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Association between Vaccination Coverage and Incidence of Vaccine-Preventable Diseases in Brazil: An Ecological Time Series Study with Data from Federative Units (2007–2024)

Associação entre Cobertura Vacinal e Incidência de Doenças Imunopreveníveis no Brasil: Estudo Ecológico de Série Temporal com Dados das Unidades Federativas (2007–2024)
Asociación entre Cobertura Vacunal e Incidencia de Enfermedades Inmunoprevenibles en Brasil: Estudio Ecológico de Serie Temporal con Datos de las Unidades Federativas (2007–2024)

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Abstract:
Vaccination is one of the main strategies for the prevention of communicable diseases and has played a fundamental role in reducing morbidity and mortality from vaccine-preventable diseases. However, the decline in vaccination coverage observed in recent years in Brazil has raised concerns regarding the possible re-emergence of previously controlled diseases. This longitudinal ecological panel study evaluated the association between vaccination coverage and the incidence of pertussis, meningococcal meningitis, measles/rubella, and yellow fever across Brazilian states from 2007 to 2024. Secondary data were obtained from the Notifiable Diseases Information System (SINAN), the National Immunization Program Information System (SI-PNI), and population estimates provided by the Brazilian Institute of Geography and Statistics (IBGE). The association between vaccination coverage and disease incidence was assessed using fixed-effects Poisson regression models by state, incorporating a one-year lag between exposure and outcome, as well as adjustments for linear temporal trends and epidemiological periods related to the COVID-19 pandemic. A total of 486 observations corresponding to the 27 Brazilian states were analyzed. A statistically significant inverse association was observed between vaccination coverage and the incidence of pertussis (IRR=0.9892; 95%CI: 0.9887–0.9896), meningococcal meningitis (IRR=0.9977; 95%CI: 0.9968–0.9986), measles/rubella (IRR=0.9866; 95%CI: 0.9858–0.9875), and yellow fever (IRR=0.9573; 95%CI: 0.9541–0.9607), all with $p<0.001$. During the pandemic period, a significant reduction in incidence was observed for all diseases analyzed. These findings reinforce the importance of maintaining high vaccination coverage and continuously strengthening immunization and epidemiological surveillance activities to control vaccine-preventable diseases in Brazil.

Keywords:
vaccination; vaccination coverage; vaccine-preventable diseases; epidemiology; public health; time series.

Resumo:
As vacinas constituem uma das principais estratégias de prevenção de doenças transmissíveis e têm desempenhado papel fundamental na redução da morbimortalidade por agravos imunopreveníveis. Entretanto, a redução das coberturas vacinais observada nos últimos anos no Brasil tem gerado preocupação quanto à possibilidade de reemergência de doenças anteriormente controladas. Este estudo ecológico longitudinal em painel avaliou a associação entre cobertura vacinal e incidência de coqueluche, meningite meningocócica, sarampo/rubéola e febre amarela nas unidades federativas brasileiras entre 2007 e 2024. Foram utilizados dados

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secundários do Sistema de Informação de Agravos de Notificação (SINAN), do Sistema de Informações do Programa Nacional de Imunizações (SI-PNI) e estimativas populacionais do Instituto Brasileiro de Geografia e Estatística (IBGE). A associação entre cobertura vacinal e incidência foi analisada por meio de modelos de regressão de Poisson com efeitos fixos por unidade federativa, utilizando defasagem temporal de um ano entre exposição e desfecho e ajuste para tendência temporal linear e períodos epidemiológicos relacionados à pandemia de COVID-19. Foram analisadas 486 observações correspondentes às 27 unidades federativas brasileiras. Observou-se associação inversa estatisticamente significativa entre cobertura vacinal e incidência de coqueluche (IRR=0,9892; IC95%: 0,9887–0,9896), meningite meningocócica (IRR=0,9977; IC95%: 0,9968–0,9986), sarampo/rubéola (IRR=0,9866; IC95%: 0,9858–0,9875) e febre amarela (IRR=0,9573; IC95%: 0,9541–0,9607), todos com p<0,001. Durante o período pandêmico observou-se redução significativa da incidência para todos os agravos analisados. Os achados reforçam a importância da manutenção de elevadas coberturas vacinais e do fortalecimento contínuo das ações de imunização e vigilância epidemiológica para o controle de doenças imunopreveníveis no Brasil.

Palavras-chave:
vacinação; cobertura vacinal; doenças imunopreveníveis; epidemiologia; saúde pública; vigilância epidemiológica.

