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Impact of childhood immunization in the state of Piauí: ecological time series study on vaccination coverage from 2000 to 2022

Impacto da imunização infantil no estado do Piauí: estudo ecológico de séries temporais sobre a cobertura vacinal de 2000 a 2022

Impacto de la inmunización infantil en el estado de Piauí: un estudio de series temporales ecológicas sobre la cobertura de vacunación de 2000 a 2022

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ABSTRACT

Objective: To analyze the temporal trend of vaccination coverage among children aged zero to 12 years in the state of Piauí. Method: Ecological time-series study following the STROBE guidelines, analyzing vaccines from the childhood calendar. Data were collected from institutional platforms (DATASUS, OpenDataSUS, and CIEGES-PI), calculated by SI-PNI, tabulated in Excel, and analyzed in SPSS 22.0 with descriptive statistics and calculation of the infant mortality rate per 100,000 live births. Results: Infant mortality in Piauí decreased between 2000 and 2022. Coverage of vaccines such as pentavalent, polio, rotavirus, and pneumococcal increased in certain periods, while BCG and hepatitis B vaccines decreased in recent years. Implications: Expanding vaccination coverage and reducing infant mortality require active targeting of unvaccinated individuals, educational campaigns, and training of professionals in the correct use of information systems. It is also necessary to strengthen BCG and hepatitis B vaccination in maternity wards, ensuring early protection.

DESCRIPTORS

Vaccination Coverage. Child Health. Vaccine-Preventable Diseases. Infant Mortality.

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INTRODUCTION

Vaccination is a fundamental action, as it allows for the elimination and control of many diseases, in addition to reducing mortality rates and related complications. It also contributes to the sustainability of healthcare systems by reducing the need for hospitalizations and medical care, as well as direct medical costs. However, this important healthcare tool faces challenges such as unequal access, lack of resources, and vaccine hesitancy[1].

Furthermore, age is an important factor in the immune response: as an individual ages, his immunity increases until it reaches a peak and eventually declines, exhibiting a saddle-shaped shift, with low immunity in early life and old age. Infants and children are generally more vulnerable to infections due to their functionally immature immune systems, which highlights the need for careful attention to the vaccination schedule and timely administration[2].

In this context, in the 1940s, the country had a mortality rate of children up to 5 years of age of 212 per thousand, while in the general population, this number was 19 per thousand inhabitants[3]. In 1974, the World Health Organization (WHO) established the Expanded Program on Immunization, with the objective of making vaccines against diphtheria, tetanus, pertussis, polio, measles and tuberculosis available to all children in the world[4].

In the same decade, with the high infant mortality rate, the Brazilian government created the National Immunization Program (NIP) in 1973, whose main objective was to provide quality vaccines to all children born annually in the country[19]. The program has historically proven effective in combating diseases through childhood immunization, as within ten years of its inception, infant mortality had decreased by more than 50% and continued to decline in the following decades, reaching a rate of 14 per thousand in 2019[3].

The NIP's work is extremely important in all states and municipalities, aiming to achieve 100% uniform vaccination coverage. The efforts in the state of Piauí stood out, showing that vaccination coverage for DTP, the vaccine that protects against diphtheria, tetanus, and pertussis, increased by 15.96 percentage points from 2022 to 2023, respectively, from 73.11% to 89.07%. This improvement, which represents the proportion of the population within the target age group that received the dose, contributed to improving the country's immunization rates and removing Brazil from the list of the 20 countries with the highest number of unvaccinated children, according to a report by the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), responsible for global monitoring of childhood immunization[4-5].

Thus, understanding variations in vaccination coverage is essential for developing more effective public health policies tailored to the regional situation, especially in a state with such critical geographic and socioeconomic challenges. By presenting a detailed overview of childhood vaccination coverage, this study is expected to assist in the development of strategies that ensure comprehensive and sustainable immunization coverage, preventing outbreaks of these infectious diseases, and strengthening the National Immunization Program (NIP). Therefore, this study aims to analyze the temporal trends in vaccination coverage among children aged zero to 12 years in the state of Piauí.

