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To study the impact of COVID-19 on the epidemiological characteristics of allergic rhinitis based on local big data in China

Ruru Tian✉, Jianhua Jiang, Jinv Ding, Jieling Zhao & Xinru Zhou

To investigate the big data characteristics and trend changes of patients with allergic rhinitis (AR) who sought medical attention at our hospital before (from 2018 to 2019) and after (from 2020 to 2023) COVID-19, and provide reference basis for the treatment of AR. This study used a descriptive epidemiological method to analyze the big data and trend changes of AR patients. A total of 62,196 AR patients were collected, of whom 32,874 were male and 29,322 were female, with an age range of 1–89 years. The monthly change trend of AR patients showed a marked seasonality. The number of AR patients increased year by year. There was no significant difference in the number of patients between different genders. There was a significant difference in the number of patients between different age groups. The number of AR patients increased markedly from 2018 to 2023, and COVID-19 seems to have accelerated this process. There is a clear seasonal pattern. The number of boy patients is significantly higher than that of girl patients, and the change in female hormones may affect the incidence of AR. Therefore, it is necessary to update management measures and formulate relevant policies in response to the changing trend of AR since the COVID-19 epidemic.

Keywords COVID-19, Allergic rhinitis, Epidemiological studies, Prevalence, Big data

Allergic rhinitis (AR) is a non-infectious inflammatory disease of the nasal mucosa, which occurs after the body is exposed to allergens and is mainly mediated by immunoglobulin E (IgE). The main clinical manifestations are nasal itching, nasal congestion, sneezing, clear nasal discharge, and often accompanied by conjunctival congestion, eye itching and other symptoms. AR has become a global health problem, affecting 10–40% of the world's population, and usually lasts for a lifetime[1]. The prevalence of allergic diseases has been steadily increasing in recent decades[2]. Allergic diseases can develop at a relatively young age, reduce quality of life, and the socioeconomic burden is increasing worldwide[3]. Therefore, there are many studies on the epidemiology of AR in the past. In 2019, a new strain of human coronavirus emerged and caused an epidemic. The virus was named Severe Acute Respiratory Syndrome coronavirus 2 (SARS-CoV-2) by the International Committee on Taxonomy of Viruses (ICTV). The disease was named "coronavirus disease 2019 (COVID-19)" by the World Health Organization (WHO)[4]. In addition to the direct pathogenic effect of the virus on host cells, COVID-19 can induce excessive immune response to damage the body by interacting with the immune system[5,6]. In order to prevent the spread of pandemic COVID-19 infection[7], countries have taken active measures, which have changed people's lifestyles and affected the spread of AR[8]. However, there is relatively little research on the change of AR prevalence trend before and after the spread of COVID-19 in 2019 and its end in 2022. Therefore, we conducted a study on the epidemiological characteristics of AR from 2018 to 2023. This study examined the impact of COVID-19 on the trend of allergic rhinitis, and provided reference for the diagnosis and treatment of AR.

Literature and methods

All methods were performed in accordance with the relevant guidelines. AR is a non-infectious chronic inflammatory disease of the nasal mucosa mainly mediated by immunoglobulin E (IgE) in atopic individuals after exposure to allergens. The main clinical manifestations are nasal itching, nasal congestion, sneezing, clear nasal discharge, and often accompanied by conjunctival congestion, eye itching and other symptoms. Exclusion criteria: patients without a clear diagnosis of allergic rhinitis.The outpatient system of our hospital was utilized to collect big data on patients diagnosed with AR from January 2018 to December 2023. The data of AR patients

Affiliated Hospital of Hangzhou Normal University, Hangzhou, China. ✉email: tianrrall@yeah.net

collected in the outpatient department were analyzed by descriptive epidemiological method. The age, gender and visiting time of the patients were recorded in detail for retrospective analysis, and the change trend of AR before (2018–2019), during (2020–2022) and after (2023) the COVID-19 epidemic was analyzed. (1) The time distribution and trend changes of AR patients in our hospital were analyzed. The seasonal index was used to reflect the changes in the number of visits in different months.(2) The trend changes of AR patients in different gender and age groups were analyzed. T test and rank sum test were used to test the statistical difference(test level $P=0.05$).

Ethical considerations

This study was approved by the Ethics Committee of Hangzhou Normal University Affiliated Hospital. Consent for this study was obtained from the relevant personnel and signed consent forms. This study has obtained the consent of the relevant personnel and signed informed consent. (A20220403)

Result

The time distribution of patients with allergic rhinitis

Monthly trend of AR patients

The monthly trends in the number of AR patients showed obvious seasonality (Fig. 1). The annual number of patients began to rise from March, peaked in April, gradually decreased from May to June, gradually increased in July, and reached the peak in October. The seasonal index was 139.63%. The number of patients decreased significantly from January to February of the next year, and the lowest rate was 53.52% in February.

