Arch Clin Pediatr. 2024;1(1):10-22.

Archives of Clinical Pediatrics | Research Article

A Community-Based Survey Exploring the Determinants of Invalid, Delayed, and Missed Immunization in Children of Urban Slums of Karachi, Pakistan

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Received date: May 10,2024, **Accepted date:** July 19, 2024

Citation: Khaliq A, Ali S, Zahid A, Lokeesan L, Holmes-Stahlman R, Lassi ZS. A community-based survey exploring the determinants of invalid, delayed and missed immunization in children of urban slums of Karachi, Pakistan. Arch Clin Pediatr. 2024;1(1):10-22.

Abstract

In children, the global burden of vaccines-preventable diseases (VPDs) and deaths can be averted by adopting timely immunization practices. Administering immunization to a child within 28 or 30 days of the designated immunization date is referred to as timely immunization. Besides timely immunization, immunization non-compliance (invalid or delayed or missed immunization) increases the risk of various forms of VPDs and death in children, particularly living in urban slums. This study was designed to examine the immunization practices and to measure the determinants of immunization non-compliance in children living in urban slums of Karachi, Pakistan. A community-based retrospective cohort was carried out from October-2018- to August-2019 in six different urban slums of Karachi. Immunization status of children aged less than 2 years was assessed by reviewing their vaccination card. Children from each slum were approached via 30x7 multistage stratified cluster sampling technique. Data of each child was analyzed descriptively and inferentially using statistical software, i.e., Jamovi version 1.2.25. The practice of timely immunization was observed in approximately half of children, i.e., 49.8% (n=457). The immunization rate at birth (first-visit) was 100%, of which 95.7% were timely immunized. Following the second immunization visit, a sharp decline in the immunization rate, including timely immunization rate was observed. Lack of knowledge, childhood illnesses, lack of interest, and vaccines unavailability were the main reasons of immunization non-compliance. However, an increase in paternal education was significantly associated with decreasing the odds of immunization non-compliance. A decrease in the practice of timely immunization is replaced by either invalid and/or delayed and/or missed immunization practices. Thus, timely immunization is crucial for preventing infectious diseases and promoting the health of a child.

Keywords: Missed, Invalid, Delayed, Immunization, Children, Karachi

Introduction

Immunization is a cost-effective health intervention for reducing the burden of many vaccine-preventable diseases (VPD), disabilities, and deaths [1-3]. Every year, more than two million children are saved through timely immunization [4], and between the years 2000 and 2015, immunization has reduced the global burden of deaths to VPDs fourfold [5].

The Centers for Disease Control and Prevention (CDC) and the Advisory Committee on Immunization Practices (ACIP) endorse the importance of timely immunization for reducing the burden of VPDs and deaths among children [6,7].

In children, timely immunization is an important strategy for reducing the global burden of VPDs [7,8]. Adherence to timely immunization in children can dramatically reduce the incidence, prevalence, and mortality of various types of VPDs [8]. Timely immunization in children refers to immunizing a child within 28 or 30 days of the scheduled immunization date [8,9]. However, early administration (invalid immunization) or delayed administration or missing the dose of vaccines in children indicates non-compliance with the recommended immunization schedule, which is associated with a higher risk of VPDs and even deaths [3,10-12].

Immunization non-compliance is a global concern for both developed and developing countries. This issue of immunization non-compliance is more common among underdeveloped nations [13,14]. However, within a country urban-rural differences pertaining to immunization compliance also exist [15,16].

Within the South Asia region, Pakistan is the second largest country, with a human development index of 161. This HDI of 161 indicates the poor socioeconomic condition of the country. The country is still a hub of wild poliovirus (WPV) despite global eradication efforts [17]. According to the Pakistan Demographic and Health Survey (PDHS) report 2017-2018, the coverage of full immunization among children in Pakistan is 66%. Of these, only 50% had received age-appropriate immunization [18]. Compared with children of middle to high socioeconomic class, more than a quarter of children from low socioeconomic class remain unimmunized [19]. Children living in urban slums are underprivileged and are more susceptible to various VPDs, such as polio, measles, and enteric fever [19,20]. However, statistics about immunization coverage and appropriate immunization practices in slum areas are not yet known.

Karachi, a densely populated metropolitan city in Pakistan with a population of 14.9 million, accommodates approximately 40% slum dwellers [21]. Despite the critical public health implications, there is a notable lack of comprehensive research regarding the immunization practices of slum dwellers in Karachi. To address this knowledge gap, this study investigated the pediatric immunization practices among slum dwellers in Karachi. The study focused on identifying the determinants of invalid, delayed, and missed immunizations within this specific urban demographic. Thus, this study provided a deeper understanding of the factors affecting immunization compliance in slum areas and contribute valuable insights to improve immunization programs and public health strategies in this urban context.

Methodology

Study design, setting, and duration

This community-based retrospective study was carried out in the urban slums of Karachi from October 2018 to August 2019. In this study, immunization data of children of urban slums aged below 2-years was extracted from their vaccination cards. The urban slums in this study were selected from six different districts of Karachi: District East, District South, District Central, District West, District Malir, and District Korangi. Each district is composed of union councils (UCs) of different sizes. Within each union council, many slums exist. Generallyral, 40% of the Karachi population is composed of slum dwellers [21,22]. People living in urban slums are underprivileged, and 89% of slum dwellers are living below the poverty line [22]. Thus, this study targeted slums from each UCs and district of Karachi, Pakistan.