METHODS

This is an ecological, time-series trend study. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE)[(6)] framework from the EQUATOR Network was used to guide and develop the research.

Data available in scientific articles and institutional platforms were used: SAGE (Strategic Advisory Group of Experts), CONASEMS (National Council of Municipal Health Secretariats), IEPS (Institute for Health Policy Studies), CIEGES-PI (Coordination of Strategic Health Management Information of Piauí), DATASUS (Information Technology Department of the Unified Health System), OpenDataSUS (Open Data Platform of the Unified Health System), and CONASS (National Council of Health Secretaries).

The formula used by SI-PNI/DataSUS to calculate vaccination coverage (CV) is: the number of children with a complete basic schedule at the target age divided by the number of children aged 0 to 12 months (target population), multiplied by 100, stratified by year.

Vaccination coverage for children aged 0 to 12 years in the state of Piauí, Brazil, from 2000 to 2022.

All vaccines targeting children aged 0 to 12 years were analyzed: BCG, hepatitis B, human rotavirus, meningococcal C, pentavalent (DTP/Hib/HB), pneumococcal, polio, yellow fever, hepatitis A, meningococcal, MMR, DTP, and varicella.

The vaccination coverage values obtained were tabulated in a Microsoft Excel Office 2016® spreadsheet. The data were exported and analyzed using the Statistical Package for Social Sciences (SPSS) version 22.0.

The data were tabulated and analyzed using TABNET, focusing on variables such as childhood vaccination coverage, number of deaths by region, sex, age group, race/color, maternal education, Human Development Index (HDI), and socioeconomic conditions. The data analysis was descriptive, statistically performed using absolute and relative frequencies. Infant mortality reduction rates were calculated based on the number of deaths of children under one year of age per 100,000 inhabitants, using the population residing in the state of Piauí as a reference.

The data used were obtained from official sources, including DATASUS, OpenDataSUS, CIEGES-PI, and population estimates from the IBGE (Brazilian Institute of Geography and Statistics), as well as supplementary data from scientific articles and institutional platforms such as SAGE, CONASEMS, IEPS, and CONASS. For the analysis of infant mortality, birth and death information available in the Mortality Information System (MIS/DATASUS) was used. Initially, the total number of infant deaths recorded in the analyzed period was collected and correlated with the number of births in the same period to calculate the infant mortality rate per 100,000 live births, according to the SI-PNI/DATASUS methodology.

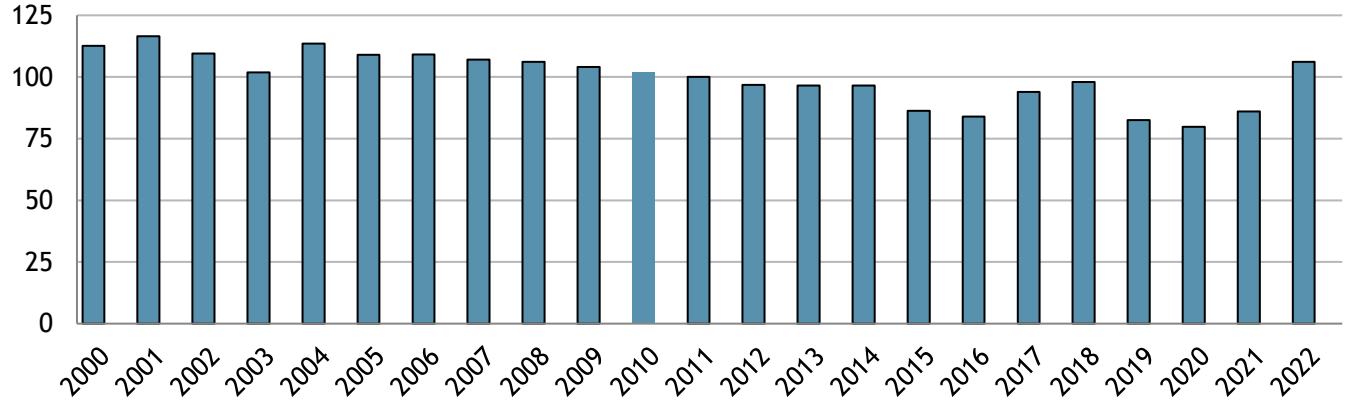
The formula used to calculate the infant mortality rate was: infant mortality rate = (number of infant deaths/number of live births) x 100,000. Subsequently, the reduction in infant mortality was estimated by comparing the rates between the analyzed years. The reduction rate was obtained by applying the following formula: reduction rate = (initial rate - final rate/initial rate) x 100. This approach allowed us to identify the percentage decrease in infant deaths over time, indicating the impact of the interventions implemented and the evolution of public health indicators in the state of Piauí[7].

