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Urban-Rural Disparities in Bronchial Asthma: A Review of Environmental Determinants and Epidemiological Insights

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Abstract

Introduction and aim of the study

Bronchial asthma, as defined by the Global Initiative for Asthma (GINA, 2024), is a heterogeneous disease characterized by chronic inflammation of the airways. This study aims to investigate the impact of environmental factors, including air quality and early-life exposure to microbiota, on the prevalence and development of asthma in urban and rural populations.

Brief overview of the current state of knowledge

Asthma currently affects approximately 300 million people worldwide, with its prevalence increasing, especially in industrialized countries. Exposure of children to diverse microbiota, typical of farming environments, is associated with a lower risk of developing asthma and atopic diseases, which supports the hygiene hypothesis. In contrast, air pollution in urban agglomerations-especially particulate matter (PM2.5, PM10), nitrogen oxides, and polycyclic

aromatic hydrocarbons-represents a significant risk factor. The pathomechanism of asthma involves complex immune responses in which chronic inflammation and bronchial hyperresponsiveness are modulated by environmental factors. Epidemiological studies indicate a higher prevalence of asthma in cities, which is associated with reduced immune stimulation by diverse microflora and increased exposure to pollutants.

Conclusion

Available data confirm the complex role of environmental factors in the etiology of asthma. Preventive strategies should include reducing air pollution, especially in urban areas, and promoting safe contact of children with natural microbiota. Further research integrating epidemiology, immunology, and environmental protection is essential to develop effective strategies for asthma prevention and treatment.

Keywords: Bronchial asthma; Microbiota; Hygiene hypothesis; Air pollution; Urban environment; Rural environment

Introduction

Bronchial asthma, according to the Global Initiative for Asthma (GINA) 2024 definition, is a heterogeneous disease characterized by chronic inflammation of the airways [1]. Typical clinical symptoms include wheezing, shortness of breath, and a dry, paroxysmal cough. The increased risk of developing asthma is influenced by both individual factors (e.g., atopy) and environmental factors, including exposure to tobacco smoke, occupational hazards, and air pollution.

Currently, approximately 300 million people worldwide have asthma, making it a significant global public health issue. The increasing incidence is particularly observed in highly developed, industrialized, and urbanized countries [2][3][4]. It is estimated that in Poland, around 4 to 5

million people suffer from asthma, which constitutes a serious social and healthcare challenge requiring preventive measures and early disease detection [5].

The impact of the microbiota on asthma development

The development of asthma can be modulated, among other factors, by early-life exposure to microbiota. Numerous studies have demonstrated that the environment in which a child grows up plays a significant role in shaping their immune system. Since the beginning of the 21st century, a reduced prevalence of asthma has been observed among children raised in agricultural environments, particularly on farms engaged in livestock breeding [1][6]. These children exhibited a lower incidence of allergic reactions and other atopic diseases [7].

Similar associations have been observed in infants who consumed raw dairy products during their first year of life [8]. These findings suggest that early and diverse exposure to microorganisms is inversely correlated with the risk of developing asthma. Contact with a rich and diverse microbiome during infancy may play a significant role in shaping immunological tolerance. Such environmental influences promote the maturation of the immune system toward allergen tolerance, which may lead to a decreased susceptibility to allergic diseases, including asthma.

The hygiene hypothesis

This phenomenon is explained by the so-called hygiene hypothesis, proposed in the 1980s by Strachan. This hypothesis suggests that the rising incidence of allergic diseases in highly developed countries may be the result of significantly reduced exposure of children to microorganisms during early life stages [9]. High sanitary standards, urbanization, smaller family sizes, and limited contact with the natural environment may lead to insufficient immune system stimulation. As a consequence, improper differentiation of T lymphocytes may occur, favoring a Th2-type immune response, which is characteristic of allergic reactions [10].

In light of the above findings, promoting early, controlled, and safe exposure of children to microbiologically diverse environments may represent a potential preventive strategy against atopic diseases, including asthma.