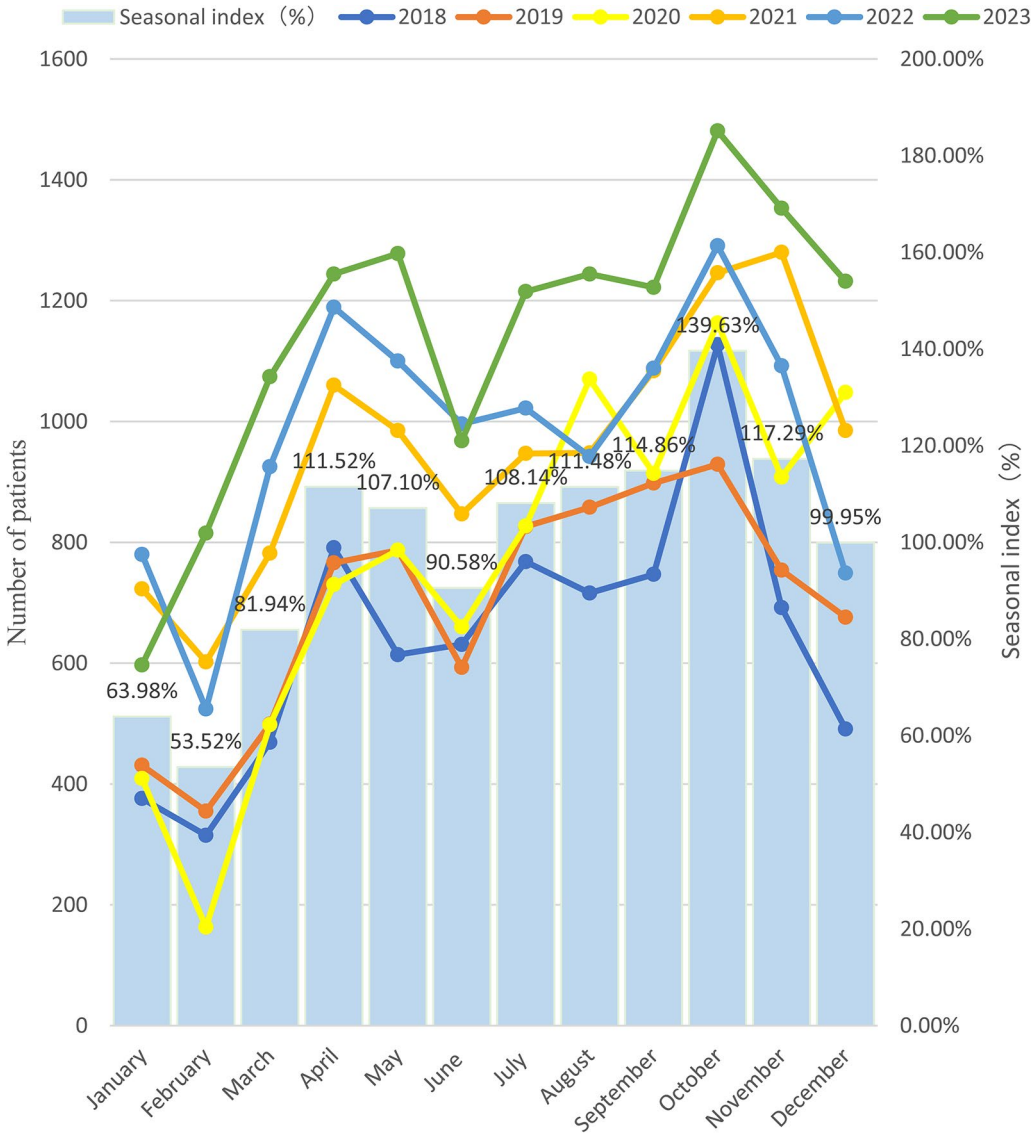


Fig. 1. Prevalence of AR from 2018 to 2023. Note seasonal index = mean value of the same month (or season)/ total mean value of each month (or season) in each year ×100%.

Annual trend of patients with AR

From 2018 to 2023, the number of AR patients in our hospital increased year by year. The number increased from 7737 to 13,723, an increase of 77.37%, with an average annual growth rate of 12.14%, as shown in Table 1. The specific analysis found that the annual growth rate increased from 2018 to 2021. The annual growth rate reached the highest 25.19% in 2021, and the growth rate decreased to only 1.82% in 2022. However, the number of patients still increased, and the growth rate returned to 17.31% in 2023, as shown in Fig. 2.

Distribution characteristics of AR patients

(See Table 1; Fig. 2 for details).

AR patients gender annual trends

From 2018 to 2023, the number of male and female patients will basically increase year by year. The former increased by 82.78%, with an average annual growth rate of 12.82%, and the latter increased by 71.67%, with an average annual growth rate of 11.41%. Although the annual growth rate of the former (4.77%) slowed down and the latter showed a negative growth rate (-1.43%) in 2022, the annual growth rates of the two groups (14.99% and 20.02%) basically returned to the same level in 2023.The number of female patients was relatively small compared with the number of male patients attending the clinic. However, the Mann-Whitney rank sum test showed that there was no significant difference in the total number of patients per year between different genders from 2018 to 2023 ($Z=-0.961$, $P=0.337$).