Study population, sample selection sampling method

This study targeted mothers of children aged less than two years from the urban slums of Karachi. The recent report of Pakistan Demographic & Health Survey (2017-2018) reported 48.6% age-appropriate immunization rate among under two-years children of urban Sindh. Considering 48.6% as the appropriate immunization practices, 95% confidence interval, and 5% margin of error, the sample size calculated was 377. The research team decided to extrapolate the sample size to triple because of concerns related to participants refusals, incomplete and/or partial responses.

For the selection of study participants, a multistage sampling technique was employed. The research team at first selected the urban slums from each district following a non-probability purposive sampling method. The non-probability purposive sampling method for the selection of slums was used because no definite information regarding the number of slums within each district of Karachi exists. In this study, the research team purposively selected each slum, and then took permission from stakeholders (union council chairman or community leaders, or religious leaders) for a household survey. Following the selection of urban slums, households and participants were selected. For the selection of participants, the 30X7 multi-stage cluster sampling technique was used. The 30X7 cluster sampling technique is a type of random sampling technique, in which the research team approaches every 7th household from each cluster. This type of sampling technique is extensively used by the Expanded Programme on Immunisation (EPI) for evaluating the vaccination program coverage and its efficacy [23]. To perform the 30X7 sampling method, the research team of this study classified each slum as a cluster. From each cluster, every 7th household was approached systematically for the data collection. A pre-enrolment screening was performed to assess the eligibility of each household.

The households were selected for data collection if they have parents/caregivers, vaccination cards, and children under two years of age. Certain households were excluded because of communication barriers, and the non-availability of community volunteers as translators. In a household where children under two years of age were not present then the next house was considered for inclusion. After eligibility determination, the research team enrolled all the parents/caregivers of all the eligible children. The research team interviewed all the enrolled parents/caregivers regarding pediatric immunization practices and assessed the vaccination status of each child from the vaccination card, which were obtained from the parents/caregiver during the household visits.

Description of data collection instrument

For conducting this survey, translated version (Urdu) of a pre-validated and structured questionnaire having a reliability coefficient of 0.714 was used. This questionnaire was adapted from a study conducted by Khaliq, *et al.*, (2017) in Karachi, Pakistan [3].

The questionnaire used in the study had seven sections, which consisted of 63 questions. The first section of this questionnaire consisted of four questions, which were related to the visit information. The second and third sections of this questionnaire determined the eligibility of each participant approached for the data collection. Participants who were found eligible after the predefined screening were invited to participate in other sections of this questionnaire. A four-digit enrolment number was provided to all the respondents who consented to participate. For each participant, further information related to the sociodemographic background, immunization-related knowledge and practices, and reasons for immunization non-adherence were collected from the questions present in section four to section six. The last section of this questionnaire provides information related to the quality control and quality assurance parameters pertaining to data collection, data reviewing, and data entry.

Measurement of study outcome

In this study, the outcome of interest was the immunization status of children, and the immunization status of each child was calculated from the vaccine administration dates and the due date of vaccination. The vaccine administration date was the date at which the child receives a vaccination, whereas the due date of vaccination was the date at which the child has either received or has to receive the succeeding vaccination dose. The information related to vaccine administration and due date were obtained from the vaccination cards. The research team identified four different types of immunization status: valid, delayed, missed, or invalid.

If the vaccine administration date was within the window period of five days before or within 28 days of the vaccine schedule date, then it was considered a valid vaccine administration. Vaccine administration to a child five days before the recommended scheduled doses, then it is considered as invalid administration [24]. The immunization was considered delayed if the difference between the vaccine schedule date and vaccine administration date exceeds more than four weeks or 28 days [25]. Likewise, when the vaccination card does not show any evidence of vaccine administration irrespective of vaccine schedule date, then it is called missed vaccine administration.

Study covariates

For assessing the determinants of immunization non-compliance, various child, maternal, paternal, household, and practices related covariates were examined. Among the children related factors, the child age, child sex, and childbirth order were included. However, for the maternal and paternal factors, the age and education of mother and father was considered separately. The household factors include number of children delivered, family size, and place of birth. The knowledge and practice related factors included a set of questions, which assessed the knowledge and practice related to the immunization practice. The mothers who responded correctly were categorized as "Knowledgeable", while others were classified as "Not knowledgeable".

Immunization visits were assessed at six different times according to the EPI schedule of Pakistan i.e., "at birth", "6-weeks", "10-weeks", "14-weeks", "9-months", and "15-months". The detail regarding these categories is presented in **Table 1**.

Table 1. Immunization visits categorization according to child age.

Visit number	Recommended age of immunization
Visit-1	At birth
Visit-2	6 weeks
Visit-3	10 weeks
Visit-4	14 weeks
Visit-5	9 months
Visit-6	15 months

Statistical analysis

The data regarding the number of each study variable was assessed descriptively using Jamovi 1.2.25 software. All the categorical and continuous variables at first were assessed descriptively. Later, the distribution of each categorical and continuous variable for each category of outcome variable was assessed descriptively. The data of all the categorical variables were presented using frequency and percentage, while for the continuous variables mean and standard deviation were used for the presentation of descriptive data. In addition, the rates of full immunization, timely (valid) immunization, invalid immunization, delayed immunization, and missed

immunization were calculated for the overall sample as well as at each immunization visit. Trend lines were used for illustrating the different types of immunization rates (overall and each visit).