Resumen:
La vacunación constituye una de las principales estrategias para la prevención de enfermedades transmisibles y ha desempeñado un papel fundamental en la reducción de la morbilidad y mortalidad por enfermedades inmunoprevenibles. Sin embargo, la disminución de las coberturas vacunales observada en los últimos años en Brasil ha generado preocupación por la posible reemergencia de enfermedades previamente controladas. Este estudio ecológico longitudinal de panel evaluó la asociación entre la cobertura vacunal y la incidencia de tos ferina, meningitis meningocócica, sarampión/rubéola y fiebre amarilla en las unidades federativas brasileñas entre 2007 y 2024. Se utilizaron datos secundarios del Sistema de Información de Agravios de Notificación (SINAN), del Sistema de Información del Programa Nacional de Inmunizaciones (SI-PNI) y estimaciones poblacionales del Instituto Brasileño de Geografía y Estadística (IBGE). La asociación entre cobertura vacunal e incidencia fue analizada mediante modelos de regresión de Poisson con efectos fijos por unidad federativa, utilizando un desfase temporal de un año entre exposición y desenlace, además de ajustes por tendencia temporal lineal y períodos epidemiológicos relacionados con la pandemia de COVID-19. Se analizaron 486 observaciones correspondientes a las 27 unidades federativas brasileñas. Se observó una asociación inversa estadísticamente significativa entre la cobertura vacunal y la incidencia de tos ferina (IRR=0,9892; IC95%: 0,9887–0,9896), meningitis meningocócica (IRR=0,9977; IC95%: 0,9968–0,9986), sarampión/rubéola (IRR=0,9866; IC95%: 0,9858–0,9875) y fiebre amarilla (IRR=0,9573; IC95%: 0,9541–0,9607), todos con p<0,001. Durante el período pandémico se observó una reducción significativa de la incidencia para todas las enfermedades analizadas. Los hallazgos refuerzan la importancia de mantener elevadas coberturas vacunales y fortalecer continuamente las acciones de inmunización y vigilancia epidemiológica para el control de enfermedades inmunoprevenibles en Brasil.

Palabras clave:
vacunación; cobertura vacunal; enfermedades inmunoprevenibles; epidemiología; salud pública; vigilancia epidemiológica.

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Introduction and Theoretical Framework

Immunization is recognized as one of the most effective public health strategies for preventing infectious diseases, reducing morbidity and mortality, and increasing life expectancy. In Brazil, the creation of the National Immunization Program (PNI) in 1973 allowed for the expansion of access to vaccines and contributed to the control, elimination, or significant reduction in the incidence of various vaccine-preventable diseases. Over the last few decades, the program has become one of the main public policies of the Unified Health System (SUS), achieving high vaccination coverage and producing a significant impact on child health indicators and communicable diseases. [8,15]

Despite the progress made, recent studies have shown a trend of declining vaccination coverage in Brazil, particularly since the 2010s. This phenomenon has been attributed to multiple factors, including difficulties in accessing health services, regional inequalities, operational problems related to information systems, decreased perception of the risk of vaccine-preventable diseases, and increased vaccine hesitancy.1 During the COVID-19 pandemic, this scenario worsened, with a significant reduction in vaccination coverage in different regions of the country, especially for immunobiologicals in the childhood immunization schedule.[7]

The decline in vaccination coverage has raised concerns due to the potential for the re-emergence of previously controlled diseases. Measles is a prime example of this process. After receiving certification from the Pan American Health Organization (PAHO) for the elimination of endemic circulation of the virus in 2016, Brazil again registered sustained transmission of the disease from 2018 onwards, culminating in the loss of measles elimination status in 2019, after endemic transmission persisted for more than 12 months. Factors associated with this scenario include reduced vaccination coverage and the formation of population pockets susceptible to infection. However, after implementing strategies to intensify epidemiological surveillance and recover vaccination coverage, the country regained PAHO certification for measles elimination in 2024, demonstrating the importance of maintaining high vaccination coverage and continuous surveillance for the sustainable control of the disease. [4,10]

Besides measles, other vaccine-preventable diseases continue to represent significant challenges for Brazilian epidemiological surveillance. Pertussis remains associated with periodic outbreaks and greater severity in young children, while meningococcal meningitis has high lethality and the potential for outbreaks. Yellow fever, on the other hand, has a distinct epidemiological dynamic, related to the sylvatic circulation of the virus, the presence of vectors,

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and environmental factors that influence its occurrence. Therefore, maintaining high vaccination coverage remains a fundamental strategy for reducing the risk of illness and controlling these diseases.11 [1]

The COVID-19 pandemic introduced further challenges to the interpretation of epidemiological indicators. In addition to the observed reduction in vaccination coverage, changes in access to health services, shifts in demand for care, reorganization of surveillance activities, and social distancing measures may have influenced the reporting of various communicable diseases. Consequently, it becomes relevant to evaluate not only the evolution of vaccination coverage but also its association with the incidence of diseases over time, considering the significant epidemiological transformations observed before, during, and after the COVID- 19 pandemic. ¹

Despite the wide availability of data from national health information systems, studies exploring the association between vaccination coverage and the incidence of vaccine-preventable diseases over time remain relevant, especially using analytical approaches capable of considering the longitudinal structure of the data and controlling for regional heterogeneities over time.

Given this scenario, the present study aimed to analyze the association between vaccination coverage and the incidence of pertussis, meningococcal meningitis, measles/rubella, and yellow fever using aggregated data from Brazilian federative units between 2007 and 2024.

