

Review

Pertussis – contemporary epidemiological challenges

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ABSTRACT

OBJECTIVE: To present the current epidemiological challenges associated with pertussis and to analyse the factors responsible for the global and national increase in incidence, with particular emphasis on waning vaccine-induced immunity, shifts in the age profile of patients, diagnostic problems, and the impact of the COVID-19 pandemic.

SUBJECT AND METHODS: A structured narrative review was conducted. PubMed and Scopus were the principal bibliographic databases; ScienceDirect and Google Scholar were used as supplementary sources. The search was completed on 13 July 2026. One reviewer selected the evidence, and no formal risk-of-bias assessment was performed. Polish surveillance data were reanalysed using official annual surveillance bulletins.

RESULTS: The observed increase in pertussis incidence is multifactorial in nature. Key causes include: the gradual waning of post-vaccination immunity, a shift in the patient age profile towards adolescents and adults, underdiagnosis of atypical infections, and the genetic and antigenic evolution of the pathogen. Non-pharmaceutical interventions during the COVID-19 pandemic temporarily reduced bacterial transmission; however, following their lifting, a sharp increase in the number of notifications was recorded. The assessment of the true scale of the problem is also significantly influenced by changes in surveillance systems and improved availability of diagnostic methods.

CONCLUSIONS: Effective control of pertussis requires maintaining high population vaccination coverage, implementing prenatal vaccination strategies, and administering regular booster doses. It is essential to optimise laboratory diagnostics, continuously monitor the genetic changes of *Bordetella pertussis*, and conduct further research to improve epidemiological surveillance programmes.

KEYWORDS

whooping cough, *Bordetella pertussis*, disease outbreaks, vaccination, epidemiological monitoring

Introduction

Pertussis is a respiratory tract infection caused mainly by *Bordetella pertussis* (*B. pertussis*) and remains difficult to control despite long-standing vaccination programmes. Although widespread immunisation programmes led to a radical decline in incidence in the mid-20th century, the last two decades have brought a concerning phenomenon of the re-emergence of this disease in countries with high vaccination coverage [1]. This problem affects both Poland and other European countries, where cyclical increases in incidence are observed. The contemporary epidemiological situation of pertussis is characterised by a significant change in the distribution of

cases across age groups. Traditionally perceived as a childhood disease, pertussis increasingly affects adolescents and adults. In older patient groups, the infection often takes atypical or paucisymptomatic forms, which contributes to the underdiagnosis of cases and the unwitting transmission of the pathogen to the highest-risk groups - infants and young children. It is among the youngest, incompletely vaccinated patients that the disease still generates the highest rates of hospitalisation, severe complications, and deaths. The reasons for the resurgence of pertussis are multifactorial and provoke extensive scientific debate. Key hypotheses mentioned include, inter alia, waning vaccine-induced immunity, shifts in the age structure of patients, insufficient administration of booster doses, as well as the genetic evolution of *B. pertussis*, encompassing antigenic changes and the loss of pertactin expression. The COVID-19 pandemic exerted a particular impact on the epidemiology of pertussis. During the period of sanitary restrictions, the number of reported cases dropped significantly, presumably as a result of reduced droplet transmission of infections. However, following the lifting of restrictions, a rapid increase in incidence was recorded in many countries, which could have resulted from both the resurgence of transmission in the population and changes in surveillance and diagnostic systems. This increase has highlighted the need to reassess the efficacy of current prophylactic strategies and to monitor epidemiological changes across various age groups. This paper constitutes a review of current knowledge regarding the challenges facing modern diagnostics and epidemiological surveillance systems, as well as an analysis of current incidence trends globally, in Europe, and in Poland. Special attention will be paid to the waning of post-vaccination immunity, shifts in the age profile of affected individuals, the issue of under-reporting, mutations and antigenic changes in *B. pertussis*, alongside the impact of the COVID-19 pandemic on the transmission and surveillance of this disease. The analysis of these aspects is essential for the optimisation of vaccination strategies and more effective protection of the population against the transmission of *B. pertussis*. This structured narrative review adds to recent reviews by comparing the type and strength of evidence for these competing explanations and by providing a reproducible reanalysis of Polish surveillance data. The review focuses on the extent to which each proposed mechanism is supported, its principal limitations, and its relevance to prevention and surveillance in Poland.

Methods

This study was designed as a structured narrative review. It was not intended to estimate a pooled effect or to meet the requirements of a systematic or scoping review. Its objectives were to appraise evidence for the principal explanations of the recent increase in pertussis notifications and to place Polish surveillance trends in an international context.

