Global Economic Review: Journal of Economics, Policy, and Business Development
ISSN: 2980-5287
Volume 2, Issue 3, March 2026
Website: ecomindspress.com

SUBCLINICAL SMALL AIRWAY DYSFUNCTION IN URBAN ADOLESCENTS WITH NORMAL SPIROMETRY: A PILOT EPIDEMIOLOGICAL ANALYSIS

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Abstract

This study evaluated the functional state of small airways among adolescents living in an urban environment, with particular attention to the detection of subclinical changes despite normal conventional spirometric parameters. A total of 30 participants aged 15–17 years underwent spirometry, including assessment of FVC, FEV_1, FEV_1/FVC, PEF, and FEF25–75 indices. The results demonstrated that although the primary spirometric parameters remained within normal limits, the mean value of FEF25–75 was 66.7 ± 21.5%, indicating significant functional heterogeneity of the small airways. In 70% of participants, FEF25–75 values were reduced or borderline, suggesting early-stage small airway impairment. When integrated with contemporary scientific evidence, these findings confirm the high diagnostic sensitivity of FEF25–75 in assessing small airway function and highlight the necessity of early detection of environmentally associated respiratory alterations in urban populations.

Keywords: Small airways, FEF25–75, spirometry, PM2.5, adolescents, air pollution, respiratory hygiene.

Introduction

Atmospheric air pollution represents one of the most pressing environmental and epidemiological challenges facing global public health. According to the World Health Organization (WHO), approximately 6.7 million premature deaths annually are attributable to ambient and household air pollution, the majority of which are associated with respiratory and cardiovascular diseases. Fine particulate matter with a diameter of less than 2.5 micrometers (PM2.5) is considered one of the most

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hazardous components, as it can penetrate deeply into the distal airways, reaching bronchioles and alveoli.

Epidemiological studies indicate that each 10 μg/m³ increase in PM2.5 concentration is associated with an approximate 6–8% increase in all-cause mortality and a 10–15% increase in respiratory-related mortality. Long-term cohort studies conducted by Gauderman and colleagues have demonstrated that air pollution significantly impairs lung development in adolescents. Furthermore, Schraufnagel et al. describe air pollution as a multifactorial risk factor not only for respiratory diseases but also for metabolic and cardiovascular conditions.

Children and adolescents represent a particularly vulnerable population to the adverse effects of air pollution. During this developmental period, the lungs are not fully matured, and processes such as alveolar development and bronchial differentiation are ongoing. Therefore, environmental pollutants—including PM2.5, nitrogen dioxide, and ozone—may induce not only functional but also structural changes. Some studies report that the prevalence of respiratory symptoms associated with air pollution among adolescents reaches 20–30%.

Conventional spirometric parameters, including forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC), although widely used in clinical practice, primarily reflect the condition of large and medium-sized airways. Consequently, early pathological changes in small airways often remain undetected. In modern pulmonology, small airways are frequently referred to as the "silent zone," as functional impairments in this region may not be reflected in clinical symptoms or standard spirometry results for extended periods.

In recent years, the FEF25–75 parameter has been increasingly discussed as a sensitive indicator of small airway function. According to current scientific evidence, a reduction in this parameter represents an early sign of airflow limitation at the bronchiolar level and, in certain cases, allows earlier detection of pathology compared to FEV_1. Studies conducted by McConnell and colleagues have demonstrated a direct association between traffic-related air pollution and decreased small airway function. Recent observations indicate that air pollution levels in Tashkent have increased significantly in recent years, particularly during the winter season. Independent monitoring systems, such as IQAir, demonstrate that on certain days PM2.5 concentrations exceed the recommended limits of the World Health Organization (WHO) by several times. This situation underscores the necessity of investigating

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subclinical changes in the respiratory system among urban populations, particularly adolescents.

From this perspective, the assessment of small airway function and the early detection of its dysfunction are of critical importance for the prevention and early diagnosis of respiratory diseases. The aim of this study was to evaluate the functional state of small airways among adolescents living in an urban environment and to determine the diagnostic significance of the FEF25–75 parameter in detecting subclinical alterations.

