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Indicators of the National Immunization Program for children under one year old: time trend in Maranhão, Brazil, 2010 to 2021

Cleia Varão Marinho (https://orcid.org/0000-0001-8157-0264) [1]
Rejane Christine de Sousa Queiroz (https://orcid.org/0000-0003-4019-2011) [2]
Waleska Regina Machado Araujo (https://orcid.org/0000-0001-5758-7947) [3]
Aline Sampieri Tonello (https://orcid.org/0000-0002-8402-9112) [2]
Erika Barbara Abreu Fonseca Thomaz (https://orcid.org/0000-0003-4156-4067) [2]

Abstract *We aimed to analyze the trend of indicators of the National Immunization Program (acronym in Portuguese. PNI) in children under one -year-old and classify municipalities regarding the risk of transmission of vaccine-preventable diseases (RTVPD) in Maranhão from 2010 to 2021. This ecological time series study was based on secondary data on vaccination coverage (VC). vaccination coverage homogeneity (VCH). proportion of abandonment (PA). and RTVPD. with state coverage for vaccines in the national children's calendar. Prais-Winsten regression estimated trends (α=5%) and the indicators' annual percentage change (APC). We identified fluctuating and discrepant VC between vaccines. with a decreasing trend (p < 0.01). except those against Hepatitis B (p = 0.709) and oral human rotavirus (p = 0.143). The sharpest falls were for Yellow Fever (APC = 12.24%) and BCG (APC = 12.25%) vaccines. All VCH rates were lower than expected. with a drop from 2014 and APC between 5.75% (Pneumococcal 10; p = 0.033) and 14.02% (Poliomyelitis; p < 0.01). We observed an increasing trend in PA for Pentavalent (APC = 4.91%; p < 0.01) and Poliomyelitis (APC = 3.55%; p < 0.01). We identified an increase of 52.54% in the proportion of municipalities in Maranhão from 2015 to 2021. with extremely high (p = 0.025) and high (p = 0.028) RTVPD. The PNI indicators deteriorated. reaffirming the susceptibility to the emergence of vaccine-preventable diseases.*

Key words *Vaccination coverage. National Immunization Program. Children's health. Basic health indicators*

[1] Programa de Pós-Graduação em Saúde da Família. Universidade Federal do Maranhão. Centro Pedagógico Paulo Freire. Campus do Bacanga. Sala de Tutoria. 1º andar. Asa Norte. 65080-805 São Luís MA Brasil. cleiavarao@gmail.com
[2] Departamento de Saúde Pública. Universidade Federal do Maranhão. São Luís MA Brasil.
[3] Superintendência de Epidemiologia e Controle de Doenças. Secretaria Estadual de Saúde do Maranhão. São Luís MA Brasil.

Introduction

Vaccination is a priority, effective, and strategic primary health care (PHC) action directly impacting the control, eradication, and elimination of vaccine-preventable diseases[1]. In Brazil, the National Immunization Program (PNI) was created in 1973 and brought fundamental achievements for improving the country's epidemiological and social conditions[2] over its nearly 50 years of existence. In this setting, the certification of smallpox eradication in the Americas occurred in 1973. Brazil also received the poliomyelitis eradication certificate in 1994 and significantly reduced the incidence of diphtheria, tetanus, pertussis, and meningitis by Haemophilus influenzae B, pneumococcal meningitis, and meningococcal disease from 2010. The country also received the certificate for the eradication of rubella and congenital rubella syndrome (2015), measles (2016), and neonatal tetanus (2017)[3].

Brazil is one of the countries that offer the largest number of free vaccines[2]. Routine vaccination should be performed under PNI standards per the vaccination schedule established by the Ministry of Health (MS)[1]. To this end, the National Immunization Program Information System (SI-PNI) was developed to allow PNI professionals to evaluate risk dynamics regarding the epidemics from immunobiological records and the number of vaccinated populations aggregated by age group, period, and geographical location[4].

The current resurgence of previously eliminated vaccine-preventable diseases, the strengthening of the anti-vaccine movement, and the abandonment of multidose regimens by the population, increasing the risk of transmitting these diseases, stirred the interest in knowing more in-depth about the current vaccine situation of the population[2,3], emphasizing children, due to their greatest vulnerability.

Moreover, the quality indicators of immunization services, such as vaccination coverage (VC), vaccination coverage homogeneity (VCH), proportion of abandonment (PA), and the classification of municipalities regarding the risk of transmission of vaccine-preventable diseases should be followed up to support monitoring and evaluation of the impact of goal-oriented interventions.

