Fall 2023

Correlates of Immunization Timeliness in Three South Asian Countries: Secondary Analysis of Demographic and Health Surveys

Tanzir Ahmed Shuvo

CORRELATES OF IMMUNIZATION TIMELINESS IN THREE SOUTH ASIAN COUNTRIES: SECONDARY ANALYSIS OF DEMOGRAPHIC AND HEALTH SURVEYS

by

Tanzir Ahmed Shuvo

Bachelor of Medicine and Bachelor of Surgery
University of Dhaka, 2009

Master of Public Health
Brac University, 2013

Submitted in Partial Fulfillment of the Requirements

For the Degree of Doctor of Philosophy in

Health Services Policy and Management

Arnold School of Public Health

University of South Carolina

2023

Accepted by:

Jan Ostermann, Major Professor

M. Mahmud Khan, Committee Member

Nicole Hair, Committee Member

Nabil Natafgi, Committee Member

Ann Vail, Dean of the Graduate School

DEDICATION

To my belated Grandmother who have left us for eternity during the COVID pandemic period and also to my family members who have supported me throughout this journey.

ACKNOWLEDGEMENTS

I would like to express my sincerest gratitude and appreciation to everyone who has supported and contributed to this dissertation's completion. Throughout this research voyage, I am indebted to my mentors, Dr. M. Mahmud Khan, Dr. Jann Ostermann, Dr. Nicole Hair, Dr. Eric Brenner, and Dr. Nabil Natafgi, for their invaluable advice, encouragement, and expertise. Their incisive feedback and unwavering support were instrumental in shaping this dissertation and pressing me to perform at my highest level. I would also like to extend my deepest gratitude to the faculty members of the Department of Health Services Policy and Management. A special thank goes to Ms. Debra Brown, who was always available whenever I required assistance from the department. She has been a motherly figure to me. I will always recall Dr. Rifat Haider as an elder brother and a guide. He will forever hold a special spot in my heart. Sharmee, my beautiful wife; I do not know how to express my gratitude for always being there for me. You abandoned your career and family to support me in my ups and downs. My princess and prince have always been my inspiration. My parents and siblings have consistently provided mental support from a distance of 8,000 miles.

Lastly, I would like to express my deepest gratitude to everyone I have encountered during my academic pursuits, whether they were colleagues, classmates, or mentors. The stimulating discussions, collaborative efforts, and shared experiences have contributed immeasurably to my academic and personal development.

ABSTRACT

Despite the availability of effective vaccines, 1.5 million children under the age of 5 years die every year because of vaccine preventable diseases. Improvements in vaccine delivery infrastructure have resulted in relatively high coverage of vaccines, but many children are not receiving their vaccines on a timely basis. Timely administration of routine vaccines recommended by the Expanded Programme on Immunization (EPI) ensures maximum efficacy. It is vital to explore rates of vaccination timeliness and the correlates of timely vaccination among children to design targeted interventions for improving both coverage and timeliness.

We conducted a secondary data analysis of the Demographic and Health Surveys from three South Asian Countries: Bangladesh, India and Pakistan. The study estimated the proportion of children receiving timely vaccination for different EPI vaccines and survival models to characterize correlates of timely vaccination among children below age 2 years.

Almost one third of the children did not have vaccination documentation in Bangladesh and Pakistan. India had a higher documentation rate of 87%.

For nearly all vaccine doses, the proportion of children receiving the vaccination in a timely manner was higher in Bangladesh than in India and Pakistan. In Pakistan, only

53% of children received the first dose of the Pentavalent vaccine within 28 days of the recommended age, compared to 72% in Bangladesh and 55% in India. Similar patterns were observed for all vaccine doses except for Bacille Calmette-Guerin (BCG). In all three countries, for multidose vaccines, the proportion of children receiving timely vaccination decreased for subsequent doses. Household wealth, media exposure, antenatal care, and facility-based delivery were consistently associated with greater vaccination timeliness across all three countries and all vaccine doses. The study also found some country-specific associations that may provide insights for targeted interventions to improve vaccination timeliness. These factors include rural versus urban residence in Bangladesh, maternal age, education, and family size in India, and maternal education and birth order in Pakistan.

The study highlights the need for national immunization programs to provide vaccination documentation to all mothers and to include vaccination timeliness as a performance metric in addition to vaccination coverage in order to optimize vaccine efficacy and provide maximum protection against vaccine-preventable infections for children.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACIP ..... Advisory Committee on Immunization Practices

aHR ..... Adjusted hazard ratios

BCG ..... Bacillus Calmette-Guérin

BDHS ..... Bangladesh Demographic and Health Survey

CDC ..... Centers for Disease Control and prevention

CI ..... confidence intervals

COVID ..... coronavirus disease

DALYs ..... Disability-Adjusted Life Years

DHS ..... Demographic and Health Surveys

DPT ..... Diphtheria, Pertussis, and Tetanus

EA ..... Enumerations Areas

EPI ..... Expanded Program on Immunization

HR ..... Hazard Ratio

IPV ..... Inactivated Polio Vaccine

LMICs ..... lower middle-income countries

MR ..... Measles and Rubella Vaccine

OPV ..... Oral Polio Vaccine

PCV ..... Pneumococcal Conjugate Vaccine

SDGs ..... sustainable development goals

SES ..... socioeconomic status

WHO ..... World Health Organization

CHAPTER 1: INTRODUCTION

1.1 Background

The past 3 decades have seen considerable improvements in the under-five (U-5) mortality rate globally. However, more than half of all U-5 deaths continue to be attributable to preventable and treatable diseases. Infectious diseases, such as pneumonia and other respiratory tract infections, diarrhea, and measles, are among the leading causes of deaths. Low- and middle-income countries (LMICs), including South Asian countries like Bangladesh, India or Pakistan, bear a disproportionately high burden of these deaths (1–5). In 2015, vaccine-preventable diseases were responsible for 14% of global disability-adjusted life years (DALYs) (6). Lower respiratory tract infections, diarrhea, and meningitis are among the top 10 causes of DALYs lost in children and adolescents (7). Despite a considerable decrease in the global prevalence of infectious diseases, they continue to contribute significantly to the global disease burden.

Childhood immunization, one of the most cost-effective health interventions, produces a high level of health benefits in terms of lives saved and diseases prevented, decreasing medical and other opportunity costs associated with disease burden and increasing future productivity. According to the World Health Organization (WHO), immunizations prevent 3.5 to 5 million deaths annually (8). Since 1974, the organization has promoted vaccination via the Expanded Program on Immunization (EPI), initially

recommending six vaccines (9). These vaccines were Bacillus Calmette-Guérin (BCG), Oral Polio Vaccine (OPV), Diphtheria-Tetanus-Pertussis (DTP), and Measles. Later, additional vaccines such as Hepatitis B, Haemophilus Influenzae type B (Hib), Rubella, Pneumococcal, and Rotavirus vaccines were added. Effective immunization programs hold potential to reduce U-5 mortality by protecting post neonatal infants and older children against preventable infectious diseases. In addition, some of the vaccines provide lifelong immunity e.g., measles and rubella (10), contributing to lower morbidity and mortality during adult life.

Despite tremendous efforts to increase vaccination coverage, which reached 81% for the third dose of the Diphtheria, Pertussis, and Tetanus vaccine) (DPT3) in 2021, 25 million children under the age of 1 year did not receive basic vaccines (11) and thus remained vulnerable to vaccine preventable diseases and increased morbidity, mortality and disability. Even with significant success, many children are still not covered by immunization programs. In 2022, 14.3 million children did not receive the first dose of DPT containing vaccine and an additional 6.2 million children were only partially vaccinated, leaving 20.5 million children unprotected (11). More than 3 million people, including 1.5 million U-5 children, die every year because of vaccine preventable diseases (12)(13). With global immunization coverage increasing over the years, it is essential to understand the causes of continued high mortality and morbidity caused by vaccine-preventable diseases.

Despite a declining global trend of infant mortality due to communicable diseases over the years, there have been significant disparities in the distribution of mortalities across regions. Vaccine-preventable infectious diseases are more prevalent in LMICs, particularly among newborns and young infants. In 2015, Streptococcus pneumoniae (pneumococcus) and Haemophilus influenzae type b (Hib) caused a total of 452,000 deaths worldwide (393,00 and 59,000, respectively), a decrease from 2008 when they were responsible for 541,000 pneumococcal deaths and 203,000 Hib deaths (13). More than half of all pneumococcal deaths occurred in four nations, namely India, Pakistan, Nigeria, and the Democratic Republic of the Congo, despite these nations comprising only 29% of the world's under-five population (13). In 2021, 60 percent of the 25 million children who were not or only partially vaccinated were from ten countries, including the four countries listed above (11). Children in these countries face numerous barriers to vaccination access, which increases their likelihood of being un- or under-vaccinated. Even in countries with high vaccination coverage, inequities exists through pockets of low coverage in different socioeconomic and geographic cohorts (14). To realize the full benefits of pediatric vaccination, it is essential to ensure high coverage rates. Another possible cause of persistent high rates of vaccine preventable mortality and morbidity in children may be that not all of them are effectively immunized. Vaccine delivery in a timely manner may be as essential as increasing coverage rates for maximizing the benefits of immunization (15).

Given continued high rates of deaths and complications attributable to vaccine preventable diseases, improved coverage and timeliness of vaccinations are essential to reduce infant morbidity and mortality associated with these diseases. To maintain the

quality of immunization services, the WHO recommended improving monitoring and surveillance systems involving age-appropriate vaccinations in LMICs, including the countries in South Asia where vaccine coverage and timeliness may be a concern (16). It is necessary to monitor the performance of national immunization programs in order to reduce delayed and incomplete vaccination, and to ensure that the full benefits of immunization are realized. To develop nationally and locally relevant strategies aimed at improving the effectiveness of vaccination programs, it is important to identify key correlates that are associated with low rates of coverage and timeliness of immunization.

The following section (Chapter 2) includes a discussion of the existing knowledge on vaccination coverage and timeliness. It will start with a discussion of the biology of vaccines to provide details on how high vaccination coverage and timeliness relate to a lower burden of communicable disease in the community. This will be followed by a discussion of vaccine hesitancy models, a description of the vaccination coverage and timeliness situation globally and in South Asia, and correlates of timeliness that different literatures have presented. Chapter 3 will discuss the methodological approach and analytical techniques used in the study. Chapters 4 and 5 will present two manuscripts, the first one presenting vaccination timeliness statistics and its correlates in Bangladesh, while the second one compares these numbers and correlates across the three countries of interest. The final chapter concludes with the summary of the results and potential policy recommendations aimed at maximizing the benefit of immunization.

CHAPTER 2: LITERATURE REVIEW

2.1: Biology of Vaccines

To comprehend the concept of vaccination coverage and timeliness and the significance of adherence to the immunization schedule, it is necessary to understand how immunization protects us from harmful infectious organisms. The primary objective of vaccination is to intentionally expose the body to a foreign particle or antigen (in this instance, the vaccine) that shares structural or chemical similarities with the infectious agent against which the vaccine is intended to provide immunity. In the majority of instances, these foreign particles or antigens are a component of or the infectious agent itself. However, they are either killed or in a non-pathogenic or mildly pathogenic state. If the immune system is functioning properly, exposure to antigens prepares the body to recognize infectious organisms as foreign invaders, generate pathogen-specific antibodies, and remember the pathogen as a harmful agent for future protection through the operation of memory cells, a type of white blood cell that remembers this foreign antigen. When reinfection occurs with the same organism, the memory cells trigger the production of specialized protein molecules called antibodies. In short, vaccines do not directly combat infectious pathogens, but rather prepare the body to do so when necessary (17).

To effectively protect the body against these infectious microorganisms and reduce the incidence of vaccine-preventable diseases, it is necessary to stimulate the production

of antibodies in sufficient quantities to counteract the effect of the infection. Certain vaccines generate immunologic memory similar to that produced by natural infections, and these vaccines frequently confer everlasting immunity. While there are some vaccines that do not require boosters, there are others that do. Typically, live attenuated vaccines (these are live infectious organisms with little or no pathogenic capability, such as the measles vaccine) provide complete immunity (often permanent) after a single dose. By contrast, killed vaccines, such as DPT vaccines, require supplemental injections at specific intervals to achieve full immunity, and in later stages of life to maintain effective immunity, as immunity tends to wane with time. In order to attain the optimal level of antibody titer and induce an effective immunologic response with the majority of vaccines, multiple doses must be administered with a specific time interval between each dose.

While maintaining a sufficient antibody titer is the primary objective of the intervals between multiple doses of vaccines, age-related susceptibility to the vaccine-preventable disease also influences the optimal time and interval between doses. Children's inherent immunity, which is acquired from their mothers, tends to deteriorate over time, making them more susceptible to various types of infection. Therefore, it is essential to administer vaccines early enough to protect against infectious diseases before innate immunity begins to wane. The following factors are considered when determining the appropriate age for administering a vaccine:

• The age at which a child's immune system can tolerate vaccine components,

• The potential interference of maternal antibodies with the immune response, and

• The age at which a child is at greatest risk for disease transmission and mortality.

From the preceding discussion, it is clear that while achieving high vaccination coverage is essential for reducing the transmission of vaccine-preventable diseases, maintaining the vaccination schedule is crucial for ensuring an individual's effective immunization, thereby contributing to the efficacy of vaccination coverage.

2.2 Vaccine Effectiveness

Vaccine effectiveness was defined by Lopalco et al. as "the capability of a vaccine to prevent specific outcomes in a "real life" situation." They suggested that after the infant receives the vaccine, the effectiveness of the vaccine is affected by a number of variables (18). These variables are detailed in Table 2.3, and include specifically schedule compliance. It is important to note that, despite the fact that Lopalco et al. listed schedule compliance under logistic issues, it is not only related to logistic issues, but individual level factors are also crucial for schedule compliance, as discussed in the next section.

2.3 Vaccine Hesitancy Models

Vaccine Hesitancy, a delay in acceptance or refusal despite availability, is one of the greatest obstacles to vaccinations (19). In 2019, the World Health Organization listed vaccine hesitancy as one of the 10 most significant threats to global health (20). It reflects a constellation of factors that may influence the decision to embrace some or all vaccines in accordance with the recommended schedule (21).

Table 2.1: Factors affecting vaccine effectiveness (18)

Host factors	• Age • Presence of conditions/co-morbidities that may either affect immune • response or influence individual disease susceptibility • Previous exposure to antigen • Interference due to co-administered vaccines or other drugs
Logistic issues	• Schedule compliance • Cold chain • Administration issues
Epidemiological factors	• Force of infection • Herd immunity • Mismatch with circulating strains • Emergence of new viral/bacterial variants

Hesitancy regarding child immunizations has contributed to decreased rates of childhood vaccination in several countries, as well as outbreaks of vaccine-preventable diseases such as pertussis, mumps, and measles (22–24). Nguyen et al. reported that parental vaccine hesitancy may account for up to 25% of the under vaccination in children (25). On the other hand several authors reported significant associations between vaccination hesitancy and delays (26,27).s

A number of models have been proposed to explain the factors which are associated with vaccine hesitancy (28), of which the 3C and 5C models are the most widely circulated (28–31). Inconvenient access to vaccines, complacency, and a lack of confidence have been

identified as key underlying causes of noncompliance to vaccination by the WHO vaccines advisory committee. Based on this, the WHO's Strategic Advisory Group of Experts on Immunization (SAGE) Working Group on Vaccine Hesitancy proposed the 3C model (Figure 2.1) which highlights the following broad categories as determinants of vaccine hesitancy

- Confidence: Vaccine confidence is defined as trust in
    - 1) the effectiveness and safety of vaccines;
    - 2) the system that delivers them, including the reliability and competence of the health services and health professionals; and
    - 3) the motivations of the policymakers who decide on the needed vaccines
- Complacency: Vaccine complacency exists when perceived risks of vaccine-preventable diseases are low and vaccination is not regarded as an essential preventive measure. For example, in many countries polio has been eradicated, thus, parents may consider it not necessary to vaccinate their child with polio vaccines.
- Convenience: Convenience is considered a crucial determinant of vaccine hesitancy which is reflected when vaccine uptake is affected by physical availability, affordability and willingness-to-pay, geographical accessibility, ability to understand (language and health literacy) and appeal of immunization services

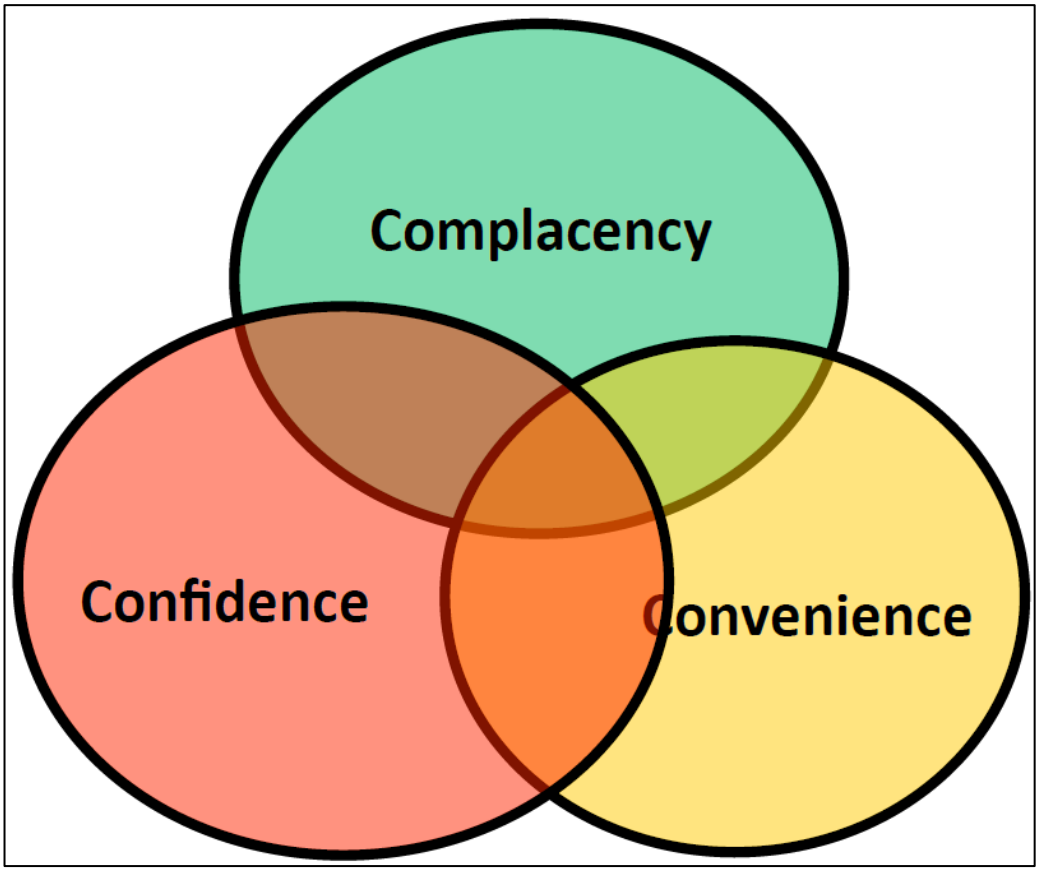

Figure 2.1: The 3C model of vaccine hesitancy

The 5C model (Figure 2.2) builds on the 3C model and proposes two additional major domains in the form of Communication and Context (38). While sharing information regarding vaccine efficacy, safety is key to building the confidence of parents in vaccinating their child, it also influences complacency by enabling the consumer to make informed decisions. On the other hand, context specific interventions are crucial to the success of any health-related interventions, including vaccination programs. These models provide preliminary understandings on what factors should be considered while developing a model of vaccination timeliness, in order to plan targeted interventions to reduce vaccine hesitancy and ultimately leading to improved immunization status of the community.

Figure 2.2: The 5C model of Vaccine Hesitancy in the context of COVID19 and recommendations on how to address the different dimensions of the model (Adapted from Razai et al)

2.4 Immunization Schedule

Before defining timeliness, it is necessary to understand the recommended schedule for infant routine immunization. "A schedule is a tool used to ensure that children and adults receive the recommended immunizations to protect them from disease when they are most susceptible" (17). Vaccination schedules vary between countries and regions of the world primarily due to the varying disease patterns in various regions (32,33). Table 2.1 shows the World Health Organization (WHO)'s recommendations for routine immunization schedules for the majority of these vaccinations. The vaccines in this table are recommended for use in all global immunization programs. There are, however, additional vaccines recommended for specific regions or populations that are not listed here.

Table 2.1 was created by the World Health Organization to facilitate the development of schedules specific to each country based on epidemiologic, programmatic, resource, and policy factors. This table is not recommended for use by local health care providers; instead, they are encouraged to adhere to the country-specific vaccination schedule when administering vaccinations to the target population.

Table 2.2: WHO recommended schedule for routine immunization(34)

Antigen		Age of 1st Dose	Doses in Primary Series	Interval Between Doses			Booster Dose	Considerations (see footnotes for details)
				1st to 2nd	2nd to 3rd	3rd to 4th		
Recommendations for all children								
BCG [1]		As soon as possible after birth	1					Birth dose and HIV; Universal vs selective vaccination; Co-administration; Vaccination of older age groups; Pregnancy
Hepatitis B [2]	**Option 1**	As soon as possible after birth (<24h)	3	4 weeks (min) with DTPCV1	4 weeks (min) with DTPCV2			Premature and low birth weight; Co-administration and combination vaccine; High risk groups
	Option 2	As soon as possible after birth High risk groups	4	4 weeks (min) with DTPCV1	4 weeks (min) with DTPCV2			
Polio [3]	**bOPV + IPV** "Preferred schedule" (fractional Salk-IPV permitted)	bOPV 6 weeks IPV 14 weeks	5 (3 bOPV and 2 IPV)	bOPV 4 weeks (min) (e.g. with DTPCV2) IPV ≥ 4 months (min) (e.g. with MCV)	bOPV 4 weeks (min) (e.g. with DTPCV3)			bOPV birth dose; Type of vaccine; Fractional dose IPV; Transmission and importation risk; Local epidemiology, programmatic implications and feasibility for "early" option
	bOPV+IPV "Early Option" (full dose IPV only)	bOPV 6 weeks IPV 6 weeks	5 (3 bOPV and 2 IPV)	bOPV 4 weeks (min) (e.g. with DTPCV2) IPV 14 weeks (min) (e.g. with DTPCV3)	bOPV 4 weeks (min) (e.g. with DTPCV3)			
	IPV / bOPV Sequential	8 weeks (IPV 1st) bOPV (4-8 weeks after 2nd IPV)	4 (2 IPV followed by ≥ 2 bOPV)	IPV (4-8 weeks)	bOPV (4-8 weeks)	bOPV (4-8 weeks)		
	IPV-only	6-8 weeks	3	4-8 weeks	4-8 weeks		IPV booster (6 months after 3rd dose) is needed when 1st dose given at < 8 weeks	Only for countries in polio-free regions with a very low risk of importation and sustained high routine immunisation coverage (DTP3 > 90%)
	Alternative IPV-only (fractional permitted)	≥14 weeks	2	≥ 4 months (e.g. with MCV)				
DTP-containing vaccine [4]		6 weeks (min)	3	4 weeks (min) - 8 weeks	4 weeks (min) - 8 weeks		3 Boosters 12-23 months (DTP-containing vaccine); 4-7 years (Td/DT containing vaccine), see footnotes; and 9-15 yrs (Td)	Delayed/ interrupted schedule Combination vaccine; Maternal immunization

Source: WHO recommendations for routine immunization - summary tables (Table 2) accessed through https://www.who.int/teams/immunization-vaccines-and-biologicals/policies/who-recommendations-for-routine-immunization---summary-tables

Table 2.3 (continued): WHO recommended schedule for routine immunization (34)

Antigen		Age of 1st Dose	Doses in Primary Series	Interval Between Doses			Booster Dose	Considerations (see footnotes for details)
				1st to 2nd	2nd to 3rd	3rd to 4th		
Recommendations for all children								
Haemophilus influenzae type b [5]	Option 1	6 weeks (min) 59 months (max)	3	4 weeks (min) with DTPCV2	4 weeks (min) with DTPCV3		(see footnote)	Single dose if >12 months of age Not recommended for children > 5 yrs Delayed/ interrupted schedule Co-administration and combination vaccine
	Option 2		2-3	8 weeks (min) if only 2 doses 4 weeks (min) if 3 doses	4 weeks (min) if 3 doses		At least 6 months (min) after last dose	
Pneumococcal (Conjugate) [6]	Option 1 3p+0	6 weeks (min)	3	4 weeks (min)	4 weeks			Schedule options (3p+0 vs 2p+1); Vaccine options; HIV+ and preterm neonate booster; Vaccination in older adults
	Option 2 2p+1	6 weeks (min)	2	8 weeks (min)			9-18 months	
Rotavirus [7]		6 weeks (min) with DTP1	2 or 3 depending on product	4 weeks (min) with DTPCV2	For three dose series – 4 week (min) with DTPCV3			Not recommended if >24 months old
Measles [8]		9 or 12 months (6 months min, see footnote)	2	4 weeks (min) (see footnote)				Co-administration live vaccines; Combination vaccine; HIV early vaccination; Pregnancy
Rubella [9]		9 or 12 months with measles containing vaccine	1					Achieve and sustain 80% coverage Co-administration and combination vaccine; Pregnancy
HPV [10]		As soon as possible from 9 years of age (females only)	1-2	6-12 months				Target 9-14 year old girls; Off-label 1 dose schedule; MACs with intro; Pregnancy; HIV and immunocompromised

Source: WHO recommendations for routine immunization - summary tables (Table 2) accessed through https://www.who.int/teams/immunization-vaccines-and-biologicals/policies/who-recommendations-for-routine-immunization---summary-tables

Owing to the fact that not all children adhere to the recommended vaccination schedule, the World Health Organization (WHO) also developed a guideline for what to do if there is a delay in receiving any of these vaccines (35). They recommend, even if there is a delay, most vaccines should be given at the earliest time possible. However, there is no specific guidance regarding what constitutes an untimely vaccination, i.e., at what point the vaccination should be considered to have been administered too early or too late for the body to achieve effective immunization.

