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Resurgence of pertussis in Slovak Republic and surrounding Central European countries

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RESEARCH ARTICLE

ABSTRACT

Bordetella pertussis, the pathogen responsible for a highly contagious respiratory disease, utilizes a broad spectrum of virulence factors that results in subacute or chronic cough.

We conducted an analysis of pertussis incidence and reported cases in the European region from 2000 to 2024. We analyzed the potential factors contributing to the rise in pertussis incidence despite high vaccination rates.

In 2024, the Slovak Republic and surrounding Central European countries (the Czech Republic, Austria, Hungary, Poland, and Ukraine) have seen a significant increase in pertussis incidence. The results of this study suggest that the resurgence of pertussis was likely due to multiple interacting factors including waning immunity in adults, the genomic changes of *B. pertussis*, the "immune debt" phenomenon following the lifting of COVID-19 restrictions, the lower vaccination rate against pertussis due to refusal to be vaccinated, a shorter duration of protection offered by acellular vaccines, the transmission of *B. pertussis* from asymptomatic individuals or patients with mild infection to pertussis-susceptible individuals, as well as improved diagnostics and surveillance.

Unimmunised or partially immunised infants are at the highest risk of severe pertussis. The most common sources of infection are family members with asymptomatic or mildly symptomatic disease. All patients with chronic cough should be tested for *B. pertussis* as part of a comprehensive diagnostic evaluation. To protect newborns, booster vaccination of parents, close family contacts and certain healthcare professionals carrying for the youngest children is recommended. This strategy helps to create a protective environment around infants in the period of pertussis resurgence.

KEYWORDS

Bordetella pertussis, chronic cough, acellular vaccine, whole-cell vaccine, pertussis incidence

INTRODUCTION

Cough is a vital defense mechanism of the respiratory tract, preventing aspiration and helping to clear accumulated secretions. However, when the cough becomes excessive and persistent, it can negatively affect the quality of life. Chronic cough affects approximately 5–10% of the adult population and is more common in women with the highest prevalence between 50 and 60 years of age. In adults, chronic cough is defined as a cough lasting more than 8 weeks [1]. A cough that lasts between 3 and 8 weeks is considered subacute [2]. In children, chronic cough is defined as a cough lasting more than 4 weeks. Chronic cough in children differs from that in adults not only in duration but also in underlying causes and physiological factors. These differences are caused by the morphological differences in the airways, the different maturity of the nervous and immune systems in different age categories of children, the higher vulnerability of their airways to harmful substances, and less developed control over the cough reflex. Consequently, chronic cough in children manifests

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differently and is typically caused by different conditions [3]. Therefore, in children, chronic cough should be considered as a manifestation of an underlying disease rather than as an isolated problem [1].

Cough can have a variety of causes, including acute and chronic infections, respiratory diseases, lung parenchymal diseases, tumors, foreign bodies in the airways, middle ear problems, cardiovascular diseases, gastroesophageal reflux disease (GERD), use of angiotensin-converting enzyme (ACE) inhibitors, smoking, sleep-disordered breathing, obesity. In some patients, the cause cannot be identified, the cough is refractory and does not respond to empirical treatment. This type of cough is called idiopathic cough [4, 5].

Respiratory pathogens are a common cause of cough and episodes tend to increase during outbreaks of respiratory infections [5, 6]. Although the cough usually resolves within a few days, some people may experience increased cough reflex sensitivity for several weeks after the infection. This post-infectious hypersensitivity is probably due to inflammatory changes affecting the vagus nerve [5]. The vagus nerve plays a key role in the regulation of the cough reflex, and any disruption of its function can contribute to the development of cough hypersensitivity and lead to persistent cough [7]. The body's response to infection is very individual. Some patients will develop cough hypersensitivity and chronic cough, while others will recover without complications [8].

Post-infectious cough was found to be the cause in approximately 11–25% of patients with chronic cough. Among those patients with subacute cough, post-infectious cough was also the most common cause. Persistent cough occurs in 25–50% of individuals following infection with *Mycoplasma* spp. or *Bordetella pertussis* (*B. pertussis*) infection. In children, the most frequent causes of cough were viral respiratory infections (particularly respiratory syncytial virus and parainfluenzae virus) as well as bacterial infections caused by *Mycoplasma* spp., *Chlamydophila pneumoniae* and *B. pertussis* [4]. A study investigating the relationship between post-infectious subacute cough and bacterial etiology used multiplex polymerase chain reaction (PCR) from nasal swabs and found that 29% of patients with subacute cough were most commonly infected with *Haemophilus influenzae*, *Streptococcus pneumoniae*, *B. pertussis*, *Mycoplasma pneumoniae*, *Legionella pneumophilia*, and *C. pneumoniae* [9]. *B. pertussis* is a gram-negative bacterium that causes a highly contagious respiratory disease called pertussis. Pertussis typically progresses through three stages: catarrhal, paroxysmal, and convalescent. Symptoms usually begin 7–10 days after exposure but may appear as late as 21 days post-infection [10]. *Bordetella parapertussis* causes a milder form of the disease [11]. Although *B. pertussis* is not routinely tested in most patients with chronic cough, earlier studies in adults have shown a prevalence of serological evidence of *B. pertussis* infection in 12–26% and have suggested that this bacterium is a common cause of chronic cough in adults. These undiagnosed individuals may represent a reservoir for *B. pertussis*, which may lead to the transmission of the bacterium to susceptible persons, including neonates and infants, in whom the disease may have a very serious or fatal course [12]. Early recognition of pertussis is crucial not only for the proper treatment of chronic cough, but can also be significant as prevention for those who might be at risk of infection from these misdiagnosed patients. Despite successful vaccination programs, many countries have reported an increased incidence of pertussis in recent years. Several experts recommend that adult patients with chronic cough should be tested for *B. pertussis* as part of a complete diagnostic evaluation [13].

