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RESEARCH ARTICLE

Timely Vaccination with Valid Doses in a High Coverage Country, Oman

Prakash KP[1], Bader Al-Rawahi[1], Noura Al-Farsi[1], Mariam Al-Shaibi[1], Athari Al-Faisal[1], Bader Al-Abri[2], Amal Al-Maani[3], Seif Al-Abri[4]

[1]Department of Communicable diseases, Centre for disease control and prevention, Ministry of Health, Oman

[2]Department of Surveillance, Centre for disease control and prevention, Ministry of Health, Oman

[3]Director General, Centre for disease control and prevention, Ministry of Health, Oman

[4]Former Director General, Centre for disease control and prevention, Ministry of Health, Oman

[*]**Corresponding Author:** Prakash KP, Department of Communicable diseases, Centre for disease control and prevention, Ministry of Health, Oman, Tel.: 96892162039, E-mail: drprakashkp@gmail.com

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Abstract

Introduction: A national immunization coverage survey conducted to assess vaccination coverage, the timeliness of vaccine administration, and the validity of various vaccine doses provided to children under the age of five.

Methods: A cross-sectional descriptive cluster survey conducted across Oman, targeting a population of 415,791 children under five years old. Using the WHO cluster sampling method, the study determined a sample size of 16,470 children from 3,294 clusters. The survey carried out over one month (February to March 2023) through face-to-face interviews using a pretested electronic questionnaire. Vaccination dates verified for accuracy against immunization cards and local health records. Descriptive statistical outcomes depicted as proportions calculated with 95% confidence intervals.

Result: The vaccination card availability was nearly 100% (99.4%). Most children surveyed (66.4%) were aged 24 to 59 months. The gender distribution nearly balanced, with 51.2% males and 48.8% females. Omani children represented 97.3% of the sample. The overall crude national vaccination coverage was nearly 100% and it varied from at birth 99.9% to 94.4% at 24 months. Overall, 98.7% of children under five fully vaccinated, with coverage ranging from 99% to 96% for children from birth to 24 months. As the age increased, crude coverage, full vaccination and validity of doses decreased.

Conclusion: Oman achieves high vaccination coverage; however, a noteworthy number of children receive invalid doses. This highlights the urgent need to educate parents and healthcare providers on timely administration of valid doses. Assessing mild illnesses and promptly administering vaccinations can improve complete vaccination rates with valid doses.

Keywords: Vaccination coverage, immunization coverage, coverage survey, fully vaccinated, valid doses, Oman

Introduction

Immunization recognized as the most effective public health intervention program, and Oman has successfully achieved high coverage rates in its routine immunization. The administrative coverage and WHO-UNICEF estimate of vaccination coverage is above targeted 90% nationally for the last 3 decades, with nearly every district having achieved at least 90% coverage. This success has strengthened community immunity, reduced the prevalence of vaccine-preventable diseases, and enhanced overall public health in the country [1-3].

Together, high vaccination coverage, complete immunization, and timely vaccination reflect a sustainable, high-quality immunization program, essential for maximizing children's protection against vaccine preventable diseases. Scheduled complete timely immunization provides optimal disease protection, establishes herd immunity to prevent outbreaks, and serves as a cost-effective public health strategy. Once a country maintains high national vaccination coverage over time, the next goal is to achieve complete and timely immunization [4, 5].

To successfully manage and control vaccine-preventable diseases (VPDs), high immunization coverage is required with a targeted coverage level of 90% as recommended by the WHO. In order to successfully control and eliminate vaccine-preventable infectious diseases, age appropriate vaccine coverage has to be achieved and sustained. However, there is no defined targeted coverage for complete and timely vaccination [3, 6-9].

Sustaining high performance and quality in immunization programs is challenging, with missed appointments and delayed valid doses as key issues. Assessments show that, despite relatively high vaccination coverage, gaps remain in timely, age-appropriate vaccinations, indicating that high coverage does not guarantee children receive valid doses on schedule [10-13].