The annual change trend of AR patients in different age groups

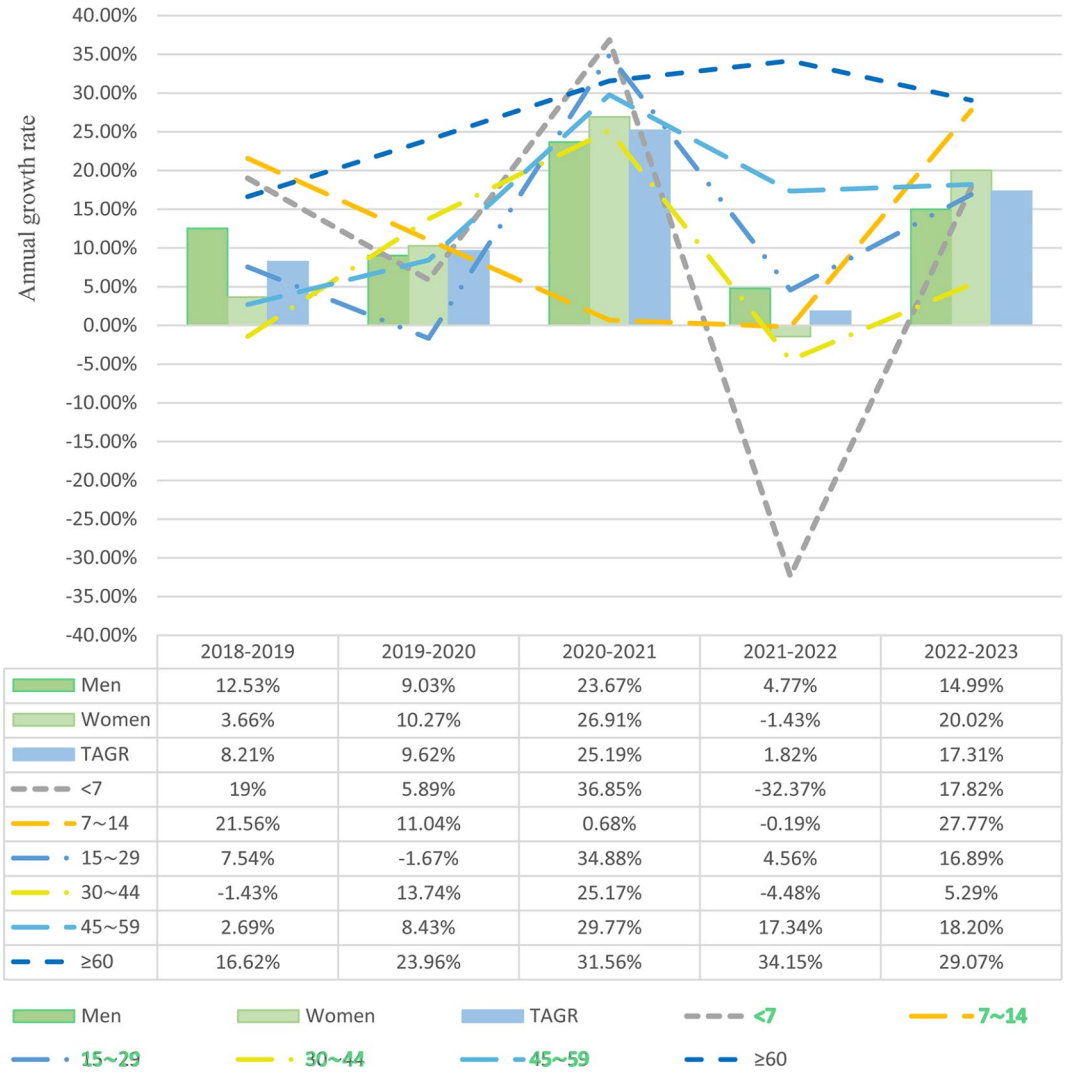
From 2018 to 2023, the number of patients (≥45 years old) in our hospital would increase year by year. The number of patients in the children group (<15 years old) and the young and middle-aged group (30–44 years old) decreased slightly in 2022, and basically recovered in 2023.The elderly group (≥60 years old) had the largest annual growth rate of 229.31%, with an average annual growth rate of 26.92%.Preschool children (<7 years old) had the smallest annual growth rate of 27.41%, with an average annual growth rate of 6.57%.The results of Kruskal-Wallis rank sum test showed that there were significant differences in the number of patients in different age groups ($X^2=601.812$, $P<0.05$).The largest number was found in young and middle-aged people, while the smallest number was found in preschool children and the elderly. Further analysis found that the number of patients by gender was different in different age groups. The number of female patients was higher than that of males in the 15–49 years old age group, and the number of children and elderly male patients was higher than that of females. There were significant differences between children with different gender ($P<0.05$), as shown in Table 2.

Discussion

China has a vast territory and diverse topography, environment and climate conditions in different regions. Therefore, AR has significant regional differences and regional seasonal differences[9]. This study showed that the monthly variation trend of the number of AR patients in the region showed obvious seasonality, starting to increase in March in spring, reaching the peak in October in autumn, and the lowest in February in winter. Reasons to consider: (1) Spring and autumn are recognized as pollen seasons, and pollen can be used as an allergen to induce the onset of AR[10]. In addition, the climate is relatively hot in summer and autumn, and air conditioning is often used, which is easy to cause dry indoor air, leading to blood circulation disorders in the nasal mucosa, and then causing AR[11]. (2) The proportion of AR caused by pets is increasing year by year[12]. It will continue to affect the changes of AR allergen spectrum in China. (3) Although previous studies showed that the peak of medical visits in this region was in September and began to decline in October[9], COVID-19 has affected the living habits and health status of patients[13]. In order to reduce the spread of the epidemic, prevention and control measures were implemented to reduce the behavior of going out and working from home. These