Because the study data are secondary, publicly and unrestrictedly accessible, do not involve data collection or intervention on human beings, and do not identify the participants by name, approval by the Research Ethics Committee/National Research Ethics Commission was not required. The study followed the ethical principles for research involving human beings, as established in Resolution number 466/12 of the National Health Council.

RESULTS

According to Figure 1, BCG (Bacille Calmette-Guérin) vaccination coverage has varied over the years, with high peaks in 2000 and 2001, when coverage exceeded 100%. However, from 2002 onwards, there was a gradual decline, with sharper drops in 2015 and 2016. In 2022, an increase in vaccination coverage was observed.

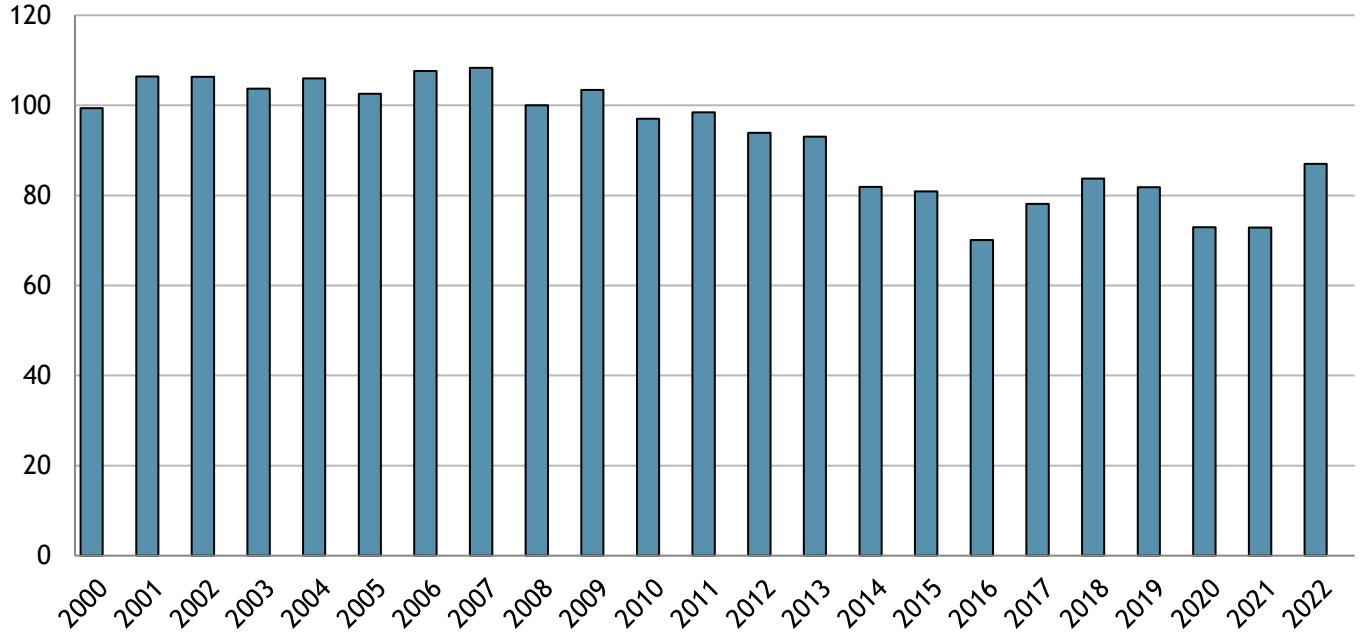
Figure 1. BCG vaccination coverage in the state of Piauí (2000-2022).