Considering the current epidemiological and social context, it is crucial to conduct studies to analyze the VC follow-up, especially in Maranhão state, where the increase in vaccine-preventable diseases such as pertussis, hepatitis B, tuberculosis, measles, and higher hospitalization levels for these diseases have been evidenced[5,6]. A more detailed observation of immunization will help to understand the reasons underlying the lower VC levels and the reemergence of previously eradicated or controlled vaccine-preventable diseases[7].

Therefore, this article aimed to analyze the vaccination coverage (VC), vaccination coverage homogeneity (VCH), and the proportion of abandonment (PA) indicators fundamental for evaluating the PNI in children under one-year -old in Maranhão and classifying the municipalities regarding the municipalities risk of transmission of vaccine-preventable diseases from 2010 to 2021.

Methods

Study design

This ecological, time series, state covery study was based on data on vaccine doses applied to children under one year old in Maranhão from 2010 to 2021.

We used PNI secondary data, available in the SI-PNI, Department of Informatics of the Unified Health System (DATASUS)[8], referring to all municipalities in Maranhão. The state has 217 municipalities divided into 18 Regional Health Units plus the Metropolitan Region, with an estimated population of 7,153,262 inhabitants for 2021[9].

Variables

The variables collected were the number of applied doses available on DATASUS, of the following vaccines included in the National Child Vaccination Calendar, for children under one-year-old:

a) Bacillus Calmette-Guérin (BCG): one dose (sum of doses recorded as a single dose or first dose); b) Yellow Fever: one dose (sum of doses recorded as initial dose or first dose); c) Oral Human Rotavirus: first and second doses; d) Meningococcal Conjugate type C: first and second doses, e) Pneumococcal 10-valent: first and second doses; f) Pentavalent [sum of doses of Hexavalent, Pentavalent (DTP+HB+Hib), Tetravalent (DTP/Hib), and Inactivated Pentavalent (DTP acellular/Hib/IPV)]: first and third doses; PS: DTP (triple viral fever); HB (Hepatitis B); Hib (Haemophilus influenzae type b); =g) Poliomyelitis [sum of the first doses of Hexavalent, Inactivated Poliomyelitis (IPV), Oral Poliomyelitis

(OPV), and IPV/OPV Sequential Scheme]: first and third doses.

Data analysis

The analyzed indicators were the VC by immunobiological, the VCH for the state and between vaccines for the municipalities, PA, and the classification of municipalities in Maranhão regarding the risk of transmission of vaccine-preventable diseases referenced by the PNI[10,11] and agreed in the assessment instruments of the SUS through the Public Health Action Organizational Contract – COAP[12] and the Program for the Qualification of Health Surveillance Actions – PQAVS[13].

Each vaccine VC was calculated by dividing the number of applied doses that complete the schedule of each vaccine by the number of live births, in each municipality, per specific year multiplied by 100. Thus, the VC numerator for the BCG and Yellow Fever vaccines corresponded to one dose (single dose). The numerator used for the Oral Human Rotavirus, Meningococcal Conjugate type C, and Pneumococcal 10-valent vaccines was the number of second doses, and the number of third doses was used for the Pentavalent and Poliomyelitis vaccines. The number of live births was obtained from the Live Births Information System (SINASC)[14]. Those that reached the VC goals established by the PNI were considered adequate, namely, 90% for BCG and Oral Human Rotavirus vaccines, 95% for Meningococcal Conjugate type C, Pneumococcal 10-valent, Pentavalent, and Poliomyelitis, and 100% for Yellow Fever.

The VCH indicator represented the percentage of municipalities that reached the VC target recommended by the Ministry of Health, for each vaccine, in each year of the historical series. This indicator was calculated by dividing the number of VC-adequate municipalities by the total number of municipalities in the state. VCH rates of less than 70% were considered inadequate. VCH between vaccines represented the proportion of vaccines that reached the VC target recommended by the Ministry of Health of Brazil, in each municipality in the state, in each year of the historical series, estimated by dividing the number of vaccines that reached the target by the total number of evaluated vaccines. As a parameter, those municipalities with at least 75% of VC-adequate vaccines were considered to have an adequate VCH[12].

PA corresponded to the proportion of vaccinees who started the multidose vaccination schedule and did not complete it, estimated by the difference between the number of first doses and the number of last doses applied, divided by the number of first doses, multiplied by 10015. Therefore, we calculated a PA for Oral Human Rotavirus, Meningococcal Conjugate type C, Pneumococcal 10-valent, Pentavalent, and Poliomyelitis vaccines. The PNI recommendations16 were followed as a parameter, classified as low (less than 5%), medium (between 5% and 10%), and high (greater than 10%).