Year	2018	2019	2020	2021	2022	2023	Growth rate	Average annual growth rate
Total number	7737	8372	9177	11,489	11,698	13,723	77.37%	12.14%
Sex								
Men	3967	4464	4867	6019	6306	7251	82.78%	12.82%
Women	3770	3908	4310	5470	5392	6472	71.67%	11.41%
Age								
<7s	842	1002	1061	1452	982	1157	27.41%	6.57%
7~14s	1192	1449	1609	1620	1617	2066	73.32%	11.62%
15~29s	1445	1554	1528	2061	2155	2519	74.33%	11.75%
30~44s	2371	2337	2658	3327	3178	3346	41.12%	7.13%
45~59s	1225	1258	1364	1770	2077	2455	100.41%	14.92%
≥60s	662	772	957	1259	1689	2180	229.31%	26.92%

Table 1. Analysis of patients in different genders and age groups from 2018 to 2023. Note Growth rate (%) =(b-a)/a ×100; Average annual growth rate (%) = ($\sqrt[n]{b/a}$-1) ×100, n = number of years – 1, a = The number of AR patients in the last year, b = The number of AR patients in the first year.



	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023
Men	12.53%	9.03%	23.67%	4.77%	14.99%
Women	3.66%	10.27%	26.91%	-1.43%	20.02%
TAGR	8.21%	9.62%	25.19%	1.82%	17.31%
<7	19%	5.89%	36.85%	-32.37%	17.82%
7~14	21.56%	11.04%	0.68%	-0.19%	27.77%
15~29	7.54%	-1.67%	34.88%	4.56%	16.89%
30~44	-1.43%	13.74%	25.17%	-4.48%	5.29%
45~59	2.69%	8.43%	29.77%	17.34%	18.20%
≥60	16.62%	23.96%	31.56%	34.15%	29.07%

Fig. 2. Changes in annual growth rates by gender and age groups from 2018 to 2023. Note TAGR: total annual growth rate.

Age	< 7s		7~14s		15~29s		30~44s		45~59s		≥ 60s	
Sex	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
2018	527	315	750	442	672	773	1078	1293	584	641	356	306
2019	641	361	953	496	768	786	1058	1279	645	613	399	373
2020	671	390	1073	536	772	756	1223	1435	622	742	506	451
2021	881	571	1109	511	988	1073	1535	1792	823	947	683	576
2022	620	362	1076	541	1102	1053	1552	1626	1015	1062	941	748
2023	749	408	1379	687	1221	1298	1607	1739	1182	1273	1113	1067
Aggregate	4089	2407	6340	3213	5523	5739	8053	9164	4871	5278	3998	3521
Sum total	6496		9553		11,262		17,217		10,149		7519	
t	4.561		5.756		-0.285		-1.348		-0.467		0.467	
p	0.001*		0.00018*		0.781		0.207		0.651		0.650	

Table 2. Analysis of patients in different gender and age groups from 2018 to 2023. Note $^{*}P < 0.05$.

measures may result in increased patient exposure to indoor allergens[14]. In addition, a global systematic review of psychological outcomes among the public during the COVID-19 pandemic[15]. It found relatively high rates of post-traumatic stress disorder and psychological stress. Acute symptoms of COVID-19 overlap with those of allergic rhinitis (AR), which may affect mental health and disease management. All these will further affect the

peak hours of outpatient visits for AR patients, so it is necessary to arrange outpatient visits reasonably to meet the changing trend of patient demand.

This study showed that the prevalence of AR increased year by year, which is consistent with previous studies[16]. And COVID-19 appears to have accelerated the annual increase in prevalence. The possible reasons are as follows. 1) COVID-19 may increase the diagnosis rate of allergic rhinitis[17,18]. However, a study in South Korea did not find significant changes in the prevalence and diagnosis of chronic allergic diseases before and after the COVID-19 epidemic, but observed changes in physical activity and sleep quality[19]. More studies are needed to further confirm the relationship between COVID-19 and AR. At the same time, medical staff should consider lifestyle changes in the treatment of AR patients. 2) COVID-19 affects the health of individuals, including physical, mental, and social health. This is related to the uncertainty of infection associated with COVID-19 and changes in dietary and exercise habits due to quarantine measures[20]. At the same time because of COVID − 19 pandemic, people's physical activity is restricted, sleep and circadian rhythm and negative effects of stress. It causes the "asynchrony" of the internal biological clock and the external biological clock, resulting in biological rhythm disorder, which may aggravate the occurrence and development of respiratory allergic diseases[21]. Animal experiments have confirmed that intervention of circadian clock gene activity can help maintain the minimum inflammatory response state of nasal mucosa and inhibit the temporal onset of AR[22]. 3) COVID-19 caused dysbacteriosis in AR patients. Human nasal epithelial cells show the highest expression of angiotensin-converting enzyme II (ACE2) among all studied cells in the upper and lower airways[23], and SARS-CoV-2 infection can also increase ACE2 expression in human nasal epithelial cells[24]. ACE2 is the receptor-binding domain of SARS-CoV-2[25]. It is an important organ for SARS-CoV-2 entry and COVID-19 development. The symbiotic flora will be unbalanced with the combination of SARS-CoV-2 virus and ACE2 receptors present in the nasal mucosa[26]. It can cause inflammation, induce allergy, and increase the prevalence of AR. 4) Because SARS-CoV-2 virus and COVID-19 mRNA vaccines have relatively large protein sequences homologous to grass pollen, dust mite and mold. Therefore, infection with SARS-CoV-2 virus and vaccination against COVID-19 may promote T cell cross-reactivity with allergens that affect allergic rhinitis[27]. Animal studies have also confirmed that previous influenza infection in mice alleviates future allergic airway reaction[28]. Therefore, in 2022, all the people in China will be basically immunized after the popularization of the vaccine, and the corresponding annual growth rate will decrease. However, after the full liberalization at the end of 2022, all living and working habits will change again, and the annual growth rate of AR prevalence will basically return to the same.

