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Progress in Laboratory Indicators of Severe Pertussis in Children

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Abstract

Pertussis is a highly infectious acute respiratory disease transmitted via droplets. Although the pertussis vaccine has been included in the childhood immunization program in China, the incidence of pertussis in children in China has increased after the COVID-19 pandemic, and the proportion of children with severe pertussis has increased. Therefore, this paper reviews the laboratory indicators related to severe pertussis in children, providing a reference for early prediction of severe cases through laboratory examination.

Keywords

Children, Pertussis, Severe Pertussis, Laboratory Indicators

1. Introduction

Pertussis, caused by Bordetella pertussis (BP), is an acute infectious respiratory disease transmitted by droplets [1]. Its typical clinical manifestations are paroxysmal spasmodic cough and a rooster-like inspiratory growl following a series of continuous coughs [2] [3]. Due to the atypical latent symptoms, many children seek medical attention in the hospital due to cough symptoms that do not respond to long-term antibiotic treatment. Because of the atypical latent symptoms of the disease and limited laboratory pathogen testing methods, these factors can easily lead to misdiagnosis and delayed diagnosis in children with pertussis, thereby increasing the risk of pertussis transmission [4]. Severe pertussis refers to cases that are diagnosed with pertussis and present with any one of the following conditions: recurrent apnea, hypoxemia, pertussis encephalopathy, or cardiovascular dysfunction [5]. Young age, lack of vaccination, poor protection after vaccination [6], etc., can increase the susceptibility of children to BP. Children are more likely to

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have severe manifestations and can even increase the risk of pertussis encephalopathy in severe cases [2]. Therefore, it is highly significant to identify the risk of severe pertussis early by analyzing the laboratory test data of children to prevent critical illness and adverse prognosis in children.

2. Epidemiological Characteristics of Pertussis Both Domestically and Internationally

Laboratory predictors of severe whooping cough. Pertussis is a highly contagious and severe respiratory disorder with an average epidemic period of 3 - 5 years [7]. From 2006 to 2021, the global incidence of pertussis was low and sporadic. During the COVID-19 pandemic in 2021, the global incidence of pertussis was the lowest in the past ten years. While the global incidence of pertussis showed an upward trend since the pandemic was lifted, peaking in 2024 [8]. Seasonal differences in the incidence of pertussis may exist in different years, mainly in summer and autumn. This is consistent with the incidence of pertussis in Germany [9].

Pertussis mainly occurs in children under 1 year old, which may be related to factors such as incomplete establishment of the immune system and inadequate vaccination coverage among young children [10]. Children are often neglected in the catarrhal stage of whooping cough due to atypical symptoms [8]. After entering the spasmodic period, they often have sudden and severe coughing fits affecting their lives. Compared with older children, infants are more likely to develop critical conditions after entering the spasmodic period [11]. Some infants even have episodes of apnea or cyanosis [12].

3. Laboratory Predictors of Severe Whooping Cough

3.1. Hyperleukocytemia often Suggests Severe Whooping Cough

Bp can produce many virulence factors after infection, and its pathogenic core is pertussis endotoxin (PT) function [13]. By interfering with the immune regulation of the body, PT causes lymphocytes from immune organs such as lymph nodes to be released in large numbers with extravascular overflow to peripheral blood [14], and inhibits lymphocyte recycling, resulting in abnormal accumulation of lymphocytes in peripheral blood and finally causing the total number of white blood cells (mainly lymphocytes) to increase significantly [15]. Hyperleukocytosis has been identified as an independent risk factor and predictor of severe pertussis in contemporary studies [16] [17].

Many studies [18] have shown that WBC $\geq 20 \times 10^9$/L has significance in the diagnosis of severe pertussis. Florence *et al.* [19] found that WBC $> 30 \times 10^9$/L significantly increases the risk of severe pertussis in children, and serious complications such as apnea, cyanosis, and bacteremia could occur. Wang Caiying *et al.* [20] retrospectively analyzed 184 cases of pertussis. It was found that when the white blood cell count (WBC) was $> 50 \times 10^6$/L, severe leukocytosis could occur. A large number of white blood cells aggregated in the pulmonary capillary network and lymphatic vessels. Due to the poor deformability of white blood cells,

white blood cell clumps were likely to form emboli at these sites, increasing the pressure in the pulmonary vessels, reducing pulmonary blood flow, decreasing oxygen delivery, and resulting in hypoxemia and pulmonary hypertension. In severe cases, heart failure could occur, increasing the risk of death in children. Meanwhile, Helen *et al.* [21] found that when WBC > 50×10^9/L, the death risk of children may be tenfold higher, and speculated that WBC elevation is related to mechanical ventilation demand, pulmonary hypertension, and death risk. Lynda *et al.* [22] further analyzed 16 cases of pertussis death and found that WBC > 55×10^9 was present in all cases. Foreign related studies [21] showed that when WBC > 100×10^9/L, if white blood cell count reduction measures were taken, the mortality rate of children could be as high as 100%.