The classification of municipalities in Maranhão regarding the risk of transmission of vaccine-preventable diseases (RTVPD) was composed of the indicators of VC, VCH between vaccines, PA, and population size of the municipality, defining five categories: (i) Extremely low risk – municipality with VCH ≥100%; (ii) Low risk – municipality with VCH ≥ 75% to <100%, Poliomyelitis VC >95% and Pentavalent VC > 95%; (iii) Medium risk – municipality with VCH ≥ 75% to < 100% and Poliomyelitis VC > 95% or Pentavalent VC > 95%; (iv) High risk – municipality with VCH < 75%; (v) Extremely high risk – municipality with VCH < 75% and PA ≥ 10%.

The Prais-Winsten linear regression model was applied using the Stata program, version 14.0 (StataCorp LP, College Station, USA), to analyze the temporal trend for the indicators of VC, PA of multidose vaccines, VCH, and transmission risk. We calculated the means and medians of the proportions of vaccines for each indicator and the annual percentage change (APC) and its 95% confidence intervals (95%CI). An increasing trend was considered when $p < 0.05$ and the regression coefficient was positive (+); decreasing when $p<0.05$ and the regression coefficient was negative (-); and stationary when $p>0.05$. The established significance level was 5%.

Ethical aspects

The present study is nested in the project entitled "Analysis of Indicators of the National Immunization Program in São Luís, in the municipalities of Maranhão and Brazil" and was approved by the Ethics Committee of the University Hospital of the Federal University of Maranhão under Opinion n° 5.049.708 of 20/10/2021. This research project complied with the ethical considerations proposed by Resolution n° 466/2012 of the National Health Council (CNS).

Results

In Maranhão, from 2010 to 2022, only two (Oral Human Rotavirus and Hepatitis B) of the nine vaccines in the National Vaccination Calendar for children under one-year-old had a stationary trend for the VC indicator, while the others had decreasing trend (BCG, Hepatitis B, Yellow Fever, Meningococcal Conjugate type C, Pneumococcal 10-valent and Pentavalent, and Poliomyelitis) whose highest APC were those of the Yellow Fever (APC = -12.24; p < 0.001) and BCG (APC = -12.25; < 0.001) vaccines (Table 1).

Most vaccines had high VC in the first years of the historical series, but they decreased sharply from 2014 to 2016, increasing slightly in 2017, and all vaccines gradually decreased until 2021. In the last year of the historical series (2021), the Pneumococcal 10-valent vaccine achieved the highest coverage (VC = 63.1%), while Yellow Fever had the lowest (VC = 49.5%) (Figure 1).

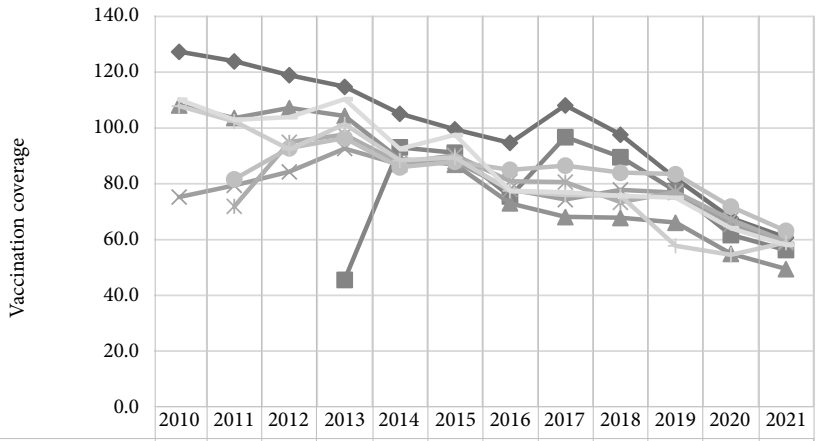
Figure 1 presents the VC for all eight vaccines over 12 years (2010 to 2021). The BCG, Yellow Fever, Oral Human Rotavirus, and Pentavalent vaccines were considered from 2010, while the Pneumococcal 10-valent and Meningococcal Conjugate type C vaccines were considered from 2011, and Hepatitis B from 2013. The BCG vaccine showed high coverage (VC = 127% in 2010 to VC = 97.6% in 2018) during the first nine years of the historical series but declined in subsequent years until reaching the lowest coverage in the last year of the historical series (VC = 60.7% in 2021). The Yellow Fever vaccine was above the VC target in the first four consecutive years (VC = 108.1% in 2010; VC = 103.6% in 2011; VC = 107.2% in 2012, and VC = 104.3% in 2013) but declined from 2014 (VC = 88.8%) until reaching

Table 1. Time trend of the National Vaccination Program indicators for children under one year old. Maranhão. Brazil. 2010-2021.

