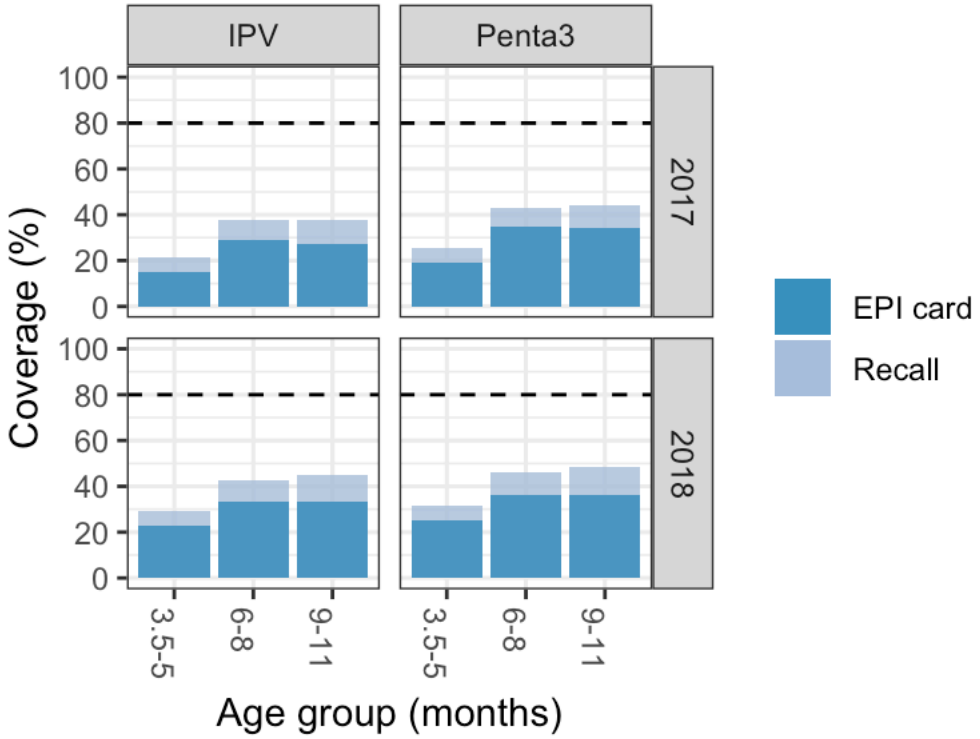

IPV
Penta3
2017
2018
100
80
60
40
20
0
Coverage (%)
3.5-5
6-8
9-11
Age group (months)
EPI card
Recall

Figure 3


A
KAB
Karachi 1
Karachi 2
Karachi 3
Karachi 4
Khyber
Peshawar 1
Peshawar 2
Pishin
Quetta
Overall
2017
2018
Coverage (%)
0
20
40
60
80
100
OPV0
OPV1
OPV2
OPV3
IPV
B
BCG
Penta1
Penta2
Penta3
PCV1
PCV2
PCV3
MCV
EPI card
Recall

Supplementary Table 1. Routine immunization schedule in Pakistan during 2017 and 2018 surveys.

Antigen	Birth	6 weeks	10 weeks	14 weeks	9 months	15 months
BCG						
OPV						
IPV						
Penta						
PCV						
MCV						
Late vaccination threshold	>56 days	>70 days	>98 days	>126 days	>280 days	-

BCG, Bacille Calmette-Guérin; IPV, inactivated poliovirus vaccine; MCV, measles-containing vaccine; OPV, oral poliovirus vaccine; Penta, pentavalent vaccine; PCV, pneumococcal conjugate vaccine.