Pathomechanism of bronchial asthma

The inflammatory pathomechanism in bronchial asthma is complex, involving both innate and adaptive immune responses. The first stage involves contact with an allergen, which triggers the activation of dendritic cells and the presentation of antigens to Th2 lymphocytes. These, in turn, secrete cytokines such as IL-4, IL-5, and IL-13, which play a key role in the development

of the inflammatory response [11]. IL-4 and IL-13 induce the production of IgE by B lymphocytes, which subsequently bind to FcεRI receptors on mast cells and basophils. Upon re-exposure to the allergen, these cells degranulate, releasing histamine, leukotrienes, and cytokines that cause bronchial smooth muscle contraction, increased vascular permeability, and mucus production [12][13]. IL-5 is crucial for the recruitment and activation of eosinophils, which release pro-inflammatory mediators such as leukotrienes and basic proteins, contributing to the maintenance of inflammation [14].

In the innate immune response, ILC2 cells, activated by IL-33, IL-25, and TSLP, produce IL-5 and IL-13, thereby supporting the Th2 response and amplifying inflammation [15]. In the chronic course of asthma, airway remodeling occurs, including thickening of the basement membrane, hypertrophy of smooth muscle cells, and increased mucus production, leading to persistent airway obstruction [12].

The described pathomechanism of bronchial asthma is, therefore, multifaceted and can be modified by environmental factors such as air pollution and limited exposure to microorganisms in early childhood.

Contrast in air quality between urban and rural areas

Considering the pathophysiological mechanisms of asthma-such as chronic inflammation of the airways and bronchial hyperresponsiveness to environmental factors-the quality and composition of the air are of significant importance. These factors can vary significantly depending on the type of residential area. These differences directly affect the level of exposure to harmful irritants and allergens, which can trigger or exacerbate disease symptoms.

Discrepancies in the chemical composition of air between urban and rural areas primarily result from different sources of atmospheric pollutant emissions. In urban environments, the predominant pollutants are particulate matter (PM10 and PM2.5), nitrogen oxides (NOx), and polycyclic aromatic hydrocarbons (PAHs) [16]. Their primary sources are heavy road traffic [3] and emissions from the residential and industrial sectors [17]. In rural areas, these pollutants are also present, but their origin is more often linked to agricultural activities and the burning of biomass, especially in individual heating sources. It is worth noting that the combustion of solid fuels can significantly impact local air pollution levels. It is known that the concentration of these pollutants depends not only on the source and volume of emissions but also on meteorological conditions, such as air circulation, temperature, wind speed, and the amount of precipitation [5]. Numerous studies have shown that concentrations of particulate matter

increase significantly during the heating season, while in urban environments, additional daily fluctuations are observed, correlating with traffic intensity, especially during morning and evening hours [18].

Available data indicate that air quality in urban areas is generally worse than in rural regions. Studies conducted in China found that the average concentration of PM2.5 in cities was 61.0 μg/m³, while in rural areas, it was 52.7 μg/m³ [19]. Referring to PAH concentrations, research conducted in the Silesian Voivodeship in Poland showed that during the heating season, PAH levels in urban areas were significantly higher than in rural areas. In particular, the toxic equivalent (TEQ) values for PAHs at urban monitoring stations were as much as 12.5 times higher than those at rural stations in that region [20]. Similar differences are observed in other European countries—for example, according to data from the European Environment Agency, average annual concentrations of PM2.5 in urban agglomerations often exceed WHO-recommended values (EEA, 2023) [21].

It is essential to note that high concentrations of particulate matter in ambient air do not necessarily reflect an individual's actual exposure level. This is because people spend most of their time indoors, where air quality can significantly differ from outdoor conditions. The amount of time spent indoors depends on many factors, including the type of work performed, age, season, and residential location-all of which significantly influence individual patterns of air pollution exposure [22]. In one study conducted in Canada, living in rural areas was associated with significantly more time spent outdoors. Rural residents spent, on average, 1.7 times more time outdoors than city dwellers, equating to approximately 58 minutes more per day [23]. Such differences in time and type of activity can affect environmental exposure levels by altering the contribution of various microenvironments to the total dose of inhaled pollutants.