MATERIAL AND METHODS

We analyzed the databases of the World Health Organization (WHO), the European Centre for Disease Prevention and Control (ECDC) in the Surveillance Atlas of infectious diseases, and the Public Health Authority of the Slovak Republic (PHA), specifically from the National reference centre for pertussis and parapertussis at the Regional Public Health Authority with the seat in Banská Bystrica [14–16], we analyzed pertussis incidence and reported cases in the European region from 2000 to 2024. We focused primarily on Slovakia and its neighbouring countries: the Czech Republic, Austria, Hungary, Poland, and Ukraine. We analyzed the potential factors contributing to the rise in whooping cough incidence.

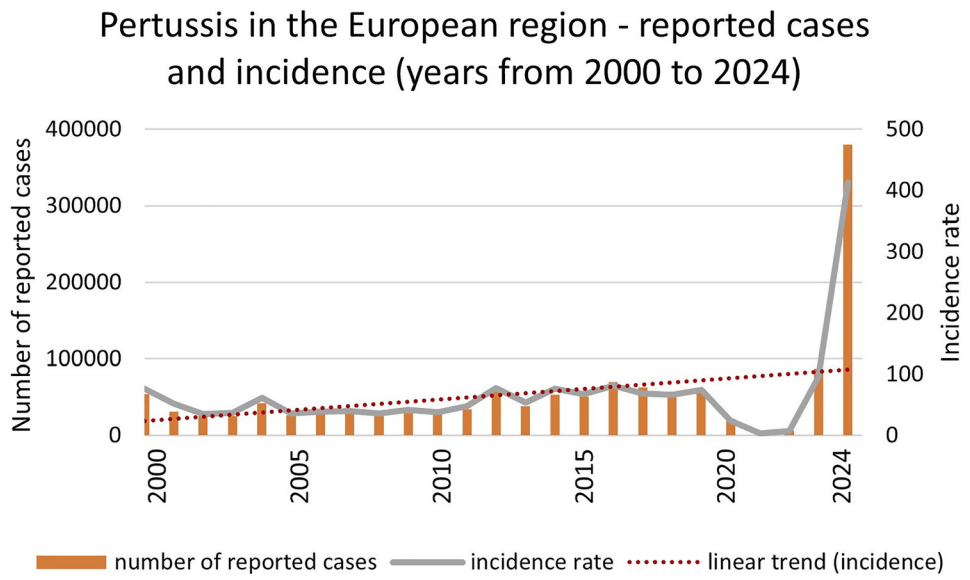
RESULTS

Assessment of the pertussis incidence in the European region from 2000 to 2024

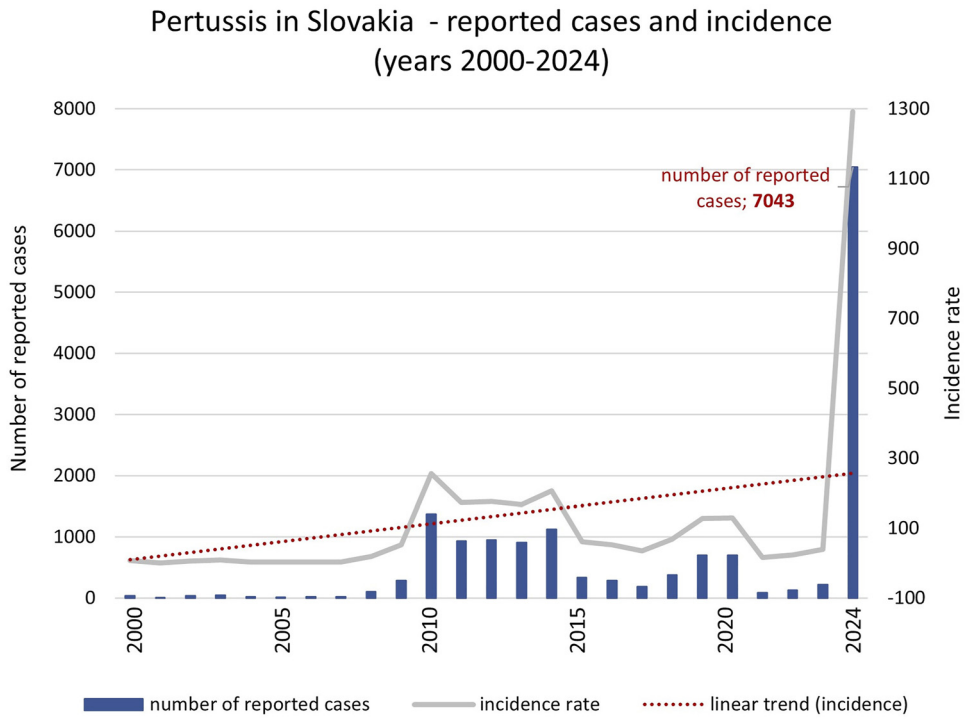
Whooping cough is widespread worldwide and occurs in epidemics. People of all age groups are susceptible to infection. According to the data from the WHO and ECDC, epidemics in the European region occur every 2–5 years, despite high vaccination rates (Graph 1) [14, 15].