Data sources and search strategy

PubMed and Scopus were treated as the principal bibliographic databases. ScienceDirect, a publisher platform, and Google Scholar were used to identify additional papers and institutional material. Official surveillance reports and guidance were obtained from WHO, ECDC, CDC, PAHO, the National Institute of Public Health (NIH), -National Research Institute (NIPH NIH-NRI), and the Chief Sanitary Inspectorate (CSI). Searches covered material available up to 20 April 2026.

The PubMed search combined: (pertussis[Title/Abstract] OR "*Bordetella pertussis*"[Title/Abstract] OR "whooping cough"[Title/Abstract]) AND (epidemiolog* OR resurgence OR surveillance OR vaccination OR "waning immunity" OR diagnos* OR COVID-19 OR "acellular vaccine" OR "whole-cell vaccine"). The corresponding Scopus search was: TITLE-ABS-KEY(pertussis OR "*Bordetella pertussis*" OR "whooping cough") AND TITLE-ABS-KEY(epidemiolog* OR resurgence OR surveillance OR vaccination OR "waning immunity" OR diagnos* OR COVID-19 OR "acellular vaccine" OR "whole-cell vaccine"). ScienceDirect and Google Scholar were searched with shorter combinations of the same concepts because their search interfaces differ and Google Scholar is not fully reproducible.

Eligibility and selection

Eligible material comprised peer-reviewed human studies, evidence reviews, molecular or experimental studies relevant to pathogen adaptation, and reports or guidance issued by public-health institutions. Sources had to address pertussis epidemiology, vaccination, diagnosis, surveillance, pathogen evolution, or changes associated with the COVID-19 period. Publications from 2016–2026 were prioritised; older landmark studies were retained when they addressed vaccine effectiveness or diagnostic principles not adequately covered by newer work. English-language sources and Polish-language national reports were eligible. Duplicates, records unrelated to human pertussis, and sources without information relevant to the review questions were excluded. Full-text availability was not used as an independent eligibility criterion. One reviewer screened and selected the material.

Evidence synthesis and appraisal

Evidence was organised thematically by proposed driver: waning immunity and vaccine performance; coverage across primary, booster, adult, and maternal programmes; diagnostic and surveillance effects; pathogen evolution; and disruption associated with the COVID-19 period. No formal risk-of-bias tool was applied. Interpretation prioritised official surveillance reports, systematic reviews, population-based studies, and findings replicated across settings. Single-centre studies and mechanistic or molecular studies were used to support narrower claims appropriate to their designs.

Poland-specific analysis

Annual voivodeship-specific notification rates for 2017–2019, 2022, and 2023 were extracted from national analyses published by Rumik et al. [2,3] and Rumik and Paradowska-Stankiewicz [4]. The versions available on 20 April 2026 were used; later revisions were not modelled separately. The 2017–2019 median was selected as the primary pre-pandemic reference, but the three-year arithmetic mean was also calculated as a sensitivity analysis because a median based on three annual observations is only the middle value and may conceal cyclical variation.

For each comparison, percentage change was calculated as $[(2023 \text{ notification rate} - \text{reference notification rate}) / \text{reference notification rate}] \times 100$. Source notification rates were retained to two decimal places, and percentage changes were calculated from those displayed values and rounded to two decimal places. The 2022–2023 comparison describes a change in notifications from an exceptionally low post-pandemic year and should not be interpreted as an equivalent change in the true incidence of infection.

Review limitations

This review has several limitations. Study designs, populations, vaccine products and schedules, case definitions, testing practices, and surveillance systems differed substantially. One reviewer selected the evidence, and no formal risk-of-bias assessment was performed. Most evidence concerning the recent resurgence is observational, molecular, or surveillance-based and cannot quantify the causal contribution of each proposed mechanism. Mild disease in adolescents and adults is frequently underdiagnosed, and pandemic-related changes in contact patterns, healthcare access, testing, and reporting limit comparisons across periods. The Poland-specific analysis is descriptive and uses only three pre-pandemic years; its sensitivity to the reference measure is therefore reported explicitly.