Source: Graph prepared by the authors based on data available at the Department of Information and Informatics of the Unified Health System (DATASUS), 2024.

Figure 2 shows polio vaccination coverage in the state of Piauí between 2000 and 2022. It can be seen that this coverage has varied over the years: in the mid-2000s, there was a steady increase in vaccination coverage, reaching over 100% in some years. However, declines in coverage were noted in some years, especially after 2010.

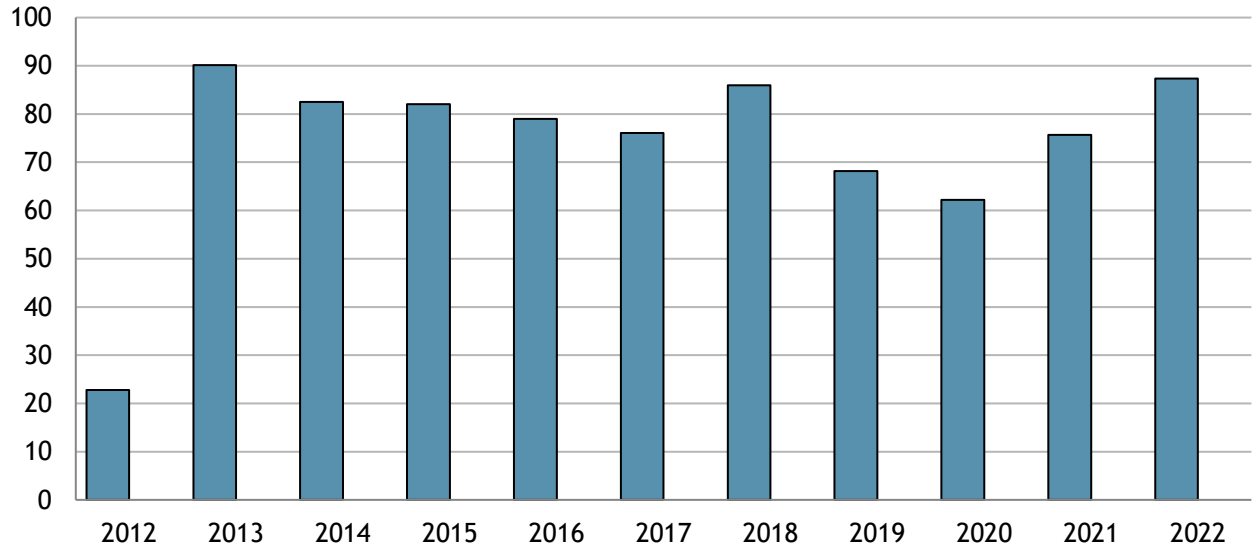
Figure 2. Polio vaccination coverage in the state of Piauí (2000-2022).



Source: Prepared by the authors based on data available at the Department of Information and Informatics of the Unified Health System (DATASUS), 2024.

Figure 3 demonstrates some trends and critical variables regarding pentavalent vaccination coverage in Piauí: in 2012, vaccination coverage was low, but a relevant increase can be noted in 2013, when it reached its peak.

Figure 3. Pentavalent vaccination coverage in the state of Piauí (2012-2022).



Source: Graph prepared by the authors based on data available at the Department of Information and Informatics of the Unified Health System (DATASUS), 2024.

Table 1 presents infant mortality data for the state of Piauí between 2000 and 2022, detailing the total number of deaths of children under one year of age, the number of births each year, and the infant mortality rate calculated per 100,000 live births. It also includes the annual rate of reduction in infant mortality compared to the previous year.

Table 1. Evolution of infant mortality and reduction rate in Piauí (2000-2022).