PNI indicators	2010(%)	2021(%)	Mean	APV	95%CI	P-value	Trend
Vaccination coverage (VC)							
Poliomyelitis	**110.00**	58.00	87.00	-10.39	-12.27 a -8.47	**< 0.001**	Decreasing
BCG	**127.00**	61.00	100.08	-12.25	-16.18 a -8.12	**< 0.001**	Decreasing
Hepatitis B[1]	46.00[1]	56.00	76.33	-2.28	-15.07 a 12.44	0.709	Stationary
Yellow fever	**108.00**	49.00	81.50	-12.24	-14.25 a -10.19	**< 0.001**	Decreasing
Oral human rotavirus	75.00	59.00	78.08	-3.52	-8.26 a 1.45	0.143	Stationary
Meningococcal conjugate type C[2]	72.00[2]	59.00	80.00	-5.65	-9.75 a -1.37	**0.016**	Decreasing
Pneumococcal 10-valent conjugate[2]	82.00[2]	63.00	83.54	-4.51	-8.15 a -0.73	**0.025**	Decreasing
Pentavalent	**108.00**	59.00	81.83	-10.55	-12.02 a -9.06	**< 0.001**	Decreasing
Proportion of abandonment of vaccines with multidose regimen (PA)							
Poliomyelitis	**4.13**	17.90	6.35	3.55	2.12 a 5.02	**< 0.001**	Increasing
Oral human rotavirus	20.88	8.50	13.39	-2.70	-3.65 a -1.75	**< 0.001**	Decreasing
Meningococcal conjugate type C[2]	87.04[2]	11.62	16.13	-9.35	-19.46 a 2.02	0.094	Stationary
Pneumococcal 10-valent conjugate[2]	89.25[2]	6.99	15.47	-9.22	-17.64 a 0.05	0.051	Stationary
Pentavalent	**2.95**	17.63	15.08	4.91	3.64 a 6.18	**< 0.001**	Increasing
Vaccination coverage homogeneity (VCH)							
Poliomyelitis	**82.03**	8.76	46.08	-14.02	-17.14 a -10.78	**< 0.001**	Decreasing
BCG	65.44	11.52	42.63	-9.80	-14.14 a -5.24	**0.001**	Decreasing
Hepatitis B[1]	1.38[1]	7.83	19.15	-2.02	-9.46 a 6.04	0.561	Stationary
Yellow fever	65.44	4.15	31.41	-12.88	-17.67 a -7.81	**< 0.001**	Decreasing
Oral human rotavirus	30.88	13.36	39.74	-3.90	-10.44 a 3.12	0.237	Stationary
Meningococcal conjugate type C[2]	20.28[2]	10.14	36.82	-7.08	-13.27 a -0.45	**0.039**	Decreasing
Pneumococcal 10-valent conjugate[2]	36.87[2]	12.90	41.60	-5.75	-10.64 a -0.59	**0.033**	Decreasing
Pentavalent	**81.57**	8.29	41.05	-13.71	-15.74 a -11.62	**< 0.001**	Decreasing

[1] Available from 2013; [2] available from 2011.

Source: Authors.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
BCG	127.4	123.9	118.9	114.8	105.2	99.5	94.7	108.1	97.6	81.8	67.7	60.7
Hepatitis B (up to 30 days)				45.6	93.1	91.1	75.5	96.7	89.6	77.4	61.7	56.3
Yellow fever	108.1	103.6	107.2	104.3	88.8	86.9	73.0	68.1	67.8	66.1	55.0	49.5
Oral human rotavirus	75.3	79.4	84.3	92.6	86.9	88.0	78.0	74.3	77.8	76.9	65.4	58.8
Meningococcal conjugate type C		71.9	95.0	97.6	87.5	90.2	80.9	80.6	73.4	77.1	67.2	59.3
Pneumococcal 10-valent		81.6	92.8	96.4	85.9	87.9	85.0	86.5	84.0	83.5	71.8	63.1
Pentavalent	107.9	102.4	92.3	101.4	88.4	89.4	77.5	76.0	75.6	57.8	54.6	58.9
Poliomyelitis	110.2	102.9	103.9	110.4	92.5	97.5	77.5	76.9	75.7	75.0	64.1	58.1

Figure 1. Vaccination coverage of vaccines of the national schedule for children under one year old. Maranhão. Brazil. 2010-2021.