Materials and Methods

Study design

This is a longitudinal ecological panel study based on secondary data aggregated by Brazilian federative unit (UF), covering the period from 2007 to 2024. The objective was to evaluate the association between vaccination coverage and the incidence of vaccine-preventable diseases in the country. The unit of analysis was composed of the combination of UF and calendar year.

Data source

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The data were obtained from public databases of the Ministry of Health, available through the Department of Informatics of the Unified Health System (DATASUS), using the TabNet system . The following databases were used:

- The Notifiable Diseases Information System (SINAN) is used to obtain confirmed cases of diseases.
- National Immunization Program Information System (SI-PNI), for vaccination coverage data;
- Intercensal population estimates from the Brazilian Institute of Geography and Statistics (IBGE), used to calculate rates and as the denominator in statistical models.
-

Population and study period

Data relating to all 27 Brazilian federative units were included for the period from 2007 to 2024.

The analyses for pertussis, meningococcal meningitis, and measles/rubella used the population under five years of age as the denominator, considering the predominantly pediatric epidemiological profile of these diseases and the fact that their respective immunization strategies are part of the routine childhood vaccination schedule. For yellow fever, the total population of the Brazilian federative units was used, due to the broader epidemiological pattern of the disease, associated with the wild circulation of the virus and population exposure in at-risk areas.

The models were adjusted using an offset term corresponding to the logarithm of the reference population, allowing for the estimation of incidence rates adjusted for population differences between the federative units and the periods analyzed.

Study variables

Dependent variables

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The following vaccine-preventable diseases were analyzed: Pertussis; Meningococcal meningitis; Measles/rubella (exanthematous diseases); Yellow fever . In the case of meningitis, only cases classified as meningococcal meningitis according to the final classification registered in SINAN were included. Measles and rubella data were analyzed in aggregate due to the availability of records in the information system, which groups exanthematous diseases, making consistent separation throughout the historical series impossible. Outcomes were considered in the form of an annual count of cases per federative unit.

Independent variables

The main explanatory variables were the annual vaccination coverage rates for the following vaccines in the national immunization schedule: Meningococcal C vaccine (associated with meningococcal meningitis); MMR vaccine (associated with measles and rubella); Yellow fever vaccine; and Pentavalent vaccine (associated with the prevention of pertussis). Regarding pertussis immunization, data from the tetravalent vaccine were used until 2011 and from the pentavalent vaccine from 2012 onwards, due to the replacement of the vaccine in the national immunization schedule.

Vaccination coverage was expressed as a percentage (%), according to the standardized calculation of the SI-PNI:

Vaccination coverage (%) = (Number of doses administered ÷ Target population) × 100

Data processing and standardization

The data were aggregated by federative unit of residence and calendar year. Intercensal population estimates from IBGE were used to standardize the analyses and calculate the rates. To account for possible delayed effects of vaccination coverage on disease incidence, vaccination coverage variables were constructed with a one-year time lag .

Furthermore, a categorical variable was created to represent distinct epidemiological periods:

- Period 1: 2007–2019 (pre -pandemic)
- Period 2: 2020–2022 (pandemic period)
- Period 3: 2023–2024 (post-pandemic period)

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This categorization was used to assess possible changes in case reporting and epidemiological dynamics during and after the COVID-19 pandemic.

Additionally, a continuous linear time trend variable was constructed, representing the chronological progression of the historical series, with the aim of controlling for secular trends independent of vaccination coverage.

The final structure of the databases consisted of panel data containing 486 observations (27 federative units × 18 years) for each disease analyzed.

Statistical analysis

Descriptive analyses were initially performed by calculating measures of central tendency and dispersion, as well as by constructing time series graphs for incidence and vaccination coverage.

The association between vaccination coverage and the incidence of diseases was evaluated using Poisson regression models with fixed effects for the federative unit, appropriate for longitudinal panel data with outcomes in counts. The logarithm of the reference population was included as an offset term to adjust for population differences between the units analyzed.

Vaccination coverage rates were incorporated into the models with a one-year time lag , considering the biological plausibility between vaccine exposure and the subsequent occurrence of health problems.

In addition to vaccination coverage, the models were adjusted for linear time trends and for epidemiological periods related to the COVID-19 pandemic, classified as pre -pandemic (2007–2019), pandemic (2020–2022), and post-pandemic (2023–2024).

The results were presented as incidence rate ratios (IRR) , accompanied by 95% confidence intervals. All analyses were performed using Stata software version 16.1, adopting a statistical significance level of 5%.

Ethical aspects

Because this study is based exclusively on aggregated, publicly available secondary data without individual identification, it is exempt from review by a Research Ethics Committee, in accordance with Resolution No. 510/2016 of the National Health Council.

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Limitations

This study has limitations inherent to its ecological design, not allowing causal inferences at the individual level and being subject to the possibility of ecological fallacy. Therefore, associations observed between vaccination coverage and the incidence of vaccine-preventable diseases should be interpreted within the population context and cannot be directly extrapolated to individuals.