2.5 Why are coverage and timeliness so important?

Vaccination coverage is typically used to evaluate the performance of immunization programs. According to the World Bank, "Immunization coverage indicators measure the proportion of a targeted population (usually, children at certain ages) that has received the recommended doses of vaccines to protect against contracting certain serious illnesses" (36). This is widely regarded as the key indicator for evaluating the efficacy of vaccination programs. The greater the coverage, the lower the probability that a community will be affected by a specific disease. Vaccinated individuals develop immunity against the organisms. High immunization coverage also contributes to herd immunity, creating an invisible barrier around the minority of the population that has not received the vaccine. However, coverage is not the only indicator we should consider when assessing the effectiveness of immunization programs.

In addition to vaccination coverage, evidence suggests that adherence to the recommended immunization schedule is crucial for children to develop effective immunity on time (3,37–40). Immunization before the recommended age may result in insufficient production of protective antibodies, thereby diminishing the efficacy of immunization. On

the other hand, delays in immunization leave children vulnerable to disease, and delaying the first dose of the primary vaccine series is reported to be a strong predictor of subsequent incomplete immunization (38,41). According to Yadav et al. (2011), delayed vaccination has more negative effects in developing nations, where the median age of infection acquisition is substantially lower than in developed nations (42). Thus, addressing vaccination delays can play a significant role in reducing under-5 mortality. s in immunization leave children vulnerable to disease, and delay

As presented in Table 2.1, the World Health Organization (WHO) has developed vaccination schedule recommendations for all routine childhood vaccines (34). For example, three doses of the Diphtheria, Pertussis, and Tetanus (DPT) vaccine are recommended in a child's first year of life, with the first dose administered at the age of 6 weeks, the second dose at 10 weeks, and the third dose at the age of 14 weeks. The recommended age range for the first dose of the measles vaccine is 9 to 12 months. If a child received vaccination doses according to the schedule, he or she is considered to have been immunized on time. However, there is no universally accepted definition of when childhood vaccinations are considered not timely (40). Most of the existing literatures used 28 days/1 month from the recommended age of vaccination to be considered as the cutoff point for defining a delay in vaccination (43–47). Some literatures used one or two weeks' time as the cutoff point (48,49); some used magnitude of the delay as a continuous measure instead of defining a time cutoff (50); while others decided to use time interval between vaccine doses (51). For this study, we considered 28 days cutoff point to define delay in our analysis. Detail will be discussed in the method section.

In light of the mortality and morbidity attributable to vaccine-preventable diseases, enhanced vaccination coverage and timeliness are necessary to reduce infant morbidity and mortality associated with these diseases. To maintain the quality of immunization services, the WHO suggested enhancing monitoring and surveillance systems involving age-appropriate vaccinations in LMICs, including in South Asian countries where vaccine coverage and timeliness are a concern (16). To ensure that the benefits of immunization are realized, it is essential to monitor the immunization program effectively so as to reduce delayed and incomplete vaccination. Therefore, it is essential to identify the factors associated with vaccination timeliness.

Even in high-income countries such as the United States, the practice of adhering to vaccination schedules was reported to be low in comparison to vaccination coverage. Fewer than half of infants born between 2004 and 2008 were vaccinated on time, according to Glanz et al. (52), although coverage was reported to be greater than 90%. In the 2014 National Immunization Survey only 58% of children followed the schedule suggested by the Advisory Committee on Immunization Practices (ACIP) (53). Multiple studies have focused on vaccination coverage and timeliness. There are numerous studies on coverage, but the majority of timeliness studies focus on African and Central Asian nations (3,40,54–57). All of these investigations focused on a specific country or region within a country. Masters et al. (2018) conducted a comprehensive systematic literature review in which they recommended conducting in-depth coverage and timeliness studies for countries in South Asia and South East Asia due to a lack of evidence in this area. Multi-country analyses will provide a broader perspective of the immunization situation in a region and identify underlying factors that influence vaccination coverage and timeliness (40).

2.5 Vaccination Timeliness in South Asia

To-date, there is little evidence regarding vaccination timeliness in South Asian countries. There has been only one study in which vaccination timeliness was investigated in Bangladesh using a nationally representative dataset. Sheikh et al. conducted a secondary analysis of the 2014 Bangladesh Demographic and Health Survey (BDHS) data and demonstrated a large gap in schedule adherence to the EPI vaccines in Bangladesh (58–60). There have been two nationally representative studies conducted in India based on the Household and Facility Survey 2008 and the National Family Health Survey 4 (2015-16) (61,62). There is only one nationally representative study from Pakistan however, this was conducted using 2005-06 DHS data (63). Two other studies in India and Bangladesh were limited to a specific region or hospital (42,64).

This study aims to characterize and compare the immunization timelines for different EPI vaccines in three South Asian countries, Bangladesh, India and Pakistan,. A cross-national comparison between these neighboring countries, which have substantial socio-cultural and geographical similarities between them, will reveal how the countries' immunization systems are performing and will aid in understanding the factors associated with vaccination timeliness in the region. This study provides the first example for a cross-national comparative overview of vaccination timeliness in South Asia, which can guide researchers and policymakers to develop focused interventions based on the specific needs of each country.

1.3 Research Questions:

Given the evidence gap described above, the study addresses two research questions:

- What proportions of children received timely vaccinations in the three South Asian countries?
- What are the correlates of timely vaccination in these countries?

CHAPTER 3: METHODS

3.1 Data Source:

A secondary data analysis was conducted using data from three datasets obtained through United States Agency for International Development (USAID')s Demographic and Health Surveys Programme:

- Bangladesh Demographic and Health Survey, 2017-18
- *Pakistan Demographic and Health Survey*, 2017-18
- India National Family Health Survey, 2019-20

Demographic and Health Surveys (DHS) are nationally-representative household surveys that collect information on a broad range of topics in more than 100 countries (65). Topics include information on infant and child mortality, fertility, family planning, maternal health, child immunization, malnutrition, HIV prevalence, and malaria, among others. Data from these surveys are freely available and accessible to qualified researchers and students. The indicators are comparable over time and across countries. This program is considered the largest and longest enduring survey program of its kind (USAID, 2018). The DHS surveys use a stratified two stage cluster design. In the first stage, enumerations areas (EA) are chosen from a pre-existing sampling frame (e.g., the national census). A sample of households is subsequently drawn from each EA in the second stage.

3.2 Research Design:

This is a cross sectional analysis of data from the latest available DHS datasets: from Bangladesh, India, and Pakistan.

3.3 Study Population:

Our preliminary study population included all children between the ages of 0-23 months. The WHO suggests that children ages 12-23 months be considered in the calculation of immunization coverage indicators for EPI, therefore children ages 24 months or older were excluded from this study. The analysis of coverage included only children ages 12-23 months, whereas analyses of timeliness included all age-eligible children, i.e., children who were old enough to receive a particular vaccine dose. Thus, the number of observations for timeliness analyses was different across different vaccine doses and was higher than the number of children included in coverage analyses. Notably, the DHS collected vaccination information from either vaccination cards or historical recall data from maternal report when the vaccination card was missing. However, vaccination dates were not collected for children whose immunization status was only reported by the mother. We therefore considered the following inclusion and exclusion criteria for our analyses.

Coverage: Children who were between the ages of 12 to 23 months during the time of the interview were included for the coverage analysis

Timeliness:

Inclusion Criteria:

- Children who were ages 0-23 months during the time of the interview
- For the descriptive analysis of timeliness, children at least 28 days older than the minimum age to receive a particular dose of the vaccine.
- For the multivariate analysis, children at least as old as the recommended age of vaccination.

Exclusion Criteria:

- Children with a vaccination card but no date of vaccination or an invalid date for the particular vaccine dose.
- Children with no vaccination card. However, in case a mother reported non-vaccination for a particular vaccine, it was included in the analyses and was recorded as not having received the vaccine.

3.4 Definition of Vaccination Coverage:

The primary source of information on the vaccination status of a child was the vaccination card. When the card was not available, non-vaccination information provided by mother was also used. If coverage for a vaccine was not indicated by either of these two sources, the child was considered unvaccinated as suggested in the Guide to DHS Statistics (66). The guide also suggests that the dataset may contain gaps in vaccination history in the case of multi-dose vaccine series, e.g., the data may show that a child received the 1st and 3rd doses of the pentavalent vaccine, but missed the 2nd dose. It suggests that in such a scenario the 3rd dose be recoded as the 2nd dose. We addressed such issues as recommended

in the Guide. Vaccination coverage at the time of the survey was calculated separately for each vaccine dose. A child ages 12-23 months was considered covered for a specific vaccine dose if he or she had received the dose at the time of the survey.

3.5 Definition of Vaccination Timeliness:

The immunization schedules for all routine vaccines implemented through the EPI program of Bangladesh, India and Pakistan are presented in Table 3.1 (67).

Table 3.1: EPI vaccination schedule for infants.

Vaccine	Bangladesh	India	Pakistan
Bacillus Calmette–Guérin (BCG): One dose	Birth	Birth	Birth
Pentavalent Vaccine (Diphtheria, Pertussis, Tetanus, Hepatitis B and Hib): Three doses	6 weeks 10 weeks 14 weeks	6 weeks 10 weeks 14 weeks	6 weeks 10 weeks 14 weeks
Oral Polio Vaccine (OPV): Three doses	 6 weeks 10 weeks 14 weeks	0 weeks* 6 weeks 10 weeks 14 weeks	0 weeks* 6 weeks 10 weeks 14 weeks
Pneumococcal Conjugate Vaccine (PCV): Three doses	6 weeks 10 weeks 14 weeks	6 weeks 10 weeks 14 weeks	6 weeks 10 weeks 14 weeks
Inactivated Polio Vaccine (IPV): Two doses	6 weeks 14 weeks	6 weeks 14 weeks	6 weeks 14 weeks
Measles and Rubella Vaccine (MR): One dose	9 months	9 months	9 months

*OPV is recommended at birth for India and Pakistan. For Bangladesh the first dose of OPV is recommended at 6 weeks. By the time this survey was conducted, IPV and PCV were not integrated in the national immunization program of India. Thus, OPV0, Pneumococcal vaccine series and IPVs were not included in the analyses to maintain uniformity across the 3 countries.

DHS collected data on the date of birth of the child, and, for children with vaccination documentation, the date of each vaccination dose in the EPI schedule. The child's age at vaccine receipt, in days, was calculated as the difference between the date of vaccination receipt as recorded in the vaccination documentation and the date of birth of the child. Based on the vaccination schedule presented in Table 1, vaccination timeliness was defined as follows:

Timely vaccination: In descriptive analyses, timely vaccination was defined as the receipt of the vaccine between 7 days prior to and 28 days after the recommended age. For example, the first dose of the Pentavalent vaccine (Penta1) is due at age 6 weeks (42 days). Thus, any Penta1 dose received between the ages of 35-70 days was considered timely.

Delayed vaccination: Delayed vaccination was defined as the receipt of the vaccine more than 28 days after the recommended age. Thus, any Penta1 dose received after the age of 70 days was considered delayed.

No vaccination: In the case the vaccination card or the mother reported that a particular dose was not received by the child then that child was considered not vaccinated for that particular dose.

In multivariable analyses, timeliness was described by the time, in days, between the recommended age as outlined in the vaccine schedule, and the actual age at the time of vaccination receipt.

Table 3.2 describes the categorical definition of timeliness for those vaccine doses that were included in the EPI schedules of all 3 countries at the time of the surveys.

Table 3.2: Categorical definition of the timeliness of vaccine administration**.**

Vaccine	**Recommended Vaccine Schedule (age in days)**	**Timeliness of vaccinations based on the age of the child at the time of vaccine administration (age in days)**	
		Timely	Delayed
*Bacillus Calmette–Guérin (*BCG)	At birth	BCG: 0 to 28 days	BCG: 29 days or more
Oral Polio Vaccine (OPV)	OPV1: 42 days	OPV1: 35 to 70 days	OPV1: 71 days or more
	OPV2: 70 days	OPV2: 63 to 98 days	OPV2: 99 days or more
	OPV3: 98 days	OPV3: 91 to 126 days	OPV3: 127 days or more
Pentavalent Vaccine (Diphtheria, Pertussis, Tetanus, Hepatitis B and Hib)	Penta1/DTP1: 42 days	Penta1/DTP1: 35 to 70 days	Penta1/DTP1:71 days or more
	Penta2/DTP2: 70 days	Penta2/DTP2: 63 to 98 days	Penta2/DTP2: 99 days or more
	Penta3/DTP3: 98 days	Penta3/DTP3: 91 to 126 days	Penta3/DTP3: 127 days or more
Measles and Rubella Vaccine (MR)	266 days	259 to 294 days	294 days or more

3.6 Statistical Analysis

Statistical analyses were conducted using STATA 15 SE (Stata Corp, College Station, TX). Sampling weights were applied as recommended in the DHS data analyses guideline (66) in order to account for the complex survey design of the DHS.

Descriptive analysis was conducted to present (1) sociodemographic information and vaccination documentation information of children ages 0-23 months at the time of the interview and their mothers; (2) proportions of children receiving timely vs. delayed vaccination for different vaccine doses among age-eligible children ages 0-23 months, i.e.,

children who were old enough to receive a particular vaccine dose. The statistical significance of differences between rural and urban residents was evaluated using two-tailed Student's t-tests for continuous and chi-squared tests for categorical variables.

Survival analysis was used to model time to vaccination. The event of interest was the receipt of the vaccine dose for which timeliness was being analyzed. If a child had not received the vaccine dose by the time of the interview, the observation was considered censored. Correlates of timely vaccination were examined using Cox proportional hazard models, where the recommended age of vaccination was designated as time zero. If a child received a vaccination on or prior to the recommended age, the time to vaccine initiation was adjusted as very close to zero (recoded to $1x10^{-6}$ days after time zero). Based on a review of existing literature (2,68) we included the following correlates of vaccination timeliness in our cox regression model: rural vs. urban residence, wealth index quintile, mother's age at birth (15-19, 20-24, 25-29, above 30 years), maternal education (primary education or less, secondary or higher education, birth order (first born vs. second or higher order), number of antenatal visits (0-3, 4 or more), place of delivery (facility delivery, home delivery), gender of the child (male, female), household size (number of persons) and media exposure (yes, no).

The Cox hazard model estimated the hazard of receiving the vaccine dose at an earlier or later time compared to the reference group. A hazard ratio greater than 1 indicates that children with the respective characteristic had a higher risk of the event occurring earlier. On the other hand, a hazard ratio less than 1 indicates that the characteristic was associated with a lower risk of the event occurring earlier (i.e., a higher chance of receiving the

vaccine at a later point than the reference group). As the schedules of the OPV and Penta vaccine series coincide, we considered the timeliness of the Pentavalent vaccine doses as proxies for other vaccine doses due at the same time. Thus, survival models were estimated for the BCG vaccine due at birth, the Pentavalent vaccine series due at 6, 10, and 14 weeks of age, and the 1st dose of the Measles vaccine due at age 9 months.

To assess potential selection biases from excluding children with unknown vaccination coverage or timeliness, we compared the characteristics of children who were included in the hazard models to those who were excluded due to lack of vaccination documentation or due to missing data on vaccination dates. In descriptive analyses, Student's t-tests and chi-squared statistics were used to assess statistical significance; a logistic regression model assessed selection bias in a multivariable model.

CHAPTER 4: CORRELATES OF IMMUNIZATION TIMELINESS IN BANGLADESH: A SECONDARY ANALYSIS OF THE 2017-2018 BANGLADESH DEMOGRAPHIC AND HEALTH SURVEY

4.1 INTRODUCTION

In the last three decades there have been considerable improvements in the global under-five (U-5) mortality rate (69). However, according to the World Health Organization (WHO), in 2018 almost 4 million children died within their first year of life, representing 75% of all under-five deaths (70). More than half of all =U-5 deaths are attributable to preventable and treatable diseases. Infectious diseases, such as pneumonia and other respiratory tract infections, diarrhea, and measles, are among the leading causes of deaths. Low- and middle-income countries (LMICs) bear a disproportionately high burden of these deaths.

Childhood immunization, one of the most cost-effective health interventions, produces high level of health benefits in terms of decreased morbidity and mortality, reduced medical and opportunity costs associated with disease, and increased future productivity. The WHO has been promoting immunization through the Expanded Program on Immunization (EPI) since 1974, initially recommending 6 vaccines (71). Since the introduction of the EPI, childhood mortality has significantly decreased globally, and with

the introduction of new vaccines in the program, vaccinated children are being protected against more and more diseases (72). According to the WHO, immunizations prevent 3.5 to 5 million deaths annually (8).Despite tremendous efforts to increase vaccination coverage, in 2021, 25 million children under the age of 1 year did not receive basic vaccines (11) and thus remain vulnerable to vaccine preventable diseases and increased morbidity, mortality and disability. More than 3 million people, including 1.5 million U-5 children, die every year because of vaccine preventable diseases (12)(13). A large majority of these children live in LMICs and significant urban rural disparities in vaccination coverage and timeliness have been documented globally (1–5). Even in countries with high vaccination coverage, inequities exist as evidenced by pockets of low coverage in various socioeconomic and geographic cohorts (14).

In the last few decades, Bangladesh has made remarkable progress in reducing childhood mortality, and the successful implementation of EPI has played an important role in this (73). The country has achieved more than 90% coverage for all EPI vaccines except the measles and rubella (MR) vaccine (88%) (74), and immunization prevents approximately 200,000 deaths every year (75). The U-5 mortality rate has been significantly reduced from 40/1000 live births in 2014 In the last few decades, ,,to 27/1000 live births in 2021 (76). While neonatal mortality contributes to almost two thirds of the U-5 mortality in Bangladesh, effective immunizations have the potential to further reduce the U-5 mortality rate by protecting older children from preventable infectious diseases and achieve Target 3.2 of the sustainable development goals (SDGs), to reduce the national U-5 mortality rate to 25/1000 live birth (77). Moreover, some of the EPI vaccines provide

lifelong immunity, contributing to reduction of preventable morbidity and mortality in the later stage of life.

To achieve the full benefit of immunization, vaccines must be delivered in a timely manner (3,15,38–40,78). Immunization before the recommended age may result in failure to generate sufficient protective antibodies, thus reducing the effectiveness of immunization. By contrast, delayed vaccinations leave children vulnerable to infections, with disproportionately negative implications for children in LMICs, where the median age for acquiring infections is lower relative to high-income countries (42). Delaying the first vaccine dose in a series is a strong predictor of subsequent incomplete immunization (38,41).

To-date, there is little evidence regarding vaccination timeliness in Bangladesh. Sheikh et al. conducted a secondary analysis of data from the 2014 Bangladesh Demographic and Health Survey (BDHS) and demonstrated a large gap in adherence to the EPI vaccines. To-date that is the only peer reviewed evidence in regards to vaccination timeliness in Bangladesh (79). There are also very few studies in the neighboring countries, which were generally limited to a specific region or hospital (42,64). This study aims to address this evidence gap by providing recent, pre-COVID estimates of the immunization coverage and timelines for EPI vaccines recommended in the first year of life in Bangladesh. The study also aims to identify correlates of vaccination timeliness to inform early detection and intervention efforts. timeliness

4.2 METHODS

4.2.1 Data Source:

A secondary data analysis was conducted using data from the 2017-18 BDHS. The BDHS is a nationally-representative household survey that collects information on a broad range of topics; Topics include information on infant and child mortality, fertility, family planning, maternal health, childhood immunization, malnutrition, HIV prevalence, and malaria. DHS survey data are freely available and accessible to qualified researchers and students; indicators are comparable over time and across countries. Demographic and Health Surveys (DHS) are implemented similarly in more than 100 countries (65)(65). The DHS program is considered the largest and longest enduring survey program of its kind (USAID, 2018).

The BDHS used a stratified two-stage cluster design as its sampling technique. In the first stage 675 enumeration areas (EAs) were identified for the whole country. These EAs were selected using data from the 2011 Population and Housing Census of the People's Republic of Bangladesh. In the second stage, a systematic sample of 30 households (on average) was drawn from an updated household list from each EA selected in the first stage.

4.2.2 Study Design:

This is a cross sectional analysis of data from the 2017-18 BDHS.

4.2.3 Study Population:

Our study population included children between the ages of 0-23 months included in the BDHS dataset. The WHO suggests that children ages 12-23 months be considered in the calculation of immunization coverage indicators for EPI, therefore all children ages 24 months or older were excluded from this study. The analysis of coverage included only children ages 12-23 months, whereas analyses of timeliness included all age-eligible children, i.e., children who were old enough to receive a particular vaccine dose. Thus, the number of observations for timeliness analyses differed across different vaccine doses and was higher than the number of children included in coverage analyses. Notably, the DHS collected information on vaccination coverage and dates from vaccination cards. When the card was missing, coverage information was obtained using historical recall from mothers.

4.2.4 Definition of Vaccination Coverage:

The primary source of information on the vaccination status of a child was the vaccination card. When the card was not available, non-vaccination information provided by the mother was also used. If coverage for a vaccine was not indicated by either of these two sources, the child was considered unvaccinated as suggested in the Guide to DHS Statistics (66). The guide also suggests that the dataset may contain gaps in vaccination history in the case of multi-dose vaccine series, e.g., the data may show that a child received the 1st and 3rd doses of the pentavalent vaccine, but missed the 2nd dose. It suggests that in such a scenario the 3rd dose be recoded as the 2nd dose. We addressed such issues as recommended in the Guide. Vaccination coverage was calculated separately for each vaccine dose. A child ages 12-23 months was considered covered for a specific vaccine dose if he or she had received the dose at the time of the survey.