Contemporary epidemiological challenges

Waning of post-vaccination immunity

One of the principal limitations of pertussis vaccination, simultaneously constituting a significant epidemiological challenge, is the gradual waning of vaccine-induced immunity. Estimating vaccine-induced immunity is often difficult because vaccine efficacy (primary vaccine failure) and the waning of immunity (secondary vaccine failure) are interrelated and potentially depend on the diversity of vaccination strategies employed in different countries [5]. In an observational clinical study, Gustafsson et al. [6] reported an increased incidence of pertussis among 7/8-year-olds, suggesting that protection wanes approximately 5–7 years after 3 doses of the aP vaccine in infancy. The results of a cohort study by Klein et al. [7] demonstrated that protection diminishes over a 5-year period following the fifth dose of the DTaP vaccine, i.e., at 5–6 years of age, and

incidence rates and the risk of pertussis significantly increased at 6 years of age. This increase is likely partly due to waning immunity after DTaP vaccines, as the decline occurs prior to the booster dose recommended for adolescents aged 11–12 years [8]. Similar conclusions were reached by the authors of a meta-analysis on the duration of immunity after DTaP vaccination [9,10]. However, no significant difference was found in the duration of protective immunity between a childhood vaccination series consisting of 3 and 5 DTaP doses. It is estimated that the average duration of protection following DTaP vaccination is 3–4 years, and 8.5 years after the last dose, merely 10% of children retain immunity. Given that considerable variation in antigen content has been observed across different wP vaccines, it is difficult to directly compare their complex immunogenicity. The most drastic decline in vaccine effectiveness was noted in the data of Chen and He [5], amounting to a drop from approximately 75% to approximately 34% within 2 years following a 3p schedule, which was most likely due to lower efficacy elicited by a specific vaccine named Connaught. In other studies, however, a minor decline in vaccine efficacy was demonstrated, and good protection was found in children up to 5 years of age [11,12,13,14]. Certain observational studies in the United Kingdom have demonstrated high efficacy (ranging from 70% to 90%) even after 10 years [14,15]. Although most of the aforementioned studies are relatively old, have limitations, and some were conducted in high-income countries where whole-cell pertussis vaccines are no longer used, the data are consistent with diminishing protection over time since wP vaccination. Nonetheless, the true rate of decline in vaccination efficacy remains unclear.

Shifts in the age profile of incidence, under-reporting, and diagnostics

Pertussis was long considered a childhood disease, but substantial evidence has been presented that it also affects teenagers, adults, and the elderly [16]. The actual burden of pertussis in older age groups is likely underestimated, partly because of underdiagnosis, misdiagnosis, and lower symptom severity compared with infants, which may reduce the likelihood of seeking medical care. Tian et al. [17] reported an increase in the proportion of pertussis cases among children aged 4 to 6 years (from 4.9% to 28.6%) and 7 to 11 years (from 0.7% to 21.2%) between 2019 and 2024. However, these findings were derived from a hospital-based study conducted at a single tertiary-care center and therefore should not be interpreted as representative of age-specific incidence trends in the general population. The observed changes in the age distribution of reported cases may reflect several interacting factors, including waning of vaccine-induced immunity, changes in vaccination strategies and booster coverage, as well as differences in case detection and surveillance [18]. Although additional mechanisms, including pathogen adaptation to vaccine-induced immune pressure and the effects of reduced exposure to infectious agents during periods

of non-pharmaceutical interventions, have also been proposed, the available evidence does not allow the relative contribution of these factors to the recent increase in pertussis incidence to be quantified. The burden of pertussis in adults is likely still underestimated. This largely stems from the fact that this disease is often routinely associated exclusively with childhood, leading medical personnel to rarely suspect it in the adult population. The consequence of this is widespread under-recognition, limited diagnostics, and a low rate of case reporting in this age group. The latter may be caused by a lack of standardised testing guidelines. Systemic changes in the pertussis diagnostic process, aimed at incorporating pertussis testing into multiplex molecular respiratory panels, could increase the frequency of pertussis testing. Targeted pertussis awareness campaigns, aimed at the rapid identification of patients with suspected disease, would also be helpful.

Mutations and antigenic changes of B. pertussis

The resurgence of pertussis incidence may also be associated with genetic mutations in the *B. pertussis* bacterium, with strain variants having been detected in many countries worldwide. Key mutations involve a change in the pertussis toxin (PT) promoter genotype ptxP from the ptxP1 allele to the ptxP3 allele, which has been shown to increase toxin production and enhance the bacterium's ability to colonise the respiratory tract. Furthermore, polymorphisms in the coding sequence for the A subunit in the PT gene are suspected to be linked to immune evasion. Alterations or deletions in the pertactin (PRN) gene are recognised as a significant factor associated with the resurgence of pertussis, while the loss of filamentous haemagglutinin (FHA) occurs much less frequently and is less well documented epidemiologically. Additionally, on a small global scale, mutations in antibiotic resistance genes may be of significance [19]. Ma et al. [20] observed that pertactin-deficient *B. pertussis* strains are increasingly reported in countries utilising acellular vaccines (aP), and in some nations, such as the United States, Australia, Sweden, and Italy, they have become dominant. This phenomenon exhibits a strong correlation with the use of PRN-containing aP vaccines, whereas in countries where whole-cell vaccines (wP) still dominate, PRN-deficient strains are much less common. The diversity of mutations leading to the loss of PRN expression, arising independently in multiple bacterial lineages, suggests the operation of selective pressure associated with vaccination. Experimental studies have demonstrated that PRN-deficient strains possess a colonisation advantage in aP-vaccinated hosts, despite a reduced colonisation capacity in unvaccinated individuals. Collectively, these observations support the hypothesis that the loss of PRN enhances the evolutionary fitness of *B. pertussis* in populations covered by aP vaccinations.