At present, leukapheresis is mainly used for hyperleukocytemia, including exchange transfusion therapy. Because leukapheresis requires high-level operational skills, vascular access status, and blood volume, it is often combined with extracorporeal membrane lung (ECMO) [22] [23]. In the reported cases treated with leukapheresis [23] [24], the children all had adverse reactions of different degrees, such as anemia, hypoalbuminemia, hemodynamic instability, and even death. Exchange transfusion therapy was safer and more applicable than that, especially for infants with severe pertussis aged ≤ 60 days [23] [25]. In the case reports at home and abroad [26] [27], the prognosis was better after exchange transfusion therapy was performed early in the WBC surge stage. However, it is not advocated to actively implement this treatment for children with severe whooping cough in China at present. Leukapheresis can be tried when the WBC is excessively elevated or when the WBC is increased with cardiovascular complications.

3.2. NLR > 1 often Indicates Poor Prognosis

The peripheral blood cell count of children with pertussis shows an increase in total white blood cells, mainly lymphocytes [11]. Lymphocytes are often used in conjunction with white blood cells to predict the malignant progression of pertussis and the probability of adverse prognosis. Ganeshalingham *et al.* [28] suggested that when WBC > 25×10^9/L and lymphocyte ratio > 50%, there is a high probability of malignant progression of pertussis; some researchers [29] also pointed out that when WBC > 20×10^9/L and lymphocyte ratio > 60%, the prognosis of children is poor; Liu Juan *et al.* [8] believed that WBC > 20×10^9/L and LY > 14×10^9/L could be used as specific indicators for the diagnosis of severe pertussis. Ratio of neutrophil to lymphocyte count. Neutrophil-to-lymphocyte ratio (NLR) can effectively suggest that WBC > 20×10^9/L and LY > 14×10^9/L could be used as specific indicators for the diagnosis of severe pertussis. The neutrophil-to-lymphocyte ratio (NLR) refers to the ratio of neutrophils to lymphocytes in peripheral blood [30]. It is a new type of inflammatory response indicator derived from white blood cell subsets. It can reflect the relative relationship of reciprocal changes between the body's inflammatory response and immune status. That is, there is an interactive and relative change relationship between the body's inflam-

matory response and immune status, where an increase in one may lead to a decrease in the other [31]. It also plays a clinical predictive role in various systems such as infectious diseases, cardiovascular diseases, autoimmune diseases, and tumors. The study [32] indicates that the normal range of NLR is 1 - 2. When the value of NLR is less than 0.7, it is common among patients with viral infections, neutropenia, or tumors [33]. An NLR > 1 indicates a more pronounced increase in neutrophil count than lymphocyte count, which may be related to the presence of an excessive and abnormal host response after infection with Bp [34]. In foreign studies, NLR inversion occurs earlier than clinical deterioration in children [34], and NLR > 1 within 48 hours of hospital admission in children with pertussis is often indicative of severe pertussis [28]. The study by Wu Xiaoying *et al.* [35] found that children with pertussis with significantly increased NLR are more likely to have severe respiratory involvement, indicating that NLR can be used as a predictor of severe pertussis pneumonia.

3.3. Cytokines Can Reflect the Level of Disease Progression

Cytokine imbalance and inflammatory storm can promote the malignant evolution of pertussis, and abnormal expression of some cytokines can be used as a key reference to judge severity risk, assess the degree of injury, and guide intervention. After BP infection, the body is first infected by innate immune cells (macrophages, dendritic cells, neutrophils, etc.), initiating an immune response and secreting cytokines to facilitate phagocytosis and killing [36]. For example, NK cells enhance the antibacterial activity of macrophages by secreting IFN-γ and induce the production of Th1 cells; dendritic cells induce T cells to proliferate and differentiate into Th1 and Th17 cells secreting IFN-γ and IL-17, further activating neutrophils and macrophages, while PT regulates T cell differentiation and thus affects cytokine expression levels [21] [36]-[38].