This study found that compared with other age groups, the number of elderly patients increased year by year, especially the growth rate was obvious, and the annual growth rate of preschool children (< 7 years old group) was the least. This is different from previous studies[29]. The possible reasons are as follows. (1) COVID − 19 elderly patients over 55 affected is larger, the majority of cases tend to be critical to the critically ill[30]. This will lead to longer persistence of the COVID-19 virus and more and longer use of drugs to treat it. Studies have shown that frequent exposure to viral infections stimulates the development of standard Th1 immune responses[31]. These activated immune cells initiate a cascade of local and systemic inflammatory responses. Many signs and symptoms of AR are caused by uncontrolled inflammation[32]. In addition, long-term and extensive use of antibiotics may lead to ecological dysbiosis in the body[33]. It may induce, amplify and maintain immunopathological phenomena related to allergic rhinitis[34], and then cause allergy. Studies have confirmed that the use of paracetamol at least once a month is considered a positive correlation factor for the occurrence of AR, and different studies have confirmed the presence of intestinal and nasal dysbiosis in AR patients[35]. (2) The impact of environmental factors aggravates the infertility of Chinese people[36]. The COVID-19 epidemic affects the economic development, population mobility and people's happiness, which will further affect the low fertility rate in China[37]. Therefore, at this stage, the birth rate of our country is declining, and the trend of national population aging is more and more serious. With the increase of the elderly population base, the prevalence rate will further increase. In addition, elderly patients have more chronic diseases, and their immune system changes significantly, leading to atypical clinical manifestations of AR. The daily life and health problems of elderly AR patients have become a topic of widespread concern in Chinese society. The diagnosis and treatment of AR in the elderly has its own particularity, which needs to be paid enough attention.

This study showed that the young and middle-aged group (30–44 years old) had the largest number of AR patients, while preschool children and the elderly were relatively the least. This is consistent with the results of previous studies. Compared to adults, the development of immune system function in children undergoes significant changes at different stages of growth. With advancing age, there is a gradual increase in prevalence until reaching its peak during the 11–13 years old period, after which it starts declining[38,39]. It increased with the increase of age and reached the peak in young adults (19–49 years old group)[38], and then showed a downward trend with the increase of age[40]. Moreover, individuals aged 0–18 years are less likely to develop severe or critical illness during COVID-19[33]. They usually have an effective and active innate immune response, less respiratory exposure, and often few or no comorbidities. Therefore, the impact of COVID-19 on preschool children is less. The above shows that age is a key factor affecting sensitization. Therefore, this study carried out a research investigation design for different ages of AR. It is better to guide medical staff to take active and effective prevention and treatment for AR in different populations.

From 2018 to 2023, there would be a consistent annual increase in the total number of male and female patients. The prevalence of male patients surpasses that of females, particularly among children (< 15 years old). A significant gender disparity exists among patients. The number of individuals aged 15–59 years exceeds that of males, while elderly patients (≥ 60 years old) are predominantly male; however, this difference is not statistically significant. These findings align with the outcomes reported in a global systematic review[41]. Due to the complexity of allergy-related diseases, the reasons and associated factors explaining this phenomenon are not well defined. 1)Genetic differences Studies have suggested that there may be genetic differences in the sensitivity of boys and girls to environmental exposure[42]. Studies have shown that IgE sensitivity declines in

girls from childhood to early adulthood and that multiple IgE sensitization is more common in boys than in girls[43,44]. This also accounts for the significantly more AR in boys than in girls. However, there does not appear to be a difference between females and males in terms of IgE multiple sensitization in adulthood[45]. 2) Hormone differences Allergic rhinitis is a type 2 inflammatory reaction. Estrogen and progesterone enhance type 2 inflammation and inhibit type 1 inflammation, while testosterone inhibits type 2 inflammation in men[46]. Estrogen and its receptors in inflammatory cells are involved in allergic reactions[47]. Estrogen affects mast cell activation and enhances IgE-mediated mast cell degranulation, which can amplify neurogenic inflammatory responses. This results in changes in allergen dose response and different nasal symptoms[48]. Other studies have also shown that estrogen increases Muc5AC and Muc5B mucin expression and mucus production, whereas progesterone decreases ciliary retraction and mucociliary clearance[49]. People with allergic diseases experienced a higher negative psychological impact during COVID-19[50]. In particular, female adults diagnosed with allergies and asthma by doctors are more likely to report stress, depression, loneliness and hopelessness[51], which affects patients' psychological state and sleep. This will also increase the risk of developing AR in female patients. But men have a higher allergy index than women[52]. Therefore, with the menopause of women, the AR patients are mainly male patients.