Year	Total deaths	Births	Infant mortality rate (per 100,000 live births)	Annual reduction rate
2000	1,345	58,615	2,294	-
2001	1,245	58,588	2,125	7.37%
2002	1,254	56,322	2,226	-4.76%
2003	1,212	55,105	2,199	1.21%
2004	1,078	54,747	1,968	10.49%
2005	1,084	56,866	1,906	3.15%
2006	1,116	55,342	2,016	-5.77%
2007	1,084	53,214	2,037	-1.04%
2008	972	52,664	1,846	9.39%
2009	913	50,996	1,790	3.04%
2010	847	49,424	1,714	4.25%
2011	837	50,144	1,669	2.63%
2012	797	47,962	1,662	0.42%
2013	743	46,419	1,600	3.73%
2014	763	47,941	1,591	0.56%
2015	741	49,253	1,504	5.47%
2016	757	46,986	1,611	-7.12%
2017	750	46,986	1,596	0.93%
2018	742	49,490	1,499	6.08%
2019	632	47,933	1,318	12.07%
2020	666	45,229	1,472	-11.68%
2021	632	45,978	1,375	6.60%
2022	666	42,247	1,576	-14.63%

Source: SESAPI; DATASUS.

Looking at the data, in 2000, the infant mortality rate was 2,294 per 100,000 live births, with a total of 1,345 deaths and 58,615 births. This year serves as the starting point for subsequent comparisons:

over the years, the infant mortality rate varied, with some fluctuations, but showed a general downward trend.

In the early years, from 2000 to 2004, there was a consistent reduction in the infant mortality rate. In 2001, for example, the rate fell to 2,125, a 7.37% reduction compared to the previous year. The downward trend continued until 2004, when the rate reached 1,968, representing a 10.49% decrease compared to 2003. Between 2005 and 2010, the rate fluctuated but remained stable. In 2005, the rate was 1,906, a slight reduction compared to the previous year. However, in 2006, the rate rose again to 2,016, an increase of 5.77%. This pattern of small variations continued, but in 2010, the rate reached 1,714, a significant reduction of 4.25% compared to 2009. From 2011 to 2019, infant mortality continued to fall, reaching the lowest rate of the analyzed period in 2019, with 1,318 deaths per 100,000 live births, representing a significant reduction of 12.07% compared to 2018.

Table 2. Vaccination coverage in Piauí and Brazil in 2022.

Immunobiological drugs	Brazil	Piauí
BCG	90.1	106.1
Hepatitis B	82.7	87.4
Human Rotavirus	76.6	83.2
Meningococcal C	78.6	87.2
Pentavalent (DTP/Hib/HB)	77.2	87.4
Pneumococcal	81.5	89.5
Polio	77.2	87.0
Yellow Fever	60.6	71.2
Hepatitis A	73.0	76.8
Pneumococcal (1st ref)	71.5	85.3
Meningococcal (1st ref)	75.3	85.6
Polio (1st ref)	67.7	75.9
Triple Viral D1	80.7	82.8
Triple Viral D2	57.6	53.2
Tetra Viral (SRC+VZ)	10.43	13.31
DTP (1st ref)	67.4	87.4
Varicella	73.3	83.0

Source: National Immunization Program Information System (SI-PNI/CGPNI/DEIDT/SVS/MS), 2025

However, starting in 2020, the mortality rate increased, reaching 1,472 in 2020 and 1,576 in 2022. Comparing the extremes of this period, we see that the infant mortality rate in 2022 was 1,576, representing a 31.30% reduction compared to the 2000 rate (2,294). This data highlights a reduction in infant mortality over these two decades.

The data in Table 2 show, comparatively, the vaccination coverage of the unit of analysis of this study, Piauí, with Brazil. It is clear that the state is in a more comfortable situation when compared to the total coverage of the country, surpassing it in almost all immunobiological coverage.

Although Piauí, in general, shows a vaccination coverage higher than the total of Brazil, there is an inversion in the coverage of the second dose of Triple Viral, which is lower in the State; however it is important to consider that this dose of the immunobiological drug can be replaced by Tetra Viral, where Piauí once again has a coverage higher than the national one.