The determinants of each type of immunization non-compliance were assessed using multinomial logistic regression. For running the multinomial logistic regression, unadjusted odds ratio (OR) and adjusted OR were calculated. A backward elimination method for calculating the adjusted ORs was used, and all the variables having a significance of over 5% were removed manually from the model. In the final model, we kept only those variables having a significance level of ≤ 0.05. The OR and 95% confidence interval for each variable were assessed to present the association of immunization status with the various predictor variables.

Ethical consideration

The protocol of this research was approved by the Management Research Cell (MRC) of the Department of Health Management, Institute of Business Management (IoBM), Karachi, Pakistan (Approval number: **MBA-MHM-16909-19**). Moreover, permissions from all the stakeholders of different slums were also taken before data collection. Verbal and written consent was taken from the participating caretaker. Principals of beneficence, non-malevolence, anonymity, and equity were maintained throughout the study.

Results

Screening, eligibility, and enrolment of study participants

A total of 1,371 households from all six clusters were approached, of which 50 refused to screen the child. Of the remaining 1,321 households, 1,034 were eligible. Among eligible households, data of 917 households were used for analysis, while the rest was removed because of several reasons highlighted in **Figure 1**.

Characteristics of study sample

Of 917 participants, around half of the children received vaccination on time (n=457~49.8%). There were 20.2% (n=185) children, who missed an immunization visit, while the prevalence of invalid and delayed immunized children was 12% (n=110) and 18% (n=165), respectively.

The distribution of male and female children was almost homogenous, there were 49.1% (n=450) males, and 50.9% (n=467) female. In this study, only 5% (n=46) of children had reached the age of sixth immunization visits (**Table 2**).

More than half (n=498~54.3%) of the mothers had correct knowledge about the number of immunization visits during the first year of child life, while the correct knowledge about the immunization visits during the second year of their child's life was near to a quarter (n=241~26.3%).

Different reasons for the immunization non-adherence reported in this study were lack of knowledge (n=648 ~ 71.3%), childhood illnesses (555 ~61.1%), lack of interest of decision-makers (n=534 ~58.7%), and unavailability of vaccines in the immunization center (n=494~54.5%) (**Table 2**).

Infant immunization status for different immunization visits

The highest immunization rate of 100% was reported at first visit, i.e., at birth. Similarly, the valid immunization rate of 95.7

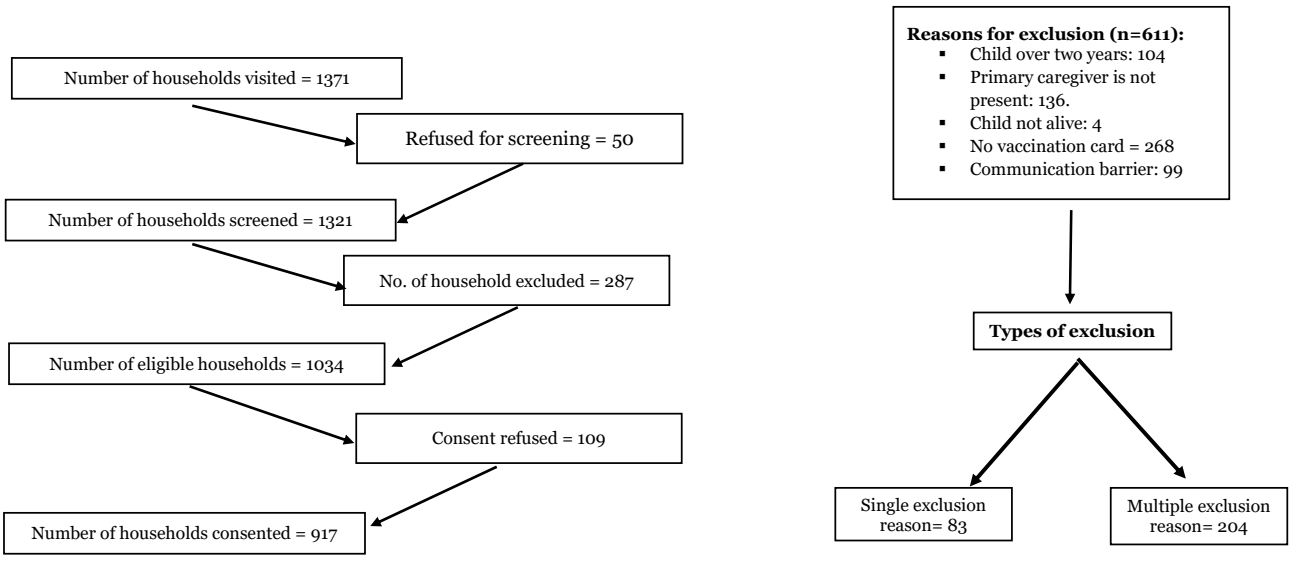


Figure 1. Participants tracking and eligibility screening.

Table 2. Distribution of valid, delayed, missed and invalid immunization cases.