Assessment of the pertussis incidence in Slovakia and neighbouring countries from 2000 to 2024

The number of pertussis cases (ICD A 37.0) in Slovakia from 2000 to 2024 is shown in Graph 2. The data were obtained from WHO and the Public Health Authority of the Slovak Republic (PHA), specifically from the National reference centre for pertussis and parapertussis at the Regional Public Health Authority with the seat in Banská Bystrica [16]. The increased incidence of whooping cough in Slovakia repeats approximately every 5 years. This cycle corresponds with a gradual increase in the number of susceptible individuals in the population allowing the disease to spread easily. The susceptible group unvaccinated individuals and those who were previously vaccinated but whose level of specific antibodies has dropped below the protective thresholds [17]. In 2024, there was a significant



Graph 1. Pertussis in the European region – reported cases and incidence from 2000 to 2024 (processed according to WHO Immunization Data portal, 2025); Incidence rate – per 1,000,000 total population



Graph 2. Pertussis in Slovakia – reported cases and incidence (ICD A37.0) from 2000 to 2024 (processed according to WHO Immunization Data portal, 2025 and the National reference centre for pertussis and parapertussis at the Regional Public Health Authority with the seat in Banská Bystrica); Incidence rate – per 1,000,000 total population

rise in pertussis cases, with up to 7,043 cases reported by the end of the year, which is an alarming increase compared to just 216 reported cases in 2023. The highest incidence was recorded in the Bratislava and Žilina regions. The lowest incidence was in the Prešov, Košice and Nitra regions. The most affected age groups were children under 1 year of age, and those aged 10–14 and 15–19 years. An analysis of reported cases and vaccination status showed that 52.9% of patients with pertussis were properly vaccinated. Other patients were either unvaccinated, partially vaccinated or their vaccination status could not be determined. The increased trend continued at the beginning of 2025 when 2,478 cases of the disease were reported between January and the end of March. During the first two months of the year 2025, two unvaccinated infants under the age of 1 year died.

In 2024, there was a significant rise in pertussis across several countries: the Czech Republic reported 37,375 cases, Austria 15,468 reported cases, Poland 32,430 cases and Ukraine 7,545 cases. Among the neighbouring countries, the most favourable situation was recorded in Hungary, with only 632 reported cases (Graphs 3 and 4). However, there was a sharp increase compared to the previous year.

By analyzing the incidence of pertussis from 2000 to 2024, we observed an upward trend in pertussis incidence since 2009, but especially in recent years across all neighbouring countries, following the COVID-19 period (Graph 5).