Currently, timeliness and valid dosing are unused routinely as indicators for evaluating immunization programs in many countries, including Oman. As vaccination coverage approaches levels necessary for herd immunity, the timing of vaccine administration has gained increasing attention. This study, therefore, aimed to assess the timely completion of valid vaccinations among under five children.

Methods

This cross-sectional study evaluated vaccination coverage, valid doses and timely vaccination coverage across Oman, encompassing all 11 provinces and 61 districts, and targeting a population of 415,791 children under five. Using the WHO cluster sampling method, the study sample size calculated at 16,470 children from 3,294 clusters [14, 15].

Households were proportionally distributed according to district populations and selected systematically, targeting children under five eligible for various vaccines. These included: BCG and HBV at birth; Penta and OPV at 6 months; MMR1 and Varicella at 12 months; PCV booster at 13 months; MMR2, DTP, and OPV booster at 18 months; and Hepatitis A at 24 months.

The survey conducted over one month (February to March 2023) using face-to-face interviews and a pretested electronic questionnaire via the "Epicollect5" mobile app. It gathered demographic and immunization data, with vaccination dates verified against immunization cards and local health records for accuracy. To ensure high data quality, a regional EPI supervisor supervised the process, and a national data manager reviewed data consistency and accuracy through an online system.

The data analyzed using Microsoft Excel and SPSS Version 21.0, employing descriptive statistics and chi-square tests for categorical data. Vaccination outcomes were categorized as fully and valid, with 95% confidence intervals. District wise coverage, timeliness, vaccination validity detailed with proportions. Statistical significance was set at $p < 0.05$. WHO (2018) guidelines ap-

plied for operational definitions, including crude immunization coverage, valid coverage, timeliness, full immunization coverage, and dropout rate [14].

The following operational definitions used: Valid doses: Doses that were administered when the child had reached the scheduled age for the vaccine and were administered with the proper timing according to the national schedule (denominator = those with immunization card for that antigen). Fully immunized child (FIC): A child who received all antigen doses included in the national schedule for the age as documented in the immunization card [At birth (BCG, HBV), at 6 months (Penta, OPV) and at 12 months (MMR1, Varicella), at 13 months (PCV booster), at 18 months (MMR2, DTP, & OPV Booster) and at 24 months (Hepatitis A)]. Denominator = Total eligible children for the age. Fully immunized child with valid doses: A child who received all antigen doses as valid doses as recorded in the immunized card. (Denominator = fully immunized children for the age). Dropout rate refers to the percentage of individuals who start but do not complete a recommended vaccination series. Timeliness refers to individuals receiving their vaccination after the due date but within 30 days of that date. [14].

Results

The dataset included 17,501 participants after excluding invalid and inconsistent records, exceeding the minimum required sample size. The distribution of clusters, households, and target children was consistent across all provinces. The households per cluster, children per household and average children in each cluster was around four, five and one respectively.

Almost all children (99.4%) had their immunization cards available during the survey. The majority of children surveyed (66.4%) were between 24 and 59 months old. The gender distribution was nearly equal, with 51.2% male and 48.8% female. Omani children represented 97.3% of the sample, while non-Omani children made up 2.7%. The mean and median age was 2.7 ± 1.3 years and 2.7 years respectively, with an age range from 4 months to 5 years.

The overall crude national vaccination coverage was nearly 100% and it varied from at birth 99.9% to 94.4% at 24 months as shown in table 1. BCG and HBV vaccines showed the highest crude (99.9%) and valid (97.9%) coverage rates respectively, followed by the pentavalent vaccine and OPV (99.9% and 92.2%). The difference between crude and valid coverage suggests early or delayed vaccinations as children aged (Table 1).