Pro-inflammatory factors' "explosive increase" directly drives syste Pro-inflammatory factors' explosive rise directly drives systemic inflammation and organ damage. On the one hand, IL-6 can damage bronchial epithelial tissue, directly stimulate airway mucosal epithelial cells to release mucus, aggravate airway stenosis, promote pneumonia, and the progression of severe disease is positively correlated with the IL-6 level [39] [40]. On the other hand, IL-6 can also activate the systemic inflammatory response through excessive secretion, causing SIRS. The higher the IL-6 level, the higher the risk of adverse prognosis and death in children [41]. Related experiments [42] showed that TNF can be significantly secreted after BP infection and induces a peak response after 1 hour. When the level of TNF-α in serum is too high, it will seriously damage bodily functions and even cause death [43]. Cytokine bias towards the 'Th2 response' will weaken the clearance ability. Li Xiaomei *et al.* [44] pointed out that the risk of immune function decline in children with pertussis increased 1.255-fold for each unit of IL-5 and 0.886-fold for each unit of IFN-γ. Tao Meiting *et al.* [45] believed that the reduction in IFN-λ expression level after BP infection could lead to a reduction in the local mucosal

immune response, which was not conducive to infection control.

3.4. The Emergence of Drug-Resistant Strains of Pertussis Exacerbates Disease Progression

Macrolides are the first-line drugs for the treatment and prevention of pertussis [46]. However, with the immune selection pressure induced by vaccines [47] and the widespread use of macrolides in clinical treatment in recent years, the number of pertussis-resistant strains is increasing. The A2047G point mutation of the 23SrRNA gene is the main molecular mechanism for generating pertussis-resistant strains. Erythromycin-resistant strains in China have increased rapidly since 2008 and have high levels of drug resistance [48] [49]. Guo Mengyang *et al.* [50] found that ptxP1 and ptxP3 pertussis-resistant strains were highly resistant to erythromycin, and studies [51] showed that ptxP3 pertussis-resistant strains secreted more PT and were more toxic. Some domestic scholars also found that children infected with resistant strains were more likely to be infected with other pathogens during the course of the disease, resulting in lower respiratory symptoms [52].

4. Summary

In conclusion, hyperleukocytosis, inversion of NLR, elevation of cytokine levels, and the emergence of drug-resistant strains of pertussis can all increase the risk of progression of severe pertussis in children. However, this study has certain limitations. For example, there is a certain subjective bias in literature screening. In laboratory tests for pertussis, it is impossible to accurately compare the differences in the effectiveness of different testing methods (such as accuracy, sensitivity, specificity, etc.).

Therefore, how to accurately define the relationship between the disease progression of children and laboratory indicators, and identify new predictive indicators with higher sensitivity and specificity, can be the content of subsequent research related to pertussis.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Zhang, J.Y., Zhuo. Y.F., Chen, Y.P., *et al.* (2023) Clinical Features of Pertussis in 248 Hospitalized Children and Risk Factors for Severe Pertussis. *Chinese Journal of Applied Clinical Pediatrics*, **38**, 275-280.

[2] Carbonetti, N.H. (2007) Immunomodulation in the Pathogenesis of Bordetella Pertussis Infection and Disease. *Current Opinion in Pharmacology*, **7**, 272-278. https://doi.org/10.1016/j.coph.2006.12.004

[3] Kang, L.M., Mi, R., Wang, Y.J., *et al.* (2025) Analysis of Clinical Characteristics of Hospitalized Children with Pertussis. *China Medical Herald*, **22**, 106-109.

[4] Hu, Y., Guo, M. and Yao, K. (2024) Infections in Preschool and School-Aged Chil-

dren Are Driving the Recent Rise in Pertussis in China. *Journal of Infection*, **88**, Article 106170. https://doi.org/10.1016/j.jinf.2024.106170

[5] Kaihu, Y. and Lijun, L. (2019) Advances in the Diagnosis of Severe Pertussis and Research on Mortality Risk Factors from Pertussis. *Chinese Journal of Applied Clinical Pediatrics*, **34**, 1681-1685.

[6] Han, Y.N. (2025) Analysis of Clinical Characteristics and Risk Factors Related to Severe Symptoms in 131 Hospitalized Children with Pertussis. *Modern Disease Control and Prevention*, **36**, 269-274.