Table S2. Routine immunization coverage by vaccination card and caregiver recall.

	n age eligible	n after exclusions*	EPI (timely), % (95% CI)	EPI (total), % (95% CI)	Recall, % (95% CI)	n early vaccination (%)	Total, % (95% CI)
2017							
OPV0	5499	5472	43.3 (42.0, 44.7)	49.3 (48.0, 50.6)	14.8 (13.8, 15.7)	27 (0.5)	64.1 (62.8, 65.3)
OPV1	4971	4844	31.5 (30.2, 32.8)	43.5 (42.1, 44.9)	13.1 (12.2, 14.1)	127 (2.6)	56.5 (55.1, 57.9)
OPV2	4531	4470	21.1 (19.9, 22.3)	36.0 (34.6, 37.4)	11.7 (10.7, 12.6)	61 (1.3)	47.7 (46.2, 49.1)
OPV3	4099	4069	13.2 (12.2, 14.3)	28.3 (27.0, 29.7)	10.5 (9.6, 11.5)	30 (0.7)	38.8 (37.3, 40.3)
IPV	4099	4073	10.0 (9.1, 11.0)	23.5 (22.2, 24.8)	8.3 (7.5, 9.2)	26 (0.6)	31.8 (30.4, 33.2)
Penta1	4972	4839	32.4 (31.0, 33.7)	45.2 (43.8, 46.7)	11.4 (10.5, 12.3)	133 (2.7)	56.6 (55.2, 58.0)
Penta2	4531	4459	21.2 (20.0, 22.5)	36.8 (35.4, 38.3)	9.5 (8.7, 10.4)	72 (1.6)	46.4 (44.9, 47.8)
Penta3	4099	4058	13.6 (12.5, 14.6)	28.9 (27.5, 30.3)	8.1 (7.3, 9.0)	41 (1.0)	37.0 (35.5, 38.5)
BCG	5499	5476	45.0 (43.7, 46.3)	52.2 (50.8, 53.5)	12.1 (11.3, 13.0)	23 (0.4)	64.3 (63.0, 65.6)
BCG scar	5499	5066	-	-	-	-	60.1 (58.7, 61.5)
PCV1	4971	4849	32.0 (30.7, 33.4)	44.6 (43.2, 46.0)	11.1 (10.2, 12.0)	122 (2.5)	55.7 (54.3, 57.1)
PCV2	4531	4465	21.0 (19.8, 22.3)	36.1 (34.6, 37.5)	9.4 (8.5, 10.3)	66 (1.5)	45.4 (44.0, 46.9)
PCV3	4099	4067	13.1 (12.0, 14.1)	28.2 (26.8, 29.6)	8.2 (7.4, 9.1)	32 (0.8)	36.3 (34.9, 37.8)
MCV	1705	1688	7.5 (6.3, 8.9)	13.6 (12.0, 15.3)	6.5 (5.4, 7.8)	17 (1.0)	20.1 (18.2, 22.1)
2018							
OPV0	5264	5204	45.2 (43.9, 46.6)	51.9 (50.5, 53.3)	13.9 (13.0, 14.9)	60 (1.1)	65.8 (64.5, 67.1)
OPV1	4771	4748	34.5 (33.1, 35.8)	47.5 (46.0, 48.9)	12.0 (11.1, 13.0)	23 (0.5)	59.5 (58.1, 60.9)
OPV2	4320	4309	23.3 (22.0, 24.5)	39.9 (38.4, 41.4)	10.6 (9.7, 11.6)	11 (0.3)	50.5 (49.0, 52.0)
OPV3	3847	3838	14.8 (13.7, 15.9)	32.2 (30.7, 33.7)	9.7 (8.8, 10.7)	9 (0.2)	41.9 (40.3, 43.5)
IPV	3847	3842	13.7 (12.6, 14.8)	29.9 (28.5, 31.4)	9.1 (8.2, 10.1)	5 (0.1)	39.0 (37.5, 40.6)
Penta1	4771	4744	36.0 (34.6, 37.4)	49.3 (47.9, 50.7)	11.9 (11.0, 12.9)	27 (0.6)	61.2 (59.8, 62.6)
Penta2	4320	4310	23.5 (22.2, 24.8)	40.7 (39.2, 42.2)	10.6 (9.7, 11.5)	10 (0.2)	51.3 (49.7, 52.8)
Penta3	3847	3841	14.8 (13.7, 16.0)	32.5 (31.0, 34.0)	9.6 (8.7, 10.6)	6 (0.2)	42.1 (40.5, 43.7)
BCG	5264	5204	46.6 (45.2, 47.9)	54.2 (52.8, 55.5)	13.7 (12.8, 14.6)	60 (1.1)	67.8 (66.5, 69.1)
BCG scar	5264	4709	-	-	-	-	63.4 (62.0, 64.8)
PCV1	4771	4740	35.1 (33.7, 36.5)	48.2 (46.8, 49.6)	11.7 (10.8, 12.7)	31 (0.6)	59.9 (58.5, 61.3)
PCV2	4320	4308	23.2 (21.9, 24.5)	39.9 (38.5, 41.4)	10.5 (9.6, 11.4)	12 (0.3)	50.4 (48.9, 51.9)
PCV3	3847	3839	14.8 (13.7, 16.0)	32.1 (30.6, 33.6)	9.6 (8.7, 10.6)	8 (0.2)	41.7 (40.1, 43.3)
MCV	1227	1223	13.0 (11.2, 15.0)	24.0 (21.6, 26.5)	7.8 (6.4, 9.5)	4 (0.3)	31.8 (29.2, 34.5)