Conclusion

This study collected data on outpatient visits from 2018 to 2023 to investigate the impact of COVID-19 on the prevalence of allergic rhinitis. The results showed that the prevalence of AR increased year by year with obvious seasonality, and COVID-19 seemed to accelerate the process. The increased number is especially reflected in the elderly, but the young and middle-aged people are still the main population. There are gender differences in different age groups of AR patients, mainly reflected in preschool children. COVID-19 seems to highlight more clearly the impact of changes in estrogen levels on AR prevalence. This relationship has not been fully demonstrated. These results provide important information for understanding the changes in the prevalence of chronic allergic diseases after the COVID-19 pandemic. It also provides direction for prevention and management. The strength of this study is the use of raw data from a representative survey. However, this study has limitations. We use self-report scale, and the lack of relevant variables to assess the patients psychological and lifestyle changes. The prevalence of AR also shows great regional differences. The findings may provide valuable insights to other countries facing similar situations. Further research is also needed to better understand the relationship between COVID-19 and chronic allergic diseases.

Data availability

The original data can be obtained from the corresponding author by email upon reasonable request. (tianrrall@yeah.net).

Received: 2 June 2024; Accepted: 11 October 2024
Published online: 23 October 2024

References

1. Esmaeilzadeh, H., Goodarzian Mr, Abbasi, A., Alamdari, M. & Mortazavi, N. Face mask correlation with allergic rhinitis symptoms severity during COVID-19 pandemic: A cross-sectional study. *Health Sci. Rep.* **6**(4),e1226. https://doi.org/10.1002/hsr2.1226 (2023).
2. Ha, J., Lee, S. W. & Yon, D. K. Ten-year trends and prevalence of asthma, allergic rhinitis, and atopic dermatitis among the Korean population, 2008–2017. *Clin. Exp. Pediatr.* **63**, 278–283. https://doi.org/10.3345/cep.2019.01291 (2020).
3. Dierick, B. J. H. et al. Burden and socioeconomics of asthma, allergic rhinitis, atopic dermatitis and food allergy. *Expert Rev. Pharmacoecon Outcomes Res.* **20**, 437–453. https://doi.org/10.1080/14737167.2020.1819793 (2020).
4. Coronaviridae Study Group of the International Committee on Taxonomy of Viruses The species severe acute respiratory syndrome-related coronavirus: classifying 2019-nCoV and naming it SARS-CoV-2. *Nat. Microbiol.* **5**, 536–544. https://doi.org/10.1038/s41564-020-0695-z (2020).
5. Lukassen, S. et al. SARS-CoV-2 receptor ACE2 and TMPRSS2 are primarily expressed in bronchial transient secretory cells. *EMBO J.* **39**(10), e105114. https://doi.org/10.15252/embj.20105114 (2020).
6. Leisman, D. E. et al. Cytokine elevation in severe and critical COVID-19: a rapid systematic review, meta-analysis, and comparison with other inflammatory syndromes. *Lancet Respir. Med.* **8**(12), 1233–1244. https://doi.org/10.1016/S2213-2600(20)30404-5 (2020).
7. Park, K. H., Kim, A. R., Yang, M. A., Lim, S. J. & Park, J. H. Impact of the COVID-19 pandemic on the lifestyle, mental health, and quality of life of adults in South Korea. **16**(2), e0247970. https://doi.org/10.1371/journal.pone.0247970 (2021).
8. Hyo, G. C. et al. Incidence of Asthma, atopic dermatitis, and allergic rhinitis in Korean adults before and during the COVID-19 pandemic using data from the Korea National Health and Nutrition Examination Survey. *Int. J. Environ. Res. Public Health* **19**(21). https://doi.org/10.3390/ijerph192114274((2022).
9. Zheng, M. et al. Clinical characteristics of allergic rhinitis patients in 13 metropolitan cities of China. *Allergy* **76**(2), 577–581. https://doi.org/10.1111/all.14561 (2021).
10. Forkel, S. et al. Allergic rhinitis to weed pollen in Germany: dominance by plantain, rising prevalence, and polysensitization rates over 20 Years. *Int. Arch. Allergy Immunol.* **181**(2),128–135. https://doi.org/10.1159/000504297 (2020).
11. Le Merre, C., Isber, J., Chediak, A. D. & Wanner, A. Effects of cold dry air nasal stimulation on airway mucosal blood flow in humans. *Arch. Physiol. Biochem.* **111**(4), 327–329. https://doi.org/10.3109/13813450312331337513 (2003).
12. Editorial Committee of Chinese Journal of Otorhinolaryngology Head and Neck Surgery, Chinese Society of Otorhinolaryngology Head and Neck Surgery, Chinese Medical Association. China guide to diagnosis and treatment of allergic rhinitis (2022 edition). *Chin. J. Otolaryngol. head neck Surg.* **57**(2), 106–129. (2022).
13. Alkotob, S. S. et al. Advances and novel developments in environmental influences on the development of atopic diseases. *Allergy* **75**(12), 3077–3086. https://doi.org/10.1111/all.14624 (2020).
14. Liva, G. A., Karatzanis, A. D. & Prokopakis, E. P. Review of rhinitis: Classification, types, pathophysiology. *J. Clin. Med.* **10**(14), 3183. https://doi.org/10.3390/jcm10143183 (2021).
15. Shaker, M. S. et al. COVID-19: pandemic contingency planning for the allergy and immunology clinic. *J. Allergy Clin. Immunol. Pract.* **8**(5):1477–1488.e5. https://doi.org/10.1016/j.jaip.2020.03.012(2020).