Furthermore, the data used are derived from secondary health information systems, and are potentially subject to underreporting, registration inconsistencies, delays in updating databases, and differences in the quality of epidemiological surveillance between federative units and throughout the study period.

Vaccination coverage estimates from the National Immunization Program Information System (SI-PNI) may contain inaccuracies due to inconsistencies in population denominators, migration of individuals between municipalities for vaccination, and incomplete administrative records, which could result in coverage exceeding 100% in certain contexts.

Another limitation relates to the joint analysis of measles and rubella. Although both diseases share the same immunization strategy through the MMR vaccine, it was not possible to obtain standardized and comparable historical series that would allow for the consistent separation of cases throughout the entire period analyzed. Thus, the diseases were evaluated in aggregate, which may mask specific epidemiological differences between the two diseases.

In the case of pertussis, the historical series of vaccination coverage required the harmonization of data from different vaccines in the childhood immunization schedule, considering the use of the tetravalent vaccine in the years prior to the introduction of the pentavalent vaccine. Although this strategy allowed for the temporal continuity of the analysis, any operational differences between the immunobiologicals may partially influence the comparability of the estimates throughout the series.

Additionally, the epidemiological dynamics of yellow fever present distinct characteristics from the other diseases analyzed, since its occurrence depends not only on human vaccination coverage, but also on ecological, environmental, and entomological factors related to the sylvatic cycle of the virus. Therefore, vaccination coverage alone may not be sufficient to explain all the variability observed in the incidence of the disease.

Finally, the COVID-19 pandemic likely simultaneously impacted epidemiological surveillance systems, the demand for healthcare services, routine immunization activities, and the circulation of infectious agents, potentially influencing both case reporting and vaccination coverage indicators observed between 2020 and 2022. Although adjustments were made for different epidemiological periods, it is not possible to completely rule out the influence of this phenomenon on the results found.

Considerations regarding reproducibility

Replicating this study is feasible by accessing public databases made available by the Department of Informatics of the Unified Health System (DATASUS) and the Brazilian Institute of Geography and Statistics (IBGE), using the same data extraction, aggregation by federative unit and calendar year, and processing criteria adopted in this research.

All analytical steps were performed in a standardized manner, including obtaining case records and vaccination coverage, organizing the databases into a panel structure, incorporating population estimates, constructing vaccination coverage variables with a one-year time lag, defining epidemiological periods related to the COVID-19 pandemic, and applying Poisson regression models with fixed effects for the federative unit.

The analyses were conducted using Stata software version 16.1 and can be reproduced using the same methodological criteria and statistical parameters described in this study.

However, periodic updates to the DATASUS databases, retrospective reviews of records, and possible changes in information systems may result in small differences in the values observed in data collected at different times. Additionally, limitations inherent to epidemiological surveillance systems, such as underreporting, delays in data consolidation, and inconsistencies in registration, should be considered in the interpretation and reproduction of the results.

Results and discussion

A total of 486 observations corresponding to the 27 Brazilian federative units were analyzed for the period from 2007 to 2024. The database included annual records of pertussis, meningococcal meningitis, measles/rubella, and yellow fever incidence, as well as the respective vaccination coverage rates used in the analytical models.

Table 1 presents the descriptive characteristics of the variables analyzed. Significant heterogeneity was observed among the diseases in relation to the number of registered cases and vaccination coverage. The highest average number of cases was observed for

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measles/rubella (193.95 cases per federative unit-year), while yellow fever presented the lowest average (4.99 cases), with a median equal to zero, evidencing a high frequency of observations without records of the disease. Vaccination coverage also showed distinct behavior among the analyzed immunobiologicals, varying from an average of 57.55% for yellow fever to 95.03% for the MMR vaccine.

Time series analysis demonstrated significant variations in disease incidence throughout the study period. Generally, a progressive reduction in the incidence of some diseases was observed until the mid-2010s, followed by fluctuations in subsequent years. Between 2020 and 2022, the period corresponding to the COVID-19 pandemic, a marked reduction in reported cases of pertussis, meningococcal meningitis, and measles/rubella was observed, coinciding with a reduction in vaccination coverage in several states. After 2022, a gradual recovery in vaccination coverage and a partial return to previous incidence levels for some diseases were observed.

Table 1. Descriptive statistics of reported cases and vaccination coverage for vaccine-preventable diseases analyzed, Brazil, 2007–2024.

Variable	Aver-age	DP	Median	Mini-mum	Maxi-mum
Whooping cough cases	62.63	145.59	16.5	0	1,624
Pentavalent coverage (%)	85.54	19.64	90.13	6.05	140.25
Cases of meningitis meningococcal	14.26	45.91	3.0	0	572

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Meningococcal C coverage (%)	83.83	23.67	88.30	0.22	148.87
Measles/rubella cases	193.95	761.72	48.0	0	15,414
Triple viral coverage (%)	95.03	13.08	95.67	52.54	146.88
Cases of yellow fever	4.99	42.12	0.0	0	520
Yellow fever coverage (%)	57.55	36.48	68.92	0.05	132.73

The mean, standard deviation (SD), median, minimum and maximum values of reported cases and vaccination coverage for pertussis, meningococcal meningitis, measles/rubella, and yellow fever are presented. Data were aggregated by federative unit and calendar year. Vaccination coverage above 100% reflects discrepancies between population numerators and denominators estimated by the information systems.