Source: National Immunization Program Information System.

the lowest VC (49.5%) in 2021. The Pentavalent vaccine started with a high VC (107.9% in 2010 and 102.4% in 2011), declined in 2012 (92.3%), increased again (101.4% in 2013), and declined in subsequent years until reaching the lowest VC (58.9%) in 2021. The vaccine against Poliomyelitis had the highest VC in the first years of the series (110.2% in 2010; 102.9% in 2011; 103.9% in 2012, and 110.4% in 2013), decreasing to the lowest VC (54.6%) in 2020, and ending the historical series with a low VC (58.1% in 2021). The Oral Human Rotavirus vaccine only reached the goal of VC = 95% recommended by the Ministry of Health in 2013. It started with low VC (75.3% in 2010), increased in subsequent years until 2013 (VC = 92.6%), decreased until 2017 (VC = 74.3%), increased slightly in 2018 (VC = 77.8%), and declined again until reaching the lowest VC = 58.8% in the last year of series (2021).

Regarding the other vaccines unavailable since 2010, the Meningococcal Conjugate type C vaccine started the historical series with a low VC (71.9%) in 2011, rising in the two subsequent years (VC = 95% in 2012 and VC = 97.6% in 2013), decreasing (VC = 87.56%) in 2014, maintaining a VC below the 95% target in subsequent years, and ending the series with the lowest VC (59.3%) in 2021. The Pneumococcal 10-valent vaccine started the first year with low coverage (VC = 81.6% in 2011), only reached the VC target in 2013 (VC = 96.4%), declined in subsequent years, and recorded the lowest VC (63.1%) in 2021.

The PA indicator referring to the five multidose vaccines showed an increasing trend for the Poliomyelitis (APC = 3.55%; $p < 0.001$) and Pentavalent (APC = 4.91%; $p < 0.001$) vaccines, a stationary trend for the vaccines Meningococcal Conjugate type C ($p = 0.094$) and Pneumococcal 10-valent ($p = 0.051$), and the trend was decreasing only for the Oral Human Rotavirus vaccine (APC = -2.70%; $p < 0.001$) (Table 1).

Figure 2 presents the PA of the multidose vaccines throughout the historical series, whose classification remained in medium (5% to 10%)

to high PA (greater than 10%). The vaccines with the highest PA were the Pentavalent vaccine at the end of the series (2020; PA = 37.5%), the Meningococcal Conjugate type C (2011; PA = 28.7%) and the Pneumococcal 10-valent (2011; PA = 22.7%) vaccines, both at the beginning of the series, while the vaccines with the lowest PA were Poliomyelitis (2013; PA = 2.8%) and Pentavalent (2010; PA = 3%), also at the beginning of the historical series.

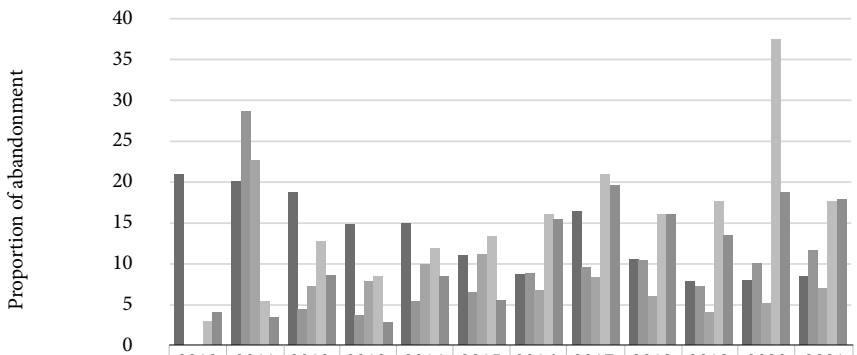
The VCH rate indicator showed a stationary trend for the Oral Human Rotavirus (APC = -3.9%; p = 0.237) and Hepatitis B (APC = -2.02%; p = 0.561) vaccines, while the other vaccines tended to decrease (p < 0.005). The highest APCs were those of Poliomyelitis (APC = -14.02) and Pentavalent (APC = -13.71) (Table 1).

Figure 3 shows the VCH rates among the municipalities of Maranhão in the twelve years of the historical series. In none of the years did 70% of the municipalities of Maranhão achieve adequate VC for the BCG, Yellow Fever, Oral Human Rotavirus, Meningococcal Conjugate type C, and Pneumococcal 10-valent vaccines. In comparison, the Pentavalent and Poliomyelitis vaccines were the only ones in which 70% of the municipalities from Maranhão had adequate VC. The Pentavalent vaccine remained the most with adequate VCH for three years (VCH = 71.9% in 2011 to VCH = 71.3% in 2013), while the vaccine against Poliomyelitis was the one that obtained VCH that was inadequate in the municipalities for the longest period (VCH = 82% in 2010; VCH = 73.3% in 2012, and VCH = 76.9% in 2013).