Organisational and social challenges

Besides *B. pertussis*, other species of the *Bordetella* genus, in particular *Bordetella parapertussis* and *Bordetella holmesii* (*B. holmesii*), are also associated with the occurrence of pertussis-like syndromes in humans [21]. In recent years, an increasingly frequent detection of these microorganisms in the human population has been observed. Some researchers suggest that the incorrect identification of non-*B. pertussis* species as classical pertussis may have been a confounding factor in epidemiological data [22,23]. This phenomenon may partially stem from diagnostic limitations [24]. The IS481 sequence, commonly used in standard PCR tests to diagnose pertussis, is present in the genomes of both *B. pertussis* and *B. holmesii*. Consequently, misclassification of infections may occur, and the lack of routine differentiation of *Bordetella* species can lead to an overestimation of pertussis diagnoses and an apparent increase in its incidence. Moreover, factors potentially favouring the occurrence of pertussis epidemics include increasing disease detection resulting from improved diagnostic tools and clinical awareness, as well as insufficient vaccination coverage in certain parts of the world, such as the West and Central Africa region, where these rates are significantly lower compared to other regions [25]. In regions where prenatal vaccinations have been recommended, data concerning the maternal vaccination rate are limited. Only nine countries reported prenatal vaccination rates in 2023, which ranged widely from 1.6% to 88.5% [26]. An excessively low vaccination rate in some regions where they are recommended can likely be explained multifactorially. A significant role is played by the limited awareness among prospective parents regarding the risk of newborns contracting pertussis and the protective benefits derived from vaccinating pregnant women. Furthermore, in some countries, the COVID-19 pandemic, in addition to reducing the number of prophylactic visits and affecting healthcare organisation, also meant that the implementation of vaccination programmes against this disease contributed to an increase in the number of doubts and enquiries concerning the safety and rationale of vaccines recommended during pregnancy [27].

The impact of the COVID-19 pandemic on pertussis surveillance and transmission

As indicated by the European Centre for Disease Prevention and Control, during the COVID-19 pandemic, the number of pertussis cases in many countries fell significantly [26]. This was likely the result of employing non-pharmaceutical methods to curb COVID-19 transmission, such as mask-wearing, maintaining social distancing, and isolation. During the pandemic in Europe, no infant deaths caused by pertussis were recorded. Simultaneously, isolated deaths associated with this disease were reported among the elderly, most frequently burdened with comorbidities, e.g., asthma, chronic obstructive pulmonary disease, or immunosuppression. It has yet to be established whether SARS-CoV-2 infection could have exacerbated the course of pertussis during

co-infection, particularly in seniors. Following the lifting of restrictions in force during the pandemic, the number of pertussis cases remained low for some time, even though other respiratory tract infections, particularly those caused by the RSV virus, surged rapidly, leading to the first post-COVID-19 wave of hospitalisations. The situation, however, changed dramatically in the second half of 2023, when a very large increase in pertussis cases was recorded in Europe, with record incidence rates in Denmark, where the number of cases in november 2023 exceeded 330 per 100 000 inhabitants [28]. Conversely, the Czech Republic recorded its largest pertussis epidemic in over 60 years [29]. Significant increases in the number of infections also emerged outside Europe, including in China [30]. To date, it has not been possible to unequivocally explain the causes of the rapid surge in the number of pertussis cases. The COVID-19 pandemic did not cause a substantial reduction in primary vaccination coverage levels, at least in Europe, where coverage with three primary doses remained high, although it declined from 97% in 2012 to 94% in 2022 [31]. However, high primary-series coverage does not exclude gaps in booster, adolescent, adult, or maternal vaccination coverage, as well as regional differences in vaccination uptake. Therefore, insufficient primary-series vaccination coverage alone is unlikely to fully explain the current increase in case numbers.