Table 1: Crude and Valid dose immunization coverage

Recommended age and Type of vaccine	Crude vaccination coverage(CI) %	Valid vaccination coverage(CI) %
At birth (BCG, HBV)	99.9 (99.9 – 1.00)	97.9 (97.7- 98.2)
At 6 months (Penta, OPV)	99.9 (99.8 – 99.9)	92.2 (91.7 - 92.5)
At 12 months (MMR1, Varicella)	99.5 (99.3 – 99.5)	90.9 (90.4 – 91.3)
At 13 months (PCV Booster)	98.9 (98.5 – 99.0)	89.9 (89.4 – 90.1)
At 18 months (MMR2, DTP & OPV Booster)	98.9 (98.7 – 99.1)	85.7 (85.1 – 86.3)
At 24 months (Hepatitis A)	94.4 (93.9 – 94.8)	82.9 (82.1 – 83.7)

We observed high vaccination coverage across all age groups, with fully vaccinated coverage ranging from 99% to 96%. Overall, 98.7% of children under five fully vaccinated, 1.3% partially vaccinated, and only 0.01% remained unvaccinated. The detailed coverage analysis by governorate indicated that coverage for various vaccines was generally high (around 99%) across most governorates, with the exception of Dhofar and Muscat, which showed slightly lower coverage for vaccines targeted at the 12-24--

month age group (89.3-98.7%). District wise coverage analysis was nearly uniform (98-100%) for the birth, six, and 12-month doses.

Figure 1 depicts the timeliness of vaccinations in the coverage survey. Majority of the vaccines at birth (98%), at 6 months (92.2%) and at 12 months of age (90.9%) were given within 30 days (timely vaccination) from the scheduled vaccination date. At later stages of children life, there was a delay in receiving vaccination at 18 months, which was nearly 11%. People who received vaccination very late (>1 years from the scheduled date) was negligible (0.1-0.3%) at different stages of vaccination. Notably, delays in receiving vaccinations at 18 months were common across several governorates, with Thumriyat and Muqshin districts exhibiting the highest rates of late vaccinations, particularly for the 12 and 18-month doses.

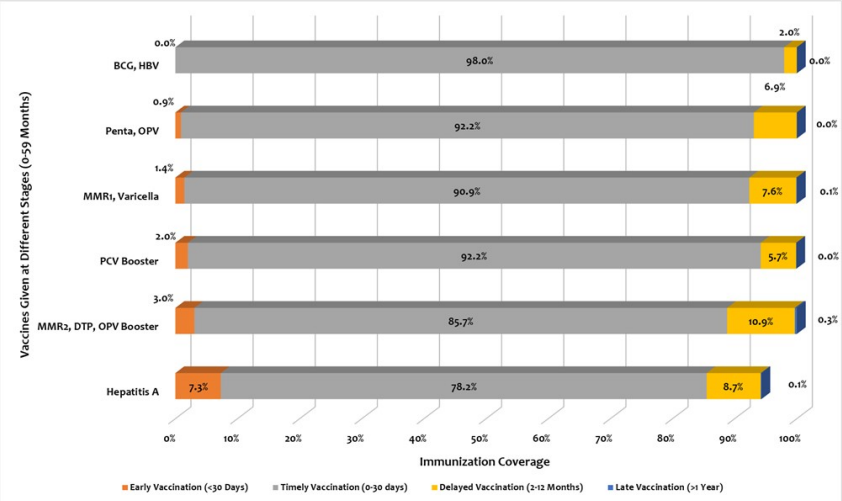

Figure 1: National vaccination coverage according to timeliness of vaccination (N=17501)

In the study, 78% of the subjects received valid vaccinations, while 22% received invalid ones. Among partially immunized children, 63.5% had valid doses. Similarly, 78.1% of fully immunized children received valid doses, indicating that approximately 78% of fully vaccinated children had valid vaccinations (Table 2).

Table 2: Comparison of fully vaccinated with valid immunization

Variable	Total Subjects	Fully Vaccinated	Partially Vaccinated
Validity X^2: 11.4, df=1, p < 0.001*			
Valid vaccination	13646 (100%)(78.0%)	13490 (98.9%)(78.1%)	156 (1.1%)(68.7%)
Invalid vaccination	3855 (100%)(22.0%)	3784 (98.2%)(21.9%)	71(1.8%)(31.3%)
Total	**17501 (100%)(100.0%)**	**17274 (98.7%)(100.0%)**	**227 (1.3%)(100.0%)**

Figure 2 illustrates the distribution of invalid vaccinations by governorate/province in the coverage survey. The proportion of invalid vaccinations ranged from 3.3% at birth to 28.1% at 18 months of age. Among the governorates, North Sharqiyah recorded the lowest average rate of invalid vaccinations, while Dhofar reported the highest average rate.