Table 2 presents the classification of municipalities in Maranhão regarding the risk of transmission of vaccine-preventable diseases, showing a growing temporal trend of very high (APC = 8.72%; p = 0.025) and high (APC = 9.32; p = 0.028) levels from 2015 (N = 49; 22.6% of the municipalities) to 2021 (N = 163; 75.1% of the municipalities), while the extremely low risk showed a decreasing trend (APC = -8.97; p < 0.001), and the medium risk evidenced a stationary trend (APC = -5.48; p = 0.313).

Discussion

In Maranhão, VC in children under one year of age fluctuated during the twelve years (2010-2021), with a downward trend, similar to national[3,17-21] and international[22,23] studies that show a drop in VC in recent years. The PNI establishes VC parameters for the vaccines in the national vaccination schedule for children (VC = 90%,



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Oral human rotavirus	20.9	20.1	18.8	14.9	15	11	8.7	16.4	10.6	7.9	8	8.5
Meningococcal conjugate type C		28.7	4.5	3.7	5.4	6.5	8.9	9.6	10.4	7.3	10	11.6
Pneumococcal 10-valent		22.7	7.3	7.9	9.9	11.2	6.8	8.4	6	4.1	5.2	7
Pentavalent	3	5.4	12.8	8.5	11.9	13.4	16.1	20.9	16.1	17.7	37.5	17.6
Poliomyelitis	4.1	3.5	8.6	2.8	8.5	5.6	15.4	19.6	16.1	13.5	18.7	17.9

Figure 2. Proportion of abandonment for vaccines with multidose scheme of the national schedule for children under one year old. Maranhão. Brazil. 2010-2021.

Source: National Immunization Program Information System.

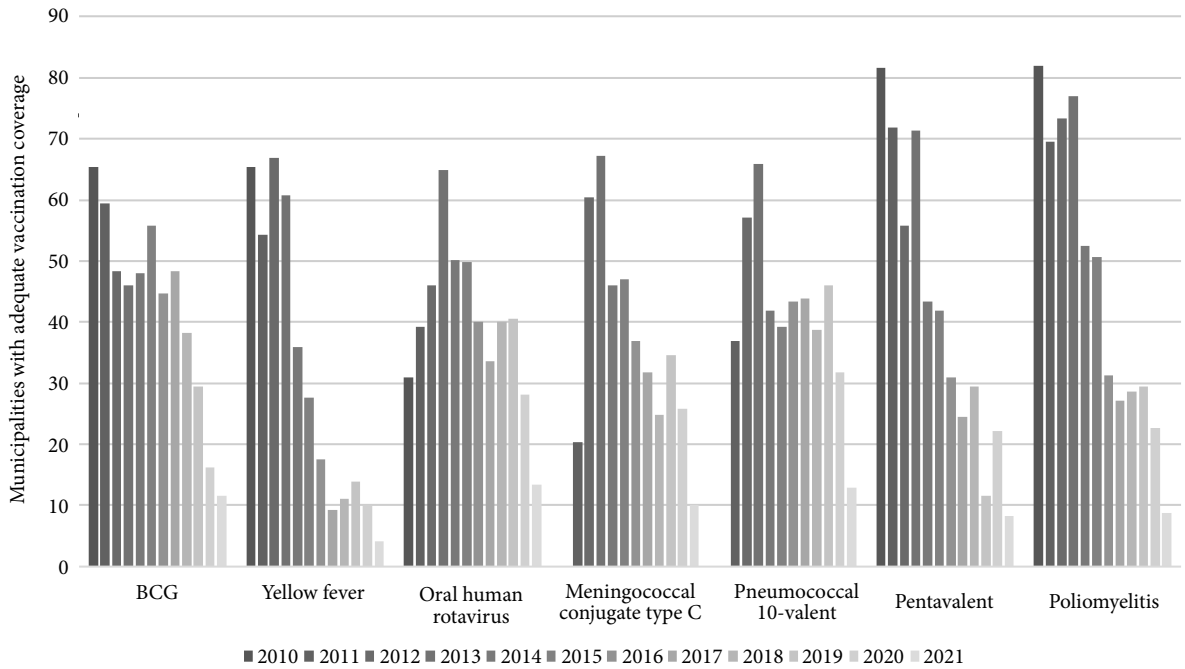


Figure 3. Vaccination coverage homogeneity rates in children under one year old. Maranhão. Brazil. 2010-2021.

Source: National Immunization Program Information System.

Table 2. Classification of municipalities in the state of Maranhão regarding the risk of transmission of vaccine-preventable diseases in children under one year old. Maranhão. Brazil. 2015 to 2021.