4.2.5 Definition of Vaccination Timeliness:

The WHO immunization schedule for all routine vaccines implemented through Bangladesh's EPI program is presented in Table 4.1 (67).

Table 4.1: EPI vaccination schedule implemented in Bangladesh for infants (less than 12 months of age).

Vaccine	Age of administration
*Bacillus Calmette–Guérin (*BCG)	Birth
Pentavalent Vaccine (Diphtheria, Pertussis, Tetanus, Hepatitis B and Hib), three doses	6 weeks, 10 weeks and 14 weeks
Oral Polio Vaccine (OPV), three doses	6 weeks, 10 weeks and 14 weeks
Pneumococcal Conjugate Vaccine (PCV), three doses	6 weeks, 10 weeks and 14 weeks
Inactivated Polio Vaccine (IPV), two doses	6 weeks and 14 weeks
Measles and Rubella Vaccine (MR), one dose	9 months

BDHS collected data on the date of birth of the child as well as the date of each vaccination in the EPI schedule; the age of vaccine receipt (in days) was calculated as the difference between the date of the vaccination as recorded on the vaccination card and the date of birth of the child. Vaccination timeliness was determined by comparing the child's age at the time of vaccine receipt with the recommended age of vaccination. If the vaccination documentation was not available or the vaccination date was not or only partially recorded, the observation was excluded from the analyses. However, if a mother

reported her child as not having received the vaccine, the child was considered unvaccinated as of the time of the survey and included in the timeliness analyses as a censored observation (see below).

In descriptive analyses, timely vaccination was defined as the receipt of the vaccine from 7 days before to 28 days after the recommended age. For example, the first dose of the pentavalent vaccine (Penta1) is due at age 6 weeks, which is 42 days. Thus, any Penta1 dose received within the age range of 35-70 days was considered timely. In order to ensure the integrity of the analysis, children who received a vaccine dose more than 7 days earlier than the recommended age were excluded from the analyses. In multivariable analyses, time to vaccination was measured continuously. Table 4.2 describes the definition of timeliness for each vaccine dose in the EPI schedule of Bangladesh

4.2.6 Statistical Analysis

Statistical analyses were conducted using STATA 15 SE (Stata Corp, College Station, TX). Sampling weights were applied as recommended in the Guide to DHS Statistics (66) in order to account for the clustering and complex survey design of the BDHS.

Descriptive analysis was conducted to present (1) sociodemographic information and vaccination documentation information of children ages 0-23 months and their mothers at the time of the interview; (2) coverage of different vaccine doses among children aged 12-23 months; and (3) proportions of children receiving timely vaccination for different vaccine doses among age-eligible children aged 0-23 months. The statistical significance

of differences between rural and urban residents was evaluated using two-tailed Student's t-tests for continuous and chi-squared tests for categorical variables.

Table 4.2: Definition of the timeliness of vaccine administration.

Vaccine	**Recommended Vaccine Schedule (age in days)**	**Timeliness of vaccinations based on the age of the child at the time of vaccine administration (age in days)**	
		Timely	Delayed
*Bacillus Calmette–Guérin (*BCG)	At birth	0 to 28 days	29 days or more
Oral Polio Vaccine	OPV1: 42 days	OPV1: 35 to 70 days	OPV1: 71 days or more
	OPV2: 70 days	OPV2: 63 to 98 days	OPV2: 99 days or more
	OPV3: 98 days	OPV3: 91 to 126 days	OPV3: 127 days or more
Pentavalent vaccine/DTP (DTP+Hep B + Hib)	Penta1/DTP1: 42 days	Penta 1/DTP1: 35 to 70 days	Penta 1/DTP1:71 days or more
	Penta2/DTP2: 70 day	Penta 2/DTP2: 63 to 98 days	Penta 2/DTP2: 99 days or more
	Penta3/DTP3: 98 days	Penta 3/DTP3: 91 to 126 days	Penta 3/DTP3: 127 days or more
Measles, Mumps and Rubella	266 day	259 to 294 days	294 days or more

Survival analysis was used to model time to vaccination. The event of interest was the receipt of the vaccine dose for which timeliness was being analyzed. If the child had not received a vaccine dose by the time of the interview, the data were considered censored.

Correlates of timely vaccination were examined using Cox proportional hazard models, where the recommended age of vaccination was designated as time zero. If a child received a vaccination on or prior to the recommended age, the time to vaccination was adjusted as very close to zero (recoded to $1x10^{-6}$ days after time zero).

Based on a review of the existing literature (2,68) we considered the following correlates of vaccination timeliness in our Cox regression model.

- Number of antenatal visits (0-3, 4 or more),
- Place of delivery (facility delivery, home delivery),
- Media exposure (yes, no) and religion (Islam and others)
- Rural vs. Urban residence,
- Maternal education (primary or less, secondary or higher education)
- Birth order (first born, second or higher order),
- Wealth index factor score,
- Mother's age at first birth (15-19, 20-24, 25-29, above 30 years),
- Gender of the child (male female),
- Household size

Cox models estimated the risk of receiving a vaccine dose at an earlier or later time compared to the reference group. A hazard ratio greater than 1 indicates that children with the respective characteristic had a higher risk of the event occurring earlier. On the other hand, a hazard ratio less than 1 indicates that the characteristic was associated with a lower risk of the event occurring earlier (i.e., a higher chance of receiving the vaccine at a later point than the reference group). As the schedules of different doses of the OPV,

pentavalent, and pneumococcal vaccines coincide, we considered the timeliness of the pentavalent vaccine doses as proxies for other vaccines due at the same time. Thus, survival models were only estimated for the BCG, pentavalent vaccines and 1st dose of the Measles vaccine.

To assess potential selection biases from excluding children with unknown vaccination coverage or timeliness, we compared the characteristics of children who were included in the hazard models to those who were excluded due to lack of vaccination documentation or due to missing data on vaccination dates. In descriptive analyses, Student's t-tests and chi-squared statistics were used to assess statistical significance; a logistic regression model assessed selection bias in a multivariable model.

4.3 Results:

4.3.1 Sample characteristics

Table 4.3 shows key characteristics of 3,462 mothers and their children ages 0-23 months. Nearly three quarters (66%) of mothers were living in rural areas. The male to female child ratio was 52:48. Wealth index scores were higher for urban than rural households (0.068 vs. -0.030 standard deviations from the mean, $p<0.001$). Urban mothers, on average, was slightly older during the birth of the child (for whom vaccination information was obtained) compared t their rual counterparts (23.98 vs 23.49 years, $p<0.014$). Mothers of urban children had higher numbers of antenatal visits (59% vs. 42% reporting 4 or more ANC visits, $p<0.001$) and higher rates of media exposure (exposure to television, radio or newspaper at least once a week) than mothers of rural children (72% vs 48%, $p<0.001$). Just over half of the children (51%) were born at a

health facility, nearly half were born at home. 68% of the mother was able to present a vaccination card for their child during the time of the interview, whereas 15% of the children did not have any document; for 17% of the children the mother reported that they had a vaccination card but could not present it to the interviewer. Rural children, on average presented a higher household size relative to urban children (6.3 vs 5.8; $p<0.000$). In addition, the proportion of children having second or highe birth order was also higher among the rural children (64.4% vs 59.5%; $p<0.011$)

Table 4.3: Sociodemographic characteristics of mothers and their children aged 0-23 months from the Bangladesh Demographic and Health Survey, 2017-18

		All participants (N=3,462)		Rural participants (N=2,286)		Urban participants (N=1,176)		
# of children		3,462		2,286		1,176		
		Mean or N	(sd or %)	Mean or N	(sd or %)	Mean or N	(sd or %)	*p value*
Residence	Rural	2,286	(66.0 %)	2,286	(100 %)			
	Urban	1,176	(34.0%)			1,176	(100 %)	
Region	Barisal	383	(11.0 %)	265	(11.6 %)	118	(10.0%)	0.000
	Chittagong	570	(16.5%)	387	(17.0%)	183	(15.6%)	
	Dhaka	502	(14.5%)	221	(10.0%)	281	(23.9%)	
	Khulna	355	(10.25%)	229	(10.0%)	126	(10.7 %)	
	Mymensingh	418	(12%)	309	(13.5%)	109	(9.2%)	
	Rajshahi	349	(10.0%)	238	(10.4%)	111	(9.4%%)	
	Rangpur	392	(11.3%)	281	(12.2%)	111	(9.4%)	
	Sylhet	493	(14.2%)	356	(15.6 %)	137	(11.6%)	
Wealth index score		-0.004	(0.10)	-0.030	(0.07)	0.068	(0.11)	0.000
Vaccination documentation	No card	505	(14.5 %)	366	(15.8 %)	139	(10.6 %)	0.007
	Had card but not seen by surveyor	593	(17.5 %)	396	(17.3 %)	197	(18.1 %)	
	Seen by surveyor	2,364	(68.0 %)	1,524	(66.8 %)	840	(71.3 %)	
Mother's age	15-19	686	(20.3 %)	467	(20.7 %)	219	(19.3 %)	0.585
	20-29	2,101	(59.7 %)	1,389	(59.5 %)	712	(60.0 %)	
	30-39	645	(19.1 %)	412	(19.0 %)	233	(19.4 %)	
	40-49	30	(0.9 %)	18	(0.8 %)	12	(1.2 %)	
Mother's age during birth of the child	(Years)	23.66	(5.51)	23.49	(5.45)	23.98	(5.61)	0.014
Mother's education	Primary or less	1,173	(33.5 %)	807	(34.0 %)	366	(32.0 %)	0.462
	Secondary or higher	2,289	(66.5 %)	1,479	(66.0 %)	810	(68.0 %)	
Birth order	First child	1,298	(36.9 %)	817	(35.6 %)	481	(40.5 %)	0.011
	Second or higher	2,164	(63.1 %)	1,469	(64.4 %)	695	(59.5 %)	
Antenatal care visits	0-3	1,808	(53.2 %)	1,327	(57.6 %)	481	(40.9 %)	0.000

		All participants (N=3,462)		Rural participants (N=2,286)		Urban participants (N=1,176)		
# of children		3,462		2,286		1,176		
		Mean or N	(sd or %)	Mean or N	(sd or %)	Mean or N	(sd or %)	*p value*
	4 or more	1,654	(46.8 %)	959	(42.4 %)	695	(59.1 %)	
Place of birth	Health facility	1,778	(51.0 %)	1,034	(46.6 %)	744	(63.5 %)	0.000
	Home delivery	1,684	(49.0 %)	1,252	(53.4 %)	432	(36.5 %)	
Sex of the child	Female	1,672	(48.2 %)	1,069	(47.3 %)	603	(50.7 %)	0.087
	Male	1,790	(51.8 %)	1,217	(52.7 %)	573	(49.3 %)	
Household Size	(Number)	6.2	(2.70)	6.3	(2.72)	5.8	(2.60)	0.000
Media exposure	No	1,613	(45.8 %)	1,258	(52.2 %)	355	(28.1 %)	0.000
	Yes	1,849	(54.2 %)	1,028	(47.8 %)	821	(71.9 %)	
Religion	Islam	3,216	(93.2 %)	2,127	(92.9 %)	1,089	(94.1 %)	0.462
	Others	246	(6.8 %)	159	(7.1 %)	87	(5.9 %)	

Notes:
*Means and percentages were calculated using weights provided in the BDHS dataset. Statistical significance of urban-rural differences was evaluated using two-tailed Student's t-tests for continuous variables and chi-squared tests for categorical variables.

*The table provides information on all children in the age range of 0-23 months.
Sd: standard deviation; N indicates the total number of observations for each attribute

4.3.2 VACCINATION COVERAGE

Table 4.4 presents information on the coverage of the 13 vaccine doses recommended in the first year of life according to the EPI schedule of Bangladesh. Vaccination data for approximately 1 in 4 children was based on reports by mothers, indicating gaps in vaccination documentation.

Table 4.4: Coverage of EPI vaccinations among children aged 12-23 months in the Bangladesh Demographic and Health Survey, 2017-18

	N	Covered, documented	Covered, maternal recall only	Total Covered (Documented+Maternal recall)	Not covered
BCG	1,666	73.7 %	24.6 %	98.3%	1.7 %
Penta 1	1,666	74.0 %	24.5 %	98.5%	1.5 %
Penta 2	1,666	73.5 %	24.0 %	97.5%	2.5 %
Penta 3	1,666	73.0 %	22.9 %	95.9%	4.1 %
OPV 1	1,666	73.6 %	24.7 %	98.3%	1.7 %
OPV 2	1,664	73.3 %	23.6 %	96.9%	3.1 %
OPV 3	1,664	72.9 %	21.9 %	94.8%	5.2 %
IPV1	1,666	0.42%	0.0%	0.42%	99.58%
IPV2	1,666	0.24%	0.0%	0.24%	99.76%
Pneumococcal 1	1,666	73.3 %	24.1 %	97.4%	2.6 %
Pneumococcal 2	1,665	72.9 %	23.4 %	96.3%	3.7 %
Pneumococcal 3	1,665	70.8 %	21.6 %	92.3%	7.7 %
Measles	1,666	67.5 %	22.7 %	90.2%	9.8 %

*Notes: Estimates of vaccination coverage are based on proportion of vaccination received among children who were aged 12-23 months during the time of the interview.

Coverage rates for most vaccine doses were high. Considering both documented and maternal recall data, coverage for the single dose of BCG was 98%. Except IPV, the first dose of all multidose vaccines, including measles, exceeded 90% coverage ranging from 90. to 98.50% for Penta1. The coverage for both doses of IPV was less than 1%.

There were minimal differences in the documented coverage between the first and subsequent doses (e.g., 74% for first dose of Pentavalent vaccine vs 73% for the third dose.) Similar statistics were observed for OPV and pneumococcal vaccine doses. The lowest coverage was reported for the measles vaccine (90%). On average, rural children presented marginally higher proportions of vaccination coverage than urban children (figure 4.1), however, the difference was not statistically significant in any of the doses.

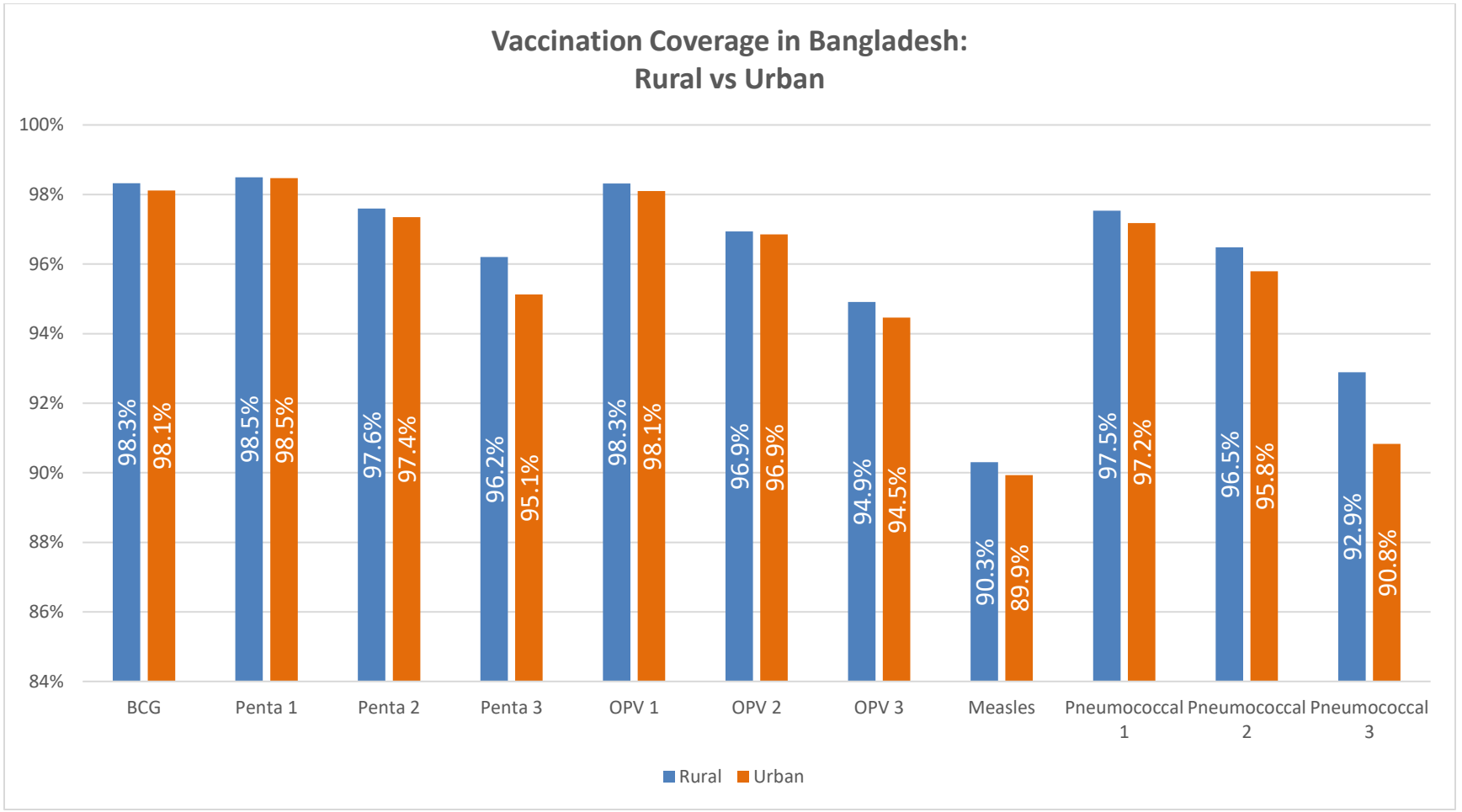

Figure 4.1: Rural Urban distribution of total vaccination coverage (Documented + maternal recall) among children aged 12-23 months in Bangladesh

4.3.3 VACCINATION TIMELINESS

Table 4.5: Timeliness of EPI vaccinations among age-eligible children ages 0-23 months in the Bangladesh Demographic and Health Survey, 2017-18

All Children	Timely[1]	Late	Not received[2]	Total (N)[3]	Not eligible [4]	Unknown [5]
BCG	608(24%)	1707 (68%)	196 (8%)	2512	163	788
OPV 1	1738(75%)	474 (21%)	97 (4%)	2310	135	766
OPV 2	1298(58%)	778 (34%)	192 (8%)	2267	176	637
OPV 3	924(43%)	978 (45%)	293 (13%)	2195	172	558
Penta 1	1756(76%)	480 (21%)	82 (4%)	2318	125	766
Penta 2	1307(58%)	786 (35%)	164 (7%)	2258	170	653
Penta 3	986(44%)	965 (44%)	267 (12%)	2218	133	575
Pneumococcal 1	1712(73%)	491 (21%)	135 (6%)	2339	140	731
Pneumococcal 2	1272(56%)	800 (35%)	208 (9%)	2279	177	627
Pneumococcal 3	543(24%)	1354 (60%)	367 (16%)	2263	139	533
Measles	992(66%)	298 (20%)	215 (14%)	1505	127	466
Rural children	**Timely**	**Late**	**Not received[2]**	**Total (N)[3]**	**Not eligible [4]**	**unknown[5]**
BCG	438(37%)	1237 (68%)	146 (8%)	1820	131	597
OPV 1	1220(73%)	381 (23%)	74 (4%)	1675	96	585
OPV 2	897(54%)	618 (37%)	151 (9%)	1665	122	474
OPV 3	640(40%)	752 (46%)	225 (14%)	1617	122	412
Penta 1	1232(73%)	385 (23%)	63 (4%)	1681	87	586
Penta 2	901(54%)	627 (38%)	127 (8%)	1655	119	488
Penta 3	687(43%)	744 (46%)	202 (12%)	1632	94	424
Pneumococcal 1	1197(71%)	395 (23%)	104 (6%)	1696	101	557
Pneumococcal 2	877(53%)	635 (38%)	161 (10%)	1673	123	467
Pneumococcal 3	386(23%)	1003 (60%)	272 (16%)	1661	101	396
Measles	747(67%)	213 (19%)	157 (14%)	1117	99	333
Urban children	**Timely**	**Late**	**Not received[2]**	**Total (N)[3]**	**Not eligible[4]**	**unknown[5]**
BCG	170(25%)	470 (68%)	51 (7%)	691	32	191
OPV 1	518(82%)	94 (15%)	23 (4%)	635	39	180
OPV 2	401(67%)	160 (27%)	40 (7%)	602	54	163
OPV 3	284(49%)	227 (39%)	68 (12%)	578	50	146

All Children	Timely[1]	Late	Not received[2]	Total (N)[3]	Not eligible [4]	Unknown [5]
Penta 1	524(83%)	95 (15%)	18 (3%)	638	37	181
Penta 2	406(68%)	159 (26%)	37 (6%)	603	51	165
Penta 3	299(51%)	221 (38%)	65 (11%)	585	39	150
Pneumococcal 1	516(80%)	96 (15%)	31 (5%)	643	39	174
Pneumococcal 2	394(65%)	165 (27%)	47 (8%)	607	54	160
Pneumococcal 3	158(26%)	351 (58%)	95 (16%)	603	39	137
Measles	245(64%)	85 (22%)	57 (15%)	388	28	133

[1] Vaccinations are classified as "timely" if received between 7 days prior and 4 weeks (28 days) after the recommended age for the respective vaccine dose.

[2] Includes documented non-receipt and maternal reports of non-receipt of the respective vaccine dose

[3] Total (N) for each vaccine dose indicates the number of children who were either vaccinated or, if not vaccinated, at least 28 days older than the recommended age. Vaccination timeliness was calculated only for vaccine-eligible children (i.e., children old enough to receive the vaccine) with written documentation of vaccination or maternal report of non-receipt of vaccination. **Therefore, N for each dose of vaccination varies as different vaccine doses are recommended at different ages of the child)**

[4] Children who were old enough to receive the vaccine dose, had not yet received the vaccine, but were within 28 days of the recommended age for the vaccine dose, as well as those with documented vaccination but unknown, incomplete, or invalid vaccination dates.

[5] Positive Vaccination reported by the mother, but no documentation was available.

*IPV was not included in timeliness analysis because of very low coverage

Notes: *Sampling weights were applied for counts and percentage.

Table 4.5 presents the distribution of vaccination timeliness among Bangladeshi children ages 0-23 months. The proportion of children receiving timely vaccination for different vaccine doses ranged from 24.2% for BCG to 76% for Penta 1. The proportions reduced dramatically for subsequent doses in multidose vaccine series, e.g., only 58% and 44% of children received the second and third doses, respectively, of the pentavalent vaccine in a timely manner. This decreasing pattern was also observed for the OPV and PCV vaccine series. As coverage for both doses of IPV were less than 1%, there were not enough observations to include these doses in the timeliness analyses. Thus, both doses were excluded from the timeliness analyses. Notably, rural children presented a higher proportion of timely vaccination for BCG and Measles than their urban counterparts. This pattern is reversed for OPV, Penta and PCV vaccine series, where urban children showed a higher proportion of timely vaccination.

Table 4.6: Distribution of age of the children in days by which specific proportion of the children has received different vaccine doses.

		Age in days by which specific proportion of vaccine dose was achieved						
	Mean	1%	10%	25%	**50%**	75%	90%	99%
BCG	**54.4**	1	13	25	**44**	61	85	427
Penta1	**70.6**	36	44	48	**58**	70	93	422
Penta2	**110.4**	67	75	81	**92**	112	145	566
Penta3	**151.9**	94	106	113	**128**	156	202	623
OPV1	**71.9**	36	44	48	**58**	70	95	475
OPV2	**113.2**	67	75	81	**93**	113	147.5	590
OPV3	**156.6**	94	106	114	**129**	158	212	655
PCV1	**74.8**	36	44	48	**58**	71	100	534
PCV2	**115.1**	67	75	81	**93**	115	152	613
PCV3	**176.9**	94	109	123	**147**	182	256	680
Measles	**317.8**	260	271	277	**291**	313	389	683

Table 4.6 and Figure 4.2 present children's age by which specific proportion of different vaccine doses were achieved. Notably, these numbers only include children with documented information on vaccination timeliness. For BCG, 50% vaccination was achieved approximately by the age of 7 weeks, 90% coverage was achieved by the age of 12 weeks. 99% coverage was achieved by the age of approximately 61 weeks, which indicates extreme delay in vaccination for the final 10%. For the first dose of the Penta and OPV multidose vaccine series, 70% vaccination coverage was achieved by the age of 10 weeks, which by definition of our study was within the limit of timely vaccination. However, for subsequent doses the magnitude of delay was much higher.