In Poisson regression models with fixed effects for federative unit, adjusted for linear time trend and epidemiological periods related to the COVID-19 pandemic, a statistically significant inverse association was observed between vaccination coverage and pertussis incidence (Table 2).

Table 2. Association between vaccination coverage and incidence of vaccine-preventable diseases in Brazil according to Poisson regression models with fixed effects by federative unit, adjusted for temporal trend and pandemic period, 2007–2024.

Variable	**Whooping cough IRR (95% CI)**	**Meningococcal men-ingitis IRR (95% CI)**	**Measles/ rub Aeola IRR (95% CI)**	**Yellow fever IRR (95% CI)**

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Vaccination coverage (1 year lag)	0.9892 (0.9887–0.9896) ***	0.9977 (0.9968–0.9986)* **	0.9866 (0.9858–0.9875)***	0.9573 (0.9541–0.9607)***
Time trend (time)	1.0005 (0.9969–1.0041)	0.8724 (0.8606–0.8844)* **	1.0428 (1.0403–1.0452)***	1.8262 (1.7751–1.8789)***
Pandemic (2020–2022)	0.0674 (0.0615–0.0737) ***	0.5888 (0.5088–0.6815)* **	0.3116 (0.3031–0.3203)***	0.0031 (0.0021–0.0044)***
Post-pan-demic (2023–2024)	0.4594 (0.4342–0.4859) ***	1.4861 (1.2599–1.7528)* **	0.1447 (0.1387–0.1509)***	0.0005 (0.0003–0.0009)***

*** p < 0.001.

Poisson regression models with fixed effects per federative unit and offset corresponding to the population logarithm. Vaccination coverage was incorporated with a one-year time lag (lag 1). The models were adjusted for linear time trends and for epidemiological periods related to the COVID-19 pandemic. For pertussis, meningococcal meningitis, and measles/rubella, the population under 5 years of age was used; for yellow fever, the total population. IRR: Incidence Rate Ratio ; 95% CI: 95% confidence interval.

In Poisson regression models with fixed effects for federative unit, adjusted for linear time trend and epidemiological periods related to the COVID-19 pandemic, a statistically significant inverse association was observed between vaccination coverage and pertussis incidence (Table 2).

The increase in pertussis vaccination coverage in the previous year was associated with a reduction in the incidence of the disease (IRR=0.9892; 95% CI: 0.9887–0.9896; p<0.001). This result indicates that each one percentage point increase in vaccination coverage was associated with an approximate 1.1% reduction in the incidence of the disease. No significant independent temporal trend was observed after adjusting for the other variables in the model (IRR=1.0005; p=0.774). These findings suggest that the observed reduction in pertussis incidence over the historical series was more related to variations in vaccination coverage and changes that occurred during the pandemic period than to an independent secular temporal trend.

During the pandemic period (2020–2022), a significant reduction in the incidence of the disease was observed compared to the pre -pandemic period (IRR=0.0674; 95% CI: 0.0615–0.0737; p<0.001). In the post-pandemic period (2023–2024), a relative increase in incidence was observed (IRR=0.4594; 95% CI: 0.4342–0.4859; p<0.001), although the levels remained substantially lower than those observed before the pandemic.

The observed findings are consistent with current epidemiological knowledge about the disease. Although vaccine-induced immunity decreases over time, high vaccination coverage in the child population remains fundamental to reducing the circulation of Bordetella. pertussis and protect more vulnerable groups, especially infants who are not yet fully immunized. [5, 6] The inverse association observed in this study reinforces the importance of maintaining high vaccination coverage for the population control of pertussis.

Figure 1. Temporal trend of pertussis incidence and pertussis vaccination coverage in Brazil, 2007–2024.

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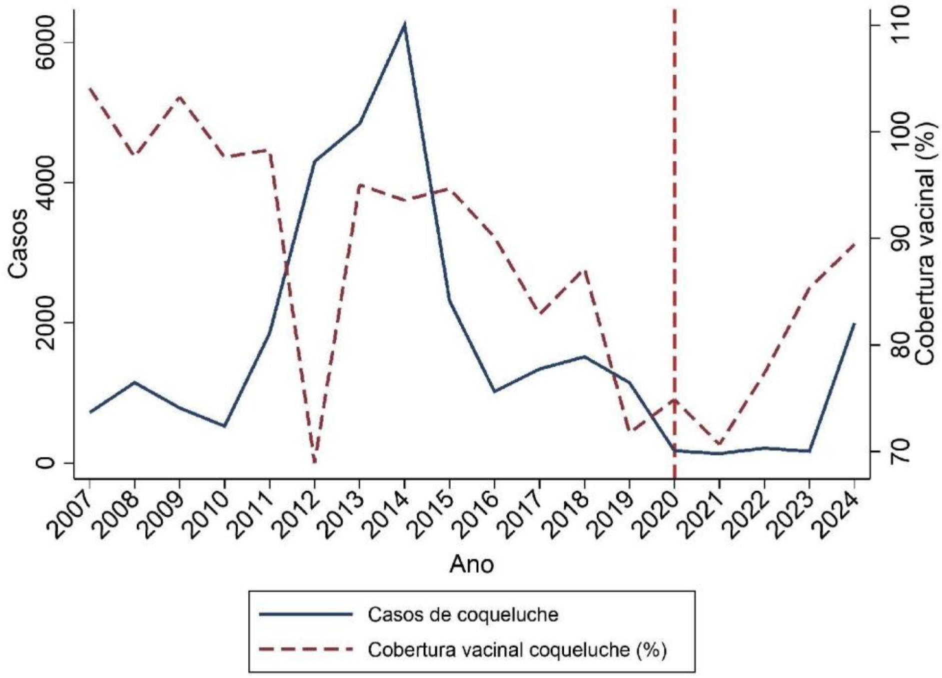