Variable	Categories	Total	Valid	Invalid	Delayed	Missed
Child factors						
Child sex	Male	450 (49.1%)	229 (50.1%)	52 (47.2%)	89 (53.9%)	80 (43.2%)
	Female	467 (50.9%)	228 (49.8%)	58 (52.7%)	76 (46.1%)	105 (56.7%)
Birth order		4.00 ± 1.82	3.80 ± 1.79	4.12 ± 1.84	4.12 ± 1.83	4.34 ± 1.81
Maternal demographic factors						
Maternal age		29.6 ± 6.17	29.2 ± 6.23	28.8 ± 6.01	30.1 ± 6.24	30.5 ± 5.93
Maternal education		4.42 ± 2.29	4.84 ± 2.27	4.43 ± 2.25	4.31 ± 2.26	3.49 ± 2.11
Paternal demographic factors						
Paternal age		34.3 ± 5.49	34.0 ± 5.35	34.3 ± 4.90	34.5 ± 5.68	35.1 ± 5.92
Paternal education		3.84 ± 2.46	4.25 ± 2.57	3.45 ± 2.15	3.73 ± 2.39	3.17 ± 2.24
Household factors						
Number of children delivered		3.81 ± 1.65	3.63 ± 1.65	3.82 ± 1.69	3.87 ± 1.65	4.21 ± 1.53
Total family size		7.00 ± 1.74	6.86 ± 1.72	7.17 ± 1.78	7.03 ± 1.77	7.22 ± 1.69
Place of childbirth	Hospital	460 (50.2%)	271 (59.2%)	59 (53.6%)	73 (44.2%)	57 (30.8%)
	Maternity center	446 (48.6%)	183 (40.1%)	50 (45.4%)	90 (54.5%)	123 (66.5%)
	Home	11 (1.2%)	3 (0.7%)	1 (0.9%)	2 (1.2%)	5 (2.7%)
Immunization knowledge and practices						
Correct knowledge of vaccination center visit in the first year	Yes	498 (54.3%)	282 (61.7%)	69 (62.7%)	89 (53.9%)	58 (31.3%)
Correct knowledge of vaccination center visit in the second year	Yes	241 (26.3%)	137 (29.9%)	34 (30.9%)	49 (29.6%)	21 (11.3%)
Vaccination visit	First visit	210 (22.9%)	201 (43.9%)	0 (0%)	9 (5.4%)	0 (0%)
	Second visit	204 (22.2%)	127 (27.7%)	19 (17.2%)	43 (26.1%)	15 (8.1%)
	Third visit	191 (20.8%)	65 (14.2%)	46 (41.8%)	43 (26.1%)	37 (20%)
	Fourth visit	161 (17.6%)	39 (8.5%)	23 (20.9%)	31 (18.8%)	68 (36.8%)
	Fifth visit	105 (11.5%)	17 (3.7%)	22 (20%)	38 (23%)	28 (15.1%)
	Sixth visit	46 (5%)	8 (1.8%)	0 (0%)	1 (0.6%)	37 (20%)
	Total	917 (100%)	457 (49.8%)	110 (11.9%)	165 (17.9%)	185 (20.1%)
Reasons for invalid, missed, and delayed immunization						
Vaccination center outside catchment area	Yes	429 (47.2%)	204 (44.6%)	48 (43.6%)	85 (51.5%)	92 (49.7%)
Family decision maker is against immunization	Yes	534 (58.7%)	305 (66.7%)	70 (63.6%)	95 (57.6%)	64 (34.6%)

Table 2. Distribution of valid, delayed, missed and invalid immunization cases.

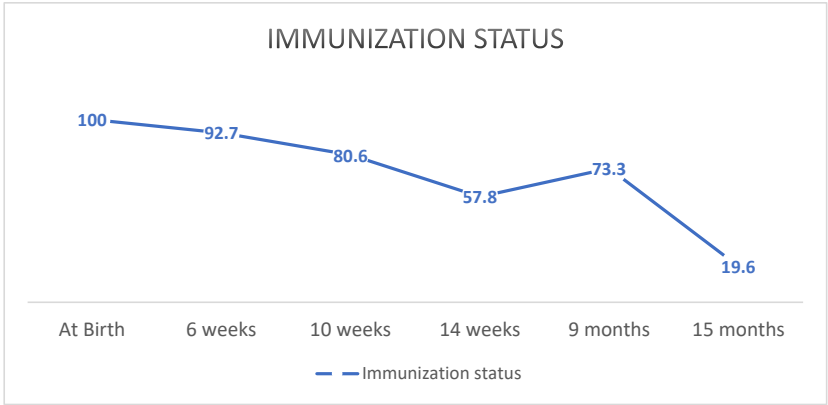
Variable	Categories	Total	Valid	Invalid	Delayed	Missed
Unavailability of vaccine in the vaccination center	Yes	495 (54.5%)	266 (58.2%)	61 (55.4%)	92 (55.8%)	76 (41.1%)
Migration of family	Yes	200 (22%)	362 (79.2%)	84 (73.6%)	129 78.2%)	134 (72.4%)
Cost of vaccine	Yes	111 (12.2%)	408 (89.3%)	98 (89%)	140 (84.8%)	152 (82.2%)
Vaccine related side-effects	Yes	432 (47.5%)	264 (57.8%)	55 (50%)	78 (47.3%)	80 (43.2%)
Child was sick	Yes	555 (61.1%)	298 (65.2%)	75 (68.1%)	103 (62.4%)	79 (42.7%)
Doctor advised not to vaccinate	Yes	263 (28.9%)	369 (80.7%)	81 (73.6%)	111 (67.3%)	85 (45.9%)
Lack of knowledge about vaccination schedule	Yes	648 (71.3%)	145 (31.7%)	14 (12.7%)	44 (26.7%)	58 (31.4%)
Lack of trust on Government	Yes	271 (29.8%)	103 (22.5%)	83 (75.4%)	103 (62.4%)	93 (50.3%)
Too many vaccines traumatize the children	Yes	392 (43.4%)	238 (52.1%)	61 (55.4%)	102 (61.8%)	111 (0%)