For all vaccine doses, extreme delays were observed to achieve the final 10% of vaccination, which is reflected by the mean age of vaccination being significantly higher than the median age (50^{th} percentile) of vaccination.

Figure 4.3 shows a graphical presentation of the difference between coverage and timeliness. There is a huge gap between the number of children receiving the vaccines within their first year of life vs. the number of children receiving the vaccines in a timely manner. The largest gaps between coverage and timeliness were observed for the BCG and Pneumococcal 3 vaccines.

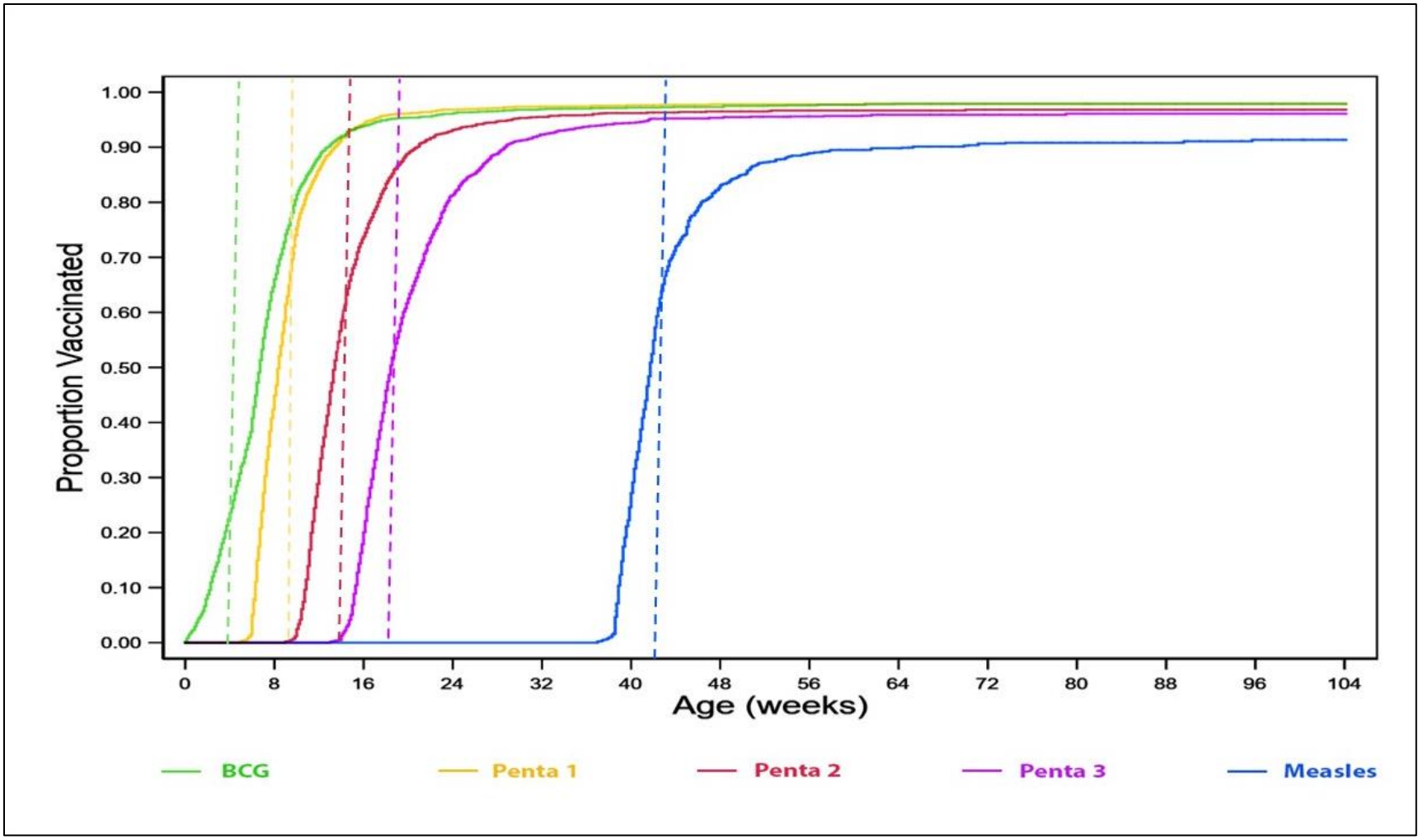

Figure 4.2**:** Distribution of age of the children in weeks by which specific proportion of the children has received different vaccine doses.

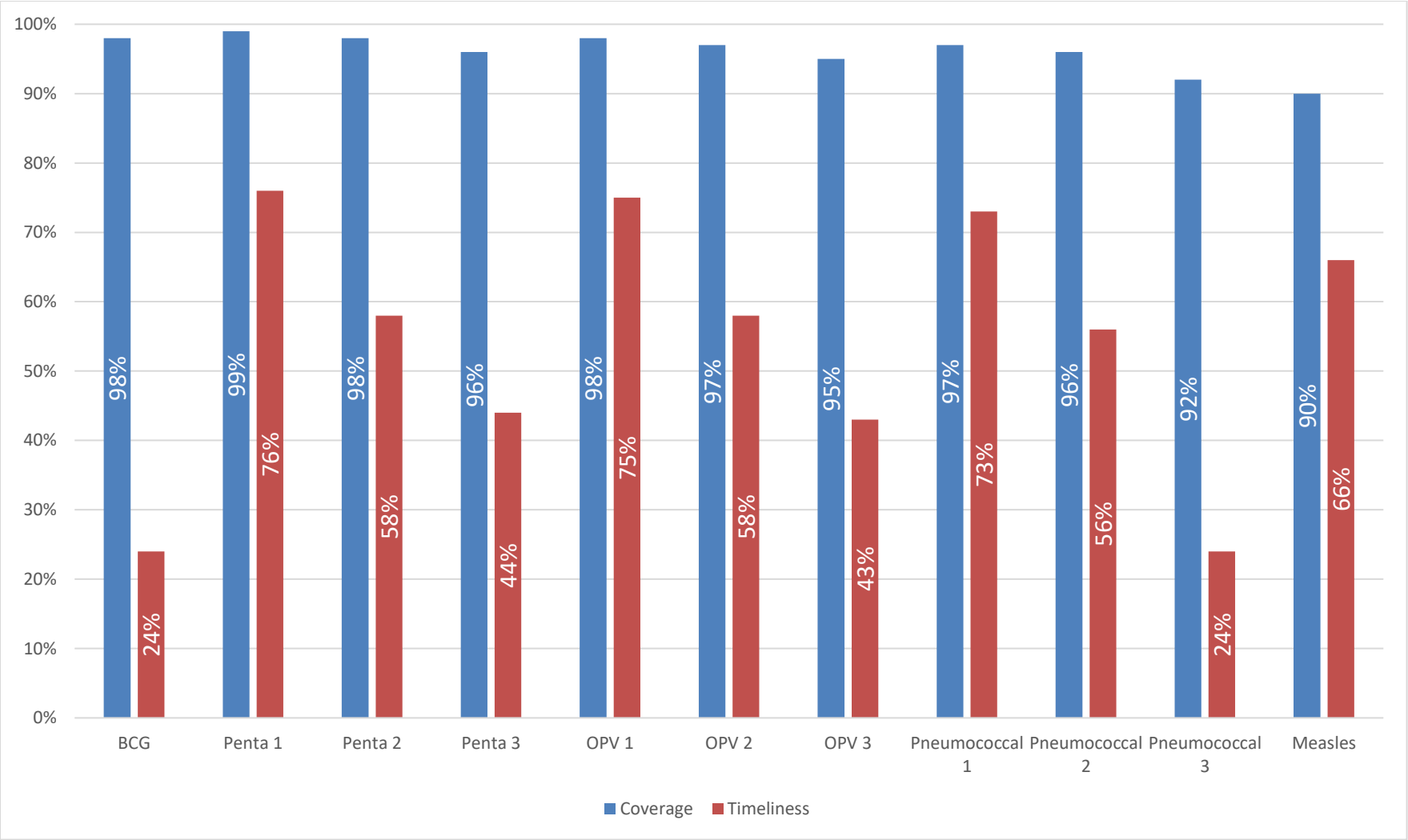

Figure 4.3: Comparison of vaccination coverage and timeliness for vaccine doses in the EPI schedule.

Table 4.7 : Correlates of timely vaccination for different vaccine doses among 0-23-month-old children in the 2017-18 BDHS

	Penta1 (N=2228)					**Penta2 (N=2137)**					**Penta3 (N=2027)**					**BCG (N=2474)**					**Measles (N**			
–	aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]	
Residence (ref: urban)																								
Rural	0.76	**0.000**	0.67	0.86		0.84	**0.005**	0.74	0.95		0.97	0.636	0.86	1.10		0.88	**0.018**	0.78	0.98		1.23	0.056	0.99	1.53
Wealth quintiles (ref: poorest quintile)																								
Poorer	0.95	0.491	0.82	1.10		0.92	0.258	0.79	1.06		0.90	0.167	0.77	1.05		0.99	0.907	0.86	1.15		1.09	0.534	0.84	1.41
Middle	0.98	0.785	0.84	1.14		0.98	0.831	0.84	1.15		0.91	0.247	0.77	1.07		0.98	0.848	0.84	1.15		0.92	0.576	0.68	1.24
Richer	1.24	**0.014**	1.04	1.47		1.19	**0.046**	1.00	1.41		1.16	0.090	0.98	1.39		1.04	0.656	0.88	1.22		0.98	0.911	0.73	1.32
Richest	1.23	**0.022**	1.03	1.46		1.25	**0.020**	1.04	1.51		1.16	0.142	0.95	1.41		1.03	0.764	0.87	1.21		1.00	1.000	0.71	1.40
Mother's age during the birth of the child																								
20-24	1.10	0.172	0.96	1.25		1.06	0.392	0.93	1.22		1.03	0.689	0.89	1.19		0.95	0.417	0.84	1.07		1.14	0.331	0.88	1.47
25-29	1.18	**0.047**	1.00	1.38		1.20	**0.039**	1.01	1.42		1.19	0.053	1.00	1.42		1.07	0.396	0.92	1.25		1.52	**0.007**	1.12	2.07
30-49	1.04	0.637	0.87	1.25		1.15	0.158	0.95	1.39		1.25	**0.026**	1.03	1.51		0.99	0.946	0.84	1.18		1.55	**0.007**	1.13	2.14
Mother's education (Ref: No education/<primary)																								
Primary	0.99	0.954	0.79	1.25		0.99	0.905	0.77	1.25		0.94	0.619	0.74	1.19		0.96	0.724	0.75	1.22		1.03	0.900	0.70	1.51
Secondary or higher	1.17	0.163	0.94	1.46		1.17	0.191	0.93	1.48		1.14	0.255	0.91	1.43		1.07	0.580	0.84	1.35		1.36	0.115	0.93	1.98
Birth order (Ref: First born)																								

	Penta1 (N=2228)					Penta2 (N=2137)					Penta3 (N=2027)					BCG (N=2474)					Measles (N			
_	aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]	
Second or higher	0.91	0.160	0.80	1.04		0.94	0.375	0.82	1.08		0.96	0.543	0.83	1.10		0.99	0.907	0.88	1.12		0.72	**0.010**	0.56	0.92
Number of ANC visit (Ref: <4)																								
4 or more	1.16	**0.003**	1.05	1.28		1.21	**0.000**	1.09	1.33		1.19	**0.002**	1.07	1.32		1.17	**0.002**	1.06	1.29		1.18	0.081	0.98	1.43
Place of Birth (Ref: Facility delivery)																								
Home delivery	0.92	0.090	0.83	1.01		0.90	**0.036**	0.81	0.99		0.87	**0.012**	0.78	0.97		0.93	0.154	0.85	1.03		1.00	0.993	0.83	1.20
Gender of Child (Ref: Female)																								
Male	0.99	0.846	0.90	1.09		1.03	0.607	0.93	1.13		1.05	0.343	0.95	1.17		1.03	0.526	0.94	1.13		0.94	0.483	0.80	1.11
Household size	0.98	0.069	0.97	1.00		0.99	0.302	0.97	1.01		1.00	0.875	0.98	1.02		0.99	0.139	0.97	1.00		1.00	0.968	0.96	1.04
Media exposure (ref: no)																								
Yes	1.14	**0.013**	1.03	1.26		1.06	0.295	0.95	1.19		1.13	**0.047**	1.00	1.27		1.12	**0.041**	1.00	1.24		1.10	0.377	0.89	1.36
Religion (ref: Islam)																								
Others	0.95	0.524	0.80	1.12		0.93	0.390	0.78	1.10		0.92	0.381	0.77	1.11		0.95	0.539	0.79	1.13		0.99	0.947	0.73	1.35

Notes: Adjusted hazard ratios (aHR) and their 95% confidence intervals (CI) obtained from cox proportional hazard models. Survival data analyzed using weights to account for the complex sampling design of the BDHS. Bold P value indicates statistical significance ($p<0.05$).

Table 4.7 presents the correlates of vaccination timeliness for different doses of the pentavalent vaccine as well as presents the correlates of timeliness for the BCG vaccine and the 1st dose of the Measles/Rubella vaccine among children ages 0-23 months. Children from households with a higher wealth index score were significantly more likely to receive the first and second doses of the pentavalent vaccine at an earlier age than those with a lower wealth index score. However, the wealth index was not associated with timely vaccinations for BCG and Measles. A higher number of antenatal visits was positively associated with early receipt of all vaccine doses evaluated except Measles. Children whose mothers were 25-29 years old during the birth of the child, were more likely to receive all the doses of the pentavalent vaccine and the measles vaccine at an earlier age than those whose mothers were younger. Children who were born at home were significantly less likely to receive the second and third doses of the pentavalent vaccine at an earlier age than those who were born in a health facility. Children in rural areas were significantly less likely to receive the first and second doses of the Pentavalent vaccine and the BCG vaccine at an earlier age than urban children. Even though having a second or higher birth order was negatively associated with timely vaccination of measles, the effect was small. Media exposure was positively associated with early receipt of Penta1, Penta 3 and BCG. Secondary or higher education for mothers was positively associated with timely vaccination of Measles, but not for other vaccines. Other characteristics were not significantly associated with vaccination timeliness of any of the vaccines.

4.4 Discussion:

Using the 2017/18 BDHS, this study finds high rates of non-documentation of vaccination and low rates of vaccination timeliness in Bangladesh. Almost 15% of children did not have any vaccination documentation at the time of the interview and for an additional 17% the interviewer was not able to access the vaccination card. The documented coverage for different vaccine doses ranged from 68%-74%; however, when maternal reports were included, coverage ranged from 90-98%. While many studies reported that for multi-dose vaccines there is a significant drop in vaccination coverage for subsequent doses (3,80–82), in this study the magnitude in the drop was minimal. Our findings are comparable with those of a secondary data analysis of the 2014 BDHS by Sheikh et al., who reported more than 90% coverage for all the EPI vaccines except measles (86%) (79). Table 4.8 presents a side-by-side comparison of the coverage and timeliness estimates for different vaccine doses reported by the current study and the study by Sheikh et al. Coverage and timeliness estimate for all vaccine doses except Penta 3 and OPV 3 were higher in 2017/18 than in 2014, whereas the timeliness of BCG was unchanged.

Minimal coverage gaps between the 1st and 3rd doses suggest that the EPI program in Bangladesh has been able to ensure consistent coverage irrespective of vaccine doses. Bangladesh has a pluralistic health system, where private and non-governmental organizations play a significant role in delivering health services in addition to the public health systems. A vast network of public, private and NGO sector providers play an influential role in maintaining the high vaccination coverage in Bangladesh (83).

Table 4.8: Immunization Coverage and timeliness comparison among children aged 12-23 months reported in the 2014 BDHS and the 2017-2018 BDHS.

Vaccine Dose	Coverage presented by Sheikh et al	Coverage in the current study	Proportion of timely vaccination presented by Sheikh et al	Proportion of timely vaccination in the current study
Data Source	BDHS 2014	BDHS2017-18	BDHS 2014	BDHS2017-18
BCG	97.9%	98.3%	24.4%	24.2%
Penta1	97.0%	98.5%	62.8%	75.7%
Penta2	95.4%	97.5%	54.2%	58.1%
Penta3	91.3%	95.9%	46.2%	43.7%
OPV1	97.4%	98.3%	62.8%	74.7%
OPV2	95.5%	96.9%	54.1%	57.9%
OPV3	91.4%	94.8%	46.0%	43.1%
Measles	86.0%	90.2%	52.3%	65.6%

Unlike vaccination coverage, the proportion of children who received vaccinations in a timely manner significantly deteriorated in subsequent doses. Almost 76% of children received Penta1 in a timely manner compared to 44% for Penta 3. This decrease in timeliness was also observed for the second and third doses of the OPV and Pneumococcal vaccines. A secondary analysis of 2014 BDHS data by Sheikh et al presented similar findings (79)(79). However, massive improvements have been observed in the timeliness proportion for 1st doses of both OPV and Pentavalent vaccines. There was significant improvement in the proportion of timely vaccination for OPV2, Penta2 as well as Measles. However, there was slight reduction in the timeliness proportion of both OPV3 and Penta3. No measurable progress was made in improving timeliness for the BCG birth dose, which remains very low. Hanifi et al. reported that mother's outreach health worker prefers to administer BCG at 6 weeks along with first dose of Pentavalent vaccines in order to

minimize workload. In addition they also reported that mother often prefer not to take their babies outside in the early days of life due to some traditional beliefs, which may contribute to low BCG vaccination within the first month of life (84). Substantial gaps between coverage and timeliness have also been reported in multiple studies in different countries including Bangladesh (15,50,51,63,79,85,86)

This study identified the number of antenatal visits as an important correlate of vaccination timeliness for all vaccine doses. Socioeconomic status and media exposure were also found to have positive associations with timely receipt of vaccination. By contrast, rural residence, home delivery, and higher birth order were associated with delayed receipt of vaccinations. Several prior studies identified these covariates as significant determinants of vaccination timeliness globally (39,47,48,50,85,87,88). Sheikh et also presented socioeconomic status and the number of antenatal visits as strong determinants of timeliness in Bangladesh, however access to media was not previously reported as a significant covariate (79). Almost half of the mother's reported that they didn't have media exposure on a regular basis (TV, radio, newspaper), however, given the improving mobile phone and internet penetration rate in the country, the potential role of targeted intervention among mobile phone using mothers and families could be explored further. Improved awareness about the vaccination schedule among pregnant women and young mothers, especially in the rural areas may result in improved adherence to vaccination schedule. Improved access to facility delivery and antenatal and postnatal visits may improve immunization awareness among mothers and family members and vaccination schedule adherence for children. Existing literature reported maternal education, gender of the child, antenatal the household size, and religion as significant

determinants of vaccination timeliness (44,49,50,68,87,89), however this study didn't find any such relationship in the 2017/18 BDHS. and

This study has several limitations. First, the results are based on secondary data that were not collected to answer questions on immunization timeliness. Specifically, a large proportion of the children did not have vaccination documentation, for these children the accuracy of coverage information based on maternal recall and the timeliness of vaccinations for these children could not be evaluated, and these children had to be excluded from the timeliness analyses. Our analysis of differences between children included in our timeliness analysis vs. those excluded due to missing vaccination information (see Appendix B, Table B.2) suggests that children whose mothers have access to media may be overrepresented and children with higher number of household size may be underrepresented in our analysis. As a result, our estimates may be subject to selection biases, however, the direction of those biases is unknown.

The study may also have missed several key characteristics that maybe associated with vaccination receipt and timeliness, e.g., distance to health facilities, lack of resources, and supply-side factors impacting vaccine availability. Our model specification was limited to variables identified as correlates of vaccination in prior literature that were available in DHS data. While the correlates of timeliness in our study align with the major domains of the vaccine hesitancy model, but many potential correlates of vaccine hesitance, coverage, and timeliness, were not available in the DHS data. The observed association of with the number of antenatal care visits correspond to the hesitancy domains of convenience and communication, as ANC provides opportunities for vaccine-related communication, but the number of ANC visits may be subject to similar barriers as

childhood vaccinations. Complacency may also be mitigated through appropriate disease- and vaccine-related risk communication during ANC visits. Similarly, place of delivery is likely to be related to two domains of the hesitancy models: communication and convenience. Home-based delivery prevents the communication of vaccine-related information at the time of delivery; it also represents a barrier to vaccination for vaccinations due at birth, by requiring women to travel to health facilities providing vaccinations. On the other hand, positive association of the media exposure with timely vaccination corresponds principally to the communication domain, which ultimately have the potential to contribute to the confidence and complacency domains, by feeding vital information regarding the importance and safety of childhood vaccinations. Birth order is likely to be related with the convenience as it might not be convenient for the parents to timely vaccinate their younger children as they have to distribute the parental time and resources with increasing number of children.

4.5 Conclusion:

Our study findings demonstrate that despite high vaccination coverage, a large proportion of Bangladeshi children do not comply with the vaccination schedule, which likely impacts vaccine effectiveness nationally. The study highlights high vaccination coverage but also significant gaps in vaccination documentation and schedule adherence in Bangladesh. The study identified several correlates of vaccination timeliness that may help policy makers identify and prioritize gaps (e.g., explore why the proportion of timely vaccination is so low for the BCG and Pneumococcal vaccines). Additionally, focusing on the identified correlates of delayed vaccinations may guide them in planning targeted interventions to improve vaccination timeliness in Bangladesh. Increasing awareness about

immunizations, for example during antenatal visits or facility-based delivery, especially among rural mothers and mothers with more than one child, should be considered as a priority strategy. Notably, our study showed small but meaningful improvements in vaccination coverage and timeliness compared to the only previous nationally representative study by Sheikh et al. using the 2014 BDHS using the 2014 BDHS (79), however, the extent to which these improvements were sustained after the COVID pandemic is, at present, unknown.

CHAPTER 5: IMMUNIZATION TIMELINESS AND ITS CORRELATES IN THREE SOUTH ASIAN COUNTRIES: SECONDARY ANALYSIS OF DEMOGRAPHIC HEALTH SURVEYS BETWEEN 2017 AND 2019

5.1 INTRODUCTION

In the last three decades there have been considerable improvements in the under-five (U-5) mortality rate. Despite this, more than half of all U-5 deaths are attributable to preventable and treatable diseases. Infectious diseases, such as pneumonia and other respiratory tract infections, diarrhea, and measles, are among the leading causes of deaths. Low- and middle-income countries (LMICs), including South Asian countries like Bangladesh, India or Pakistan, bear a disproportionately high burden of these deaths (1–5). According to the WHO, immunizations prevent 3.5 to 5 million deaths annually (8). Despite tremendous efforts to increase vaccination coverage, in 2021, 25 million children under the age of 1 year did not receive basic vaccines (11) and thus remained vulnerable to vaccine preventable diseases and increased morbidity, mortality and disability. Consequently, more than 3 million people, including 1.5 million U-5 children, die every year because of vaccine preventable diseases (12,13). Even in countries with high vaccination coverage, inequities exists through pockets of low coverage in different socioeconomic and geographic cohorts (14). Effective immunization programs hold potential to reduce U-5 mortality by protecting post neonatal infants and older children against preventable infectious diseases. In addition, some of the vaccines provide lifelong

immunity e.g., measles and rubella (10), contributing to lower morbidity and mortality during adult life.