BCG, Bacille Calmette-Guérin; EPI, Expanded Program on Immunization; MCV, measles-containing vaccine; PCV, pneumococcal conjugate vaccine.
* Infants were excluded from the denominator if vaccinated early or (for BCG scar) if unavailable at the time of the survey. In 2017, early vaccination was only observed in Pishin and Karachi, while in 2018, all areas reported early vaccination.

ROUTINE IMMUNISATION SURVEY FOR CHILDREN UNDER 1 YEAR OLD IN CBV TIER ONE DISTRICTS

[*Pakistan*]

CLUSTER, HOUSEHOLD, & SURVEYOR INFORMATION	
This questionnaire is to be administered to all mothers or caretakers who care for a child who is under 1 year of age and is living in the household being surveyed. *A separate questionnaire should be used for each eligible child.*	
1. Cluster ID: ___ ___ ___ ___	2. Household number: ___ ___
3. Interviewer name: Name_____	4. Day / Month / Year of interview: ___ ___ / ___ ___ / ___ ___ ___ ___

Introduction & Greeting:

I AM FROM THE NATIONAL EMERGENCY OPERATIONS CENTRE AND WORKING ON A SURVEY FOR ROUTINE IMMUNIZATION. I WOULD LIKE TO TALK TO YOU ABOUT CHILDREN LIVING IN THE HOME UNDER ONE YEAR OF AGE. THE INTERVIEW WILL TAKE ABOUT 10 TO 20 MINUTES. ALL THE INFORMATION WE OBTAIN WILL REMAIN STRICTLY CONFIDENTIAL AND YOUR ANSWERS WILL NEVER BE SHARED WITH ANYONE OTHER THAN OUR PROJECT TEAM.

MAY I START NOW?

☐ *Yes, permission is given ⇨ Go to SECTION 1 to begin the interview.*

☐ *No, permission is not given ⇨ Answer Question 5 and move to the next eligible household*

5. Data entry clerk (Name):	Signature: _____

SECTION 1: DEMOGRAPHIC DATA	
Q1. NOW I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT THE AGE OF THE CHILD. WHEN WAS THE CHILD BORN? DAY, MONTH, YEAR (ACCORDING TO CAREGIVER)?	Date of birth (Caregiver) Day __ __ Month __ __ Year __ __ __ __
Q1B. WHAT IS THE CHILD'S DATE OF BIRTH (ACCORDING TO CBV REGISTER)?	Date of birth (CBV Register) Day __ __ Month __ __ Year __ __ __ __
Q2. WHAT IS THE SEX OF THE CHILD?	☐ MALE ☐ FEMALE

SECTION 2: IMMUNISATION HISTORY (EPI CARD)		
	YES	NO
Q3. DO YOU HAVE A CARD WHERE THE CHILD'S VACCINATIONS ARE WRITTEN DOWN? (*If YES*) MAY I SEE IT PLEASE?		
Q4. IF THERE IS AN EPI CARD, WHAT IS THE DATE OF BIRTH WRITTEN ON IT (DD/MM/YYYY)?		
Q5. HOW OLD IS THE CHILD? *Probe*: HOW OLD IS CHILD PRESENTLY? WAS CHILD BORN AFTER MAY 2017? CHILD MUST BE BETWEEN 0 TO 11 MONTHS	Age (in months) — —	
Q6. WHAT IS THE FINAL DATE OF BIRTH OF THE CHILD (DD/MM/YYYY)? PROBE: IF DATE OF BIRTH IS ON EPI CARD, TAKE THAT DATE AS THE FINAL DOB IF NO EPI CARD, TAKE THE DATE WRITTEN IN THE CBV BOOK AS THE FINAL DOB IF NO DOB IN CBV BOOK, TAKE CAREGIVER RECALL AS FINAL DOB		
DIRECTIONS *(a) Check "Y" under EPI card if you PHYSICALLY SAW the card* *(b) Check "N" under EPI card if mother **does not** have card or says has card but card is **not** available* *(c) Examine child's upper left or right arm to find BCG scar* ● *Check "Y" ONLY if scar is visible* If no scar seen, check "N" regardless of whether mother or card says child received BCG		