Epidemiology of pertussis worldwide

Global data

According to the position of the Centers for Disease Control and Prevention (CDC), pertussis is a significant cause of death among unvaccinated or incompletely vaccinated infants and young children. Despite a fairly high vaccination rate, a sustained decline in it is being observed, largely caused by the COVID-19 pandemic [32,33]. Studies from Europe, the United States, Brazil, Chile, Peru, and China point to the cyclical nature of pertussis incidence; however, it is not universal. The length of the cycles (usually every 3–5 years) varies between countries and has been disrupted by the pandemic, which may result in a greater intensification of subsequent waves [19]. Pertussis, as an upper respiratory tract disease, is subject to the influence of seasonal changes. Studies conducted in China, Vietnam, the United States, Australia, and Germany have shown cyclical, higher incidence rates during the summer and spring periods; however, since the introduction of the vaccine, the seasonality of pertussis in many countries, including Germany, has been weakly marked or absent [19,34]. In 2024, according to data from the World Health Organization (WHO), 941 893 pertussis cases were reported globally compared with 163 400 cases in 2023. Thus, 5.8 times as many cases were reported in 2024 as in 2023, corresponding to an approximately 476% increase in the number of reported cases [35].

It must be emphasised, however, that these data are based on notification rates, and the observed increase may largely result from the recovery of post-pandemic epidemiological surveillance and increased testing intensity, rather than exclusively from an increase in the true number of cases. Since 2023, a clear increase in the number of reported pertussis cases has been observed globally, being particularly evident in Europe [35]. In high-income countries such as the United Kingdom, the Czech Republic, France, Denmark, the United States, and Australia, significant outbreaks of the disease have been recorded, with the number of cases in some of them returning to ranges observed pre-pandemic, which were characterised by considerable inter-annual variability. Similar post-COVID-19 phenomena have also been observed in middle- and low-income countries, including Afghanistan, Bolivia, China, Ecuador, Indonesia, Malaysia, Papua New Guinea, Russia, and Serbia [19].

Epidemiology in North and South American countries

The United States swiftly returned to pre-pandemic patterns, when approximately 10,000 pertussis cases were registered annually. In 2024, the number of cases rose nearly sixfold compared to the previous year and clearly exceeded the level observed in 2019. In 2025, preliminary surveillance data indicated that reported case numbers remained elevated compared with the pre-pandemic period, although a downward trend had been observed since the peak in November 2024 [33]. The seasonality of pertussis is weakly marked; nevertheless, in many observations, an increased number of cases is noted during the summer-autumn period. The highest risk of contracting the disease and its most severe course concern infants under 1 year of age, as both the highest incidence and the highest mortality rate are recorded in this group [35]. On 31 May 2025, PAHO published an epidemiological alert regarding the rise in pertussis incidence in the Americas region. In the early months of 2025, a clear increase in the number of pertussis cases was noted in many North and South American countries. However, the available data covered only part of the year; for the United States, the data presented in the alert covered epidemiological weeks 1-18 of 2025 and were therefore not directly comparable with complete annual data from previous years [33]. The available country data are summarised in Table I.

Table I. Pertussis cases and deaths reported in selected countries in the Americas during early 2025 (based on [33])

Country	Reporting period	Confirmed/reported cases	Deaths
Brazil	EW 1-19	1 634	5
Colombia	EW 1-18	318	2
Ecuador	EW 1-19	593	15

Mexico	EW 1-19	943	51
Paraguay	EW 1-19	37	2
Peru	EW 1-19	404	13
United States	EW 1-18	10 062*	5

EW – epidemiological week

*Data are based on the PAHO epidemiological alert published on 31 May 2025 and cover epidemiological weeks 1-19, except for the Colombia and United States, for which data cover epidemiological weeks 1-18. The reported case numbers are preliminary/provisional and may be subject to subsequent revision.

Epidemiology in European countries

According to the Annual Epidemiological Report for 2023 published on the European Centre for Disease Prevention and Control (ECDC) website, a total of 26 033 pertussis cases were reported across 29 EU/EEA countries in 2023. Among these nations, Denmark, Croatia, the Netherlands, and Austria accounted for 64% of all reported cases, of which Denmark and Croatia were responsible for over 40% of all notifications.