Risk classification of vaccine-preventable diseases	2015		2021		Mean	Median	APC[1]	95%CI	P-value	Trend
	N	(%)	N	(%)						
Extremely high	33	15.20[1]	91	41.90	28.43	27.19	8.72	1.57 to16.37	0.025	Increasing
High	16	7.40[1]	72	33.20	14.82	11.06	9.32	1.46 to17.79	0.028	Increasing
Medium	80	36.90[1]	37	17.10	34.24	36.90	-5.48	-16.94 to 7.55	0.313	Stationary
Low	27	12.40[1]	10	4.60	8.68	7.37	-1.28	-4.15 to 1.67	0.312	Stationary
Extremely low	61	28.10[1]	7	3.20	13.82	11.52	-8.97	-11.46 to -6.41	< 0.001	Decreasing
Total municipalities	217		217							

[1] APC: annual percentage change.

Source: Authors.

BCG, and Oral Human Rotavirus vaccines; VC = 95%, Meningococcal Conjugate type C, Pneumococcal 10-valent, Pentavalent, and Poliomyelitis, and VC = 100 % for Yellow Fever), but in the last two years of the historical series, the VC of all vaccines was below the recommended level in Maranhão. The highest VC drop was for Yellow Fever, while BCG was the one that reached the goal stipulated by the PNI for VC (from 2010 to 2018) for the longest time. In contrast, the Pneumococcal 10-valent and Oral Human Rotavirus vaccines reached the goal only in 2013. In late 2016 and early 2017, some states showed an increase in yellow fever cases, whose factors were areas with relatively low VC and ecosystems favorable to virus transmission[24]. The drop in the yellow fe-

ver VC is troubling since Maranhão is an endemic area whose vaccination target is VC = 100% for children under one-year-old. The Human Oral Rotavirus vaccine has a limitation for its realization, which concerns the maximum age to be administered (seven months and 29 days; after reaching that age, one cannot start the regimen).

Similar findings were found in the study by Muniz et al. (2021)[20], also with data from the SI -PNI for Brazil, indicating that the Pneumococcal VC significantly declined from 2015 to 2020 in all regions of the country, highlighting the North region.

In our study, none of the vaccines had an increasing trend of VCH (≥ 70% of municipalities with adequate vaccination coverage). The vaccines that reached this parameter established by the PNI for some time were the pentavalent (2010, 2011, and 2013) and poliomyelitis (2010, 2012, and 2013), which lasted for three years at the onset of the historical series. The results obtained in a study in the state of Roraima, considering the 2013-2017 period, found a higher VCH rate for the 10-valent pneumococcal vaccine (2016), while the lowest rate was for the BCG vaccine[25].

We should mention that the SI-PNI changed data recording in 2014, previously performed by applied doses and now by nominal records. Thus, the need for material structure, human resources, and logistics may have led to decreased records and a consequent decline in VC. The VC drop, especially in the last two years, indicates that the supply and demand for immunization services fell sharply[26-30] with the COVID-19 pandemic. We should underscore that several social distancing measures were implemented in Maranhão to minimize COVID-19 transmission[31].

Other factors are also identified as difficulties in achieving VC: society's complacency due to the PNI success since most of the population and health professionals have not experienced the complications caused by vaccine-preventable diseases20; difficulties in accessing health services; misinformation and vaccine hesitancy[32-34]; anti-vaccination actions and fake news; low national production and irregular distribution of vaccines18. Moreover, the incomplete vaccination schedule was higher in white mothers, who had paid maternity leave, multiparous, with fewer prenatal care appointments, without partners, and babies who had access to daycare[35].

Medium (5%-10%) and high (> 10%) PA levels were classified for the multidose vaccines. The highest PAs were for Pentavalent and Oral Human Rotavirus, mainly in the early years of the series (2010 to 2015), while the lowest were for Pneumococcal 10-valent (2011 and 2015) and Meningococcal Conjugate type C (2011, 2018, and 2021). The pentavalent vaccine, in general, has post-vaccination effects, which leads to greater vaccine hesitancy.

A study in Roraima from 2013 to 2017 pointed to the highest PAs for poliomyelitis vaccines, followed by oral human rotavirus vaccine. In contrast, the lowest PAs were for the meningococcal conjugate type C, the Pneumococcal 10-valent, and poliomyelitis vaccines[25]. In Minas Gerais state36, a PA of 24.63% was recorded for pneumococcal 10-valent, poliomyelitis, pentavalent, and human rotavirus vaccines in children under one year from 2018 to 2020. The authors discuss some of the probable reasons for the high PA: difficulties in accessing health services[37], social vulnerability38, limited family support[39], ideological anti-vaccination currents[40], shortage of vaccines[41], and COVID-19-pandemic-related factors, such as social distancing[42], strangulated health services[43], lack of human resources, physical and mental exhaustion of the professionals[44], and a political agenda that opposed group protection measures, broadening the deleterious pandemic effects[45].