[7] Moosa, F., Tempia, S., Kleynhans, J., McMorrow, M., Moyes, J., du Plessis, M., *et al.* (2023) Incidence and Transmission Dynamics of *Bordetella pertussis* Infection in Rural and Urban Communities, South Africa, 2016-2018. *Emerging Infectious Diseases*, **29**, 294-303. https://doi.org/10.3201/eid2902.221125

[8] Domenech de Cellès, M., Magpantay, F.M.G., King, A.A. and Rohani, P. (2016) The Pertussis Enigma: Reconciling Epidemiology, Immunology and Evolution. *Proceedings of the Royal Society B*: *Biological Sciences*, **283**, Article 20152309. https://doi.org/10.1098/rspb.2015.2309

[9] Nguyen, P.N.T., Heininger, U., Muloiwa, R., von König, C.H.W., Hozbor, D., Ong-Lim, A., *et al.* (2025) Pertussis in Southeast Asia: Country-Level Burden and Recommendations from the Global Pertussis Initiative. *IJID Regions*, **14**, Article 100559. https://doi.org/10.1016/j.ijregi.2024.100559

[10] Zhang, M., Wu, D., Li, Y.X., *et al.* (2023) Challenges to Global Pertussis Prevention and Control. *Chinese Journal of Epidemiology*, **44**, 491-497.

[11] Zhang, H.M. and Wang, T.Y. (2024) Research Progress on the Epidemiological and Clinical Characteristics of Pertussis in Children. *Chinese Pediatric Emergency Medicine*, **31**, 288-294.

[12] Liu, J., Lu, X.L., Zhu, D.S., *et al.* (2022) Clinical Features of Pertussis and Risk Factors of Severe Pertussis in Children. *Chinese Pediatric Emergency Medicine*, **29**, 796-802.

[13] Zeng, X.Y. and Chen, B.Q. (2023) Research Progress on the Mechanism and Treatment of Spasmodic Cough Caused by Pertussis. *Chinese Remedies & Clinics*, **23**, 200-204.

[14] Tian, S.F. and Deng, J.K. (2019) Mechanism of Pertussis-Associated Hyperleukemia and Progress in Exchange Blood Therapy. *Chinese Journal of Infectious Diseases*, **37**, 58-61.

[15] Carbonetti, N.H. (2016) *Pertussis leukocytosis*: Mechanisms, Clinical Relevance and Treatment. *Pathogens and Disease*, **74**, ftw087. https://doi.org/10.1093/femspd/ftw087

[16] Zhou, X.L., Huang, S.W. and Yan, Y.Y. (2025) Clinical Characteristics of Children with Pertussis and Analysis of Risk Factors for Severe Pertussis. *Journal of Women and Children's Health Guide*, **4**, 47-50.

[17] Liu, L.Y., Xia, Z., Tang, W. and Shi, B.Y. (2025) Clinical Analysis of 55 Children with Severe Pertussis. *Chinese Journal of Infection Control*, **24**, 932-939.

[18] Han, Y.N., Yang, Q.Y., Wang, L.H. and Zhang, Y.L. (2022) Epidemiology, Clinical Characteristics, and Risk Factors of 148 Severe Pertussis Cases in Yunnan. *Journal of Kunming Medical University*, **43**, 145-149.

[19] Birru, F., Al-Hinai, Z., Awlad Thani, S., Al-Mukhaini, K., Al-Zakwani, I. and Al-Abdwani, R. (2021) Critical Pertussis: A Multi-Centric Analysis of Risk Factors and Outcomes in Oman. *International Journal of Infectious Diseases*, **107**, 53-58. https://doi.org/10.1016/j.ijid.2021.04.046

[20] Wang, C., Zhang, H., Zhang, Y., Xu, L., Miao, M., Yang, H., *et al.* (2021) Analysis of Clinical Characteristics of Severe Pertussis in Infants and Children: A Retrospective Study. *BMC Pediatrics*, **21**, Article No. 65. https://doi.org/10.1186/s12887-021-02507-4

[21] Rowlands, H.E., Goldman, A.P., Harrington, K., Karimova, A., Brierley, J., Cross, N., *et al.* (2010) Impact of Rapid Leukodepletion on the Outcome of Severe Clinical Pertussis in Young Infants. *Pediatrics*, **126**, 816-827. https://doi.org/10.1542/peds.2009-2860

[22] Hu, Y., Zhuang, Y., Wu, Y.Q. and Xiao, Z.H. (2024) Application of Exchange Transfusion in Neonates with Severe Pertussis and Hyperleukocytosis. *Chinese Journal of Contemporary Pediatrics*, **26**, 1155-1161.