To achieve the full benefit of immunization, vaccines should be delivered in a timely manner (3,38–40,78). Immunization before the recommended age may result in failure to generate sufficient protective antibodies, thus reducing the effectiveness of immunization. By contrast, delayed vaccinations leave children vulnerable to infections. Vaccination delays have disproportionately negative implications for children in LMICs, where the median age for acquiring infections is lower relative to high-income countries (42). Delaying the first vaccine dose in a multi-dose vaccine series is a strong predictor of subsequent incomplete immunization (38,41).

To-date, there is little evidence regarding vaccination timeliness in South Asian countries. There has been only one study in which vaccination timeliness was investigated in Bangladesh using a nationally representative dataset. Sheikh et al. conducted a secondary analysis of the 2014 Bangladesh Demographic and Health Survey (BDHS) data and demonstrated a large gap in schedule adherence to the EPI vaccines in Bangladesh (58–60). There have been two such nationally representative studies conducted in India based on the Household and Facility Survey 2008 and the National Family Health Survey 4 (2015-16) (61,62). There is only one nationally representative study from Pakistan however, this was conducted using 2005-06 DHS data (63). Two other studies in India and Bangladesh which were limited to specific region or hospital (42,64). This study aims to characterize and compare the immunization timelines for different EPI vaccines in three South Asian countries, Bangladesh, India and Pakistan, which have substantial socio-cultural and geographical similarities between them. In addition, it aims to investigate the

correlates of timely vaccination. A more recent analysis of vaccination timeliness in these countries will reveal how the national vaccination systems are performing and what changes may have had a positive or negative impact on their performance over time. In addition, a cross-national comparison between neighboring countries with comparable sociocultural backgrounds will aid in understanding the factors associated with vaccination timeliness in the region. This study provides the first example for a cross-national comparative overview of vaccination timeliness in South Asia, which can guide researchers and policymakers to develop focused interventions based on the specific needs of each country and the region.

5.2 METHODS

5.2.1 Data Source:

A secondary data analysis was conducted using data from three datasets obtained through United States Agency for International Development (USAID)'s Demographic and Health Surveys Programme:

- Bangladesh Demographic and Health Survey, 2017-18
- Pakistan Demographic and Health Survey, *2017-18*
- India National Family Health Survey, 2019-20

Demographic and Health Surveys (DHS) are nationally representative household surveys that collect information on a broad range of topics in more than 100 countries (65). Topics include information on infant and child mortality, fertility, family planning, maternal health, child immunization, malnutrition, HIV prevalence, and malaria, among others. Data from these surveys are freely available and accessible to qualified researchers

and students. The indicators are comparable over time and across countries. This program is considered the largest and longest enduring survey program of its kind (USAID, 2018). DHS surveys use a stratified two stage cluster design. In the first stage, enumerations areas (EAs) are chosen from a pre-existing sampling frame (e.g., Census). A sample of households is subsequently drawn from each EA in the second stage.

5.2.2 Research Design:

This is a cross sectional analysis of data from the latest available DHS datasets from Bangladesh, India, and Pakistan.

5.2.3 Study Population:

Our preliminary study population included all children between the ages of 0-23 months. Analyses of timeliness included only age-eligible children, i.e., children who were old enough to receive a particular vaccine dose. Notably, the DHS collected vaccination information from either vaccination cards or historical recall data from maternal report when the vaccination card was missing. However, vaccination dates were not collected for children whose immunization status was only reported by the mother. We therefore considered the following inclusion and exclusion criteria for our analyses of timeliness:

Inclusion Criteria:

- Children who were 0-23 months old at the time of the interview
- For the descriptive analysis of timeliness, children at least 28 days older than the minimum age to receive a particular dose of the vaccine.
- For the multivariable analysis, children at least as old as the recommended age of vaccination.

Exclusion Criteria:

- Children with a vaccination card but no date of vaccination or an invalid date for the particular vaccine dose.
- Children with no vaccination card. However, in case a mother reported non-vaccination for a particular dose, it was included in the analyses and was recorded as not received.

5.2.4 Definition of Vaccination Timeliness:

The immunization schedules for all routine vaccines due in children's first year of life and implemented through the EPI programs of Bangladesh, India and Pakistan are presented in Table 5.1 (67).

DHS collected data on the date of birth of the child, and, for children with vaccination documentation, the date of each vaccination in the EPI schedule. The child's age at vaccine receipt, in days, was calculated as the difference between the date of vaccination receipt as recorded in the vaccination documentation and the date of birth of the child. Based on the vaccination schedule presented in tableT 1 vaccination timeliness was defined as follows:

Timely Vaccination: In descriptive analyses, timely vaccination was defined as receipt of the vaccine between 7 days prior to and 28 days after the recommended age. For example, the first dose of the Pentavalent vaccine (Penta1) is due at age 6 weeks (42 days). Thus, any Penta1 dose received between the ages of 35-70 days was considered timely.

Delayed Vaccination: Delayed vaccination was defined as the receipt of the vaccine more than 28 days after the recommended age. Thus, any Penta1 dose received after the age of 70 days was considered delayed.

No vaccination: In cases where the vaccination card or the mother reported that a particular dose was not received by the children then that children was considered as not vaccinated for that particular dose.

In multivariable analyses, timeliness was assessed by the time, in days, between the recommended age as outlined in the vaccine schedule, and the actual age at the time of vaccination receipt.

Some observations in the dataset contain gaps in vaccination history in the case of multi-dose vaccine series, e.g., the data may show that a child received the 1st and 3rd doses of the Pentavalent vaccine but missing the 2nd dose. The Guide to DHS Statistics suggests that in such a scenario the 3rd dose be recoded as the 2nd dose. (66).(66). We addressed such issues as recommended in the Guide. Table 5.2 describes the definition of timeliness for those vaccine doses that were included in the EPI schedules of all 3 countries at the time of the surveys.

5.2.5 Statistical Analysis

All statistical analyses were conducted using STATA 15 SE (Stata Corp, College Station, TX). Sampling weights were applied as recommended in the DHS data analyses guidelines (66) in order to account for the complex survey design of the DHS.

Descriptive analysis was conducted to present (1) sociodemographic information and vaccination documentation information of children ages 0-23 months at the time of the interview and their mothers; (2) proportions of children receiving timely vaccination for

different vaccine doses among age-eligible children ages 0-23 months, i.e., children who were old enough to receive a particular vaccine dose.

Table 5.1: EPI vaccination schedule for infants**.**

Vaccine	Bangladesh	India	Pakistan
*Bacillus Calmette–Guérin (*BCG): One dose	Birth	Birth	Birth
Pentavalent Vaccine (Diphtheria, Pertussis, Tetanus, Hepatitis B and Hib): Three doses	6 weeks 10 weeks 14 weeks	6 weeks 10 weeks 14 weeks	6 weeks 10 weeks 14 weeks
Oral Polio Vaccine (OPV): Three doses	 6 weeks 10 weeks 14 weeks	0 weeks* 6 weeks 10 weeks 14 weeks	0 weeks* 6 weeks 10 weeks 14 weeks
Pneumococcal Conjugate Vaccine (PCV): Three doses	6 weeks 10 weeks 14 weeks	6 weeks 10 weeks 14 weeks	6 weeks 10 weeks 14 weeks
Inactivated Polio Vaccine (IPV): Two doses	6 weeks 14 weeks	6 weeks 14 weeks	6 weeks 14 weeks
Measles and Rubella Vaccine (MR): One dose	9 months	9 months	9 months

*OPV is recommended at birth for India and Pakistan. For Bangladesh the first dose of OPV is recommended at 6 weeks. By the time this survey was conducted, IPV and PCV were not integrated in the national immunization program of India. Thus, OPV0, Pneumococcal vaccine series and IPVs were not included in the analyses to maintain uniformity across the 3 countries.

Table 5.2: Definition of the timeliness of vaccine administration**.**

Vaccine	**Recommended Vaccine Schedule (age in days)**	**Timeliness of vaccinations based on the age of the child at the time of vaccine administration (age in days)**	
		Timely	Delayed
*Bacillus Calmette–Guérin (*BCG)	At birth	BCG: 0 to 28 days	BCG: 29 days or more
Oral Polio Vaccine (OPV)	OPV1: 42 days	OPV1: 35 to 70 days	OPV1: 71 days or more
	OPV2: 70 days	OPV2: 63 to 98 days	OPV2: 99 days or more
	OPV3: 98 days	OPV3: 91 to 126 days	OPV3: 127 days or more
Pentavalent Vaccine (Penta: Diphtheria, Pertussis, Tetanus, Hepatitis B and Hib)	Penta1/DTP1: 42 days	Penta 1/DTP1: 35 to 70 days	Penta 1/DTP1:71 days or more
	Penta2/DTP2: 70 days	Penta 2/DTP2: 63 to 98 days	Penta 2/DTP2: 99 days or more
	Penta3/DTP3: 98 days	Penta 3/DTP3: 91 to 126 days	Penta 3/DTP3: 127 days or more
Measles and Rubella Vaccine (MR)	266 days	MR: 259 to 294 days	MR: 294 days and more

Survival analysis was used to model time to vaccination. The event of interest was the receipt of the vaccine dose for which timeliness was being analyzed. If the child had not received the vaccine dose by the time of the interview, the data were considered censored. Correlates of timely vaccination were examined using Cox proportional hazard models, where the recommended age of vaccination was designated as time zero. If a child

received a vaccination on or prior to the recommended age, the time to vaccine initiation was adjusted as very close to zero (recoded to $1x10^{-6}$ days after time zero).

Based on a review of existing literature (2,68)(2,68) we included the following correlates of vaccination timeliness in our cox regression model: rural vs. urban residence, wealth index quintile, mother's age at birth (15-19, 20-24, 25-29, above 30 years), maternal education (primary education or less, secondary or higher education, birth order (first born vs. second or higher order), number of antenatal visits (0-3, 4 or more), place of delivery (facility delivery, home delivery), gender of the child (male, female), household size (number of persons) and media exposure (yes, no).

The Cox hazard model estimated the hazard of receiving the vaccine dose at an earlier or later time compared to the reference group. A hazard ratio more than 1 indicates that children with the respective characteristic had a higher risk of the event occurring earlier. On the other hand, a hazard ratio less than 1 indicates that the characteristic was associated with a lower risk of the event occurring earlier (i.e., a higher chance of receiving the vaccine at a later point than the reference group). As the schedules of the OPV and Penta vaccine series coincide, we considered the timeliness of the Pentavalent vaccine doses as proxies for other vaccine doses due at the same time. Thus, survival models were estimated for the BCG, vaccine due at birth, the Pentavalent vaccine series due at 6, 10, and 14 weeks of age, and the 1st dose of the Measles vaccine due at age 9 months.

To assess potential selection biases from excluding children with unknown vaccination coverage or timeliness, we compared the characteristics of children who were included in the hazard models to those who were excluded due to lack of vaccination documentation or due to missing data on vaccination dates. In descriptive analyses,

Student's t-tests and chi-squared statistics were used to assess statistical significance; a logistic regression model assessed selection bias in a multivariable model.

5.3 Result:

Table 5.3 presents the major sociodemographic characteristics of mothers and their children ages 0-23 months from Bangladesh, India and Pakistan. Approximately two-thirds of the children resided in the rural areas for both Bangladesh and Pakistan. For India the proportion of rural residence was much higher (80%).

The male-to-female ratio among the children was close to 1 for all three countries. Bangladesh presented the highest level of maternal education, followed by India and Pakistan. The proportion of facility delivery was highest for India (89.80%), while 75% of Pakistani children were born at health facilities. In Bangladesh the proportions of facility and home delivery were nearly equal. In terms of vaccination documentation, almost one third of the mother from Bangladesh and Pakistan failed to present a vaccination card during the interview, while in India almost 88% of mothers were able to present the documentation.

Table 5.3: Sociodemographic characteristics of eligible mothers and their children aged 0-23 months from three South Asian Countries.

		Bangladesh (N=3462)			**India (N=86516)**			**Pakistan (N=3860)**	
		Mean or N	(sd or %)		Mean or N	(sd or %)		Mean or N	(sd or %)
Residence	Rural	2,286	66.0%		17,503	80.12%		2,081	66.5%
	Urban	1,176	34.0%		22,883	19.88%		1,779	33.5%
Wealth index score	Mean	-0.004	0.1		-0.008	0.1		-0.004	0.1
Mother's age	Mean	686	20.3%		25.95	4.81		239	5.3%
Mother's marital status	Currently married	3,428	99.1%		85588	98.93%		3,835	99.1%
	Currently not married	34	0.9%		928	1.07%		25	0.9%
Mother's age at birth	(Years)	18.5	3.24		25.03	4.7		21.5	3.93
Mother's education	Primary or less	1,173	33.5%		26,783	30.96%		2,505	62.0%
	Secondary or higher	2,289	66.5%		59,733	69.04%		1,355	38.0%
Birth order	First child	1,298	36.9%		34,017	39.32%		911	24.5%
	Second or higher	2,164	63.1%		52,499	60.68%		2,949	75.5%
Antenatal care visits	3 or less	1,808	53.2%		34,698	40.11%		1,777	43.8%
	4 or more	1,654	46.8%		51,818	59.89%		2,083	56.2%
Media exposure	No	1,613	45.8%		44,871	51.86		2,037	50.4%

		Bangladesh (N=3462)			**India (N=86516)**			**Pakistan (N=3860)**	
		Mean or N	(sd or %)		Mean or N	(sd or %)		Mean or N	(sd or %)
	Yes	1,849	54.2%		61,997	48.14		1,823	49.6%
Place of birth	Health facility	1,778	51.0%		77,695	89.80%		2,787	74.9%
	Home delivery	1,684	49.0%		8,821	10.20%		1,073	25.1%
Sex of the child	Female	1,672	48.2%		41,926	48.46%		1,918	49.7%
	Male	1,790	51.8%		44,590	51.54%		1,942	50.3%
Vaccination documentation	No card	505	14.5%		2,320	2.68%		976	19.1%
	Have card, but not seen by surveyor	593	17.5%		8,438	9.75%		669	17.1%
	Seen by surveyor	2,364	68.0%		75,758	87.57%		2,215	63.8%
Number of household members	Mean	6.2	2.7		6.35	2.62		9.2	4.71

Notes: *Means and percentages were calculated using weights provided in the BDHS dataset. Statistical significance of urban-rural differences was evaluated using two-tailed Student's t-tests for continuous variables and chi-squared tests for categorical variables.
*The table provides information on all children in the age range of 0-23 months.
Sd: standard deviation; N indicates the total number of observations for each attribute

Table 5.4 presents the proportion of eligible children with timely or delayed vaccination in the three countries. Figure 1 presents a visual comparison of the three countries. Apart from the BCG vaccine, the proportions of timely vaccination for all vaccine doses were higher in Bangladesh compared to India and Pakistan. The proportion of timely vaccination was lowest among Pakistani children. Only 53% of Pakistani children received the 1st dose of the Pentavalent vaccine within 28 days of the recommended age, compared to 72% in Bangladesh and 57% in India. Similar patterns were observed across all vaccine doses except BCG.

Table 5.4: Proportion of eligible children with timely or delayed vaccination in Bangladesh, India and Pakistan

	Bangladesh			India			Pakistan		
	Timely	Late	Not received	Timely	Late	Not received	Timely	Late	Not received
BCG	24%	68%	8%	69%	19%	12%	62%	19%	19%
OPV 1	75%	21%	4%	59%	25%	16%	59%	29%	13%
OPV 2	58%	34%	8%	44%	38%	19%	43%	36%	20%
OPV 3	43%	45%	13%	31%	46%	23%	31%	37%	33%
Penta 1	76%	21%	4%	61%	25%	13%	53%	24%	24%
Penta 2	58%	35%	7%	45%	38%	17%	39%	31%	30%
Penta 3	44%	44%	12%	31%	46%	22%	28%	34%	38%
Measles	66%	20%	14%	43%	28%	29%	41%	21%	38%

Only 24% of Bangladeshi children received the BCG vaccine within 28 days of the recommended age compared to 69% in India and 62% in Pakistan respectively. Notably, in all three countries, for multidose vaccines, the proportion of children receiving timely vaccination decreased in subsequent doses.

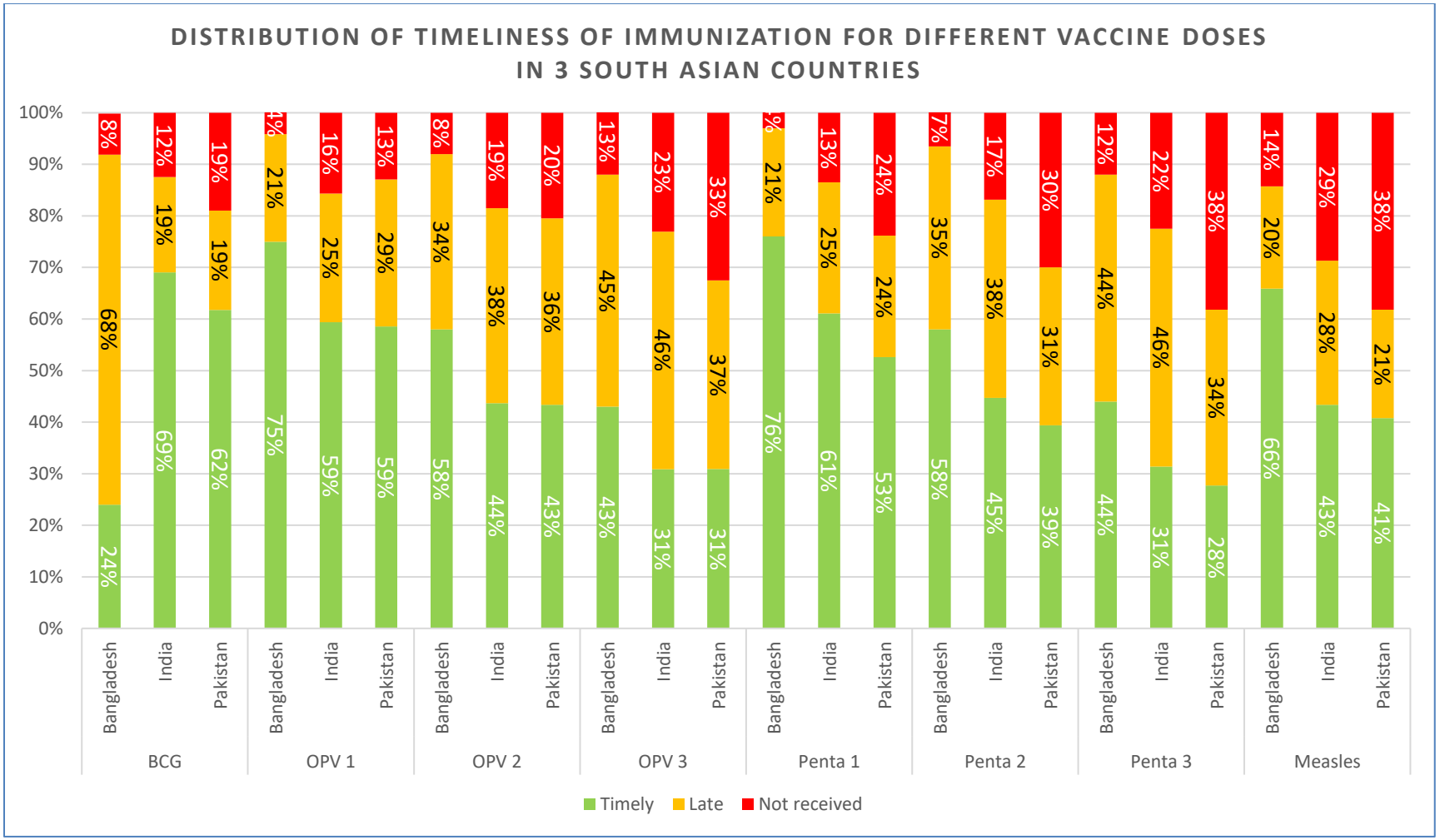

Figure 5.1: Distribution of timeliness of Immunization for different vaccine doses in 3 South Asian countries

5.3.1 Correlates of timely vaccination

Figures 5.2 to 5.6 present hazard ratios for different correlates of timely vaccination for different vaccine doses in Bangladesh, India and Pakistan. In the figure, the red dots indicate the Hazard Ratios (HRs) for each correlate and the blue lines indicate the corresponding 95% confidence intervals. The black vertical reference line for each forest plot indicates a hazard ratio of 1. If the red dot falls on the right side of the central line, this indicates that children with the respective characteristic had a higher risk of receiving the particular vaccine dose earlier and vice versa. If the blue line (95% CI) touches the reference line, it indicates that the specific characteristic is not statistically significantly associated with timely vaccination. In the case that the blue line doesn't touch the reference line, this indicates that the specific characteristic has a statistically significant association with timely vaccination of the particular dose.

Wealth index quintile, number of antenatal visits, place of delivery, media exposure, birth order, and urban vs. rural residence were found to have statistically significant associations with timely vaccination for multiple vaccine doses across all three countries (Annex A). Household wealth, the number of antenatal visit (4 or more), and media exposure showed positive associations, while home delivery and second or higher birth order showed negative associations with timely vaccination. For India rural residence was slightly positively associated with timely vaccination of multiple vaccine doses (Penta 2, Penta3 and Measles) but for Bangladesh rural residence presented strong negative association (aHR: 0.76-0.88) with timely vaccination with the Penta 1, Penta3 and BCG vaccines. However, for Measles vaccine the direction of the association was inverse (aHR: 1.23), despite being marginally not significant statistically. Several additional, country-

specific associations were observed. In Bangladesh, children of mothers whose age at first birth was 25 years or older were more likely to receive the Pentavalent and BCG vaccines earlier than those who were younger than 20 years (the reference group). For India, this association was observed only for the second dose of the Pentavalent vaccine, while for Pakistan there was no statistically significant association between maternal age and vaccination timeliness.

In terms of the magnitude of the association, the effect size and significance for number of antenatal visits were roughly comparable across the three countries. Household wealth presented maximum impact in Pakistan (aHR ranging from 1.21 to 1.93 for different wealth quintiles and vaccine doses). In Bangladesh the rich and richest had a sizeable effect (aHR: 1.19 to 1.25) on timely vaccination of the first two doses of pentavalent vaccines. While in India despite being statistically significant for all vaccine doses the effect, size varied from marginal to modest (aHR: 1.05 to 1.26).

For Pakistan higher level of maternal education was strongly associated with higher likelihood of receiving timely vaccination for all doses (aHR: 1.52 to 1.78) compared to those who reported less than primary education or no education. In India, despite being statistically significant the magnitude of impact was modest (aHR: 1.09-1.22). However, for Bangladesh there was no significant association between maternal education and timely vaccination. Greater household size was associated with slightly lower likelihood of receiving timely vaccination for all vaccine doses in Pakistan (aHR: 0.88-0.93). However, for India the effect was marginal despite being statistically significant (aHR: 0.96-0.97). Household size did not show significant associations in Bangladesh.