NAME OF ANTIGEN		EPI CARD			BCG SCAR 	
		YES	NO	Date on Card (dd/mm/yyyy)	YES	NO
BCG	BCG					
POLIO AT BIRTH	OPV0					
ORAL POLIO AT 6 WEEKS	OPV1					
PENTAVALENT 1 AT 6 WEEKS	PENTA1					
PNEUMOCOCCAL 1 AT 6 WEEKS	PNEUMO1					
ORAL POLIO AT 10 WEEKS	OPV2					
PENTAVALENT 2 AT 10 WEEKS	PENTA2					
PNEUMOCOCCAL 2 AT 10 WEEKS	PNEUMO2					
POLIO AT 14 WEEKS	OPV3					
PENTAVALENT 3 AT 14 WEEKS	PENTA3					

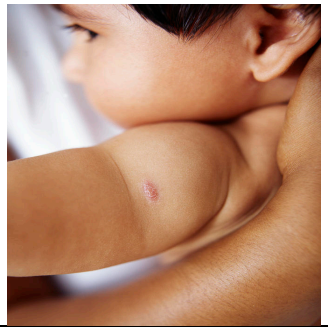
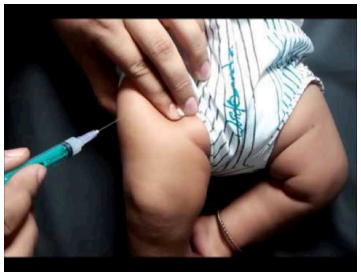
PNEUMOCOCCAL 3 AT 14 WEEKS	PNEUMO3				
IPV AT 14 WEEKS	IPV				
MEASLES AT 9 MONTHS	MEASLES1				

Section 2B: Caregiver Recall

Fill this section if NO EPI Card was seen
Show the pictures to better explain the vaccine
Hints
Try as best as possible to distinguish between injections given because
- *Child was sick and had to receive treatment*

versus

- *Child was due for routine immunisation doses*

	YES	NO
Q7. HAS THE CHILD EVER RECEIVED A BCG VACCINATION AGAINST TUBERCULOSIS – THAT IS, AN INJECTION IN THE ARM OR SHOULDER THAT USUALLY CAUSES A SCAR? (AT BIRTH)  		
Q8. HAS THE CHILD EVER RECEIVED ANY "VACCINATION DROPS IN THE MOUTH" TO PROTECT HIM/HER FROM GETTING DISEASES – THAT IS, POLIO? WAS THE FIRST POLIO VACCINE RECEIVED IN THE FIRST TWO WEEKS FROM BIRTH? 		
Q9. HAS THE CHILD EVER RECEIVED A PENTAVALENT VACCINATION – THAT IS, AN INJECTION IN THE THIGH– TO PREVENT HIM/HER FROM GETTING TETANUS, WHOOPING COUGH, HIB, HEPATITIS B, OR DIPHTHERIA AT 6 WEEKS ?  *Probe by indicating that Penta vaccination is sometimes given at the same time as*		