[23] Chen, X.Q. and Jiang, S.H. (2020) Case Report of Infant Severe Pertussis with Encephalopathy Treated by Leukapheresis. *Chinese Journal of Applied Clinical Pediatrics*, **35**, 1908-1910.

[24] Xiang, L., Cao, Q., Xi, Y.L., Ren, H., Zhang, J., Luo, C.Y., Qian, J., Wang, Y. and Li, B.R. (2018) Application of Leukoreduction Therapy in Severe Pertussis with Leukocytosis and Pulmonary Hypertension: 3 Infant Case Reports and Literature Review. *Chinese Pediatric Emergency Medicine*, **25**, 801-807.

[25] Smith, B.K., Bleiweis, M.S., Zauhar, J. and Martin, A.D. (2011) Inspiratory Muscle Training in a Child with Nemaline Myopathy and Organ Transplantation. *Pediatric Critical Care Medicine*, **12**, e94-e98. https://doi.org/10.1097/pcc.0b013e3181dde680

[26] Son, P.T., Reda, A., Viet, D.C., Quynh, N.X.T., Hung, D.T., Tung, T.H., *et al.* (2021) Exchange Transfusion in the Management of Critical Pertussis in Young Infants: A Case Series. *Vox Sanguinis*, **116**, 976-982. https://doi.org/10.1111/vox.13085

[27] Liu, J., Lu, X.L., Zhu, D.S., *et al.* (2021) Clinical Application of Exchange Transfusion in Children with Severe Pertussis Pneumonia. *Chinese Pediatric Emergency Medicine*, **28**, 625-629.

[28] Ganeshalingham, A., McSharry, B., Anderson, B., Grant, C. and Beca, J. (2017) Identifying Children at Risk of Malignant Bordetella Pertussis Infection. *Pediatric Critical Care Medicine*, **18**, e42-e47. https://doi.org/10.1097/pcc.0000000000001013

[29] Cao, J.Y., Xu, L. and Pan, J.H. (2020) Analysis of Multiple Factors Involved in Pertussis-Like Coughing. *Clinical Pediatrics*, **59**, 641-646. https://doi.org/10.1177/0009922820905871

[30] Pan, M.M., Song, W. and Liao, M.Y. (2020) Progress in the Study of the Neutrophil-Lymphocyte Ratio in Sepsis. *International Journal of Respiration*, **40**, 70-73.

[31] Li, F. and Yin, H.N. (2017) Research Progress of Blood Routine Parameters in the Assessment of Sepsis and Infective Diseases. *Medical Recapitulate*, **23**, 2370-2373.

[32] Zahorec, R. (2021) Neutrophil-to-Lymphocyte Ratio, Past, Present and Future Perspectives. *Bratislava Medical Journal*, **122**, 474-488. https://doi.org/10.4149/bll_2021_078

[33] Zahorec, R., Hulin, I. and Zahorec, P. (2020) Rationale Use of Neutrophil-to-Lymphocyte Ratio for Early Diagnosis and Stratification of Covid-19. *Bratislava Medical Journal*, **121**, 466-470. https://doi.org/10.4149/bll_2020_077

[34] Ganeshalingham, A., Wilde, J. and Anderson, B.J. (2017) The Neutrophil-to-Lymphocyte Ratio in Bordetella Pertussis Infection. *Pediatric Infectious Disease Journal*, **36**, 1100-1102. https://doi.org/10.1097/inf.0000000000001665

[35] Wu, X.Y. and Gan, C. (2022) Peripheral Blood Cell Count and Their Ratio in Predicting the Severity of Pertussis. *Journal of Chongqing Medical University*, **47**, 602-606.

[36] Brummelman, J., Wilk, M.M., Han, W.G.H., van Els, C.A.C.M. and Mills, K.H.G. (2015) Roads to the Development of Improved Pertussis Vaccines Paved by Immunology. *Pathogens and Disease*, **73**, ftv067. https://doi.org/10.1093/femspd/ftv067

[37] Byrne, P., McGuirk, P., Todryk, S. and Mills, K.H.G. (2004) Depletion of NK Cells Results in Disseminating Lethal Infection with *Bordetella pertussis* Associated with a Reduction of Antigen-Specific Th1 and Enhancement of Th2, but Not Tr1 Cells. *European Journal of Immunology*, **34**, 2579-2588. https://doi.org/10.1002/eji.200425092

[38] Zhao, F. and Zhu, X.P. (2022) Advances in the Immunologic Mechanism and Mucosal Immunity of *Bordetella pertussis*. *International Journal of Pediatrics*, **49**, 377-380.