The number of reported cases and incidence rates in selected years are presented in Table II. The reported incidence in 2023 was distinctly higher than in 2021–2022, when fewer than 1 case per 100 000 inhabitants was noted; however, the interpretation of this difference requires caution. During the COVID-19 pandemic, there may have been limited detection and reporting of pertussis in connection with changes in the functioning of epidemiological surveillance systems, reduced social contacts, and a lower number of diagnostic tests performed. Despite these limitations, 2023 was among the years with the highest pertussis notification rates in the last five years with the highest rate recorded in 2019. Out of 27 countries reporting individual data, a higher proportion of cases involved the population under 18 years of age than adults in 17 countries. Conversely, in eight countries, cases predominantly occurred in the ≥ 18 years group, including the Czech Republic (62%), Germany (68%), Greece (78%), Latvia (64%), Malta (100%; a total of 4 cases), Norway (53%), Slovakia (77%), and Sweden (56%) [36]. In EU/EEA countries, infants continue to account for the highest percentage of hospitalisations and deaths. In 2023, 10 fatalities were recorded, five among infants under 1 year of age and five among individuals over 75 years of age. In the first quarter of 2024, a clear increase in new cases exceeding 32 000 could be observed [37]. Evaluating the course of incidence from 2019 to 2023, a decline in the number of cases was noted as early as March–April 2020 and remained at a very low level until 2022. In 2023, a low level of incidence was also observed in the first months of the year; however, from May onwards, the number of cases began to gradually rise, reaching peak values in November and December. The collected data also allowed for the assessment of the age of individuals infected with *B. pertussis*.

Over half of the cases, as much as 52%, constituted individuals over 14 years of age, of which 31% were individuals aged 30 and over, and 21% were individuals in the 15–29 age bracket. The highest incidence was recorded in the 10–14 years group (34.1 per 100 000 inhabitants), followed by infants under 1 year of age (33.4 per 100 000 inhabitants). This was the first situation since 2010 where the highest incidence rate occurred in a group other than infants, although the difference between these groups was slight. Despite such a significant number of cases, only 10 fatalities were recorded, five in the under-one age group and five in individuals over 75 years of age [26,37].

Table II. Reported pertussis cases and incidence rates in EU/EEA countries in 2019–2023 (based on [26,38,39])

Period	Reported cases	Incidence rate per 100 000
2019	34 468	9.0
2021	1 578	0.4
2022	2 623	0.7
2023	26 033	6.7

National data

Following a period of very low incidence during the COVID-19 pandemic years, a sudden, rapid resurgence in the number of pertussis cases is being observed in Poland. According to data from the National Institute of Public Health – National Institute of Hygiene, in the period from 1 January to 31 December 2024, 32 656 individuals contracted pertussis, representing almost 35 times more cases than in the previous year. It should be borne in mind, however, that data from the years immediately following the COVID-19 pandemic might have been partially underestimated due to limited detection and reporting of cases, which can affect the scale of the observed increase [40]. Since 2010, a decline in mandatory vaccination coverage was observed, linked, among other things, to growing distrust towards vaccinations. The negative consequences of these phenomena may only become apparent after some time, leading to an increased risk of the resurgence of infectious diseases previously considered well-controlled. Similar trends are also being observed in other European region countries. Furthermore, in 2023 in Poland, according to the NIH, 922 cases were registered, representing 149% more than the previous year [41]. To further assess the regional dynamics of the resurgence, the published data reported by Rumik and Paradowska-Stankiewicz [4] were reanalysed. Annual incidence data for 2017–2019 were used to calculate the median pre-pandemic incidence for each voivodeship. The median of the 2017–2019 incidence was used as a descriptive pre-pandemic reference measure to summarize the incidence observed during the three consecutive years preceding the COVID-19 pandemic. Annual incidence data for

2017–2019 were obtained from the cited publications [2,3] and used as reported. No additional corrections or modifications to the reported surveillance data were made by the authors. The percentage change in incidence was calculated for 2023 compared with both 2022 and the median incidence for 2017–2019, using the formula: % change = [(incidence in 2023 - incidence in the reference period) / incidence in the reference period] × 100. Annual incidence data for 2017–2019, together with the calculated median for each voivodeship, are presented in Table III. In 2023, the incidence of pertussis exceeded the median incidence for 2017–2019 in only three voivodeships. In contrast, all voivodeships experienced an increase in incidence between 2022 and 2023, although the magnitude of this increase varied considerably (Table IV). At the national level, incidence increased from 0.98 per 100 000 inhabitants in 2022 to 2.45 per 100 000 in 2023, corresponding to a 150% increase. However, this change should be interpreted cautiously, as 2022 was characterized by exceptionally low reported incidence following the COVID-19 pandemic and therefore represents a low baseline for comparison. Nevertheless, the 2023 incidence remained below the pre-pandemic median (Table IV). Overall, the 2023 increase represented a substantial resurgence compared with 2022, but incidence remained below pre-pandemic levels in most voivodeships [7]. Individuals over 15 years of age constituted over 55% of all cases; however, the highest incidence continued to be maintained in the 0–4 years age group. In 2023, 350 individuals were hospitalized due to pertussis; however, according to data from ZLK-5 forms, no deaths were recorded. The comparison with the 2017–2019 median should, however, be interpreted with caution due to the natural cyclicity of pertussis and variability between individual epidemic seasons. Analysis of the age structure indicates that the highest incidence rates still pertain to children aged 0–4 years, despite an increase in the number of cases also among older children, adolescents, and adults. It is necessary here to distinguish the percentage share of cases in individual age groups from the incidence rates, as these indicators describe different aspects of the epidemiological situation [7,41].