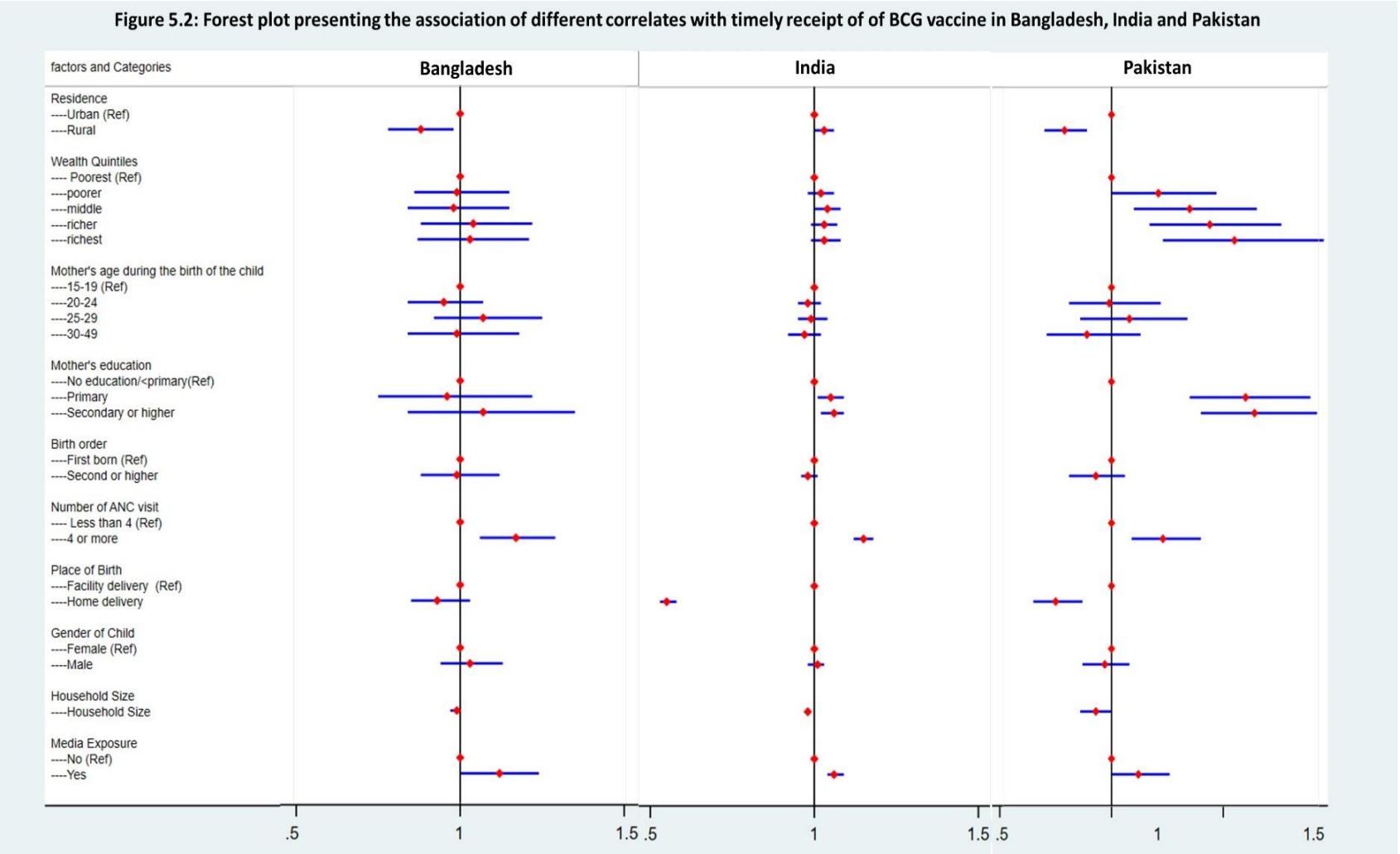

Figure 5.2: Forest Plot presenting the association of different correlates of timely receipt of BCG vaccine in Bangladesh, India and Pakistan

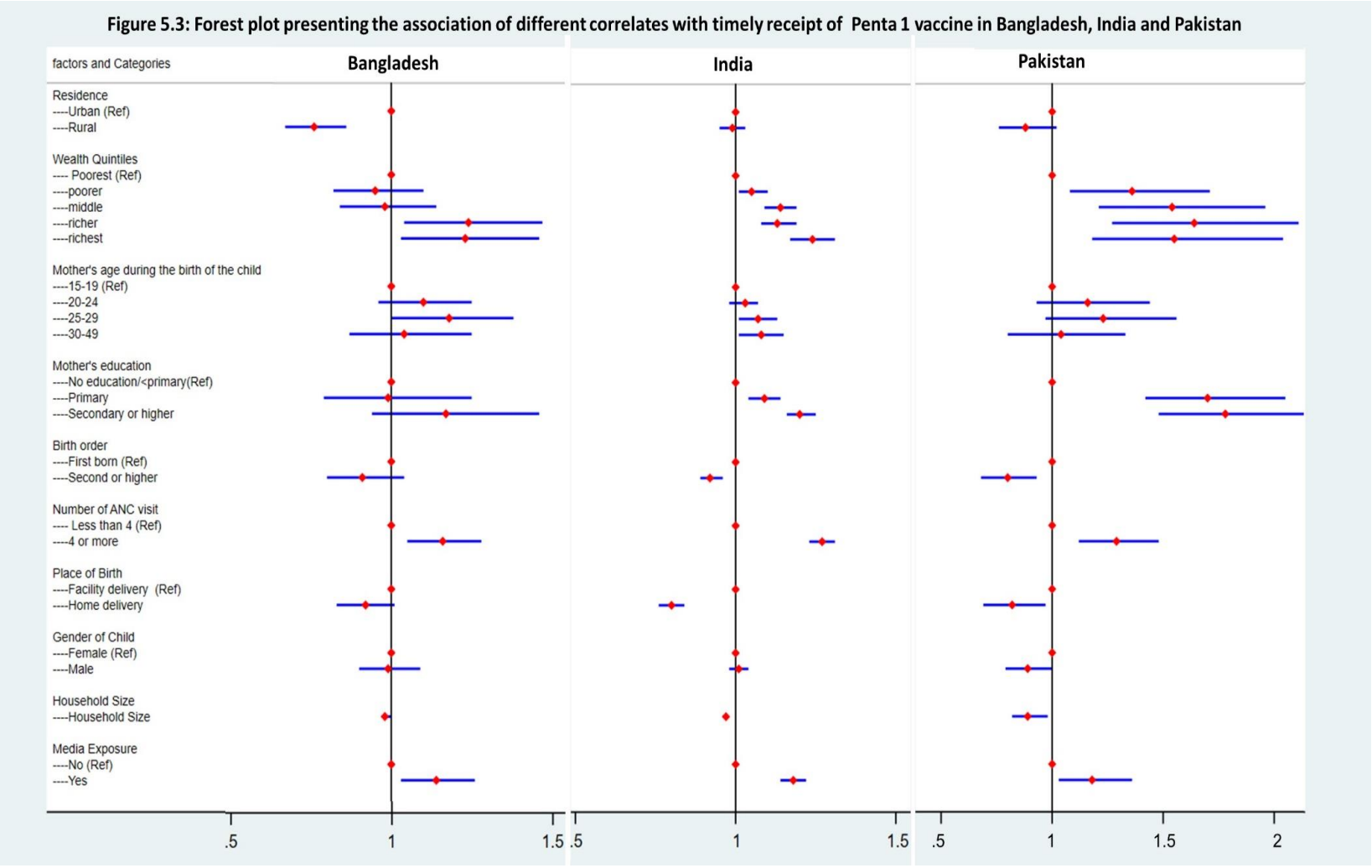

Figure 5.3: Forest Plot presenting the association of different correlates of timely receipt of Penta1 vaccine in Bangladesh, India and Pakistan

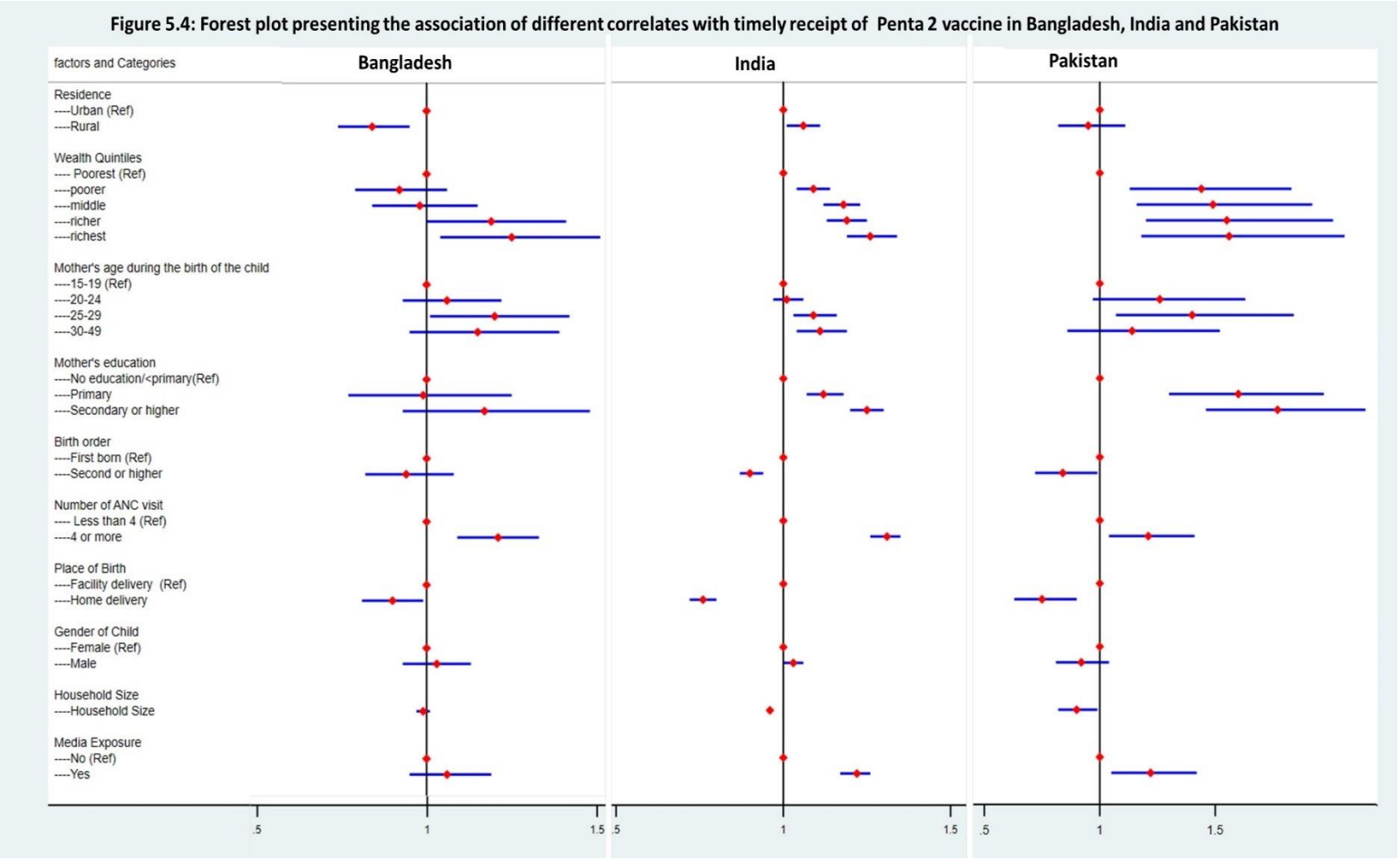

Figure 5.4: Forest Plot presenting the association of different correlates of timely receipt of Penta2 vaccine in Bangladesh, India and Pakistan

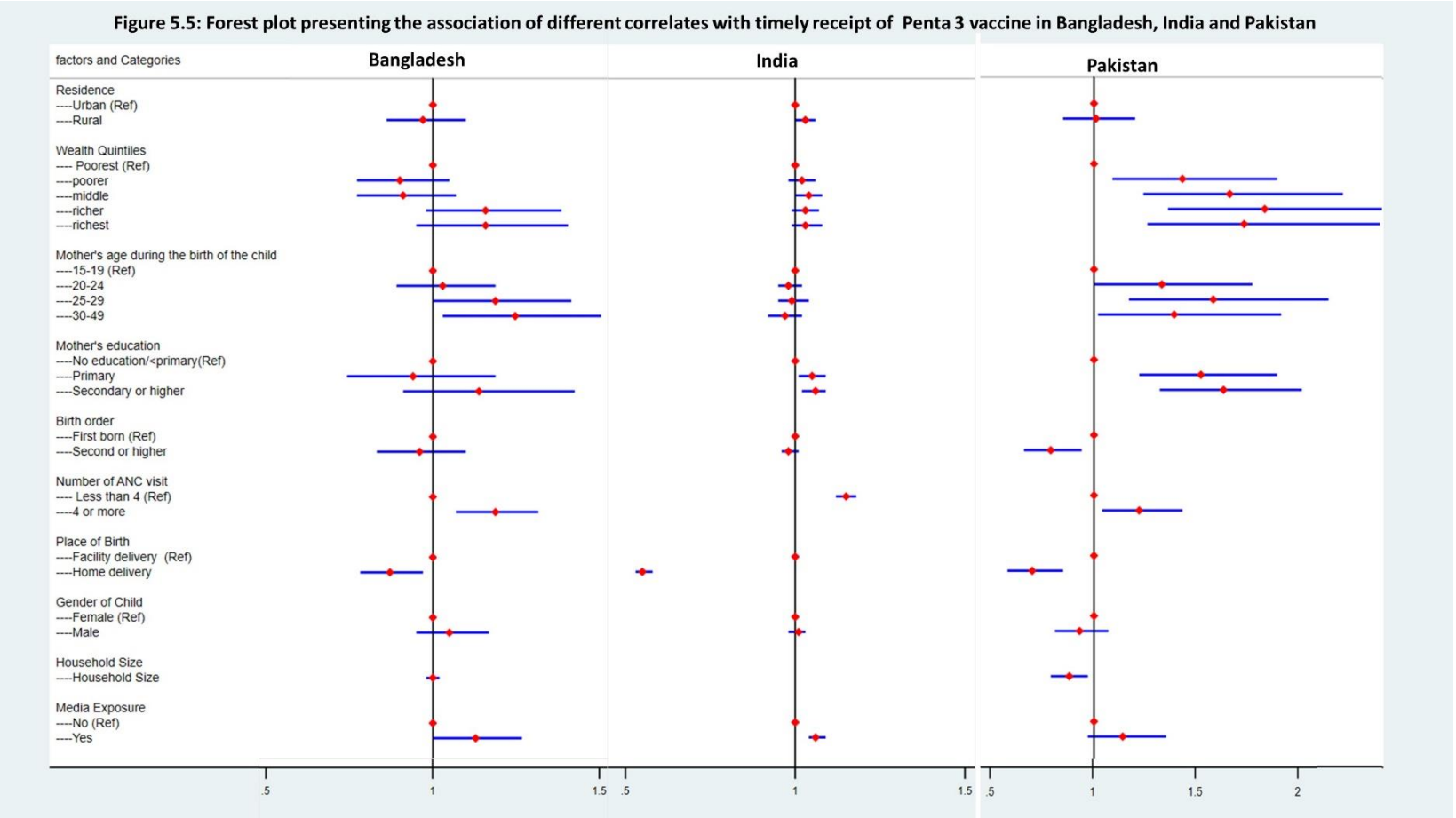

Figure 5.5: Forest Plot presenting the association of different correlates of timely receipt of Penta3 vaccine in Bangladesh, India and Pakistan

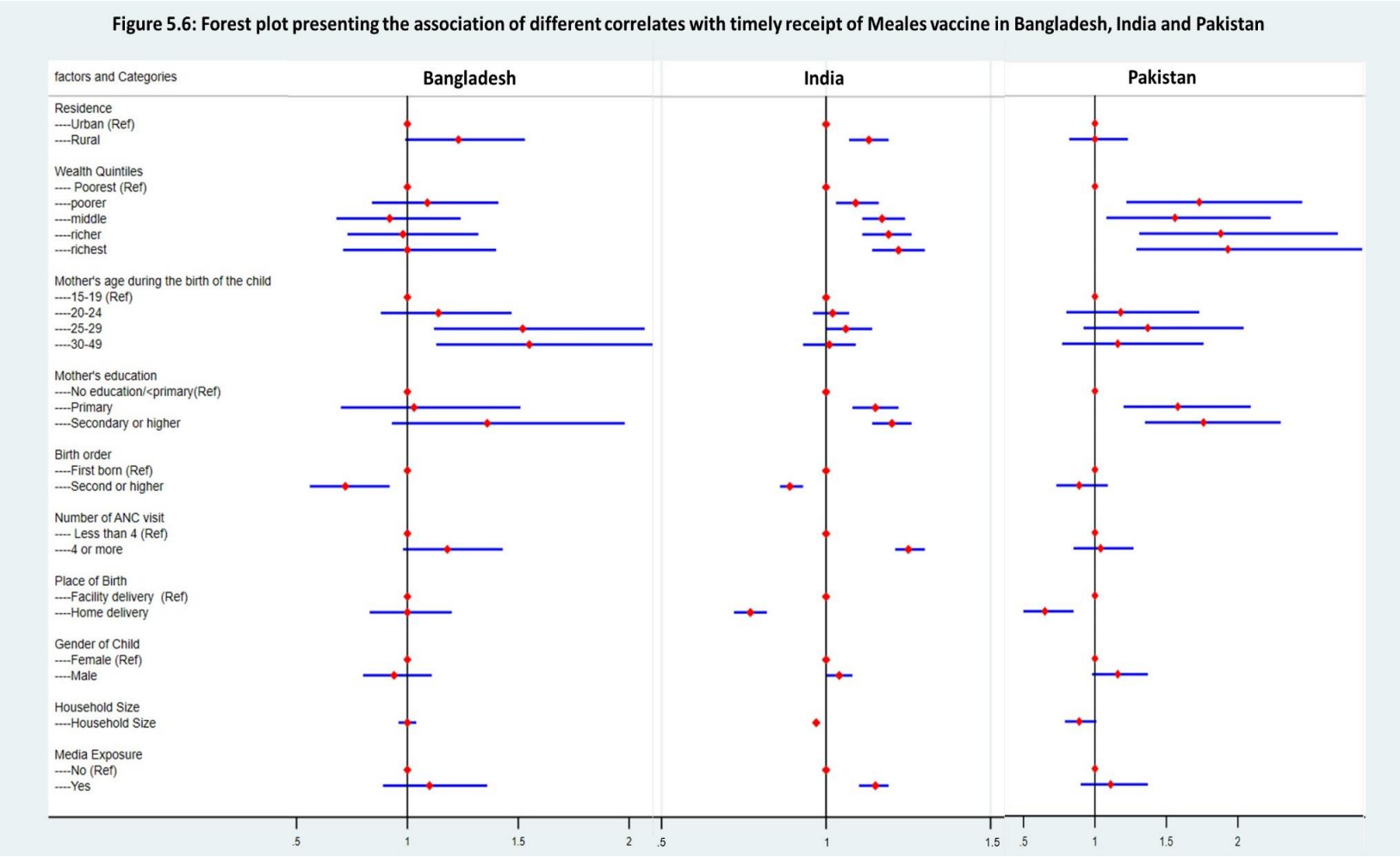

Figure 5.6: Forest Plot presenting the association of different correlates of timely receipt of Penta2 vaccine in Bangladesh, India and Pakistan

5.4 Discussion:

The study finds high rates of non-documentation of vaccinations in all three countries. In Bangladesh almost 15% children did not have any vaccination card and for another 17%, the card could not be accessed during the interview. In Pakistan, 19% of the children did not have any vaccination card, while the interviewer was not able to see the card for another 17% even though the participant reported that they had it. However, in India almost 90% of women were able to present the vaccine card during the time of interview.

Despite Bangladesh lagging in terms of the proportion of facility delivery and antenatal care visits, our study suggests that the proportion of children who received timely vaccination was highest in Bangladesh, this pattern was observed across all vaccine doses except BCG. However, even in Bangladesh only 76% of the eligible children received first dose of Pentavalent vaccine in a timely manner followed by 55% and 42% for the second and third doses, respectively. The observed decrease in the timeliness of subsequent doses is consistent with previous studies conducted in different parts of the world (2,39,68,79). Hanifi et al. provided possible explanations for the extremely low proportion of opportune BCG vaccination. They reported that outreach health workers in Bangladesh preferred to administer BCG along with the first dose of the Pentavalent vaccine at six weeks to reduce their workload. In addition, they reported that many mothers prefer not to take their newborn children outdoors during the first month of life due to traditional beliefs, which may account for the low BCG vaccination rate within the first month. Notably, the proportion of eligible children not being vaccinated was also lowest in Bangladesh, ranging from 4% to 14% for different vaccine doses. Both India and Pakistan had higher non-

vaccination rates, ranging from 12% to 29% and 13% to 38%, respectively, for different vaccine doses. Francis et al identified certain factors which were negatively associated with vaccination status in India, including female gender, Muslim religion, lower caste, urban residence, lower level of maternal education, non-institutional delivery, and fewer antenatal care visits (90). In Pakistan, Riaz et al. reported lack of awareness among mothers/caregivers, fear of side effects, lack of vaccination centers, and vaccine supply issues as major causes of non-vaccination (91). In our study, mothers in India and Pakistan presented lower proportions of secondary or higher education compared to Bangladesh. This may have contributed to higher proportion of non-vaccination in these two countries.

Importantly, the existing policy interventions and vaccination infrastructure play a very important role in the overall performance of the immunization programs. For example, in Bangladesh, instead of centralizing vaccination programs inside healthcare clinics, the EPI program has been implemented to administer vaccines directly to the households of hard to reach areas. In regions lacking community clinics or educational institutions, the residence of the village chief, or a villager's house has been utilized as a venue for administering vaccinations to the children residing in the community. The active engagement of the community in participating in EPI aid has played a crucial role in the program's success (83,92). On the other hand in India, targeted interventions in the rural areas to reduce vaccination dropout has played significant role in improved immunization coverage (93). This might have also contributed to the higher timeliness rates in rural India compared to urban areas. The government of India recently developed a framework to strengthen immunization program in urban areas, which could play significant role in improving the urban vaccination scenario (94). On the other hand, in Pakistan, the lack of

an integrated approach to overcome the cultural, religious and infrastructural barriers results in limited success of the immunization program (95).

An intriguing difference was observed between Bangladesh and India regarding the association between timely vaccination and urban vs. rural residence. Compared to their urban counterparts in Bangladesh, rural children were less likely to receive vaccinations on time. In contrast, rural children in India were more likely to be vaccinated on time. Urban slums, which are home to a significant portion of the urban population in India, lack access to health care and community-based health care workers. This could be a contributing factor to the poor performance in urban areas (93). On the other hand, the extensive dissemination of health workers from various NGOs in Bangladesh's urban slums may contribute to the relatively high vaccination rates in urban Bangladesh. In all three countries, higher socioeconomic status (SES), higher number of antenatal visits, facility-based delivery, and higher media exposure were positively associated with timely vaccination. On the other hand, children with second or higher birth order were less likely to receive timely vaccinations compared to their older siblings. These findings are consistent with prior evidence from different countries of Africa and Asia (2,39,68). Multiple authors cited allocation of family resources as a potential explanation for the inverse relationship between birth order and child immunization status. This includes financial resources, familial initiative, and time commitment. While the firstborn typically receives these resources alone, subsequent children must share these resources with their elder siblings. As a consequence, the younger child is frequently a victim of limited resource allocation during their vaccination age, which leads to vaccine hesitancy and negatively impacts the overall immunization status (96–98).

Our study findings from Bangladesh are broadly in line with those of Sheikh et al. and Sarker et al. who reported that SES, parental education, the number of antenatal visits, place of delivery, and urban vs. rural residence were significant correlates of vaccination timeliness in Bangladesh in 2014 (79,99).

Maternal education was found to be a significant correlate of timeliness for all vaccine doses in India and Pakistan. Higher maternal education was strongly positively associated with timely vaccination. The point estimates were largest in Pakistan, and similar in Bangladesh and India. The difference in significance between Bangladesh and India may be attributable to differences in sample size. Greater household size was negatively associated with timely vaccination for nearly all vaccine doses in India and Pakistan. These findings are consistent with existing literature reporting maternal education and household size as important correlates of vaccination timeliness (39,42,50). Despite prior literature reporting the gender of the child to be an important determinant of vaccination timeliness (50,51,68,87), we did not find this to be a significant correlate in our study.