Annual evolution of reported cases of pertussis (left axis) and pertussis vaccination coverage (right axis). The dashed vertical line indicates the beginning of the COVID-19 pandemic (2020). Vaccination coverage was represented by the quadrivalent vaccine in the years prior to the introduction of the pentavalent vaccine and, subsequently, by pentavalent vaccine coverage.

A similar result was observed for meningococcal meningitis. Coverage of the meningococcal C vaccine in the previous year showed an inverse and statistically significant association with the incidence of the disease (IRR=0.9977; 95% CI: 0.9968–0.9986; p<0.001). This result indicates that each one percentage point increase in vaccination coverage was associated with an approximate 0.23% reduction in the incidence of meningococcal meningitis.

In addition to the observed association with vaccination coverage, an important independent temporal trend of reduced incidence was found throughout the historical series (IRR=0.872; 95% CI: 0.861–0.884; p<0.001), suggesting that additional factors related to epidemiological surveillance, herd immunity, and changes in the agent's circulation profile may have contributed to the decline in the disease during the study period.

During the pandemic period (2020–2022), the incidence remained significantly lower than that observed in the pre -pandemic period (IRR=0.589), while in the post- pandemic period (2023–2024) there was a relative increase in incidence (IRR=1.486), although without a return to the levels historically observed in the first decades of the series.

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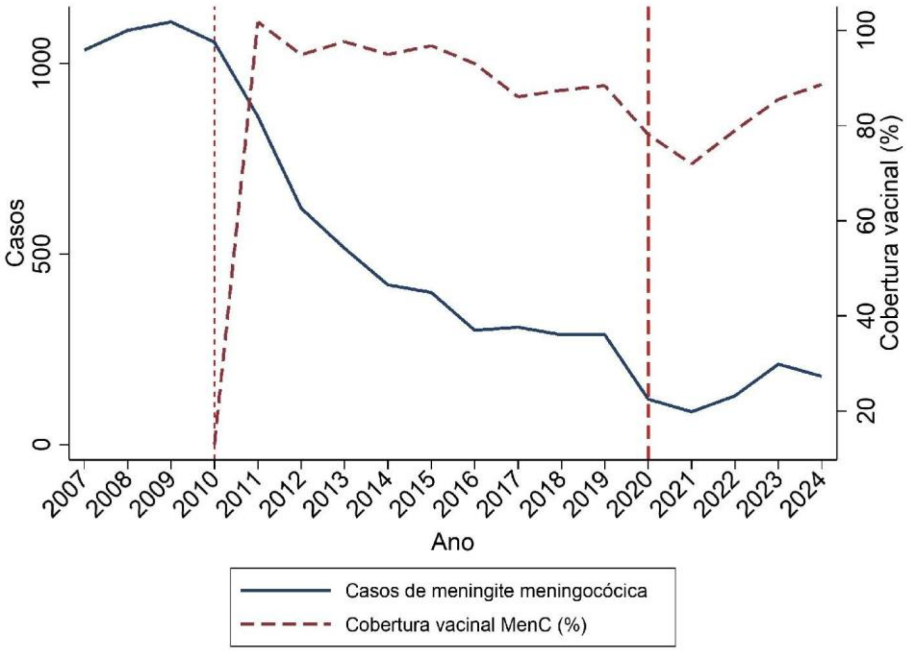
The results found are consistent with national and international evidence demonstrating the impact of meningococcal vaccination in reducing the disease burden. The sustained decrease in incidence observed over the time series suggests that expanding vaccination coverage contributed to the population control of meningococcal meningitis, reducing the circulation of the infectious agent and benefiting even unvaccinated individuals through indirect protection. This pattern can also be seen in Figure 2, which shows a consistent reduction in incidence after the introduction of the meningococcal C vaccine into the national immunization schedule. The observed behavior is consistent with the impact described after the introduction of meningococcal conjugate vaccines in several countries.1 [3]

Figure 2. Temporal trend of meningococcal meningitis incidence and meningococcal C vaccine coverage in Brazil, 2007–2024.