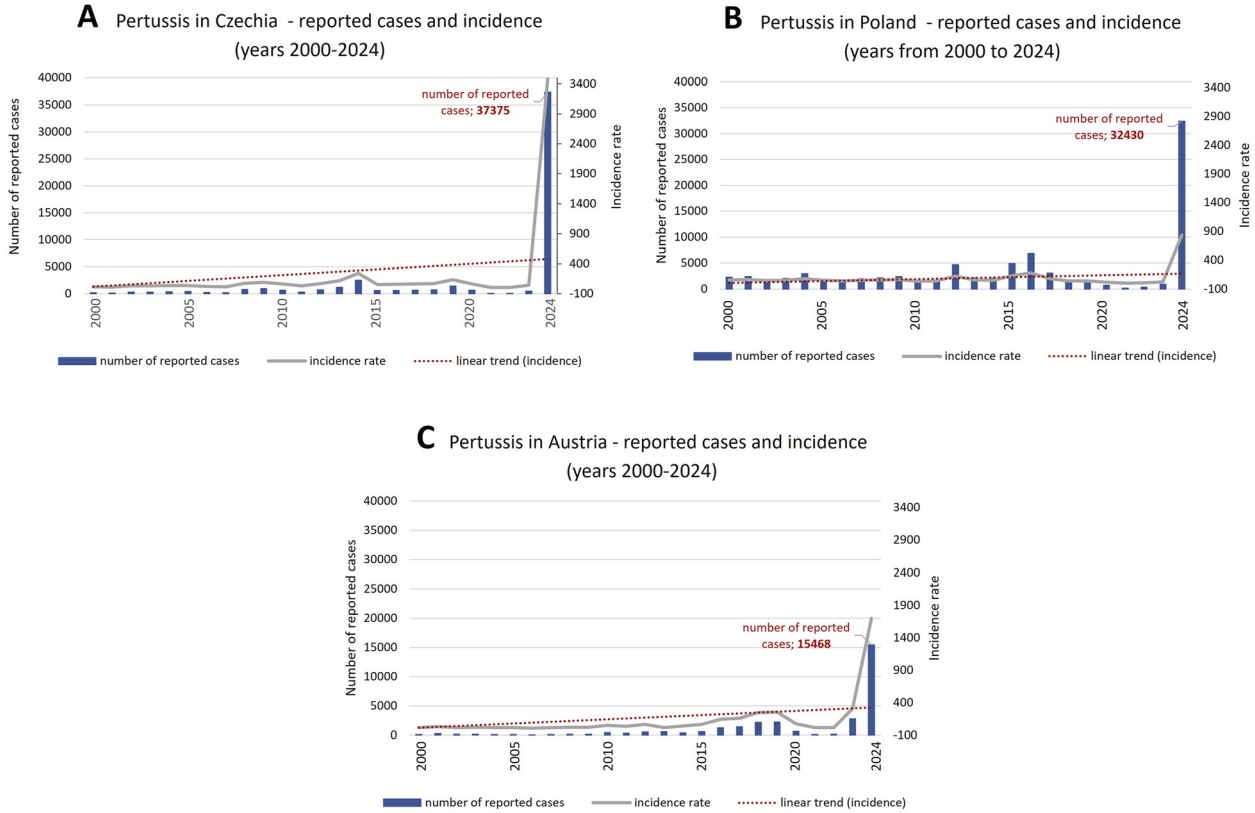
DISCUSSION

Pertussis spreads through respiratory secretions via droplet infection. Up to 90% of cases are contracted within the household, 50–80% in the classroom environment [11]. The patient is contagious during the first three weeks of coughing, although the cough can persist for several months and is also known as the "100-day cough" [10]. Earlier studies in adults have suggested that pertussis is a common cause of chronic cough in adults [12, 13]. The introduction of pertussis vaccination has dramatically reduced the incidence of whooping cough. However, concerns about adverse reactions after vaccination have led to the replacement of standard whole-cell pertussis vaccines (wP) with acellular vaccines (aP). aP vaccines contain only a few selected antigens and cause fewer adverse reactions. Primary vaccination is carried out in infancy through a three-dose schedule (at 3, 5 and 11 months) followed by booster doses at 6 and 13 years. In many countries, vaccination during pregnancy in the third trimester is also recommended, as it is an effective way to protect the newborn, and the pregnant woman [10].

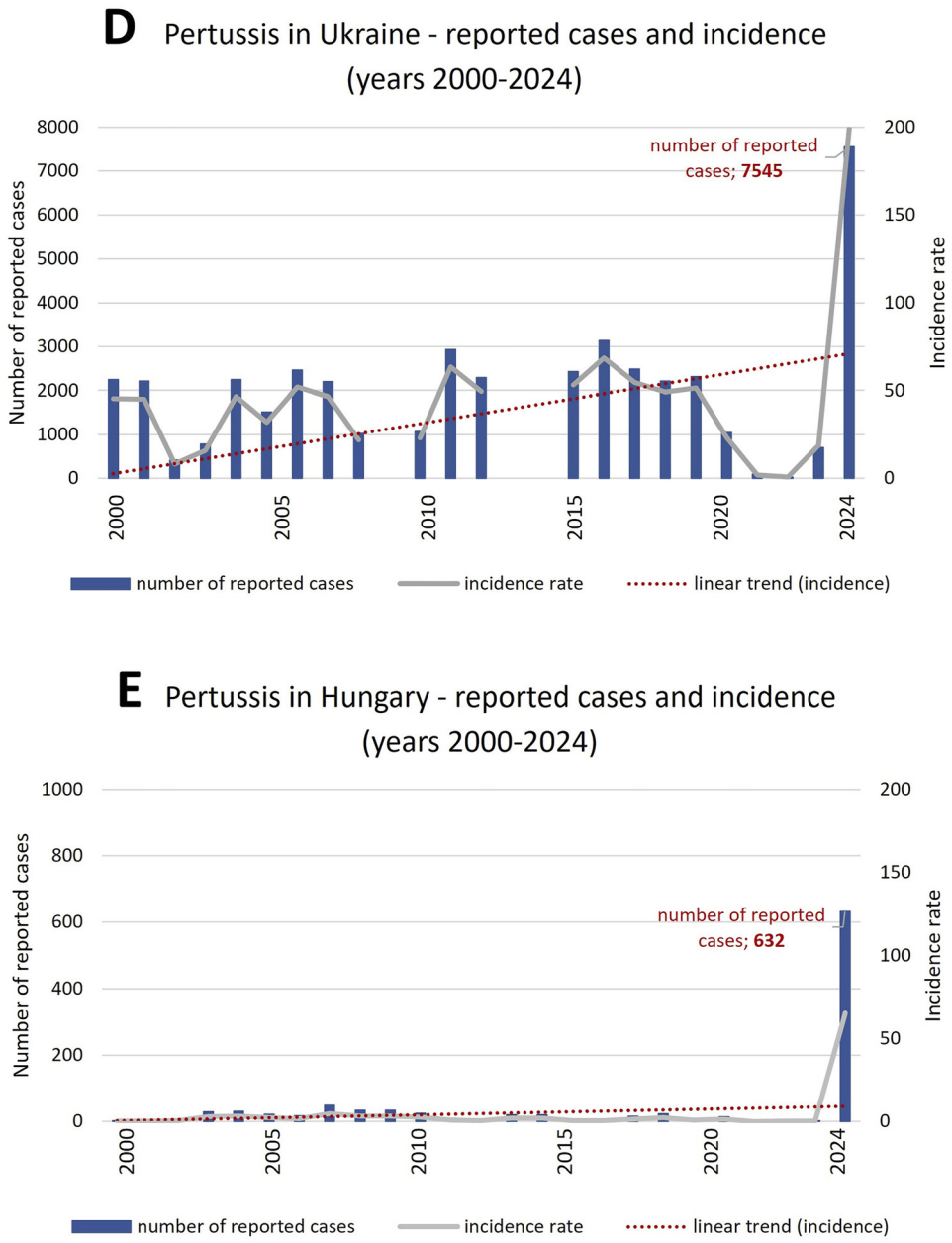
In 2023–2024, several countries in the European Union (EU) and the European Economic Area (EEA) reported an increase in the incidence of pertussis. Slovakia and its neighbouring countries are among those countries, as shown in Graphs 2–4. Mandatory vaccination against pertussis began in Slovakia in the 1950s with wP vaccines, which significantly reduced the incidence of the disease. Since 2003, these vaccines were gradually replaced by aP vaccines, which cause fewer adverse post-vaccination reactions compared to wP vaccines. However, since 2009, an increase in the number of cases has been recorded. In recent years, the number of cases has increased dramatically. This worsening situation is likely due to multiple interacting factors.