per 100 children was observed at first visit. However, no single case of invalid and missed immunization was reported at that visit. Following the second immunization visit, this study reported a sharp decline in the immunization rate, including valid immunization rate. The immunization rate at second visit (6th week) was 92.7 per 100 children, which decreased to 19.6 per 100 children at the sixth visit (15th-month). Similarly, the valid immunization rate at second immunization visit was 62.2 per 100 children, which decreased to 16.2 per 100 children and 17.4 per 100 children during the 5th and 6th immunization visits, respectively. The decrease in the immunization rate, including valid immunization rate at each succeeding immunization visit was accompanied by an upsurge of invalid and/or delayed and/or missed immunization among children (**Figure 2**).

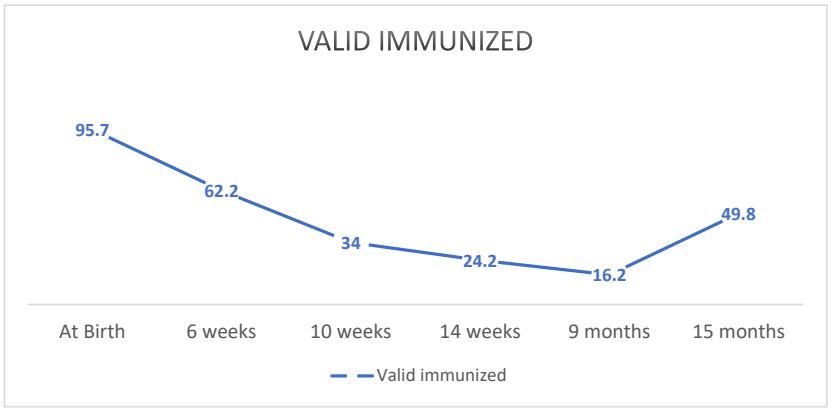
Determinants of invalid, delayed, and missed immunization

An increase in paternal education was significantly associated to decrease the odds of invalid, delayed, and missed immunization in children. Similarly, concerns regarding the vaccines non-availability significantly reduce the odds of invalid and missed immunization but showed no association with the delayed immunization (**Table 3**). However, incorrect knowledge about the number of immunization visits during the first year of life, lack of knowledge about the immunization schedule, and lack of trust in the government significantly increase the odds of invalid, delayed, and missed immunization (**Table 3**).

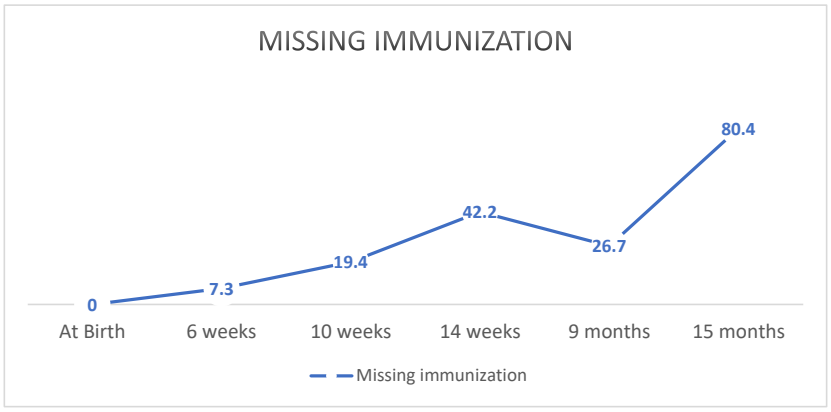
A. Child immunization status at each immunization visit:



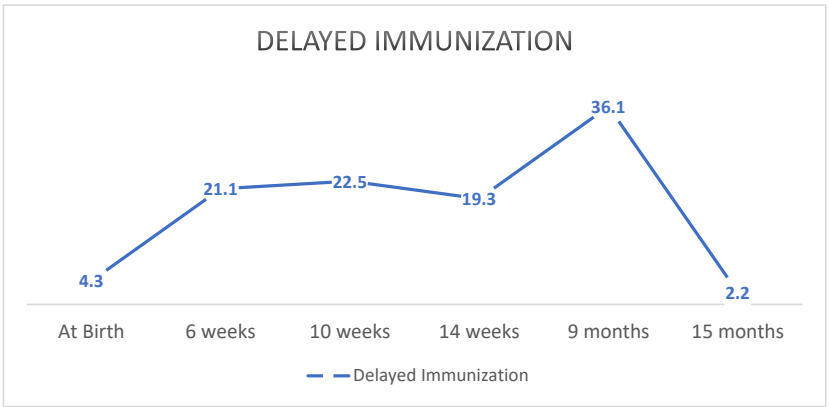
B. Children with valid immunization status at each immunization visit:



C. Children with missing immunization status at each immunization visit:



D. Children with delayed immunization status at each immunization visit:



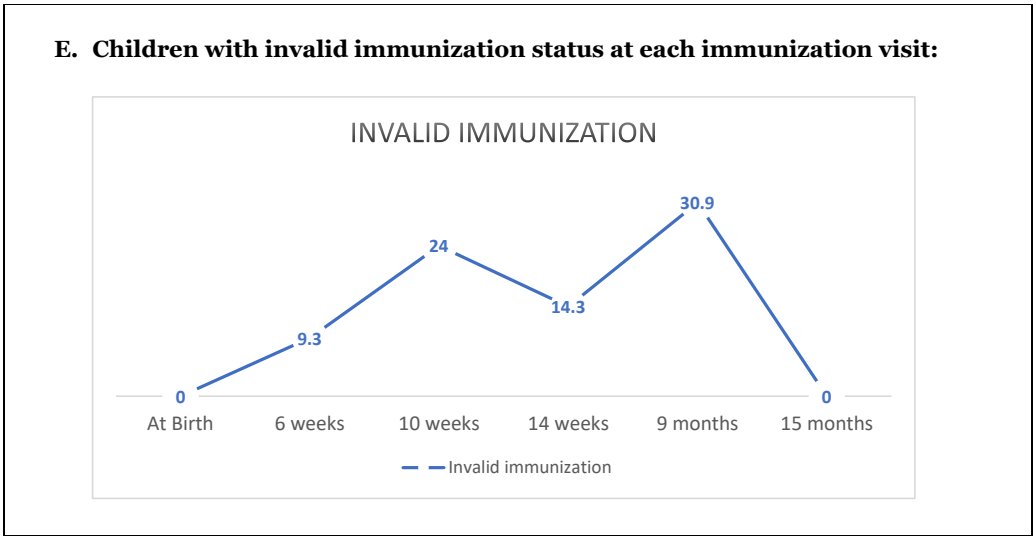


Figure 2. Graphical illustration of full immunization, valid immunization, invalid immunization, delayed immunization and missing immunization in children (N=917).

Discussion

Age-proportionate and timely immunization are crucial for preventing infectious diseases and promoting the health of a child. In this study, we found that invalid and delayed immunization replaced the valid immunization with the increase in age. The rate of valid immunization decreased with the age of a child while the rate of missing and delayed immunization increased with the age. The rate of valid immunization is high at birth while the rate of delayed immunization is high at the age of 9 months and the missing immunization is high at the age of 15 months. The percentage of fully immunized children for all the vaccines recommended in EPI program of Pakistan was 20% and this percentage is far lower than the finding reported by earlier studies held in other regions of Pakistan [26-28]. The low percentage of fully immunized children can be attributed to the limited information on the source of data. In our study, data related to child immunization were collected from the vaccination card of a child. However, in other studies [26,27], the data was collected from the vaccine registries or caregivers' verbal recall. Despite the source of information, it may be important for recording child immunization on vaccination card as clinical records may be valid than the caregivers' or parents' recall over the time [29].

We found in our study that inadequate knowledge about the number of immunization visits during the first year of life, lack of knowledge about the immunization schedule significantly increased the odds of in-valid, delayed, and missed immunization. Giving inadequate information to parents regarding immunization may be a reason for the increased odds of invalid or missed immunization of child [30] as parents may not be aware of their child's immunization schedule. Similarly in a study conducted in Pakistan, it was revealed that parents having lack of knowledge about immunization schedules or the interval between subsequent doses of vaccines were significantly positively associated with missed or delayed immunization in children [3]. However, reasons for lack of knowledge in parents were not explored in detail in our study. Therefore, it may be worth assessing parents' knowledge about vaccination against various factors related to their socio-demographic characteristics and factors related to health services support in the future. However, the findings of our study emphasize that education regarding the importance of child immunization, frequent awareness of child immunization schedule is required for parents in Pakistan regardless of any circumstances.

Our study demonstrated a significant association between vaccine unavailability and immunization non-compliance. This vaccine unavailability is linked to uneven vaccine distribution and disparities in delivering community health services within a country, mirroring results from a study conducted in the United Kingdom [31]. Therefore, it is important that Pakistan health services should monitor the supply of vaccines and accessibility of vaccine doses across the mandatory immunization periods to avoid delayed or missed immunization to children. Further, this study has been limited to the parents and children from Karachi, Pakistan. Therefore, it may be worth assessing whether availability of vaccines an issue across other regions of Pakistan. It may be meaningful to do such assessment across other regions to identify the process of vaccine supplies and equity in accessing vaccines across the county to take nation level action to avoid inequity in health services.

Table 3. Multinomial logistic regression for assessing the determinants of immunization status.