Annual evolution of reported cases of meningococcal meningitis (left axis) and meningococcal C vaccine coverage (right axis). The solid vertical line indicates the introduction of the meningococcal C vaccine into the National Immunization Schedule in 2010. The dashed vertical line indicates the beginning of the COVID-19 pandemic (2020).

For measles/rubella, a statistically significant inverse association was also observed between vaccination coverage and disease incidence. Increased coverage of the MMR vaccine in the previous year was associated with a reduction in the incidence of the disease (IRR=0.9866; 95% CI: 0.9858–0.9875; p<0.001), indicating that each one percentage point

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increase in vaccination coverage was associated with an approximate 1.3% reduction in incidence.

Furthermore, an independent temporal trend of increasing incidence was observed throughout the historical series (IRR=1.0428; 95% CI: 1.0403–1.0452; $p<0.001$). During the pandemic period (2020–2022), a significant reduction in reported cases was observed (IRR=0.3116; 95% CI: 0.3031–0.3203; $p<0.001$), while levels remained lower than those observed in the pre -pandemic period during the post-pandemic period (2023–2024) (IRR=0.1447; 95% CI: 0.1387–0.1509; $p<0.001$).

The observed association between higher vaccination coverage and lower incidence rates is particularly relevant due to the high transmissibility of these diseases. Small reductions in vaccination coverage can result in an increase in the number of susceptible individuals, favoring the occurrence of outbreaks and the reintroduction of viral circulation. The increasing temporal trend observed in the model is consistent with the episodes of measles resurgence recorded in Brazil after the loss of the disease elimination certificate, highlighting the vulnerability of the population in the face of sustained reductions in vaccination coverage. The results found reinforce the importance of maintaining homogeneous and high coverage over time, especially in light of recent episodes of viral reintroduction observed in Brazil and other countries in the Americas.[10,16]

MMR vaccine coverage in Brazil, 2007–2024.

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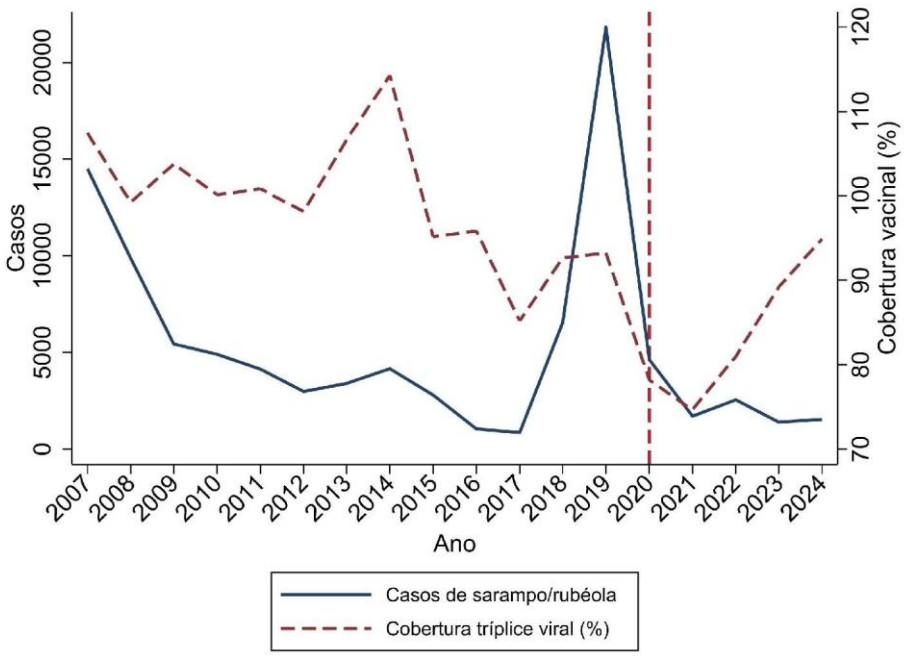

Annual evolution of reported cases of measles/rubella (left axis) and MMR vaccine coverage (right axis). A progressive reduction in vaccination coverage is observed throughout the time series, followed by a resurgence of incidence associated with episodes of reintroduction of measles virus circulation in the country. The dashed vertical line indicates the beginning of the COVID-19 pandemic (2020).

For yellow fever, a statistically significant inverse association was also observed between vaccination coverage and disease incidence. Increased vaccination coverage in the previous year was associated with a reduction in yellow fever incidence (IRR=0.9573; 95% CI: 0.9541–0.9607; p<0.001), indicating that each one percentage point increase in vaccination coverage was associated with an approximate 4.3% reduction in disease incidence.

A strong temporal trend of increasing incidence was also observed throughout the historical series (IRR=1.8262; 95% CI: 1.7751–1.8789; p<0.001). In contrast, a significant reduction in incidence was observed during the pandemic period (2020–2022) (IRR=0.0031; 95% CI: 0.0021–0.0044; p<0.001), maintaining extremely low levels also in the post-pandemic period (2023–2024) (IRR=0.0005; 95% CI: 0.0003–0.0009; p<0.001).