DISCUSSION

Vaccination adherence depends on multiple factors, such as ease of access, recognition of its importance, trust in vaccines, and social influences that can reinforce the persistence of anti-vaccine stances[8]. In this context, vaccination campaigns contribute to the dissemination of reliable information and the expansion of vaccination coverage. In the state of Piauí, the reduction in infant mortality over the

years is linked to vaccination campaigns and improvements in health practices: vaccination campaigns began to gain greater traction in the 1980s, with the institutionalization of the National Immunization Program (NIP). Vaccines such as BCG and the polio vaccine, introduced systematically in the 1960s, were fundamental to reducing the incidence of fatal diseases. This demonstrates that, when implemented correctly, vaccines can drastically reduce infant mortality.

The significant reduction in the percentage of BCG and Hepatitis B vaccination coverage between 2022 and 2023 in Brazil is related to the restructuring of vaccine registration. Until 2022, records in the states' own information systems were compiled by the Ministry of Health and presented on the Tabnet platform—the National Health Program Information System. However, starting in 2023, data began to be sent to the National Health Data Network (NHDN)[9]. The NHDN centralizes and organizes citizens' health information, ensuring that clinical data can be accessed securely and in a standardized manner by authorized professionals[10]. Despite this, delays in system communication and registration with the NHDN interfered with vaccination coverage calculations[9].

Furthermore, the late implementation of the BCG vaccine, which protects against severe forms of tuberculosis, especially meningeal and miliary tuberculosis in children, in Brazil's National Health Program, almost five decades after its introduction in 1920, reflects a gap in the country's public health policy, primarily impacting less developed states, such as Piauí[3-5]. In this context, although the institutionalization of the National Immunization Program (NIP) in 1976 reduced the incidence of severe forms of tuberculosis, the delay in the official incorporation of BCG likely resulted in unequal and insufficient protection for many years[11]. This particularly aggravated the vulnerability of rural and remote populations to challenges in health infrastructure and vaccine distribution logistics, highlighting the importance of continued efforts to ensure universal and equitable access to vaccines[12].

According to the National Immunization Program (NIP), polio vaccination coverage in Brazil has faced challenges, especially in the last decade. In 2020, for example, national vaccination coverage was approximately 76%, well below the 95% target established by the Ministry of Health[5]. This decline may be influenced by several factors, such as a decreased perception of the risk of polio due to the absence of recent cases, leading the population to underestimate the threat of the disease. Therefore, by not witnessing the serious effects of polio, many parents may not feel the immediate need to vaccinate their children, resulting in lower vaccination uptake. Consequently, this reduction in immunization increases the risk of reintroduction of the virus and outbreaks, highlighting the need to maintain awareness of the importance of vaccination, even when the disease is not visibly present[13].

However, in Piauí, there has been an apparent recovery in polio vaccination coverage in recent years, particularly in 2022, when more than 142,000 doses of the vaccine were administered in the state. During this period, 77 municipalities reached or exceeded the 95% vaccination coverage target for children aged one to under five years[14]. This is likely a result of new vaccination campaigns driven by the COVID-19 pandemic, which brought greater focus to the importance of vaccines.

After 2013, coverage remained relatively stable, although with minor fluctuations. However, since 2018, there has been a noticeable decline in vaccination coverage, particularly in 2019 and 2020. This may be related to disruptions in the vaccine supply chain, vaccine hesitancy, and logistical challenges. In 2021 and 2022, vaccination coverage gradually resumed, although it has not yet reached the levels seen in 2013. Nationally, the pentavalent vaccine has faced similar challenges. According to data from the Ministry of Health, vaccination coverage for the pentavalent vaccine fell from 95% in 2015 to approximately 75% in 2020. Given this outlook, the Federal Government, in conjunction with states and municipalities, has implemented vaccination recovery campaigns. In 2021, multi-vaccination campaigns were promoted to update children's vaccination records and ensure protection against multiple diseases[5-14].