Variable	Categories	Invalid		Delayed		Missed	
		Unadjusted	**Adjusted**	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**
Child sex	**Male**	0.89 (0.58 to 1.35)	-	1.16 (0.81 to 1.66)	-	0.75 (0.53 to 1.07)	-
	Female	Ref		Ref		Ref	
Birth order		1.10 (0.98 to 1.23)	-	1.10 (0.99 to 1.21)	-	1.18 (1.07 to 1.29) *	-
Maternal age		0.98 (0.95 to 1.02)	-	1.02 (0.99 to 1.05)	-	1.03 (1.00 to 1.06)	-
Maternal education		0.92 (0.84 to 1.01)	-	0.90 (0.83 to 0.97) *	-	0.75 (0.69 to 0.82) *	-
Paternal age		1.01 (0.97 to 1.04)	-	1.02 (0.98 to 1.05)	-	1.03 (1.00 to 1.07) *	-
Paternal education		0.87 (0.79 to 0.95) *	0.81 (0.72 to 0.91) *	0.91 (0.85 to 0.98) *	0.90 (0.83 to 0.99) *	0.82 (0.76 to 0.89) *	0.81 (0.73 to 0.91) *
Number of children delivered		1.07 (0.94 to 1.22)	-	1.09 (0.98 to 1.22)	-	1.24 (1.12 to 1.39) *	-
Total family size		1.11 (0.98 to 1.25)		1.05 (0.95 to 1.17)		1.12 (1.02 to 1.24) *	
Place of childbirth	**Hospital**	Ref	-	Ref	-	Ref	-
	Maternity centre	1.25 (0.82 to 1.91)		1.82 (1.27 to 2.62) *		3.19 (2.21 to 4.60) *	
	Home	1.53 (0.15 to 14.97)		2.47 (0.40 to 15.09)		7.92 (1.84 to 34.10) *	
Correct knowledge of vaccination centre visit in the first year	**Yes**	Ref	Ref	Ref	Ref	Ref	Ref
	No	0.95 (0.62 to 1.47)	0.99 (0.58 to 1.66)	1.37 (0.96 to 1.97)	1.20 (0.76 to 1.88)	3.52 (2.45 to 5.07) *	3.09 (1.80 to 5.31) *
Correct knowledge of vaccination centre visit in the second year	**Yes**	Ref	-	Ref	-	Ref	-
	No	0.95 (0.60 to 1.50)		1.01 (0.68 to 1.49)		3.34 (2.03 to 5.49) *	
Vaccination visit		2.38 (1.99 to 2.84) *	2.73 (2.24 to 3.33) *	2.20 (1.89 to 2.57) *	2.59 (2.17 to 3.09) *	3.67 (3.08 to 4.38) *	5.51 (4.39 to 6.91) *
Vaccination centre in catchment area	**Yes**	0.94 (0.62 to 1.43)	-	1.31 (0.91 to 1.87)	-	1.24 (0.88 to 1.76)	-
	No	Ref		Ref		Ref	

Table 3. Multinomial logistic regression for assessing the determinants of immunization status.

Variable	Categories	Invalid		Delayed		Missed	
		Unadjusted	**Adjusted**	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**
Family decision maker is against immunization	**Yes**	1.17 (0.76 to 1.82)	-	1.49 (1.03 to 2.16) *	-	3.80 (2.64 to 5.45) *	-
	No	Ref		Ref		Ref	
Vaccine availability issues	**Yes**	1.14 (0.75 to 1.73)	0.60 (0.36 to 0.99) *	1.11 (0.77 to 1.59)	0.82 (0.52 to 1.28)	1.98 (1.40 to 2.81) *	0.43 (0.25 to 0.73) *
	No	Ref	Ref	Ref	Ref	Ref	Ref
Migration of family	**Yes**	1.23 (0.75 to 2.02)	-	1.07 (0.69 to 1.67)	-	1.42 (0.95 to 2.13)	-
	No	Ref		Ref		Ref	
Cost of vaccine	**Yes**	1.11 (0.56 to 2.17)	-	1.55 (0.91 to 2.64)	-	1.78 (1.08 to 2.94) *	-
	No	Ref		Ref		Ref	
Vaccine related side-effects	**Yes**	1.39 (0.92 to 2.12)	-	1.54 (1.07 to 2.20)	-	0.20 (0.15 to 0.27) *	-
	No	Ref		Ref		Ref	
Child was sick	**Yes**	0.89 (0.57 to 1.40)	-	1.13 (0.78 to 1.65)	-	2.50 (1.76 to 3.56) *	-
	No	Ref		Ref		Ref	
Doctor advised not to vaccinate	**Yes**	1.57 (0.96 to 2.55)	1.40 (0.70 to 2.82)	2.09 (1.40 to 3.14) *	1.54 (0.85 to 2.79)	5.01 (3.44 to 7.29) *	2.73 (1.41 to 5.30) *
	No	Ref	Ref	Ref	Ref	Ref	Ref
Lack of knowledge about vaccination schedule	**Yes**	3.22 (1.78 to 5.85) *	4.00 (2.05 to 7.83) *	1.28 (0.86 to 1.91)	1.80 (1.11 to 2.91) *	1.00 (0.69 to 1.45)	1.86 (1.05 to 3.30) *
	No	Ref	Ref	Ref	Ref	Ref	Ref
Lack of trust on Government	**Yes**	1.24 (0.76 to 2.02)	1.89 (0.95 to 3.76)	2.26 (1.53 to 3.34) *	3.11 (1.76 to 5.49) *	3.65 (2.52 to 5.28) *	3.53 (1.84 to 6.78) *
	No	Ref	Ref	Ref	Ref	Ref	Ref
Too many vaccines traumatize the children	**Yes**	0.87 (0.57 to 1.33)	-	0.66 (0.46 to 0.96) *	-	0.70 (0.49 to 1.00)	-
	No	Ref		Ref		Ref	