Similar to governorates/provinces, as the age increases the invalid vaccinations increases in the districts/wilayats. The average invalid vaccinations ranged from 1.7 to 31.0% in Haima and Thumrayt respectively. Of the 61 districts, 31.1% (19/61) had average invalid vaccinations more than 10%. Four districts had average invalid vaccinations between 10-15% and five districts average invalid vaccinations 15-31% (Table 3).

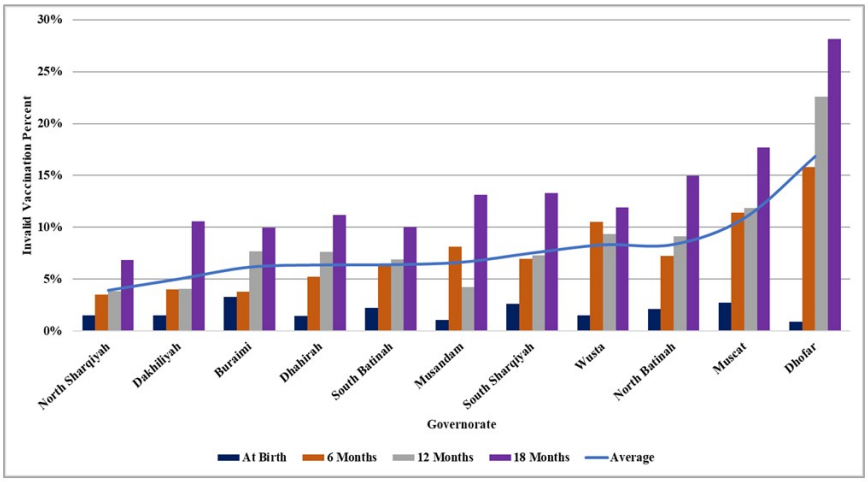

Figure 2: Invalid vaccinations according to governorate/province

Table 3: Average invalid vaccinations more 10% according to governorate and district

Governorate/Province	District/Wilayat	At Birth	6 Months	12 Months	18 Months	Average
Muscat	Seeb	2.4%	9.2%	11.5%	16.9%	10.0%
	Muscat	1.7%	12.8%	10.1%	20.5%	11.3%
	Bawshar	2.5%	13.2%	12.9%	19.1%	11.9%
	Hallaniyat	3.8%	11.5%	15.4%	20.0%	12.7%
	Mutrah	5.4%	20.5%	16.7%	22.7%	16.4%
North Batinah	Liwa	2.8%	10.8%	20.4%	17.4%	12.9%
	Shinas	1.1%	12.0%	14.8%	24.1%	13.0%
Buraimi	Madha	0.0%	17.9%	7.1%	16.0%	10.3%
	Sunaynah	0.0%	25.0%	25.0%	33.3%	20.8%
	Mahdha	0.0%	0.0%	50.0%	50.0%	25.0%
Wusta	Al Jazir	0.0%	21.9%	20.0%	18.5%	15.1%
Dakhiliyah	Manah	4.1%	7.4%	4.4%	26.3%	10.5%
Dhofar	Mirbat	1.4%	8.3%	18.8%	25.5%	13.5%
	Dalkut	0.0%	10.3%	15.4%	31.8%	14.4%
	Salalah	0.9%	16.0%	23.0%	28.2%	17.0%
	Rakhyut	0.0%	20.0%	20.0%	37.5%	19.4%
	Mazyunah	1.5%	23.9%	32.1%	32.6%	22.5%
	Muqshin	0.0%	40.0%	40.0%	40.0%	30.0%
	Thumrayt	0.0%	27.8%	46.3%	50.0%	31.0%

Table 4 shows the dropout rate for various vaccines. It demonstrates that there is marginal increase in dropout rate as the age of the child increases from birth vaccine to the subsequent vaccination. Further, it noticed among 12-23 months' children, there was 4.0% dropout from the birth dose (BCG, HBV) to 18 months' dose MMR2, DTP & OPV Booster. Muscat and Dhofar iden-

tified as the areas with the highest number of missed doses, including a significant prevalence of multiple missed doses in these governorates. Moreover, Mehwat and Mazyoona districts recorded the highest dropout rates.