Table III. Annual pertussis incidence per 100 000 inhabitants in Poland by voivodeship in 2017–2019 and median incidence for 2017–2019

Voivodeship	2017	2018	2019	Median 2017–2019
Poland	7,97	4,03	4,24	4,24
1. Dolnośląskie	4,03	3,96	2,10	3,96
2. Kujawsko-Pomorskie	15,89	7,60	3,37	7,60

3. Lubelskie	3,71	1,04	1,70	1,70
4. Lubuskie	2,07	4,14	1,58	2,07
5. Łódzkie	21,21	12,67	8,86	12,67
6. Małopolskie	12,52	4,12	7,69	7,69
7. Mazowieckie	9,14	4,10	3,70	4,10
8. Opolskie	4,14	1,21	2,13	2,13
9. Podkarpackie	2,87	1,08	1,88	1,88
10. Podlaskie	8,02	5,07	9,92	8,02
11. Pomorskie	10,09	3,35	6,72	6,72
12. Śląskie	5,01	3,11	3,05	3,11
13. Świętokrzyskie	3,92	1,77	2,18	2,18
14. Warmińsko-Mazurskie	3,07	0,91	2,59	2,59
15. Wielkopolskie	7,37	3,70	4,38	4,38
16. Zachodnio-pomorskie	3,69	3,46	4,47	3,69

Voivodeship-specific incidence data for 2017 were obtained from Rumik et al. [2], data for 2018 and 2019 were obtained from Rumik et al. [3]. The median incidence for 2017–2019 was calculated by the authors for each voivodeship. Incidence values are presented to two decimal places. Percentage changes were calculated using the available incidence values and rounded to two decimal places.

Table IV. Pertussis incidence per 100 000 in Poland by voivodeship in 2022 and 2023 compared with the median incidence for 2017–2019

Voivodeship	Median 2017–2019	2022	2023	Percentage change in 2023 compared with the median incidence for 2017–2019 (%)	Percentage change in 2023 compared with 2022 (%)
Poland	4,24	0,98	2,45	-42,22%	150%
1. Dolnośląskie	3,96	0,55	1,53	-61,36%	178,18%
2. Kujawsko-Pomorskie	7,60	0,75	1,80	-76,31%	140%
3. Lubelskie	1,70	0,34	0,64	-62,35%	88,24%

4. Lubuskie	2,07	0,61	1,53	-26,08%	150,82%
5. Łódzkie	12,67	4,49	13,08	3,24%	191,31%
6. Małopolskie	7,69	1,20	2,04	-73,47%	70%
7. Mazowieckie	4,10	0,85	1,52	-62,93%	78,82%
8. Opolskie	2,13	0,95	4,26	100%	348,42%
9. Podkarpackie	1,88	0,14	0,43	-77,13%	207,14%
10. Podlaskie	8,02	3,05	8,94	11,47%	193,11%
11. Pomorskie	6,72	1,23	2,63	-60,86%	113,82%
12. Śląskie	3,11	0,39	1,55	-50,16%	297,43%
13. Świętokrzyskie	2,18	0,34	0,51	-76,61%	50%
14. Warmińsko-Mazurskie	2,59	0,22	0,73	-71,81%	231,82%
15. Wielkopolskie	4,38	0,60	1,20	-72,60%	100%
16. Zachodnio-pomorskie	3,69	0,67	0,73	-80,22%	8,96%

Authors' calculations based on data reported by Rumik and Paradowska-Stankiewicz [4]. Incidence values are presented to two decimal places. Percentage changes were calculated using the available incidence values and rounded to two decimal places.

Discussion

The evidence supports several plausible, interacting explanations for the recent rise in pertussis notifications, but it does not establish the proportion attributable to each mechanism. Table V summarises the principal evidence and limitations.