Prevalence of asthma

The severity of asthma as a public health issue is clearly illustrated by the Polish ECAP study, which involved nearly 19,000 respondents, a quarter of whom underwent ambulatory evaluation. This study demonstrated that bronchial asthma is the second most common allergic disease in the Polish population. Moreover, it was found that only 30% of individuals suffering from asthma had previously received a correct diagnosis-an alarming statistic suggesting that up to 70% of asthma cases may remain undiagnosed in Poland [4]. Although the study authors acknowledged the possibility of selection bias-due to the higher likelihood of participation

among individuals with suspected respiratory conditions-the data still indicate a significant underdiagnosis problem of asthma in both urban and rural environments.

The ECAP study also showed that children aged 6–7 years, and to a lesser extent those aged 13–14 years living in rural areas, had nearly twice the prevalence of asthma compared to their urban peers. However, among adults, the opposite trend was observed-those residing in urban areas were more frequently diagnosed with asthma. It was concluded that individuals in urban settings may be more susceptible to allergic diseases (including asthma) and that genetic predisposition plays a significant role in disease development [24].

This is not the only study indicating lower asthma prevalence in rural areas. One study conducted among a randomly selected group of residents of the Łódź Voivodeship compared the prevalence of atopic diseases, including asthma, in urban and rural populations. The results revealed substantial differences in the distribution of asthma depending on the living environment. Among adults living in city centers, the prevalence of asthma was 13.2%, compared to only 4.2% among adults living in rural areas. Similarly, among children, asthma was found in 18.4% of urban residents and only 6.0% of rural children [25].

International data largely support these trends. In Canada, a study involving school-aged youth found that asthma prevalence was lowest in rural areas (14.8%), slightly higher in suburban areas (15.6%), and highest in urban areas (17.7%). These differences were not associated with health behaviors or obesity, suggesting a likely influence of environmental factors [26]. A study conducted in China among children aged 14 years and younger showed that asthma prevalence was significantly lower in rural areas (1.25%) compared to urban areas (3.68%) [27]. In two Brazilian cities, Caruaru and Santa Maria, a study of adolescents aged 13–14 years revealed a higher prevalence of asthma and rhinitis among youth living in urban areas compared to those in rural regions. In Caruaru, the prevalence of asthma was 18.6% in urban areas and 12.5% in rural areas. However, in Santa Maria, no significant difference was found-prevalence was 16.7% in cities versus 15.3% in rural areas [28].

A global analysis comprising a systematic review and meta-analysis of cohort studies found that the risk of developing asthma was higher in urban areas compared to rural ones (relative risk [RR] = 1.27). These differences were particularly evident in the age groups 0–6 years and 0–18 years, with RRs of 1.21 and 1.35, respectively [29].

Conclusions

Available data suggest that the higher prevalence of asthma in urban populations may result from the interplay of multiple environmental factors, including air pollution and reduced exposure to microorganisms during early childhood. The inflammatory pathomechanisms involved in asthma are strongly modulated by these environmental influences, underscoring the need for further research into the environmental determinants of the disease. A better understanding of these mechanisms is crucial for developing effective asthma prevention strategies and public health policies.

It is essential to promote contact with natural environments, support efforts to reduce urban air pollution and design health programs tailored to the specific needs of both urban and rural populations. Early education and preventive measures, along with improved asthma diagnostics—particularly in rural populations-are key to reducing the overall disease burden. Furthermore, continued interdisciplinary research that integrates epidemiology, immunology, and environmental science is necessary to deepen our understanding of how environmental factors influence the development of asthma. This, in turn, will facilitate the creation of effective prevention and treatment strategies.

DISCLOSURE

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization: Wiktoria Cecuła. Methodology: Kamil Ciechomski, Wiktoria Cecuła. Investigation: Wiktoria Cecuła, Joanna Rypel-Bośka, Elżbieta Siuda. Data curation: Klaudia Goleniewska, Jakub Miaśnikiewicz, Aleksandra Stupecka. Writing – Original Draft: Kamil Ciechomski, Izabela Brynczka, Wiktoria Cecuła. Writing–Review & Editing: Natalia Siuta, Marcin Migiel. Supervision: Wiktoria Cecuła.

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The study was conducted in accordance with the Declaration of Helsinki. Ethical review and approval were waived because the data analyzed were retrospective and anonymized.

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