Table 4: Crude dropout rate for various vaccines for 12-23 months' children

Type of vaccine (N=4476)	Percentage reduction (%)	Dropout Percent (%)
BCG and HBV to Penta 3 (HBV, Hib, DTP)	99.96 to 99.89	0.07
BCG and HBV to MMR1 and Varicella	99.9 to 98.3	1.6
BCG and HBV to MMR2, DTP & OPV Booster	99.9 to 95.9	4.0
MMR1 and Varicella to MMR2, DTP & OPV Booster	99.9 to 98.9	1.0
Penta 3 and OPV to MMR2, DTP & OPV Booster	99.9 to 95.9	4.0

Discussion

Receiving all required doses according to the recommended vaccination schedule is essential for achieving full immunity. The validity and timeliness of vaccinations are critical factors in ensuring adequate protection against diseases. However, studies conducted globally have revealed that many children receive incomplete vaccinations or doses administered at inappropriate times, leading to suboptimal immune responses. The World Health Organization (WHO) categorizes these as invalid doses, which include cases of premature administration, insufficient intervals between doses, and delayed administration [16-20].

Mothers played a key role in healthcare decisions, with most children receiving vaccinations at government facilities, underscoring maternal influence and the success of government immunization programs in Oman. Oman, with a 99% vaccination card retention rate, aligns with WHO recommendations for reliable documentation, similar to China (99%) and Iran (93%) [21, 22].

Oman achieved nearly 100% vaccination coverage, surpassing the global target of 90% and aligning with past WHO administrative reports. Oman's coverage was equal across genders and national vaccination coverage was comparable to countries like China (99%), Iran (97.8%), the USA (>90%) and Saudi Arabia (>90%) [23, 24]. However, many countries still fall short of the 90% target [25].

High immunization rates do not guarantee age-appropriate vaccination, as many children remained unprotected for months despite eventual vaccination with invalid doses and missed opportunities. Presence of such pool of susceptible children increases the risk of vaccine-preventable disease outbreaks, particularly when vaccination coverage rates are low. [26, 27].

In our study, 78% of the study subjects fully vaccinated and had valid vaccinations similar to a study in Uganda and UK [28, 29]. Partial vaccinations and invalid vaccinations reported to be higher in countries of the WHO African Region [30]. We observed that fully vaccinated children were more likely to receive valid doses (78%) compared to partially vaccinated individuals (68.7%), highlighting the level of commitment needed to achieve the desired immunity both individually and within the community. We observed that invalid doses were commonly attributed to delays caused by acute illness (medical reasons) around the vaccination due date in our study (50.7%). However, unless the illness is severe, children can receive vaccinations on time, as mild illnesses do not affect the vaccine's response. Therefore, immunization staff clinically evaluate the child and administer the vaccine on schedule rather than delaying it [31].

Studies have shown that missed or delayed vaccinations influenced by various factors, such as maternal education and age, birth order, family income, and residential area which was a limitation in our study. This is crucial because the economic and logistical costs of repeating invalid vaccinations can be significant. Therefore, it is essential to educate both parents and health-

care workers on the importance of ensuring complete and timely vaccination.

Conclusion

The study reaffirms that vaccination coverage under Oman's national immunization program is strong and satisfactory. However, the 22% rate of invalid vaccinations at various stages of child's age impedes achieving the desired immunity, making it essential to address vaccination delays to enhance immunization efforts and reduce risks. Evaluating mild illnesses and administering vaccinations immediately can enhance complete vaccination rates with valid doses.

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Ethical Approval

This study is part of the Ministry of Health's national immunization program evaluation. As no invasive procedures were involved, ethical approval was not required.

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Declarations of Competing Interest

The authors have no competing interests to declare.

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