Factors contributing to the increased incidence of whooping cough

One of the possible reasons could be the genomic changes of *B. pertussis*, which allowed it to evade the effectiveness of current vaccines. Since the introduction of the pertussis



Graph 3. Pertussis – reported cases and incidence from 2000 to 2024 (processed according to WHO Immunization Data portal, 2025 and the ECDC Surveillance Atlas of infectious diseases, 2025); Incidence rate – per 1,000,000 total population (**A** – Pertussis in Czechia, **B** – Pertussis in Poland, **C** – Pertussis in Austria)

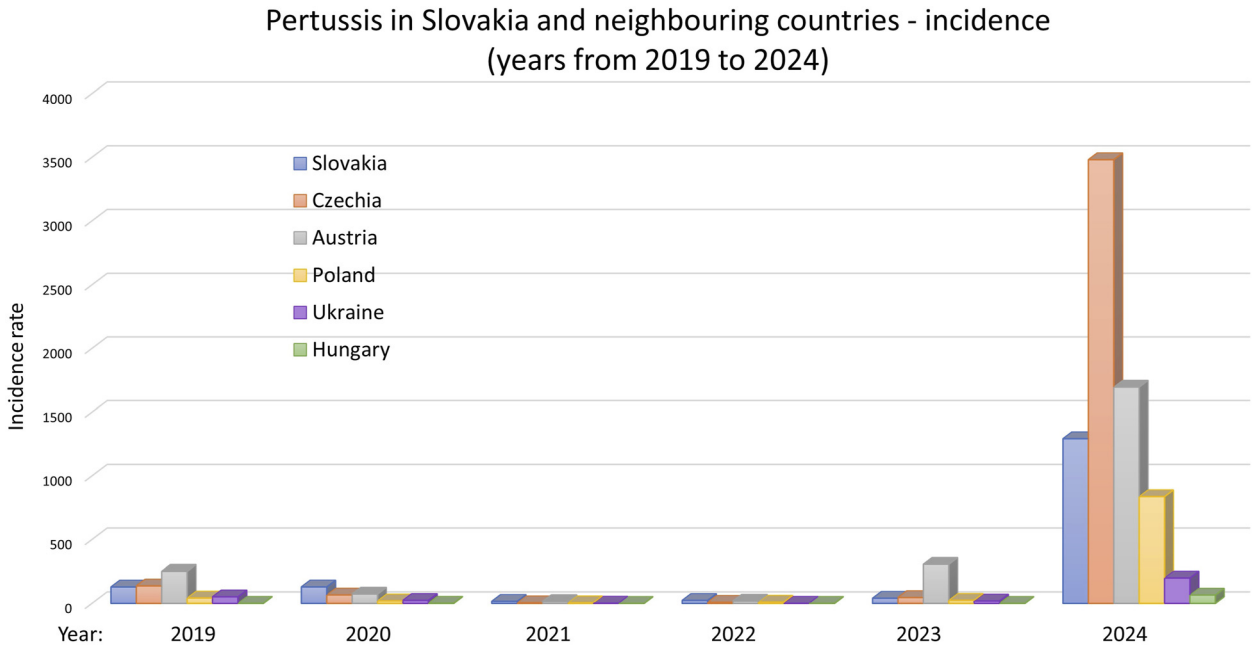


Graph 4. Pertussis – reported cases and incidence from 2000 to 2024 (processed according to WHO Immunization Data portal, 2025 and the ECDC Surveillance Atlas of infectious diseases, 2025); Incidence rate – per 1,000,000 total population (**D** – Pertussis in Ukraine, **E** – Pertussis in Hungary)

vaccination, changes in pertussis toxin and pertactin have been observed in *B. pertussis* isolates, particularly in the Netherlands [18]. Over time, strains of *B. pertussis* with a combination of PTxA1 and PRN2 began to dominate vaccinated populations worldwide, replacing the original variants (PTxA2 and PRN2). One of the components found in current aP pertussis vaccines is pertactin [19]. Following the introduction of aP vaccination, *B. pertussis* strains that did not express pertactin (so-called PRN-negative strains) were detected in several countries. However, these strains remained fully virulent, and were able to cause disease even without this protein [20]. This could contribute to an increase in cases of disease even in vaccinated populations, as the aP vaccine will no longer be able to provide sufficient protection against the altered *B. pertussis* strains [19].