The interpretation of these results requires caution. Unlike the other diseases analyzed, the epidemiological dynamics of yellow fever are strongly influenced by ecological, environmental, and entomological factors, including viral circulation in non-human primates, the geographic distribution of vectors, and the occurrence of epizootics. Thus, the observed incidence does not depend exclusively on the vaccination coverage of the human population, but also on the natural dynamics of the sylvatic cycles of the disease.[3, 9]

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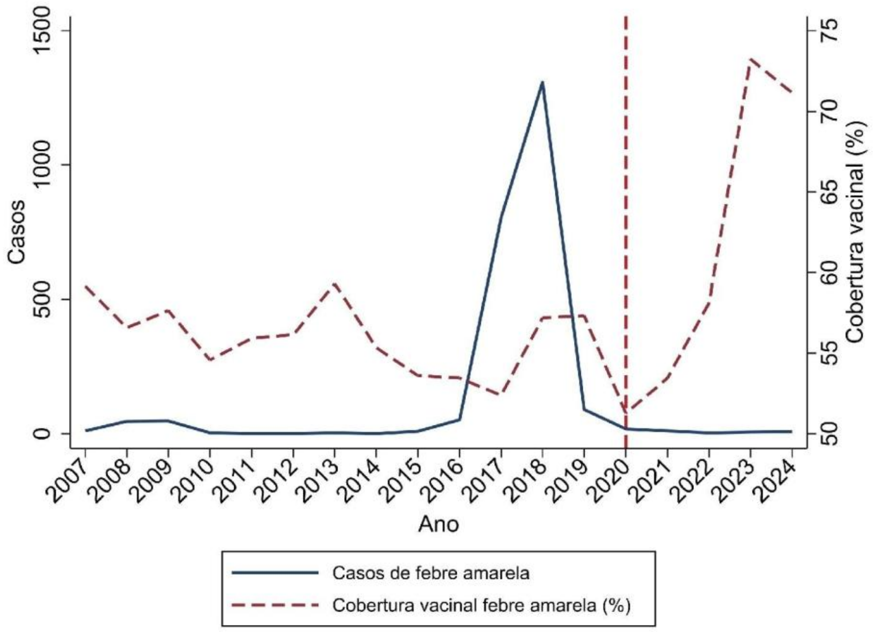
Additionally, 11 federative units were automatically excluded from the fixed effects model because they did not present any registered cases of yellow fever during the entire analyzed period. This finding highlights the heterogeneous spatial distribution of the disease in Brazilian territory and reinforces the need to interpret the results in light of its particular epidemiology. Even so, the inverse association observed suggests that maintaining high vaccination coverage remains fundamental to reducing the risk of outbreaks in susceptible areas.

Figure 4. Temporal trend of yellow fever incidence and yellow fever vaccination coverage in Brazil, 2007–2024.



Annual evolution of reported cases of yellow fever (left axis) and yellow fever vaccination coverage (right axis). Prolonged periods of low incidence are observed, interspersed with outbreaks concentrated in specific years, reflecting the episodic and spatially heterogeneous nature of the disease. The dashed vertical line indicates the beginning of the COVID-19 pandemic (2020).

Another relevant aspect concerns the impact of the COVID-19 pandemic on the analyzed indicators. In all diseases evaluated, a significant reduction in incidence was observed during the pandemic period, even with the concomitant drop in vaccination coverage. This pattern suggests that factors external to the usual dynamics of the diseases may have influenced the observed results. Social distancing measures, reduced population mobility, changes in the search for medical care, alterations in the circulation of infectious agents, and possible

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modifications in epidemiological surveillance processes likely contributed to the decrease in the notification of communicable diseases during this pandemic period.[2 ,1 4] Thus , the results for the years 2020 to 2022 should be interpreted considering this exceptional epidemiological context.

Overall, the analyses demonstrated an inverse association between vaccination coverage and incidence for all diseases evaluated, even after adjusting for temporal trends and epidemiological periods related to the pandemic. The results reinforce the importance of maintaining high vaccination coverage for the control of vaccine-preventable diseases and

These results highlight the influence of large-scale population events, such as the COVID-19 pandemic, on health surveillance indicators. The complete results of the regression models are presented in Table 2.

Conclusion

This study demonstrated that higher vaccination coverage was associated with a lower incidence of vaccine-preventable diseases in Brazil between 2007 and 2024, reinforcing the relevance of immunization programs as a fundamental strategy for protecting public health.

The findings show that the reduction in vaccination coverage observed in recent years represents a real risk for the re-emergence of previously controlled diseases, highlighting the need to strengthen routine vaccination programs, epidemiological surveillance, and strategies aimed at expanding access to and adherence to vaccines.

In addition to its impact on public health practice, the study demonstrates the usefulness of national information systems for monitoring epidemiological trends and for evaluating large-scale immunization policies. Maintaining high and homogeneous vaccination coverage remains one of the main challenges and, at the same time, one of the most effective measures for preventing vaccine-preventable diseases in the country.

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