Also, it is evident from global studies, that personal beliefs of parents regarding child immunization, myths around immunization, lack of trust on health services, and socio-economic status of a child's family significantly influence the vaccine uptake during the first two years of a child's life [32-34]. However, we did not find associations between these factors and immunization status of child from Karachi, Pakistan. Therefore, broader research may be needed across other regions of Pakistan to identify the factors related to parent's knowledge and beliefs around child immunization. In addition to improving the practice of health services, developing a positive attitude in parents towards child immunization may add value to time uptake of vaccines. This may minimize the chances of delayed of missed immunization in children from Pakistan [34,35].

Strengths and limitations of the study

To the best of our knowledge, this study is amongst the few studies which examined the determinants of non-adherence to immunization and its relationship with maternal knowledge. This study provided strong evidence regarding the determinants of non-adherence to immunization because in this study the immunization status of each child was assessed through the vaccination card. Moreover, the use of a pre-validated structured questionnaire and 30X7 sampling technique for the recruitment of a large sample further strengthens the findings of this study. However, there were several limitations in this study. The data of this study were collected retrospectively from the child vaccination card only at once and it was not validated from the other sources, like vaccination centers. Thereby, raising concerns over recall and reporting biases. Additionally, the observational design of this study further weakens the study findings, because the observational design of this study failed to show the causation of immunization non-adherence with various covariates. Some parents did not know about the exact date of birth of their children, and many parents reported different ages of their child from the ages written on the vaccination card. Due to this reason, the relationship of child age with the immunization status was not assessed in this study. Furthermore, the validity and reliability of the questionnaire adopted from the previous study [3] was not tested for this study context and population, rather this study relies solely on the reliability and validity of the adopted questionnaire. The findings of this study represent the determinants of immunization non-adherence of selected slums in Karachi and is therefore unable to present the immunization status of other areas and localities of Karachi and of Pakistan. Moreover, the relationship of immunization non-adherence in this study was only examined with people belonging to poor socio-economic class. Due to this reason, this study only presented the immunization non-adherence of people belonging to poor socio-economic class. Similarly, this study did not assess the association of immunization practices with parenteral employment and household total income, etc. The data was only collected from mothers who were able to communicate in the local language, while migrants from the rural and tribal areas who are unable to communicate in local language also constitute a large segment of the population. Therefore, scaling further research with continuous follow-up across different regions of Pakistan and among various group of people from Pakistan may help in evaluating the real gap of valid immunization timing among the immunized children.

Recommendations

This study has assessed the immunization practices and determinants of non-adherence in children below two years of age. Although reliable data collection methods, a large sample size, and a validated questionnaire were used, this study cannot prove a cause-and-effect relationship between immunization non-adherence and other factors. To strengthen the relationship between immunization non-adherence and various covariates, a prospective study with follow-up would be more useful compared to a retrospective study. A prospective follow-up study can track immunization records in real-time using immunization registries and vaccination cards. Moreover, a prospective follow-up study will also facilitate real-time monitoring, enabling healthcare providers to intervene promptly, address barriers to immunization, and ultimately enhance vaccination coverage rates for optimal public health outcomes. Analytically, the determinants of immunization non-adherence can be analyzed by employing mediation analysis and structural equation modelling (SEM). Utilizing these statistical methods will provide a more holistic approach to understanding the causal relationship between immunization non-adherence and various covariates. To deeply understand the underlying determinants and causes of immunization non-adherence, qualitative exploration through focus group discussions and in-depth interviews will provide richer insights into the personal and contextual factors associated with non-adherence. This will help inform policymakers and program managers about more focused and effective interventions.

Conclusion

From this study, it is evident that the proportion of timely immunized children is far less than the percentage of timely immunized children. With every subsequent immunization visit or progression in infant age, the proportion of fully and timely immunized children decreases exponentially. Thus, vaccinating infants at the right time is crucial for preventing the burden of VPDs among infants.

Acknowledgment

We would like to thank all the stakeholders who provided us with permission for the data collected from different slums. We also would like to thank Mr. Shahid Hussain for providing logistics support.

Funding

The project was self-funded by the primary researcher. All the costs related to transportation and stationery were borne by the primary researcher.

Declaration

This research was the thesis project of Ms. Saher Mukhtar Ali, who did her MBA-MHM from the Institute of Business Management (IoBM), Karachi, Pakistan, under the supervision of Dr. Asif Khaliq and Dr. Asima Zahid.

Conflict of Interest

All authors declare no conflict of interest.

Author's Contribution

The idea of this research was conceived by SM, who worked on data collection, and data entry. Introduction of this manuscript was written by RSH and AK, SM helped AK and RSH for the review of literature. The methodology of this project was designed by AZ but written by AK. The data of this project was analyzed by AK and results were written by SM. Discussion was written by LL. The final draft of this manuscript was reviewed and edited by ZL.

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