16. Shcherbakov, A. I. et al. Anosmia in COVID-19 and allergic rhinitis. Effect of masking on the severity of symptoms. *Immunologiya* **43**(2), 224–234. https://doi.org/10.33029/0206-4952-2022-43-2-224-234 (2022).
17. Chung, T. W. H. et al. Olfactory dysfunction in coronavirus disease 2019 patients: Observational cohort study and system¬atic review. *Open. Forum Infect. Dis.* **7**(6), ofaa199. https://doi.org/10.1093/ofid/ofaa199 (2020).
18. Ghaznavi, C. Changes in marriage, divorce and births during the COVID-19 pandemic in Japan. *BMJ Glob. Health.* **7**(5):e007866. https://doi.org/10.1136/bmjgh-2021-007866 (2022).
19. Choi, S. & Kim, B. Comparison of the prevalence and risk factors of chronic allergic diseases before and after COVID-19: using raw data from the Korea National Health and Nutrition Examination Survey in 2019 and 2021. *J. Asthma: Off. J. Assoc. Care Asthma* **60**(12), 2093–2103. https://doi.org/10.1080/02770903.2023.2220791 (2023).
20. Lee, D. et al. The influence of public fear, and psycho-social experiences during the coronavirus disease 2019 (COVID-19) pandemic on depression and anxiety in South Korea. *KJCP* **32**(4), 2119–2156. https://doi.org/10.23844/kjcp.2020.11.32.4.2119 (2020).
21. Nakao, A. Circadian regulation of the biology of allergic disease: Clock disruption can promote allergy. *Front. Immunol.*. **11**, 1237. https://doi.org/10.3389/fimmu.2020.01237 (2020).
22. Cheng, F. L., Zhang, Y. T., Kang, R. & Zhao, C. Clock regulate respiratory allergic disease. The new development of research on the Chinese medical journal **101**(18), 1377–1380. https://doi.org/10.3760/cma.j.c.n112137-20201209-03321 (2021).
23. Sungnak, W. et al. SARS-CoV-2 entry factors are highly expressed in nasal epithelial cells together with innate immune genes. *Nat. Med.* **26**(5), 681–687. https://doi.org/10.1038/s41591-020-0868-6 (2020).
24. Ziegler, C. G. K. et al. SARS-CoV-2 receptor ACE2 is an interferon-stimulated gene in human airway epithelial cells and is detected in specific cell subsets across tissues. **181**(5), 1016–1035.e19. https://doi.org/10.1016/j.cell.2020.04.035. (2020).
25. Suzaki, I. & Kobayashi, H. Coronavirus Disease 2019 and nasal conditions: a review of current evidence. In vivo (Athens, Greece). **35**(3), 1409–1417. https://doi.org/10.21873/invivo.12393 (2021).
26. Wu, Y. et al. Altered oral and gut microbiota and its association with SARS–CoV–2 viral load in COVID–19 patients during hospitalization. *NPJ Biofilms Microbiomes.* **7**(1), 61. https://doi.org/10.1038/s41522-021-00232-5 (2021).
27. Hartwell, M., Greiner, B. H. & Nicks, S. Examination of homologies between COVID-19 vaccines and Common allergens: The potential for T cell-mediated responses for allergic Rhinitis and Asthma. *Infect. Dis. Immun.* **2**(4), 282–284. https://doi.org/10.1097/ID9.0000000000000056 (2022).
28. Skevaki, C. et al. Influenza-derived peptides cross-react with allergens and provide asthma protection. *J. Allergy Clin. Immunol.* **142**(3), 804–814. https://doi.org/10.1016/j.jaci.2017.07.056 (2018).
29. Wang, T. Q. et al. Analysis of the characteristics of patients with allergic rhinitis in Beijing from 2016 to 2021 using big data. *Chin. J. Prev. Med.* **57**(9), 1380–1384. https://doi.org/10.3760/cma.j.cn112150-20220928-00936 (2023).
30. Verma, V. K. et al. Differential host responses to COVID-19: Unraveling the complexity. Diagnostic microbiology and infectious disease. **109**(2), 116281. https://doi.org/10.1016/j.diagmicrobio.116281 (2024).
31. Urrutia-Pereira, M. et al. Prevalence of rhinitis and associated factors in adolescents and adults: A global asthma network study. *Revista paulista de pediatria: orgao oficial da Sociedade de Pediatria de Sao Paulo* **41**, e2021400. https://doi.org/10.1590/1984-0462/2023/41/2021400 (2023).
32. Krsmanović, L. et al. The impact of cytokines on health-related quality of life in adolescents with allergic rhinitis. *Biomedicines* **12**, 2. https://doi.org/10.3390/biomedicines12020428 (2024).
33. Schuler, C. F. I. V. & Montejo, J. M. Allergic rhinitis in children and adolescents. *Pediatr. Clin. North Am.* **66**(5), 981–993. https://doi.org/10.1016/j.pcl.2019.06.004 (2019).
34. Cait, A. et al. Prenatal antibiotic exposure, asthma, and the atopic march: a systematic review and meta-analysis. *Allergy* **77**(11), 3233–3248. https://doi.org/10.1111/all.15404 (2022).
35. Kelly, M. et al. The environmental microbiome, allergic disease and asthma. *J. Allergy Clin. Immunol. Pr.* **10**(9), 2206–2217e1. https://doi.org/10.1016/j.jaip.2022.06.006 (2022).