Another study in Sergipe state, with data from the SI-PNI[46] but with children up to two years of age, evaluated VC for 2017. The highest PAs were the Meningococcal Conjugate type C vaccine (53.3%), followed by Poliomyelitis (49.3%), Pentavalent (44%), and Oral Human Rotavirus (40%) vaccines. These results corroborate our study since, when analyzing only 2017, the highest PAs were for the Pentavalent (20.9%) and Poliomyelitis (19.6%) vaccines, followed by the Oral Human Rotavirus (16.4%) vaccine. Using Brazil national data, Donalísio et al.[47] also identified high abandonment rates for the poliomyelitis vaccine, especially in the North and Northeast regions.

The results for the PA of the multidose vaccines during the 12 years (2010 to 2021) showed that the highest PA was for the Pentavalent vaccine (37.5%) in 2020, followed by the Meningococcal Conjugate type C (28.7%) in 2021, the Pneumococcal 10-valent (22.7%) in 2011, and the Oral Human Rotavirus (20.9%) in 2010. Those with the lowest PAs were Poliomyelitis (2.8%) in 2013, followed by Pentavalent (3.0%) in 2013. A study in the capital of Maranhão in 2010 found greater incompleteness of the vaccination schedule for the new vaccines, the Meningococcal type C and Pneumococcal 10-valent vaccines (incom-

pleteness of 51.1%) at the time, compared to the old vaccines (BCG, hepatitis B, human rotavirus, poliomyelitis, yellow fever, and triple viral fever), with incompleteness of 33.2% in children aged 13 to 35 months[20].

The growing trend of extremely high and high risk from 2015 to 2021 expresses the concern that vaccine-preventable diseases will resurface, as more than half of the municipalities evidenced extremely high and high risk levels, reinforcing the need to monitor the PNI indicators to implement the necessary interventions as early as possible.

Other studies found similar results in Sergipe46 and Pernambuco48 states, whose most municipalities were classified in the extremely high and high risk categories. These results alert to potential inequalities in the VC distribution, as already pointed out by other studies in low- and middle-income countries[49].

In Ceará state[50], due to the high risk of vaccine-preventable diseases transmission during the measles epidemic (December 2013 to September 2015), 90% of confirmed cases had no vaccination history and adopted the following measures: search for the susceptible population; vaccination campaigns; vaccination of the at-risk population; reorientation and systematization of blocking and sweeping actions throughout the state.

In a study in the capital of Maranhão, Silva et al. (2018)[51] analyzed the factors associated with vaccine incompleteness for new vaccines (Meningococcal type C and Pneumococcal 10-valent) in 2010. It indicated the following factors: older children, belonging to the lower social classes, children of less educated mothers, unavailable outpatient care or hospitalization for children, and lack of vaccines in health services. Common factors (old and new vaccines) were living with one or more siblings, children of adolescent mothers, smokers, who did not plan the pregnancy, becoming pregnant in the first year after the birth of the child under study, having less than six prenatal care visits, and started prenatal care in the third trimester.

We should underscore the following limitations of the study: use of secondary data that may contain underreporting and failures in data collection and processing regarding vaccine doses or live births, obtained from the SI-PNI and SINASC, respectively; and the new dose recording method adopted during the historical series. As potentialities, we mention using data easily accessible and obtainable by the municipalities for immunobiologicals in the vaccination schedule for children under one year old, which can be readily incorporated into local monitoring routines. Moreover, we analyzed each vaccine's behavior over the twelve-year historical series, which included important changes, such as in the SI-PNI and the pandemic, through the regression models.

This study's findings point to a deteriorating trend of the PNI indicators from 2010 to 2021 in children up to one year of age in Maranhão, susceptible to the emergence of vaccine-preventable diseases. However, we observed an improved PA for the multidose regimen of the oral human rotavirus vaccine, with a decreasing trend, but a deterioration in achieving VC goals, as no vaccine reached the goal in the last two years of the historical series, culminating with the first two years of the COVID-19 pandemic. We recommend implementing public policies directed at the determinants of the low VCs to resume past coverage, following health recommendations for the control of vaccine-preventable diseases.

Collaborations

CV Marinho, RCS Queiroz, and WRM Araujo contributed to the design, analysis, and interpretation of data, drafting and critically reviewing the article. AS Tonello and EBAF Thomaz contributed to data analysis, drafting, and critically reviewing the article. Finally, all authors approved the final version for publication.

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