This study is subject to limitations. First, there is a lack of clarity in the existing literature regarding the definition of vaccination delay. Similar to several other studies we used 28 days from the recommended age as a cutoff point to define delay in descriptive analyses. The sensitivity of our estimates to the definition of timeliness was not assessed. However, to address this limitation in multivariable analyses of correlates of timeliness we conducted survival analyses to explore correlates of timely vaccination, where time was treated as a continuous measure (likelihood of receiving vaccine at an earlier or later date rather than a dichotomization into timely vs. delayed vaccination).

Incompleteness of data was another limitation of this study. Significant proportions of children did not have vaccination documentation in all three countries. We had to exclude those children from our timeliness analyses. The exclusion of the children with non-documentation may have resulted in selection bias. We did some comparison between children with vaccine card and no card (Table B1 and B2 in Appendix B) and found out that in India the key characteristics were significantly different between the two groups. However, for Bangladesh and Pakistan most characteristics were comparable. Integrating vaccination documentation into a unified electronic record system has the potential to reduce gaps in vaccination documentation and provide better quality data on considerably larger numbers of children. Ideally, such data could be merged with large surveys, like DHS, to describe socioeconomic and other characteristics of each mother-child dyad. Recently Bangladesh has implemented an online database of COVID vaccinations, which could act as an excellent platform to integrate individual level sociodemographic and vaccination data.

Another limitation of the analysis is that the existing variables in the datasets did not cover all correlates of vaccine hesitancy, such as those described by comprehensive vaccine hesitancy models. Data availability and prior literature determined the vaccine hesitancy model. specification, and important correlates of vaccination decisions may be missing from the model. The omission of such variables may have biased parameter estimates and limited policy recommendations for improving vaccination timeliness.

Finally, due to vastly differing sample sizes across DHS cohorts, timeliness models were estimated separately for each country, precluding an assessment of the statistical significance of similarities and differences in correlates of timeliness across countries. The

smaller sample sizes of the Bangladesh and Pakistan surveys, compared to India, may have affected precision and statistical significance. However, a descriptive comparison of the magnitude and statistical significance of country-specific estimate provides preliminary guidance on overall and country-specific associations interventions needed to improve vaccination timeliness scenario.

5.5 Conclusion:

This study documents substantial variation in the rates of vaccination documentation, coverage, and timeliness of routine childhood vaccinations across three Asian countries. Despite extensive differences in these metrics across countries, Bangladesh, India, and Pakistan share key common correlates of vaccination timeliness. In particular, household wealth, media exposure, antenatal care, and facility-based delivery were consistently associated with greater vaccination timeliness across countries and across the vaccine doses evaluated. The findings suggest that policymakers should consider these factors as primary targets for identifying at-risk children and/or improving vaccination timeliness across South East Asia. In addition, the study identified several country-specific or vaccine-specific associations that may offer information on potential targeted strategies for the development and targeting of interventions aimed at improving vaccination timeliness. These include rural vs. urban residence in Bangladesh, maternal age, education, and household size in India, and maternal education and birth order in Pakistan. Most importantly, the study highlights the urgent need for national immunization programs to provide vaccination documentation to all mothers and add vaccination timeliness as a performance metric beyond vaccination coverage, in order to optimize vaccine efficacy and offer maximum protection against vaccine-preventable infections in U-5 children.

CHAPTER 6: CONCLUSION

Despite a large number of children receiving delayed immunization, vaccination timeliness is an overlooked health problem in Bangladesh, India and Pakistan. This study documents substantial gaps in vaccination documentation, coverage, and timeliness of routine childhood vaccinations across three Asian countries. Despite extensive differences in these metrics across countries, Bangladesh, India, and Pakistan share key common correlates of vaccination timeliness. In particular, household wealth, media exposure, antenatal care, and facility-based delivery were consistently associated with greater vaccination timeliness across countries and across the vaccine doses evaluated. The findings suggest that policymakers should consider these factors as primary targets for identifying at-risk children and/or improving vaccination timeliness across South East Asia. In addition, the study identified several country-specific or vaccine-specific associations that may offer information on potential targeted strategies for the development and targeting of interventions aimed at improving vaccination timeliness. These include rural vs. urban residence in Bangladesh, maternal age, education, and household size in India, and maternal education and birth order in Pakistan. Most importantly, the study highlights the urgent need for national immunization programs to provide vaccination documentation to all mothers and add vaccination timeliness as a performance metric beyond vaccination coverage, in order to optimize vaccine efficacy and offer maximum protection against

vaccine-preventable infections in U-5 children. The definitions, methods and analytic techniques employed in this study have the potential to serve as a reference for future analyses of vaccination timeliness, nationally and globally.

REFERENCES

1. Ameyaw EK, Kareem YO, Ahinkorah BO, Seidu AA, Yaya S. Decomposing the rural–urban gap in factors associated with childhood immunisation in sub-Saharan Africa: evidence from surveys in 23 countries. BMJ Glob Health. 2021 Jan 1;6(1):e003773.

2. Yelverton V, Hair NL, Ghosh SH, Mfinanga SG, Ngadaya E, Baumgartner JN, et al. Beyond coverage: Rural-urban disparities in the timeliness of childhood vaccinations in Tanzania. Vaccine. 2022;

3. Adetifa IMO, Karia B, Mutuku A, Bwanaali T, Makumi A, Wafula J, et al. Coverage and timeliness of vaccination and the validity of routine estimates: Insights from a vaccine registry in Kenya. Vaccine. 2018 Dec 18;36(52):7965–74.

4. Ijarotimi IT, Fatiregun AA, Adebiyi OA, Ilesanmi OS, Ajumobi O. Urban–rural differences in immunisation status and associated demographic factors among children 12-59 months in a southwestern state, Nigeria. PLoS ONE. 2018 Nov 5;13(11):e0206086.

5. Oleribe O, Kumar V, Awosika-Olumo A, Taylor-Robinson SD. Individual and socioeconomic factors associated with childhood immunization coverage in Nigeria. Pan Afr Med J. 2017;26:220.

6. Phillips DE, Dieleman JL, Lim SS, Shearer J. Determinants of effective vaccine coverage in low and middle-income countries: a systematic review and interpretive synthesis. BMC Health Serv Res [Internet]. 2017 Sep 26 [cited 2020 Apr 21];17. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5615444/

7. Reiner RC, Olsen HE, Ikeda CT, Echko MM, Ballestreros KE, Manguerra H, et al. Diseases, Injuries, and Risk Factors in Child and Adolescent Health, 1990 to 2017: Findings From the Global Burden of Diseases, Injuries, and Risk Factors 2017 Study. JAMA Pediatr. 2019 Jun 1;173(6):e190337–e190337.

8. Vaccines and immunization [Internet]. [cited 2022 Nov 14]. Available from: https://www.who.int/health-topics/vaccines-and-immunization

9. Essential Programme on Immunization [Internet]. [cited 2023 Jul 18]. Available from: https://www.who.int/teams/immunization-vaccines-and-biologicals/essential-programme-on-immunization

10. About MMR and MMRV Vaccines: For Providers | CDC [Internet]. 2023 [cited 2023 Jun 26]. Available from: https://www.cdc.gov/vaccines/vpd/mmr/hcp/about.html

11. Immunization coverage [Internet]. [cited 2022 Nov 14]. Available from: https://www.who.int/news-room/fact-sheets/detail/immunization-coverage

12. World Health Organization. Children: reducing mortality [Internet]. 2019 [cited 2019 Oct 15]. Available from: https://www.who.int/news-room/fact-sheets/detail/children-reducing-mortality

13. Wahl B, O'Brien KL, Greenbaum A, Majumder A, Liu L, Chu Y, et al. Burden of Streptococcus pneumoniae and Haemophilus influenzae type b disease in children in the era of conjugate vaccines: global, regional, and national estimates for 2000-15. Lancet Glob Health. 2018 Jul;6(7):e744–57.

14. Ali HA, Hartner AM, Echeverria-Londono S, Roth J, Li X, Abbas K, et al. Vaccine equity in low and middle income countries: a systematic review and meta-analysis. Int J Equity Health. 2022 Jun 11;21(1):82.

15. Grant CC, Roberts M, Scragg R, Stewart J, Lennon D, Kivell D, et al. Delayed immunisation and risk of pertussis in infants: unmatched case-control study. BMJ. 2003 Apr 19;326(7394):852–3.

16. World Health Organization. Immunization surveillance, assessment and monitoring [Internet]. 2019. Available from: https://www.who.int/immunization/monitoring_surveillance/en/

17. Institute of Medicine (U.S.). The Childhood Immunization Schedule and Safety : Stakeholder Concerns, Scientific Evidence, and Future Studies [Internet]. Washington, District of Columbia: National Academies Press; 2013. Available from: https://login.pallas2.tcl.sc.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=e000xna&AN=867762&site=eds-live

18. Lopalco PL, DeStefano F. The complementary roles of Phase 3 trials and post-licensure surveillance in the evaluation of new vaccines. Vaccine. 2015 Mar 24;33(13):1541–8.

19. COVID-19 vaccine hesitancy: the five Cs to tackle behavioural and sociodemographic factors - Mohammad S Razai, Pippa Oakeshott, Aneez Esmail, Charles Shey Wiysonge, Kasisomayajula Viswanath, Melinda C Mills, 2021 [Internet]. [cited 2023 Jul 28]. Available from: https://journals.sagepub.com/doi/full/10.1177/01410768211018951

20. Ten health issues WHO will tackle this year [Internet]. [cited 2023 Jul 28]. Available from: https://www.who.int/news-room/spotlight/ten-threats-to-global-health-in-2019

21. Strategic Advisory Group of Experts on Immunization. REPORT OF THE SAGE WORKING GROUP ON VACCINE HESITANCY [Internet]. 2014 Nov. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.asset-scienceinsociety.eu/sites/default/files/sage_working_group_revised_report_vaccine_hesitancy.pdf

22. Kempe A, Saville AW, Albertin C, Zimet G, Breck A, Helmkamp L, et al. Parental Hesitancy About Routine Childhood and Influenza Vaccinations: A National Survey. Pediatrics. 2020 Jul;146(1):e20193852.

23. Omer SB, Pan WKY, Halsey NA, Stokley S, Moulton LH, Navar AM, et al. Nonmedical exemptions to school immunization requirements: secular trends and association of state policies with pertussis incidence. JAMA. 2006 Oct 11;296(14):1757–63.

24. Barskey AE, Schulte C, Rosen JB, Handschur EF, Rausch-Phung E, Doll MK, et al. Mumps outbreak in Orthodox Jewish communities in the United States. N Engl J Med. 2012 Nov 1;367(18):1704–13.

25. Nguyen KH, Srivastav A, Lindley MC, Fisher A, Kim D, Greby SM, et al. Parental Vaccine Hesitancy and Association With Childhood Diphtheria, Tetanus Toxoid, and Acellular Pertussis; Measles, Mumps, and Rubella; Rotavirus; and Combined 7-Series Vaccination. Am J Prev Med. 2022 Mar;62(3):367–76.

26. Gilkey MB, McRee AL, Magnus BE, Reiter PL, Dempsey AF, Brewer NT. Vaccination Confidence and Parental Refusal/Delay of Early Childhood Vaccines. PLoS ONE. 2016 Jan 1;11(7):e0159087.

27. Smith PJ, Humiston SG, Marcuse EK, Zhao Z, Dorell CG, Howes C, et al. Parental Delay or Refusal of Vaccine Doses, Childhood Vaccination Coverage at 24 Months of Age, and the Health Belief Model. Public Health Rep. 2011;126(Suppl 2):135–46.

28. Tostrud L, Thelen J, Palatnik A. Models of determinants of COVID-19 vaccine hesitancy in non-pregnant and pregnant population: Review of current literature". Hum Vaccines Immunother. 2022 Nov 30;18(6):2138047.

29. Rancher C, Moreland AD, Smith DW, Cornelison V, Schmidt MG, Boyle J, et al. Using the 5C model to understand COVID-19 vaccine hesitancy across a National and South Carolina sample. J Psychiatr Res. 2023 Apr;160:180–6.

30. St-Amant O, Lapum J, Dubey V, Beckermann K, Huang CS, Weeks C, et al. Considerations for Vaccine Hesitancy: 3Cs Model. [cited 2023 Aug 15]; Available from: https://ecampusontario.pressbooks.pub/immunizations/chapter/considerations-for-vaccine-hesitancy-3cs-model/

31. Geweniger A, Abbas KM. Childhood vaccination coverage and equity impact in Ethiopia by socioeconomic, geographic, maternal, and child characteristics. Vaccine. 2020 Apr 29;38(20):3627–38.

32. Center for Disease Control. Principles of Vaccination | Epidemiology of vaccine-preventable diseases [Internet]. 2012 [cited 2019 Nov 1]. Available from: https://www.cdc.gov/vaccines/pubs/pinkbook/prinvac.html

33. Lopalco P, de Carvalho H, Kreidl P, Leitmeyer K, Giesecke J. Childhood vaccination schedules in Europe vary widely. Is this a problem? Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz. 2009 Nov;52(11):1095–8.

34. World Health Organization. Summary of WHO Position Papers - Recommended Routine Immunizations for Children [Internet]. 2019. Available from: https://www.who.int/immunization/policy/Immunization_routine_table2.pdf?ua=1

35. WHO recommendations for routine immunization - summary tables [Internet]. [cited 2023 Jul 16]. Available from: https://www.who.int/teams/immunization-vaccines-and-biologicals/policies/who-recommendations-for-routine-immunization---summary-tables

36. Bos E, Batson A. Using immunization coverage rates for monitoring health sector performance: measurement and interpretation issues. 2000;

37. Dolan SB, Carnahan E, Shearer JC, Beylerian EN, Thompson J, Gilbert SS, et al. Redefining vaccination coverage and timeliness measures using electronic immunization registry data in low- and middle-income countries. Vaccine. 2019 Mar 22;37(13):1859–67.

38. Grant CC, Turner NM, York DG, Goodyear-Smith F, Petousis-Harris HA. Factors associated with immunisation coverage and timeliness in New Zealand. Br J Gen Pract J R Coll Gen Pract. 2010 Mar;60(572):e113–20.

39. Hu Y, Li Q, Chen Y %J I journal of environmental research, public health. Timeliness of childhood primary immunization and risk factors related with delays: evidence from the 2014 Zhejiang provincial vaccination coverage survey. 2017;14(9):1086.

40. Masters NB, Tefera YA, Wagner AL, Boulton ML. Vaccine hesitancy among caregivers and association with childhood vaccination timeliness in Addis Ababa, Ethiopia. Hum Vaccines Immunother. 2018;14(10):2340–7.

41. Guyer B, Hughart N, Holt E, Ross A, Stanton B, Keane V, et al. Immunization Coverage and Its Relationship to Preventive Health Care Visits Among Inner-City Children in Baltimore. Pediatrics. 1994 Jul 1;94(1):53.

42. Yadav K, Srivastava R, Kumar R, Chinnakal P, Rai SK, Krishnan A. Significant Vaccination Delay can Occur Even in a Community with Very High Vaccination Coverage: Evidence from Ballabgarh, India. J Trop Pediatr. 2011 Jul 8;58(2):133–8.

43. Akmatov MK, Kretzschmar M, Krämer A, Mikolajczyk RT. Timeliness of vaccination and its effects on fraction of vaccinated population. Vaccine. 2008 Jul 23;26(31):3805–11.

44. D'Ardenne KK, Darrow J, Furniss A, Chavez C, Hernandez H, Berman S, et al. Use of rapid needs assessment as a tool to identify vaccination delays in Guatemala and Peru. Vaccine. 2016 Mar;34(14):1719–25.

45. Delrieu I, Gessner BD, Baril L, Roset Bahmanyar E. From current vaccine recommendations to everyday practices: An analysis in five sub-Saharan African countries. Vaccine. 2015 Dec 16;33(51):7290–8.

46. Laryea DO, Abbeyquaye Parbie E, Frimpong E. Timeliness of childhood vaccine uptake among children attending a tertiary health service facility-based immunisation clinic in Ghana. BMC Public Health. 2014 Jan 29;14(1):90.

47. Mbengue MAS, Sarr M, Faye A, Badiane O, Camara FBN, Mboup S, et al. Determinants of complete immunization among senegalese children aged 12-23 months: evidence from the demographic and health survey. BMC Public Health. 2017 Jul 6;17(1):630–630.

48. Jadidi R, Mohammadbeigi A, Mohammadsalehi N, Ansari H, Ghaderi E. Inequity in Timeliness of MMR Vaccination in Children Living in the Suburbs of Iranian Cities. Int J Biomed Sci IJBS. 2015 Jun;11(2):93–8.

49. Chiabi A, Nguefack FD, Njapndounke F, Kobela M, Kenfack K, Nguefack S, et al. Vaccination of infants aged 0 to 11 months at the Yaounde Gynaeco-obstetric and pediatric hospital in Cameroon: how complete and how timely? BMC Pediatr. 2017 Dec 19;17(1):206–206.

50. Clark A, Sanderson C. Timing of children's vaccinations in 45 low-income and middle-income countries: an analysis of survey data. The Lancet. 2009 May 2;373(9674):1543–9.

51. Bicaba A, Haddad S, Kabore M, Taminy E, Feletto M, Fournier P. Monitoring the performance of the Expanded Program on Immunization: the case of Burkina Faso. BMC Int Health Hum Rights. 2009 Oct 14;9 Suppl 1(Suppl 1):S12–S12.

52. Glanz JM, Newcomer SR, Narwaney KJ, Hambidge SJ, Daley MF, Wagner NM, et al. A Population-Based Cohort Study of Undervaccination in 8 Managed Care Organizations Across the United States. JAMA Pediatr. 2013 Mar 1;167(3):274–81.

53. Hargreaves AL, Nowak G, Frew P, Hinman AR, Orenstein WA, Mendel J, et al. Adherence to Timely Vaccinations in the United States. Pediatrics [Internet]. 2020 Mar 1 [cited 2020 May 23];145(3). Available from: https://pediatrics.aappublications.org/content/145/3/e20190783

54. Hu Y, Wang Y, Chen Y, Liang H, Chen Z. Measles vaccination coverage, determinants of delayed vaccination and reasons for non-vaccination among children aged 24-35 months in Zhejiang province, China. BMC Public Health. 2018 Nov 27;18(1):1298–1298.

55. Mvula H, Heinsbroek E, Chihana M, Crampin AC, Kabuluzi S, Chirwa G, et al. Predictors of Uptake and Timeliness of Newly Introduced Pneumococcal and Rotavirus Vaccines, and of Measles Vaccine in Rural Malawi: A Population Cohort Study. PloS One. 2016 May 6;11(5):e0154997–e0154997.

56. Nadella P, Smith ER, Muhihi A, Noor RA, Masanja H, Fawzi WW, et al. Determinants of delayed or incomplete diphtheria-tetanus-pertussis vaccination in parallel urban and rural birth cohorts of 30,956 infants in Tanzania. BMC Infect Dis. 2019 Feb 26;19(1):188–188.

57. Scott S, Odutola A, Mackenzie G, Fulford T, Afolabi MO, Lowe Jallow Y, et al. Coverage and timing of children's vaccination: an evaluation of the expanded programme on immunisation in The Gambia. PloS One. 2014 Sep 18;9(9):e107280–e107280.

58. NIPS/Pakistan NI of PS, ICF. Pakistan Demographic and Health Survey 2017-18. 2019 Jan 1 [cited 2023 Jun 26]; Available from: https://dhsprogram.com/publications/publication-fr354-dhs-final-reports.cfm

59. IIPS/India II for PS, ICF. India national family health survey NFHS-5 2019-21. 2022 Mar 15 [cited 2023 Jun 26]; Available from: https://dhsprogram.com/publications/publication-FR375-DHS-Final-Reports.cfm

60. Bangladesh DHS 2022 - Key Indicators Report (English) [Internet]. [cited 2023 Jun 24]. Available from: https://dhsprogram.com/publications/publication-PR148-Preliminary-Reports-Key-Indicators-Reports.cfm

61. Choudhary TS, Reddy NS, Apte A, Sinha B, Roy S, Nair NP, et al. Delayed vaccination and its predictors among children under 2 years in India: Insights from the national family health survey-4. Vaccine. 2019 Apr 17;37(17):2331–9.

62. Shrivastwa N, Gillespie BW, Lepkowski JM, Boulton ML. Vaccination Timeliness in Children Under India's Universal Immunization Program. Pediatr Infect Dis J. 2016 Sep;35(9):955–60.

63. Zaidi SMA, Khowaja S, Kumar Dharma V, Khan AJ, Chandir S. Coverage, timeliness, and determinants of immunization completion in Pakistan: evidence from the Demographic and Health Survey (2006-07). Hum Vaccines Immunother. 2014 Jun 1;10(6):1712–20.

64. Vasudevan L, Labrique AB, Mehra S, Wu L, Levine O, Feikin D, et al. Maternal determinants of timely vaccination coverage among infants in rural Bangladesh. Vaccine. 2014 Sep 22;32(42):5514–9.

65. The DHS Program - Survey Process [Internet]. [cited 2020 Jan 18]. Available from: https://dhsprogram.com/What-We-Do/Survey-Process.cfm

66. Guide to DHS Statistics [Internet]. [cited 2022 Jun 18]. Available from: https://dhsprogram.com/data/Guide-to-DHS-Statistics/index.cfm

67. Organization WH. SEAR factsheet 2020: expanded programme on Immunization (EPI). 2020;

68. Akmatov MK, Mikolajczyk RT. Timeliness of childhood vaccinations in 31 low and middle-income countries. J Epidemiol Community Health. 2012 Jul 1;66(7):e14.

69. Child Mortality - UNICEF DATA [Internet]. [cited 2023 Jul 16]. Available from: https://data.unicef.org/topic/child-survival/under-five-mortality/

70. Children: improving survival and well-being [Internet]. [cited 2022 Nov 14]. Available from: https://www.who.int/news-room/fact-sheets/detail/children-reducing-mortality

71. World Health Organization. WHO. [cited 2019 Aug 22]. WHO | The Expanded Programme on Immunization. Available from: https://www.who.int/immunization/programmes_systems/supply_chain/benefits_of_immunization/en/

72. Organization WH. Principles and considerations for adding a vaccine to a national immunization programme: from decision to implementation and monitoring. 2014;

73. UNICEF. UNICEF DATA. 2015 [cited 2022 Jun 12]. Levels and Trends in Child Mortality 2015. Available from: https://data.unicef.org/resources/levels-and-trends-in-child-mortality-2015/

74. Strengthening vaccination coverage [Internet]. [cited 2022 Aug 8]. Available from: https://www.who.int/bangladesh/activities/strengthening-vaccination-coverage/strengthening-vaccination-coverage

75. Sarkar PK, kumar Sarker N, Doulah S, Bari TIA. Expanded programme on immunization in Bangladesh: A success story. Bangladesh J Child Health. 2015;39(2):93–8.

76. Mortality rate, under-5 (per 1,000 live births) - Bangladesh | Data [Internet]. [cited 2022 Aug 8]. Available from: https://data.worldbank.org/indicator/SH.DYN.MORT?locations=BD

77. United Nations. Sustainable Development Goals. 2015.

78. Dolan SB, Carnahan E, Shearer JC, Beylerian EN, Thompson J, Gilbert SS, et al. Redefining vaccination coverage and timeliness measures using electronic immunization registry data in low- and middle-income countries. Vaccine. 2019 Mar 22;37(13):1859–67.

79. Sheikh N, Sultana M, Ali N, Akram R, Mahumud RA, Asaduzzaman M, et al. Coverage, Timelines, and Determinants of Incomplete Immunization in Bangladesh. Trop Med Infect Dis. 2018 Jun 25;3(3):72.

80. Ntenda PAM, Sixpence A, Mwenyenkulu TE, Mmanga K, Chirambo AC, Bauleni A, et al. Determinants of pentavalent and measles vaccination dropouts among children aged 12–23 months in The Gambia. BMC Public Health. 2022 Mar 17;22:520.