The measures implemented to control the spread of COVID-19 between March 2020 and July 2021 also had an impact on the transmission of other infectious diseases, including pertussis. Due to the reduced circulation of *B. pertussis*, population-level immunity declined, leading to what is referred to as an "immune debt". This phenomenon is considered a possible explanation for the significant rise in pertussis cases observed in recent years across many countries following the lifting of COVID-19 restrictions [10, 21].

Another factor may be the lower vaccination rate against pertussis in the population due to refusal to be vaccinated,



Graph 5. Pertussis – incidence in Slovakia, the Czech Republic, Austria, Poland, Ukraine and Hungary from 2019 to 2024. Incidence rate in 2024: Slovakia – 1292.2; Czechia – 3481.3; Austria – 1695.9; Poland – 837.1; Ukraine – 199.3; Hungary – 65.3 (processed according to WHO Immunization Data portal, 2025 and the ECDC Surveillance Atlas of infectious diseases, 2025); Incidence rate – per 1,000,000 total population

even though only more gentle aP vaccines are currently used. Data from the Public Health Office of the Slovak Republic indicates that as of August 2023, the national vaccination rate for basic immunizations exceeded 95%. Revaccination at the age of six reached 94.5% nationally, but certain regions reported lower rates (Trenčín region 92%, Bratislava region 92.9%). In many other regions, the vaccination rate did not reach the required 95% threshold. Children born in 2016 lack adequate protection from collective immunity and are exposed to a higher risk of disease if they come into contact with an infected individual. Although revaccination at the age of thirteen exceeded 95% nationally, the rates in the Bratislava and Košice regions, were only 93.2% and 93.6%, respectively [22].

The decline in post-vaccination immunity is becoming an increasing problem. This may be associated with the incomplete and shorter-lasting immunity provided by current aP vaccines compared to wP vaccines [23, 24]. Neither overcoming the disease nor vaccination results in long-lasting immunity. The duration of protection offered by aP vaccines remains uncertain but is generally shorter than that of wP vaccines [25]. After vaccination with the wP vaccine, protection lasts approximately 6–10 years, while after vaccination with the aP vaccine, the protection period is approximately 4–8 years [26]. The mechanisms of immune responses triggered by aP and wP vaccines differ significantly. aP vaccines elicit a Th2-polarized immune response and through mechanisms that are still unclear, aP vaccines cannot remove *B. pertussis* from the infected nasopharyngeal mucosa. Although pertussis toxin-neutralizing antibodies effectively protect infants from life-threatening pertussis pneumonia, they do not prevent infection of the nasopharyngeal mucosa or transmission of *B. pertussis* [27]. In contrast, wP vaccines (despite being more reactogenic) induce a broader antibody response similar to natural infection and trigger Th1/Th17-polarized T-cell immunity [27, 28]. Occasional serious adverse reactions due to high endotoxin content in some batches of wP pertussis vaccines have led to a transition toward the less reactogenic aP vaccines in high-income industrialized countries since 1998. However, this change came at the cost of a reduced duration and breadth of immunity [27]. Rubin et al. [25] focused on findings from multiple studies involving highly vaccinated populations. These studies showed that aP vaccines reduce the risk of severe pertussis but do not prevent asymptomatic or mild infections, nor do they stop the transmission of *B. pertussis*. It is hypothesized that the inability of the aP vaccines to prevent asymptomatic nasopharyngeal colonization of the nasopharynx contributes to the increasing incidence of symptomatic disease, even in well-vaccinated populations [25]. Since several research teams have confirmed that the immune protection provided by aP vaccines declines rapidly and does not prevent the circulation of *B. pertussis*, the use of aP vaccines is one of the important factors in the recent increase in pertussis cases. In response to the resurgence in countries that had switched to aP vaccines, the WHO recommended in 2014 that countries still using wP vaccines continue to do so for primary vaccination programs. Currently, there is an increasing interest in modifying the composition of the pediatric hexavalent vaccines to replace the aP component with the wP component. However, this step requires further research

to reduce the reactogenicity of the wP vaccines through targeted bacterial modifications, while maintaining the protective efficacy of the resulting vaccine [27].

Improved diagnostics and surveillance contribute to a higher detection rate of *B. pertussis*. The basic diagnostic method is the direct detection of *Bordetella* DNA using polymerase chain reaction (PCR) performed on samples usually collected from the posterior nasopharyngeal wall or nasopharyngeal aspirates. Since *B. pertussis* is difficult to culture, specialized enriched culture media (Bordet-Gengou medium or Charcoal agar) are required. Cultivation must be prolonged (3–7 days) at a temperature of 35–37 °C. Transport of samples is also a challenge, as *Bordetella* is highly sensitive to drying and environmental conditions, such as cotton swabs. Therefore, the collection should be done using special dacron or calcium-alginate swabs, and rapid transport should be ensured in transport media containing activated charcoal or starch such as Amies medium. Serological testing is used for indirect diagnosis. The levels of specific IgA and IgG antibodies are measured usually from the second week of clinical symptoms. Paired serum samples taken approximately three weeks apart are recommended. A fourfold increase in antibody titers or seroconversion in the second paired sample is considered diagnostically significant [29].