36. Feng, R. & Chen, B. Environmental risks and infertility in China. *Science (New York, NY)* **383**(6680), 267–268. https://doi.org/10.1126/science.adn3214 (2024).
37. Xiao, X. D., Chang, B. R. & Lian, R. Does China's residential mobility reduce fertility intentions? The mediating role of well-being. *Acta. Psychol.* **241**, 104082. https://doi.org/10.1016/j.actpsy.2023.104082 (2023).
38. Lin, Y. et al. Analysis of specific sIgE of dermatophagoides pteronyssinus and aspergillus fumigatus in 2 535 patients with respiratory allergic diseases and respiratory infectious diseases in Guangzhou area. *Chin. Prev. Med. J.* **56**6, 755–762. https://doi.org/10.3760/cma.j.c.n112150-20211209-01141 (2022).
39. Wang, R. K. et al. Prevalence of allergic rhinitis in children and adolescents in China from 2001 to 2021: A meta-analysis. *Chin. Prev. Med. J.* **56**(6), 784–793. https://doi.org/10.3760/cma.j.c.n112150-20220315-00242 (2022).
40. HU, S. J. et al. Prevalence and risk factors of allergic rhinitis: a Meta-analysis. *J. Clin. Otorhinolaryngol. Head Neck Surg.* **31**(19), 1485–1491. https://doi.org/10.13201/j.issn.1001-1781.2017.19.006 (2017).
41. Fröhlich, M. et al. Is there a sex–shift in prevalence of allergic rhinitis and comorbid asthma from childhood to adulthood? A meta–analysis. *Clin. Transl Allergy* **7**, 44. https://doi.org/10.1186/s13601-017-0176-5 (2017).
42. Almqvist, C., Worm, M. & Leynaert, B. Impact of gender on asthma in childhood and adolescence: A ga2LEN review. *Allergy* **63**(1), 47–57. https://doi.org/10.1111/j.1398-9995.01524.x (2008).
43. Ballardini, N. et al. Resolved allergen-specific IgE sensitization among females and early poly-sensitization among males impact IgE sensitization up to age 24 years. *Clin. Experimental Allergy: J. Br. Soc. Allergy Clin. Immunol.* **51**(6), 849–852. https://doi.org/10.1111/cea.13846 (2021).
44. Siroux, V. et al. The asthma-rhinitis multimorbidity is associated with IgE polysensitization in adolescents and adults. *Allergy* **73**(7), 1447–1458. https://doi.org/10.1111/all.13410 (2018).
45. Dor-Wojnarowska, A. et al. The impact of sex and age on the prevalence of clinically relevant sensitization and asymptomatic sensitization in the general population. *Arch. Immunol. Ther. Exp. (Warsz)* **65**(3), 253–261. https://doi.org/10.1007/s00005-016-0425-7 (2017).
46. Cephus, J. Y. et al. Estrogen receptor–α signaling increases allergen–induced IL–33 release and airway inflammation. *Allergy* **76**(1), 255–268. https://doi.org/10.1111/all.14491 (2021).
47. Chen, W., Mempel, M., Schober, W., Behrendt, H. & Ring, J. Gender difference, sex hormones, and immediate type hypersensitivity reactions. *Allergy* **63**(11), 1418–1427. https://doi.org/10.1111/j.1398-9995.2008.01880.x (2008).
48. Tomljenovic, D. et al. Females have stronger neurogenic response than males after non-specific nasal challenge in patients with seasonal allergic rhinitis. *Med. Hypotheses* **116**, 114–118. https://doi.org/10.1016/j.mehy.2018.04.021 (2018).
49. Tam, A., Wadsworth, S., Dorscheid, D., Man, S. F. & Sin, D. D. Estradiol in creases mucus synthesis in bronchial epithelial cells. *PLoS One* **9**, e100633. https://doi.org/10.1371/journal.pone.0100633 (2014).
50. Camacho-Rivera, M., Islam, J. Y., Vidot, D. C. & Jariwala, S. Prevalence and risk factors of COVID-19 symptoms among U.S. adults with allergies. *Int. J. Environ. Res. Public. Health* **18**(5), 2231. https://doi.org/10.3390/ijerph18052231 (2021).
51. Gonzalez-Diaz, S. N. et al. Psychological impact of the COVID-19 pandemic on patients with allergic diseases. *World Allergy Organ. J.* **14**(3), 100510. https://doi.org/10.1016/j.waojou.2021.100510 (2021).
52. Boulet, L. P. et al. Comparative degree and type of sensitization to common indoor and outdoor allergens in subjects with allergic rhinitis and/or asthma. *Clin. Exp. Allergy* **27**(1), 52–59. https://doi.org/10.1111/j.1365-2222.tb00672.x (1997).

Author contributions

Conceptualization: R.T., J.D., J.Z. and J.J. Data curation: R.T. , X.Z. and J.Z. Formal analysis: R.T.. Funding acquisition: R.T., J.D. and J.J. Investigation: R.T.. Methodology: J.D. and J.J. Project administration: J.D. and J.J. Supervision: J.D. and J.J. Writing—original draft: R.T. Writing—review & editing: J.D. and J.J.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to R.T.

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