81. Mane AB. Immunization Dropout Rates: Some Issues. Ann Med Health Sci Res. 2015;5(2):153.

82. Haji A, Lowther S, Ngan'ga Z, Gura Z, Tabu C, Sandhu H, et al. Reducing routine vaccination dropout rates: evaluating two interventions in three Kenyan districts, 2014. BMC Public Health. 2016 Feb 16;16(1):152.

83. El Arifeen S, Christou A, Reichenbach L, Osman FA, Azad K, Islam KS, et al. Community-based approaches and partnerships: innovations in health-service delivery in Bangladesh. Lancet Lond Engl. 2013 Dec 14;382(9909):2012–26.

84. Hanifi SMA, Das S, Rahman M. Bangladeshi neonates miss the potential benefits of early BCG vaccination. Int J Epidemiol. 2018 Feb 1;47(1):348–9.

85. Babirye JN, Engebretsen IMS, Makumbi F, Fadnes LT, Wamani H, Tylleskar T, et al. Timeliness of Childhood Vaccinations in Kampala Uganda: A Community-Based Cross-Sectional Study. PLOS ONE. 2012 Apr 23;7(4):e35432.

86. Calhoun LM, van Eijk AM, Lindblade KA, Odhiambo FO, Wilson ML, Winterbauer E, et al. Determinants and coverage of vaccination in children in western Kenya from a 2003 cross-sectional survey. Am J Trop Med Hyg. 2014 Feb;90(2):234–41.

87. Barman D, Dutta A. Access and barriers to immunization in West Bengal, India: quality matters. J Health Popul Nutr. 2013 Dec;31(4):510–22.

88. Gibson DG, Ochieng B, Kagucia EW, Were J, Hayford K, Moulton LH, et al. Mobile phone-delivered reminders and incentives to improve childhood immunisation coverage and

timeliness in Kenya (M-SIMU): a cluster randomised controlled trial. Lancet Glob Health. 2017 Apr;5(4):e428–38.

89. Ettarh RR, Mutua MK, Kyobutungi C. Ethnicity and delay in measles vaccination in a nairobi slum. Trop Med Health. 2012 Jun;40(2):59–62.

90. Francis MR, Nohynek H, Larson H, Balraj V, Mohan VR, Kang G, et al. Factors associated with routine childhood vaccine uptake and reasons for non-vaccination in India: 1998-2008. Vaccine. 2018 Oct 22;36(44):6559–66.

91. Riaz A, Husain S, Yousafzai MT, Nisar I, Shaheen F, Mahesar W, et al. Reasons for non-vaccination and incomplete vaccinations among children in Pakistan. Vaccine. 2018 Aug 23;36(35):5288–93.

92. Hanifi SMA, Jahan N, Sultana N, Hasan SA, Paul A, Reidpath DD. Millions of Bangladeshi Children Missed Their Scheduled Vaccination Amidst COVID-19 Pandemic. Front Public Health. 2022 Jan 17;9:738623.

93. Kulkarni S, Thampi V, Deshmukh D, Gadhari M, Chandrasekar R, Phadke M. Trends in Urban Immunization Coverage in India: A Meta-Analysis and Meta-Regression. Indian J Pediatr. 2023 Jan 1;90(1):38–48.

94. Ministry of Health and Family Welfare. strenthening immunization in urban areas [Internet]. 2022 [cited 2023 Aug 14]. Available from: https://www.google.com/search?q=strenthening+immunization+in+urban+areas&rlz=1C1GCEU_enBD1031BD1031&oq=strenthening++immunization+in+urban+areas&aqs=chrome..69i57j0i22i30.8876j0j7&sourceid=chrome&ie=UTF-8

95. Butt M, Mohammed R, Butt E, Butt S, Xiang J. Why Have Immunization Efforts in Pakistan Failed to Achieve Global Standards of Vaccination Uptake and Infectious Disease Control? Risk Manag Healthc Policy. 2020 Feb 12;13:111–24.

96. Rodrigue ND, Vincent de Paul NK. Birth Order and Demand for Immunization for Children under the Age of Five in Cameroon. AERC; 2020.

97. Gavrielov-Yusim N, Battat E, Neumann L, Friger M, Balicer RD. Birth order and private voluntary immunization—A study of 110,902 children. Vaccine. 2012 Jan 5;30(2):442–7.

98. Schaffer SJ, Szilagyi PG. Immunization Status and Birth Order. Arch Pediatr Adolesc Med. 1995 Jul 1;149(7):792–7.

99. Sarker AR, Akram R, Ali N, Chowdhury ZI, Sultana M. Coverage and Determinants of Full Immunization: Vaccination Coverage among Senegalese Children. Medicina (Mex) [Internet]. 2019 Aug 14 [cited 2020 Apr 21];55(8). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6723170/

APPENDIX A: SUPPLEMENTERY TABLES

Table A.1: correlates of timely vaccination for different vaccine doses in Bangladesh

	Penta1 (N=2228)					Penta2 (N=2137)					Penta3 (N=2027)					BCG (N=2474)					Measles (N			
_	aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]	
Residence (ref: urban)																								
Rural	0.76	0.00	0.67	0.86		0.84	0.01	0.74	0.95		0.97	0.64	0.86	1.10		0.88	0.02	0.78	0.98		1.23	0.06	0.99	1.53
Wealth quintiles (ref: poorest quintile)																								
Poorer	0.95	0.49	0.82	1.10		0.92	0.26	0.79	1.06		0.90	0.17	0.77	1.05		0.99	0.91	0.86	1.15		1.09	0.53	0.84	1.41
Middle	0.98	0.79	0.84	1.14		0.98	0.83	0.84	1.15		0.91	0.25	0.77	1.07		0.98	0.85	0.84	1.15		0.92	0.58	0.68	1.24
Richer	1.24	0.01	1.04	1.47		1.19	0.05	1.00	1.41		1.16	0.09	0.98	1.39		1.04	0.66	0.88	1.22		0.98	0.91	0.73	1.32
Richest	1.23	0.02	1.03	1.46		1.25	0.02	1.04	1.51		1.16	0.14	0.95	1.41		1.03	0.76	0.87	1.21		1.00	1.00	0.71	1.40
Mother's age during the birth of the child																								
20-24	1.10	0.17	0.96	1.25		1.06	0.39	0.93	1.22		1.03	0.69	0.89	1.19		0.95	0.42	0.84	1.07		1.14	0.33	0.88	1.47
25-29	1.18	0.05	1.00	1.38		1.20	0.04	1.01	1.42		1.19	0.05	1.00	1.42		1.07	0.40	0.92	1.25		1.52	0.01	1.12	2.07
30-49	1.04	0.64	0.87	1.25		1.15	0.16	0.95	1.39		1.25	0.03	1.03	1.51		0.99	0.95	0.84	1.18		1.55	0.01	1.13	2.14
Mother's education (Ref: No education/<primary)																								
Primary	0.99	0.95	0.79	1.25		0.99	0.91	0.77	1.25		0.94	0.62	0.74	1.19		0.96	0.72	0.75	1.22		1.03	0.90	0.70	1.51
Secondary or higher	1.17	0.16	0.94	1.46		1.17	0.19	0.93	1.48		1.14	0.26	0.91	1.43		1.07	0.58	0.84	1.35		1.36	0.12	0.93	1.98
Birth order (Ref: First born)																								

	Penta1 (N=2228)					Penta2 (N=2137)					Penta3 (N=2027)					BCG (N=2474)					Measles (N			
_	aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]	
Second or higher	0.91	0.16	0.80	1.04		0.94	0.38	0.82	1.08		0.96	0.54	0.83	1.10		0.99	0.91	0.88	1.12		0.72	0.01	0.56	0.92
Number of ANC visit (Ref: <4)																								
4 or more	1.16	0.00	1.05	1.28		1.21	0.00	1.09	1.33		1.19	0.00	1.07	1.32		1.17	0.00	1.06	1.29		1.18	0.08	0.98	1.43
Place of Birth (Ref: Facility delivery)																								
Home delivery	0.92	0.09	0.83	1.01		0.90	0.04	0.81	0.99		0.87	0.01	0.78	0.97		0.93	0.15	0.85	1.03		1.00	0.99	0.83	1.20
Gender of Child (Ref: Female)																								
Male	0.99	0.85	0.90	1.09		1.03	0.61	0.93	1.13		1.05	0.34	0.95	1.17		1.03	0.53	0.94	1.13		0.94	0.48	0.80	1.11
Household size	0.98	0.07	0.97	1.00		0.99	0.30	0.97	1.01		1.00	0.88	0.98	1.02		0.99	0.14	0.97	1.00		1.00	0.97	0.96	1.04
Media exposure (ref: no)																								
Yes	1.14	0.01	1.03	1.26		1.06	0.30	0.95	1.19		1.13	0.05	1.00	1.27		1.12	0.04	1.00	1.24		1.10	0.38	0.89	1.36
Religion (ref: Islam)																								
Others	0.95	0.52	0.80	1.12		0.93	0.39	0.78	1.10		0.92	0.38	0.77	1.11		0.95	0.54	0.79	1.13		0.99	0.95	0.73	1.35

Table A.2: correlates of timely vaccination for different vaccine doses in India

	Penta1 (N=44513)				**Penta2 (N=42397)**				**Penta 3 (N= 39769)**				**BCG (N=50630)**				**Measles (N=30383)**			
	aHR	P>z	[95% Conf. Interval]		aHR	P>z	[95% Conf. Interval]		aHR	P>z	[95% Conf. Interval]		aHR	P>z	[95% Conf. Interval]		aHR	P>z	[95% Conf. Interval]	
Residence (ref: urban)																				
Rural	0.99	0.68	0.95	1.03	1.06	0.01	1.01	1.11	1.05	0.03	1.00	1.11	1.03	0.09	1.00	1.06	1.13	0.00	1.07	1.19
Wealth quintiles (ref: poorest quintile)																				
Poorer	1.05	0.02	1.01	1.10	1.09	0.00	1.04	1.14	1.10	0.00	1.04	1.16	1.02	0.39	0.98	1.06	1.09	0.00	1.03	1.16
Middle	1.14	0.00	1.09	1.19	1.18	0.00	1.12	1.23	1.22	0.00	1.15	1.28	1.04	0.03	1.00	1.08	1.17	0.00	1.11	1.24
Richer	1.13	0.00	1.08	1.19	1.19	0.00	1.13	1.25	1.26	0.00	1.19	1.33	1.03	0.20	0.99	1.07	1.19	0.00	1.11	1.26
Richest	1.24	0.00	1.17	1.31	1.26	0.00	1.19	1.34	1.27	0.00	1.19	1.36	1.03	0.18	0.99	1.08	1.22	0.00	1.14	1.30
Mother's age during the birth of the child																				
20-24	1.03	0.28	0.98	1.07	1.01	0.57	0.97	1.06	1.04	0.13	0.99	1.10	0.98	0.42	0.95	1.02	1.02	0.59	0.96	1.07
25-29	1.07	0.02	1.01	1.13	1.09	0.00	1.03	1.16	1.11	0.00	1.04	1.18	0.99	0.68	0.95	1.04	1.06	0.06	1.00	1.14
30-49	1.08	0.03	1.01	1.15	1.11	0.00	1.04	1.19	1.12	0.01	1.03	1.21	0.97	0.20	0.92	1.02	1.01	0.82	0.93	1.09
Mother's education (Ref: No education/<primary)																				
Primary	1.09	0.00	1.04	1.14	1.12	0.00	1.07	1.18	1.10	0.00	1.04	1.17	1.05	0.03	1.01	1.09	1.15	0.00	1.08	1.22
Secondary or higher	1.20	0.00	1.16	1.25	1.25	0.00	1.20	1.30	1.22	0.00	1.16	1.28	1.06	0.00	1.02	1.09	1.20	0.00	1.14	1.26
Birth order (Ref: First born)																				
Second or higher	0.92	0.00	0.89	0.96	0.90	0.00	0.87	0.94	0.88	0.00	0.84	0.92	0.98	0.28	0.96	1.01	0.89	0.00	0.86	0.93
Number of ANC visit (Ref: <4)																				
4 or more	1.27	0.00	1.23	1.31	1.31	0.00	1.26	1.35	1.35	0.00	1.30	1.40	1.15	0.00	1.12	1.18	1.25	0.00	1.21	1.30

	Penta1 (N=44513)					**Penta2 (N=42397)**					**Penta 3 (N= 39769)**					**BCG (N=50630)**					**Measles (N=30383)**			
	aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]	
Place of Birth (Ref: Facility delivery)																								
Home delivery	0.80	0.00	0.76	0.84		0.76	0.00	0.72	0.80		0.74	0.00	0.69	0.78		0.55	0.00	0.53	0.58		0.77	0.00	0.72	0.82
Gender of Child (Ref: Female)																								
Male	1.01	0.45	0.98	1.04		1.03	0.09	1.00	1.06		1.04	0.04	1.00	1.07		1.01	0.52	0.98	1.03		1.04	0.03	1.00	1.08
Household size	0.97	0.00	0.96	0.97		0.96	0.00	0.96	0.97		0.96	0.00	0.95	0.97		0.98	0.00	0.975	0.98		0.97	0.00	0.97	0.98
Media exposure (ref: no)																								
Yes	1.18	0.00	1.14	1.22		1.22	0.00	1.17	1.26		1.20	0.00	1.16	1.25		1.06	0.00	1.04	1.09		1.15	0.00	1.10	1.19
Religion (ref: hindu)																								
Islam	0.81	0.00	0.77	0.84		0.75	0.00	0.72	0.79		0.75	0.00	0.71	0.78		0.92	0.00	0.89	0.95		0.83	0.00	0.79	0.88
Christian	1.04	0.46	0.94	1.15		1.09	0.12	0.98	1.22		1.05	0.39	0.94	1.19		0.93	0.01	0.88	0.99		0.99	0.86	0.89	1.10
Others	1.00	0.98	0.90	1.11		0.99	0.84	0.88	1.10		1.01	0.91	0.89	1.13		0.96	0.28	0.89	1.03		0.95	0.43	0.84	1.08

Table A.3: correlates of timely vaccination for different vaccine doses in Pakistan

	Penta1 (N=2221)					**Penta2 (N=2200)**					**Penta3 (N==2102)**					**BCG (N=2633)**					**Measles (N=1339)**			
	aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]	
Residence (Ref: Urban)																								
rural	0.88	0.09	0.76	1.02		0.95	0.53	0.82	1.11		1.01	0.90	0.85	1.20		0.79	0.00	0.70	0.89		1.00	0.98	0.82	1.23
Wealth Quintiles (Ref: Poorest Quintile)																								
poorer	1.36	0.01	1.08	1.71		1.44	0.00	1.13	1.83		1.43	0.01	1.09	1.89		1.21	0.06	1.00	1.47		1.73	0.00	1.22	2.45
middle	1.54	0.00	1.21	1.96		1.49	0.00	1.16	1.92		1.66	0.00	1.24	2.21		1.35	0.00	1.10	1.65		1.56	0.02	1.08	2.23
richer	1.64	0.00	1.27	2.11		1.55	0.00	1.20	2.01		1.83	0.00	1.36	2.45		1.44	0.00	1.17	1.76		1.88	0.00	1.31	2.70
richest	1.55	0.00	1.18	2.04		1.56	0.00	1.18	2.06		1.73	0.00	1.26	2.39		1.55	0.00	1.23	1.95		1.93	0.00	1.29	2.87
Mother's age during the birth of the child																								
20-24	1.16	0.20	0.93	1.44		1.26	0.08	0.97	1.63		1.33	0.05	1.00	1.77		0.99	0.95	0.81	1.22		1.18	0.41	0.80	1.73
25-29	1.23	0.09	0.97	1.56		1.40	0.01	1.07	1.84		1.58	0.00	1.17	2.14		1.08	0.52	0.86	1.34		1.37	0.12	0.92	2.04
30+	1.04	0.79	0.80	1.33		1.14	0.36	0.86	1.52		1.39	0.04	1.02	1.91		0.89	0.34	0.71	1.13		1.16	0.47	0.77	1.76
Mother's education (Ref: No education/<primary)																								
Primary	1.70	0.00	1.42	2.05		1.60	0.00	1.30	1.97		1.52	0.00	1.22	1.89		1.60	0.00	1.35	1.89		1.58	0.00	1.20	2.09
Secondary or higher	1.78	0.00	1.48	2.14		1.77	0.00	1.46	2.15		1.63	0.00	1.32	2.01		1.64	0.00	1.40	1.92		1.76	0.00	1.35	2.30
Birth order (Ref: First born)																								
second or higher	0.80	0.00	0.68	0.93		0.84	0.04	0.72	0.99		0.79	0.01	0.66	0.94		0.93	0.28	0.81	1.06		0.89	0.27	0.73	1.09

	Penta1 (N=2221)					**Penta2 (N=2200)**					**Penta3 (N==2102)**					**BCG (N=2633)**					**Measles (N=1339)**			
	aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]			aHR	P>z	[95% Conf. Interval]	
Number of ANC visit (Ref: <4)																								
4 or more	1.29	0.00	1.12	1.48		1.21	0.02	1.04	1.41		1.22	0.02	1.04	1.43		1.23	0.00	1.09	1.40		1.04	0.70	0.85	1.27
Place of Birth (Ref: Facility delivery)																								
Home delivery	0.82	0.02	0.69	0.97		0.75	0.00	0.63	0.90		0.70	0.00	0.58	0.85		0.75	0.00	0.65	0.87		0.65	0.00	0.50	0.85
Gender of Child (Ref: Female)																								
male	0.89	0.05	0.79	1.00		0.92	0.20	0.81	1.04		0.93	0.31	0.81	1.07		0.97	0.56	0.87	1.08		1.16	0.09	0.98	1.37
Household Size	0.89	0.02	0.82	0.98		0.90	0.04	0.82	0.99		0.88	0.01	0.79	0.97		0.93	0.06	0.86	1.00		0.89	0.07	0.79	1.01
Media Exposure (Ref: No)																								
Yes	1.18	0.02	1.03	1.36		1.22	0.01	1.05	1.42		1.14	0.11	0.97	1.35		1.12	0.06	1.00	1.26		1.11	0.33	0.90	1.37

Appendix B: Comparison Between Eligible Children vs Non-eligible Children

Table B.1: Sociodemographic Comparison between children who had vaccination documentation vs who didnt

		Bangladesh (N=3,457)				India (N=86516)				Pakistan (N=3860)		
# of children		Vaccination card (N=2361)	No Vaccination card (N=1096)			Vaccination card (N=75,758)	No Vaccination card (N=8438)			Vaccination card (N=2633)	No Vaccination card (N=1227)	
		Mean or Proportion	Mean or Proportion	*p value*		Mean or Proportion	Mean or Proportion	*p value*		Mean or Proportion	Mean or Proportion	*p value*
Residence	Rural	66.71%	33.29%	0.005		80.31%	78.41%	0.000		55.91%	47.72%	0.000
	Urban	71.38%	28.62%			19.69%	21.59%			44.09%	52.28%	
Wealth index score		-0.002	-0.007	0.170		-0.084	-0.150	0.000		-.001	.001	0.581
Mother's age	(Years)	24.73	24.24	0.203		25.04	24.94	0.050		26.79	26.89	0.650
Mother's education	Years	7.02	6.93	0.000		8.05	7.34	0.000		5.05	4.16	0.000
Number of ANC visit	Number	3.94	3.64	0.001		6.03	5.96	0.569		4.35	4.51	0.568
Sex of the child	Male	52.60%	49.91%	0.355		51.52%	51.67%	0.076		49.93%	51.58%	0.395
	Female	47.40%	50.09%			48.48%	48.33%			50.07%	48.42%	
Household Size	(Number)	5.97	2.70	0.000		6.31	6.65	0.000		9.75	9.91	0.417
Place of Birth	Facility Delivery	52.48%	46.22%	0.033		90.09%	87.52%	0.000		71.49%	74.74%	0.06

		Bangladesh (N=3,457)				India (N=86516)				Pakistan (N=3860)		
# of children		Vaccination card (N=2361)	No Vaccination card (N=1096)			Vaccination card (N=75,758)	No Vaccination card (N=8438)			Vaccination card (N=2633)	No Vaccination card (N=1227)	
		Mean or Proportion	Mean or Proportion	*p value*		Mean or Proportion	Mean or Proportion	*p value*		Mean or Proportion	Mean or Proportion	*p value*
	Home Delivery	47.52%	53.78%			9.91%	12.48%			28.51%	25.26%	
Media Exposure	No	54.06%	56.80%	0.000		51.39%	55.61%	0.000		53.89%	49.24%	0.016
	Yes	45.94%	43.20%			48.61%	44.39%			46.11%	50.76%	

Table B.2: Multivariate logit model presenting the Comparison between children who had vaccination documentation vs who didn't.

	Bangladesh (N=3457)					India (N=86516)					Pakistan (N=3860)			
Has vaccination Documentation	Odds Ratio	P>t	[95% Conf.	Interval]		Odds Ratio	P>z	[95% Conf.	Interval]		Odds Ratio	P>t	[95% Conf.	Interval]
Residence (ref: urban)														
Rural	0.89	0.56	0.60	1.32		0.78	0.00	0.74	0.83		0.76	0.08	0.57	1.03
Wealth Quintiles (Ref: poorest)														
Poorer	1.03	0.89	0.70	1.52		0.99	0.78	0.93	1.06		1.18	0.40	0.80	1.73
Middle	1.09	0.74	0.67	1.77		1.04	0.32	0.97	1.11		1.37	0.12	0.93	2.04
Richer	0.72	0.13	0.46	1.11		1.07	0.07	0.99	1.16		1.34	0.11	0.94	1.93
Richest	1.35	0.26	0.80	2.29		0.99	0.72	0.91	1.07		1.37	0.14	0.90	2.07
Mother's age at birth (ref: 15-19)														
20-24	0.69	0.09	0.46	1.06		1.09	0.01	1.02	1.17		0.90	0.63	0.59	1.38
25-29	0.60	0.05	0.36	0.99		1.18	0.00	1.09	1.27		0.83	0.40	0.55	1.27
30-49	0.81	0.48	0.45	1.46		1.23	0.00	1.12	1.34		0.94	0.81	0.59	1.51
Maternal education (Ref: Less than primary or no education)														
Primary	1.20	0.55	0.67	2.14		1.16	0.00	1.08	1.26		1.08	0.64	0.77	1.52
Secondary or higher	1.74	0.07	0.96	3.14		1.35	0.00	1.27	1.43		0.79	0.15	0.58	1.09
Birth order (Ref: birth order)														
Second or higher	1.15	0.48	0.79	1.68		0.93	0.01	0.89	0.98		0.92	0.60	0.68	1.24

	Bangladesh (N=3457)					India (N=86516)					Pakistan (N=3860)			
Has vaccination Documentation	Odds Ratio	P>t	[95% Conf.	Interv al]		Odds Ratio	P>z	[95% Conf.	Interv al]		Odds Ratio	P>t	[95% Conf.	Interv al]
Number of ANC (Ref: 3 or less)														
4 or more	1.16	0.39	0.83	1.62		1.34	0.00	1.29	1.41		1.06	0.65	0.83	1.36
Place of Delivery (Ref: facility delivery)														
Home delivery	1.07	0.69	0.77	1.48		0.91	0.01	0.85	0.98		0.95	0.68	0.76	1.20
Sex of the child (Ref: Female)														
Male	1.16	0.30	0.87	1.55		0.99	0.73	0.95	1.04		0.86	0.19	0.69	1.08
Household size	0.88	0.00	0.84	0.93		0.96	0.00	0.95	0.97		0.99	0.20	0.96	1.01
Media Exposure (Ref: No exposure)														
Yes	1.47	0.04	1.03	2.09		1.06	0.03	1.01	1.11		1.05	0.69	0.83	1.33
_Cons	9.92	0.00	4.24	23.17		6.96	0.00	6.31	7.68		5.16	0.00	3.22	8.24