In the current epidemiological situation, it is necessary to focus on ensuring the most effective protection of susceptible individuals, particularly newborns and infants under one year of age. Susceptible individuals are those who are not fully immune to pertussis including people who have never had the disease, are not vaccinated, are only partially vaccinated, or received their last dose of pertussis vaccine more than 5–10 years ago. The most vulnerable group are children under one year of age, particularly premature babies under three months, who are not yet fully vaccinated [30]. Given the various factors that contribute to the rise in pertussis incidence, several expert recommendations have been developed to protect this highly vulnerable group as much as possible. These recommendations include: vaccination of susceptible family members who will be in contact with the newborn, as family outbreaks are the most frequently recorded. Ensure indirect protection of newborns through targeted vaccination of healthcare professionals and others who come into contact with newborns. Recommend vaccination of pregnant women during the third trimester, because protective IgG antibodies produced after vaccination cross the placenta and provide protection to the fetus and subsequently to the child until the time when he or she can be vaccinated. In addition, maternal vaccination will protect the pregnant woman from severe pertussis, which could lead to complications during pregnancy, particularly during the paroxysmal stage of the disease. These complications may include premature contractions, rupture of the amniotic sac, preterm birth or infection.

CONCLUSION

The increase in pertussis cases in recent years is alarming, even in countries with high vaccination rate, due to the interaction of multiple factors. Since the immune response to infection varies between individuals, some patients recover without complications, while others may develop cough hypersensitivity and chronic cough. In some cases, the only manifested symptom in adults may be chronic cough. However, these patients can transmit *B. pertussis* to susceptible individuals in their environment. Therefore, early recognition of pertussis in patients with chronic cough is essential not only to proper treatment for affected individuals but also to reduce the risk of transmission to vulnerable populations. The risk is higher when patients with undiagnosed chronic cough unknowingly carry *B. pertussis* in the nasopharynx, thereby representing a source of infection to those around them. The most vulnerable groups are newborns and infants under one year of age, particularly those who have not yet completed the basic vaccination against pertussis. In this group, pertussis can lead to severe, potentially life-threatening complications. One effective strategy that could protect these infants is the „cocooning“ approach. It consists of creating a protective environment around the child that minimizes the likelihood of their exposure to the potential source of *Bordetella*. This strategy includes several recomendations: revaccination of parents and all potentially susceptible household contacts (especially grandparents, siblings, etc.) who will come into contact with the newborn; vaccination of selected professional workers who care for the youngest children; and recommendation of vaccination for pregnant women during their third trimester.

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REFERENCES

1. Morice AH, Millqvist E, Bieksiene K, Birring SS, Dicpinigaitis P, Domingo Ribas C, et al. ERS guidelines on the diagnosis and treatment of chronic cough in adults and children. Eur Respir J 2020; 55(1): 1901136.
2. Lätti AM, Pekkanen J, Koskela HO. Defining the risk factors for acute, subacute and chronic cough: a cross-sectional study in a Finnish adult employee population. BMJ Open 2018; 8(7): e022950.
3. Chang AB. Pediatric cough: children are not miniature adults. Lung 2010; 188(Suppl 1): S33–40.
4. Chung KF, Pavord ID. Prevalence, pathogenesis, and causes of chronic cough. Lancet 2008; 371(9621): 1364–74.
5. Alhajjaj MS, Sankari A, Bajaj P. Chronic cough. 2024. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan–.
6. Song WJ, Hui CKM, Hull JH, Birring SS, McGarvey L, Mazzone SB, et al. Confronting COVID-19-associated cough and the post-COVID syndrome: role of viral neurotropism, neuroinflammation, and neuroimmune responses. Lancet Respir Med 2021; 9(5): 533–44.