Waning immunity and vaccine performance

Cohort studies and meta-analyses provide consistent observational evidence that protection declines with time after vaccination [5,7,8,9,10]. The magnitude varies across products and schedules, and findings from one whole-cell or acellular vaccine cannot be transferred automatically to another. Primary vaccine failure, lower initial effectiveness, and secondary waning should therefore be distinguished. Evidence from comparative studies suggests that the duration and magnitude of protection may differ between whole-cell and acellular pertussis vaccines. However, these findings are heterogeneous and depend on vaccine composition, primary series, booster schedule, population, and outcome definition. Therefore, evidence from a

specific vaccine product or schedule should not be directly extrapolated to programmes using other vaccine formulations or schedules.

Vaccination coverage across the life course

High DTP3 coverage reduces the likelihood that failure of the infant programme alone explains the resurgence, but it does not exclude gaps in DTP4, childhood and adolescent boosters, adult boosters, maternal vaccination, or local coverage [26]. Recommendations should specify the target group and should be linked to current national or international guidance rather than presented as new conclusions of this review.

Detection, surveillance, and age distribution

Improved PCR access and clinical awareness can increase notifications, while mild disease in adults can produce underdiagnosis [18]. Hospital case series describe the patients who reached a particular centre and cannot establish population incidence [17]. Age patterns are also shaped by programme schedules and surveillance practices, which limits cross-country comparisons.

Pathogen evolution

Molecular surveillance and experimental studies support adaptation of *B. pertussis*, including the spread of pertactin-deficient strains in some acellular-vaccine settings [19,20]. This evidence is biologically plausible but does not show that pathogen evolution is the dominant cause of the recent increase, particularly in countries using different products or schedules.

COVID-19 period and epidemic cycles

The fall in notifications during 2020–2022 is compatible with reduced transmission, changes in healthcare use, and reduced testing [26,31]. The later rise may reflect renewed transmission, expected epidemic cycling, waning immunity, altered natural boosting, and recovery of surveillance. Surveillance data cannot partition these effects.

Implications for Poland

Polish data show a large increase in reported cases in 2024. The 2023 regional analysis also shows that conclusions depend on the reference measure: three voivodeships exceeded the three-year median, but only one exceeded the three-year mean. This sensitivity, together with the exceptionally low 2022 baseline, argues against interpreting short-term percentage changes as equivalent changes in true infection incidence. Priorities supported by existing guidance include timely childhood vaccination, recommended boosters, maternal pertussis vaccination during pregnancy, accurate laboratory confirmation, and complete reporting [26].

Table V. Evidence supporting proposed drivers of the recent increase in pertussis notifications

Proposed driver	Principal evidence type	Supported interpretation	Major limitation	Prevention implication
Waning immunity	Cohort studies; meta-analysis	Consistent decline with time since vaccination	Product, schedule, and outcome heterogeneity	Timely boosters for nationally defined groups
Coverage gaps	Surveillance and programme data	Gaps may occur beyond DTP3 and within regions	Sparse DTP4, adult, and maternal data	Monitor each programme stage separately
Detection and surveillance	Laboratory guidance; surveillance data	Testing intensity and assay choice affect notifications	True infections cannot be separated fully from ascertainment	Standardised PCR, serology, and reporting
Pathogen evolution	Molecular and experimental studies	Adaptation is biologically plausible	Population contribution is not quantified	Sustain molecular surveillance
COVID-19 disruption	Surveillance time series	Low circulation was followed by renewed activity	Multiple concurrent changes and epidemic cycling	Interpret pre/post comparisons cautiously

Conclusions

This structured narrative review indicates that the recent increase in pertussis notifications is best explained by several interacting mechanisms rather than a single cause. Waning immunity is supported by cohort and meta-analytic evidence, while gaps in booster and maternal vaccination, changes in detection and surveillance, pathogen adaptation, expected epidemic cycling, and disruption during the COVID-19 period remain plausible contributors. The available evidence does not quantify their relative contributions.

For Poland, the surveillance data document a marked increase in reported cases, but short-term comparisons are sensitive to the exceptionally low 2022 baseline and to the pre-pandemic reference measure. Existing evidence supports timely primary vaccination, nationally recommended boosters, maternal pertussis vaccination during pregnancy, appropriate laboratory diagnosis, complete reporting, and continued molecular surveillance. Further population-based studies are needed before stronger causal claims or major changes to vaccination policy can be justified.

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Consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials (data transparency)

No datasets were generated or analyzed during the current study.

Code availability

Not applicable

Authors' contribution

Study design – G. Mysłek, D. Nicz, M. Otocka, K. Lis, K. Lau, J. Kasperczyk

Data collection – G. Mysłek, D. Nicz, M. Otocka, K. Lis

Manuscript preparation – G. Mysłek, D. Nicz, M. Otocka, K. Lis, K. Lau, J. Kasperczyk

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