[39] Xin, F., Wang, J. and Shu, C.H. (2022) Clinical Value of Serum C-Reactive Protein (CRP), Procalcitonin (PCT), Parvalbumin (PA), and Interleukin 6 (IL-6) Levels in the Diagnosis and Prognosis of Acute Respiratory Tract Infection in Children. *Zhejiang Journal of Integrated Traditional Chinese and Western Medicine*, **32**, 640-642.

[40] Liu, H.Q., Li, F., Zhang, A.G., *et al.* (2019) Changes and Significance of MMP-9, TIMP-1, sICAM-1, and IL-6 in Children with Pneumonia. *Experimental and Laboratory Medicine*, **37**, 477-479.

[41] Min, W. (2024) Clinical Value of IL-6, IL-10, and IL-6/IL-10 in assessing the Prognosis of Patients with Sepsis. Master's Thesis, Inner Mongolia Medical University.

[42] Khiter, F., Kherrouche, Z., Dubois, V., Slupek, S., Petit, E., Debrie, A., *et al.* (2023) Combined Regulation of Pro-Inflammatory Cytokines Production by STAT3 and STAT5 in a Model of B. Pertussis Infection of Alveolar Macrophages. *Frontiers in Immunology*, **14**, Article 1254276. https://doi.org/10.3389/fimmu.2023.1254276

[43] Long, C.Y. and Ling, W.S. (2023) Analysis of the Levels of Serum Inflammatory Cytokines and Humoral Immunity Indexes in Children with Pertussis. *Maternal and Child Health Care of China*, **38**, 45-48.

[44] Li, X.M., Kuang, S.Q., Zeng, M.L., *et al.* (2024) Serum IFN-γ and IL-5 Levels in Children with Pertussis and Their Relationship with Immune Status. *Laboratory Medicine and Clinic*, **21**, 2243-2247.

[45] Tao, M.T., Zhong, L.L., Liu, S.L., Zeng, D., Liu, D. and Peng, L. (2024) Study on the Expression Level of IFN-λ1 mRNA in the Airway Epithelium of Children Infected with *Bordetella pertussis*. *Journal of Practical Shock*, **8**, 273-276.

[46] Chen, H. and Chen, J.H. (2020) Advances in the Treatment and Prevention of Pertussis. *Journal of Pediatric Pharmacy*, **26**, 60-63.

[47] Shi, X.S., Fu, S.J., He, X.H., *et al.* (2025) Antigenic and Genotypic Characteristics and Antibiotic Resistance Analysis of *Bordetella pertussis* in Two Regions of Fujian Province. *Journal of Clinical Pediatrics*, **43**, 575-582.

[48] Barkoff, A.M. and He, Q.S. (2019) Molecular Epidemiology of *Bordetella pertussis*. In: *Advances in Experimental Medicine and Biology*, Springer, 19-33. https://doi.org/10.1007/5584_2019_402

[49] Wang, L.B., Wang, H.P., Qi, Z.H., Yao, P.P., Teng, S., Wu, Z.Y., Wu, B.B., Zhao, S.Y. and Yang, Z.Y. (2024) Analysis of Antibiotic Resistance and Infection of *Bordetella pertussis* in Children with Suspected Pertussis and Close Family Members. *Chinese Journal of Microbiology and Immunology*, **44**, 473-479.

[50] Guo, M.Y., Wang, B.S., Yuan, L., *et al.* (2024) A Comparative Study on the Clinical Manifestations of Children Infected with Erythromycin-Resistant *Bordetella pertussis* of ptxP1 and ptxP3 Genotypes. *Chinese Journal of Applied Clinical Pediatrics*, **39**, 89-93.

[51] King, A.J., van der Lee, S., Mohangoo, A., van Gent, M., van der Ark, A. and van de

Waterbeemd, B. (2013) Genome-Wide Gene Expression Analysis of *Bordetella pertussis* Isolates Associated with a Resurgence in Pertussis: Elucidation of Factors Involved in the Increased Fitness of Epidemic Strains. *PLOS ONE*, **8**, e66150. https://doi.org/10.1371/journal.pone.0066150

[52] Zhang, Z., Hua, C.Z., Xie, Y.P., Wang, H.J., Li, J.P. and Yu, H.M. (2021) Analysis of Clinical Features, Antibiotic Resistance of *Bordetella pertussis* Isolates, and Treatment Outcomes in 211 Children with Pertussis. *Chinese Journal of Infectious Diseases*, **39**, 168-174.