7. Mazzone SB, Satia I, McGarvey L, Song WJ, Chung KF. Chronic cough and cough hypersensitivity: from mechanistic insights to novel antitussives. Lancet Respir Med 2022; 10(12): 1113–5.
8. Chung KF, McGarvey L, Mazzone S. Chronic cough and cough hypersensitivity syndrome. Lancet Respir Med 2016; 4(12): 934–5.
9. Moon JY, Lee H, Kim MH, Song WJ, Lee SM, Kim SH, et al. Allergy and clinical immunology. Bacterial etiology in subacute cough. Allergy Asthma Immunol Res 2023; 15(5): 673–81.
10. Khalil A, Samara A, Campbell H, Ladhani SN, Amirthalingam G. Recent increase in infant pertussis cases in Europe and the critical importance of antenatal immunizations: we must do better…now. Int J Infect Dis 2024; 146: 107148.
11. Decker MD, Edwards KM. Pertussis (Whooping Cough). J Infect Dis 2021; 224(12 Suppl 2): S310–20.
12. Birkebaek NH, Kristiansen M, Seefeldt T, Degn J, Moller A, Heron I, et al. Bordetella pertussis and chronic cough in adults. Clin Infect Dis 1999; 29(5): 1239–42.
13. Chadwick KA, Mattioni J, Sataloff RT. *Bordetella pertussis* infection presenting as chronic cough. Ear Nose Throat J 2020; 99(3): NP25–6.
14. WHO. Pertussis reported cases and incidence; 2025. Available at: https://immunizationdata.who.int/global/wiise-detail-page/pertussis-reported-cases-and-incidence?CODE=EUR&YEAR=, Accessed 24 May 2025.
15. ECDC. Surveillance Atlas of infectious diseases; 2025. Available at: https://atlas.ecdc.europa.eu/public/index.aspx?Dataset=27&HealthTopic=38, Accessed 30 May 2025.
16. RUVZ. Monthly reports of the occurrence of other communicable diseases in the Slovak Republic (Mesačné hlásenia výskytu ďalších prenosných ochorení v SR); 2025. Available at: https://www.uvzsr.sk/web/uvz/mesacne-hlasenia-vyskytu-dalsich-prenosnych-ochoreni, Accessed 25 May 2025.
17. UVZ. Current information on the occurrence of whooping cough in Slovakia (Aktuálne informácie o výskyte čierneho kašľa na Slovensku); 2025. Available at: https://www.uvzsr.sk/web/uvz/tla%C4%8Dov%C3%A9-spr%C3%A1vy/-/asset_publisher/xeme/content/aktualne-informacie-o-vyskyte-cierneho-kasla-na-slovensku, Accessed 20 May 2025.
18. Mooi FR, van Oirschot H, Heuvelman K, van der Heide HG, Gaastra W, Willems RJ. Polymorphism in the Bordetella pertussis virulence factors P.69/pertactin and pertussis toxin in The Netherlands: temporal trends and evidence for vaccine-driven evolution. Infect Immun 1998; 66(2): 670–5.
19. Dorji D, Mooi F, Yantorno O, Deora R, Graham RM, Mukkur TK. Bordetella Pertussis virulence factors in the continuing evolution of whooping cough vaccines for improved performance. Med Microbiol Immunol 2018; 207(1): 3–26.
20. Safarchi A, Octavia S, Luu LD, Tay CY, Sintchenko V, Wood N, et al. Pertactin negative Bordetella pertussis demonstrates higher fitness under vaccine selection pressure in a mixed infection model. Vaccine 2015; 33(46): 6277–81.
21. Reicherz F, Golding L, Lavoie PM, Abu-Raya B. Decay of anti-Bordetella pertussis antibodies in women of childbearing age following COVID-19 non-pharmaceutical measures. Vaccine 2022; 40(27): 3746–51.
22. UVZ SR. Zaočkovanosť na Slovensku klesá. Musíme spojiť sily, aby sme chránili zdravie detí; 2024. Available at: https://www.uvzsr.sk/web/uvz/tla%C4%8Dov%C3%A9-spr%C3%A1vy/-/asset_publisher/xeme/content/zaockovanost-na-slovensku-klesa-musime-spojit-sily-aby-sme-chranili-zdravie-deti, Accessed 1 June 2025.
23. Vandecraen J, Chandler M, Aertsen A, Van Houdt R. The impact of insertion sequences on bacterial genome plasticity and adaptability. Crit Rev Microbiol 2017; 43(6): 709–30.
24. Smits K, Pottier G, Smet J, Dirix V, Vermeulen F, De Schutter I, et al. Different T cell memory in preadolescents after whole-cell or acellular pertussis vaccination. Vaccine 2013; 32(1): 111–8.
25. Rubin K, Glazer S. The pertussis hypothesis: bordetella pertussis colonization in the etiology of asthma and diseases of allergic sensitization. Med Hypotheses 2018; 120: 101–15.
26. Šafárová D. Pertussis with a focus on the increased incidence in 2024 (Čierny kašeľ vo svetle zvýšeného ochorenia v roku 2024). Via prac 2025; 22(1): 24–8.
27. Škopová K, Holubová J, Bočková B, Slivenecká E, Santos de Barros JM, Staněk O, et al. Less reactogenic whole-cell pertussis vaccine confers protection from *Bordetella pertussis* infection. mSphere 2025; 10: e00639–24.
28. Willemsen L, Lee J, Shinde P, Soldevila F, Aoki M, Orfield S, et al. Th1 polarization in Bordetella pertussis vaccine responses is maintained through a positive feedback loop. Nat Commun 2025; 16(1): 3132.
29. Liptáková A, Buc M, Slobodníková L, Ondriska F, Růžička F, Čurová K, et al. Medical microbiology (Lekárska mikrobiológia). Bratislava: HERBA; 2023. 792 p ISBN 978-80-8229-027-4.
30. UVZ SR hlavný hygienik. Guidelines of the Chief Hygienist of the Slovak Republic regarding anti-epidemic measures in the pertussis outbreak (Usmernenie hlavného hygienika Slovenskej republiky týkajúce sa protiepidemických opatrení v ohnisku pertussis); 2024. Available at: https://www.uvzsr.sk/documents/d/uvz/usmernenie-hlavneho-hygienika-slovenskej-republiky-tykajuce-sa-protiepidemickych-opatreni-v-ohnisku-pertussis-pdf, Accessed 20 May 2025.