It is also worth noting that the pentavalent vaccine (DTP/HB/Hib) is a combination that prevents five diseases: pertussis, diphtheria, tetanus, hepatitis B, and *Haemophilus influenzae* type B infections[20]. Therefore, since 2012, the Ministry of Health's National Immunization Program (NIP) has offered this immunobiological drug in the National Vaccination Calendar, replacing the tetravalent vaccine. In Brazil, the pentavalent vaccine is imported via the Strategic Fund of the Pan American Health Organization (PAHO) due to the lack of production laboratories in the country. The vaccine is administered in three doses at 2, 4, and 6 months of age, as recommended in the National Childhood Vaccination Calendar[5].

Furthermore, the COVID-19 pandemic has affected vaccination routines in many Brazilian states, including Piauí. In 2020 and 2021, vaccination coverage for several diseases, including polio, BCG, and

pentavalent vaccination, declined due to social distancing measures and the overload of the healthcare system[15-16]. Therefore, to minimize the decline in vaccination coverage, multi-vaccination campaigns were launched in 2021 and 2022, aiming to restore immunization rates and protect children against vaccine-preventable diseases.

Thus, this study demonstrates that vaccination is a determining factor in infant mortality in the state of Piauí. Despite its overall reduction and advances in state vaccination coverage, challenges remain in achieving optimal coverage. Rural and remote populations still face logistical barriers and lower vaccine protection[17]. The recent decline in BCG and hepatitis B vaccination rates, coupled with fluctuations in vaccines such as polio and pentavalent vaccination, highlights vulnerabilities related to access barriers, vaccine hesitancy, and logistical weaknesses. The decreased perception of the risk of preventable diseases, as well as the reduced number of recent cases, also influenced this decline. Due to this changeable acceptance of vaccination, it is necessary to create analytical models capable of verifying the social, cultural, and political tripod of each location[18]. In 2022, 77 municipalities in Piauí reached or exceeded the target of 95% coverage for polio, which indicates that the resumption of the targets has a positive impact and that post-COVID-19 educational and operational strategies must be maintained to prevent the return of diseases preventable by immunobiological treatments.

Among the limitations of this study is the impossibility of individually analyzing the vaccination status of children who died. There is also underreporting, which remains a national challenge, even in cases of mandatory reporting.

Another limitation of this study is the unavailability of the exact number of children analyzed during the study period, since the DATASUS platform does not provide this information disaggregated by age group in some segments. This limitation restricts the possibility of a more detailed analysis of the target population and must be considered when interpreting the results.

This study highlights the need to strengthen strategies for screening unvaccinated individuals and educational initiatives aimed at primary care healthcare professionals to improve their skills in effectively using and filling out information systems and enabling them to welcome and educate the population about the importance of vaccinations.

The increase in infant mortality since 2020 may be a reflection of the COVID-19 pandemic, due to disruptions in basic services, vaccine hesitancy, or even deficiencies in neonatal and child care. Therefore, it is essential that health teams adopt infant death surveillance protocols with a vaccine focus, verifying the absence of vaccines and the cause of death.

CONCLUSION

The data show that between 2000 and 2022, there was fluctuation in coverage rates, influenced by factors specific to each immunobiological drug and the period analyzed. The overall trend was positive, with a notable increase in coverage for vaccines such as pentavalent, polio, rotavirus, and pneumococcal, reflecting advances in public health, even in the face of the challenges posed by the COVID-19 pandemic. However, the reduction in coverage for vaccines such as BCG and hepatitis B remains a cause for concern, highlighting the need for ongoing and targeted strategies to increase uptake of these vaccines, aiming to reduce infant morbidity and mortality.

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AUTHOR CONTRIBUTIONS

Study conception or design: Rodrigues, MCS; Soares, LV. Data collection: Rodrigues, MCS; Soares, LV; Pereira, LSA. Article writing or critical review: Rodrigues, MCS; Pereira, LSA; Araújo, LB; Pierot, EV. Final approval of the version to be published: Pierot, EV.

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The study used secondary data, which is in the public domain and open access. It was not necessary to submit it to the Research Ethics Committee or the National Research Ethics Commission. The research was conducted in accordance with the ethical principles applicable to research involving human subjects, as established in Resolution No. 466/2012 of the National Health Council.

CONFLICT OF INTEREST

The authors declare no conflict of interest.