Polio 1 and Pneumococcal		
Q10. HAS THE CHILD EVER RECEIVED ANY "VACCINATION DROPS IN THE MOUTH" TO PROTECT HIM/HER FROM GETTING DISEASES – THAT IS, POLIO AT 6 WEEKS?		
Q11. HAS THE CHILD EVER RECEIVED A PNEUMOCOCCAL VACCINATION – THAT IS, AN INJECTION IN THE THIGH– TO PREVENT HIM/HER FROM GETTING PNEUMONIA AT 6 WEEKS? 		
Q12. HAS THE CHILD EVER RECEIVED A PENTAVALENT VACCINATION – THAT IS, AN INJECTION IN THE THIGH– TO PREVENT HIM/HER FROM GETTING TETANUS, WHOOPING COUGH, HIB, HEPATITIS B, OR DIPHTHERIA AT 10 WEEKS ? *Probe by indicating that Penta vaccination is sometimes given at the same time as Polio and Pneumococcal*		
Q13. HAS THE CHILD EVER RECEIVED ANY "VACCINATION DROPS IN THE MOUTH" TO PROTECT HIM/HER FROM GETTING DISEASES – THAT IS, POLIO AT 10 WEEKS?		
Q14. HAS THE CHILD EVER RECEIVED A PNEUMOCOCCAL VACCINATION – THAT IS, AN INJECTION IN THE THIGH– TO PREVENT HIM/HER FROM GETTING PNEUMONIA AT 10 WEEKS?		
Q15. HAS THE CHILD EVER RECEIVED A PENTAVALENT VACCINATION – THAT IS, AN INJECTION IN THE THIGH– TO PREVENT HIM/HER FROM GETTING TETANUS, WHOOPING COUGH, HIB, HEPATITIS B, OR DIPHTHERIA AT 14 WEEKS ? *Probe by indicating that Penta vaccination is sometimes given at the same time as Polio and Pneumococcal*		
Q16. HAS THE CHILD EVER RECEIVED ANY "VACCINATION DROPS IN THE MOUTH" TO PROTECT HIM/HER FROM GETTING DISEASES – THAT IS, POLIO AT 14 WEEKS?		
Q17. HAS THE CHILD EVER RECEIVED A PNEUMOCOCCAL VACCINATION – THAT IS, AN INJECTION IN THE THIGH– TO PREVENT HIM/HER FROM GETTING PNEUMONIA AT 14 WEEKS?		
Q18 HAS THE CHILD EVER RECEIVED A MEASLES INJECTION– THAT IS, A SHOT IN THE ARM AT THE AGE OF 9 MONTHS OR OLDER - TO PREVENT HIM/HER FROM GETTING MEASLES? 		

SECTION 3: REASONS FOR FAILURE TO VACCINATE

*Fill this section **IF**:*

- *CHILD DID NOT RECEIVE EVERY ANTIGEN THEY WERE ELIGIBLE FOR (EPI CARD)*

  OR

- *Caregiver recall is **'NO'** at least one time*

Q19. WHY WAS THE CHILD NOT FULLY IMMUNISED FOR THEIR AGE?	*(tick **ALL** that apply)*
(A) LACK OF INFORMATION	☐ FEAR OF SIDE EFFECTS ☐ PLACE/TIME OF IMMUNISATION UNKNOWN ☐ UNAWARE OF NEED TO IMMUNIZE ☐ UNAWARE OF NEED TO RETURN FOR 2ND AND 3RD DOSES ☐ WRONG IDEAS ABOUT CONTRAINDICATION ☐ NONE OF THE ABOVE ☐ OTHERS _____
(B) LACK OF MOTIVATION	☐ POSTPONE TIME OF IMMUNIZATION ☐ RUMORS ☐ NONE OF THE ABOVE ☐ OTHERS _____
(C) BARRIERS TO IMMUNIZATION	☐ CHILD ILL ☐ FAMILY PROBLEMS ☐ LONG WAITING TIME ☐ MOTHER TOO BUSY ☐ PLACE OR TIME IS INCONVENIENT ☐ VACCINATOR ABSENT ☐ VACCINE NOT AVAILABLE ☐ NONE OF THE ABOVE ☐ OTHERS _____

YOU HAVE COME TO THE END OF THIS QUESTIONNAIRE

Is there another child under 12 months of age living in this household?

☐ *Yes ⇨ Begin filling out next questionnaire form*

☐ *No ⇨ End the interview with this respondent by thanking him/her for his/her cooperation*

1. *Refer to the randomization list for the next household you are supposed to visit.*
2. *If there is an eligible child in that house, sample the house*
3. *If there is no eligible child in that house, proceed to the immediate next house and check*
4. *Enter the household and fill next questionnaire form*

Observations