Materials and Methods

The study was designed as a cross-sectional observational investigation involving 30 adolescents aged 15–17 years residing in Tashkent. Data collection was conducted between February and March 2026. Participants were recruited voluntarily, and informed consent was obtained from all respondents. Individuals with chronic respiratory diseases or acute infections were excluded from the study.

Data collection involved the use of a standardized questionnaire assessing living conditions, subjective evaluation of air quality, respiratory symptoms, passive smoking exposure, physical activity, and history of allergic diseases.

Pulmonary function was measured using a digital spirometer in accordance with ATS/ERS standards. Each participant performed at least three acceptable maneuvers, and the best result was selected for analysis. The parameters FVC, FEV_1, FEV_1/FVC, PEF, and FEF25–75 were measured, and results were expressed as percentages of predicted values.

Statistical analysis included descriptive measures (mean and standard deviation), coefficient of variation, categorical distribution, and χ^2 test. The association between FEF25–75 and potential environmental factors was considered at a theoretical level using Pearson correlation analysis. Statistical significance was set at $p < 0.05$.

Results and Discussion

The findings indicate that the majority of participants demonstrated normal values of FVC, FEV_1, and FEV_1/FVC, suggesting the absence of obstructive changes at the level of large and medium-caliber bronchi. However, significant alterations were observed in the FEF25–75 parameter, which reflects small airway function.

The mean value of FEF25–75 was 66.7 ± 21.5%, and the high coefficient of variation (approximately 32%) indicates pronounced heterogeneity in small airway function.

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In one-third of participants (33%), FEF25–75 values were below 50%, corresponding to a clearly pathological reduction. Borderline values were observed in 37% of cases, representing a subclinical risk group, while only 30% of participants exhibited values within the normal range.

The χ^2 statistical analysis revealed significant differences between categories ($p < 0.05$), indicating that small airway dysfunction is not a random finding. From an epidemiological perspective, subclinical functional alterations were identified in 70% of participants, reflecting a high prevalence.

These findings further confirm the limitations of conventional spirometric parameters in assessing small airway function. While normal values of FVC, FEV_1, and FEV_1/FVC indicate preserved respiratory function at the macrostructural level, the significant reduction in FEF25–75 suggests the presence of subclinical changes at the level of distal bronchi. This phenomenon may be interpreted in clinical practice as the "normal spirometry paradox," wherein standard spirometric indices remain within normal limits despite the presence of early pathological processes.

The mean value of FEF25–75 observed in the study (66.7 ± 21.5%), together with a high coefficient of variation (≈32%), indicates pronounced heterogeneity of small airway function within the population. This heterogeneity may be explained, on the one hand, by individual susceptibility and, on the other hand, by uneven exposure to environmental factors. Notably, the detection of reduced FEF25–75 values in 70% of participants (33% pathological and 37% borderline) represents an epidemiologically significant signal. This finding suggests a widespread subclinical impairment of small airways and indicates a potentially increased risk of future respiratory disease development in this population.

From a pathophysiological perspective, a decrease in FEF25–75 reflects reduced airflow velocity at the level of the bronchioles. Structural and functional alterations in small airways are typically associated with inflammatory infiltration, epithelial dysfunction, increased mucus secretion, and thickening of bronchial walls. These processes often occur without overt clinical symptoms, which is why small airways are commonly referred to as the "silent zone." The findings of this study provide empirical support for this concept.

Urban environmental factors, particularly elevated concentrations of PM2.5, exert a direct impact on small airways. Fine particulate matter penetrates to the alveolar level, induces the formation of reactive oxygen species, and enhances oxidative stress. This

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leads to increased release of inflammatory mediators and the development of bronchial hyperreactivity. As a result, airflow velocity decreases, which is reflected in reduced FEF25–75 values. These mechanisms are well supported in the scientific literature; for instance, studies by Gauderman and colleagues have demonstrated impaired lung development associated with PM2.5 exposure, while Schraufnagel et al. have emphasized the systemic impact of air pollution on multiple disease processes.

Another important implication of the results is that small airway dysfunction is detectable not only in individuals with overt pathology but also in populations considered clinically healthy. This supports the need to utilize FEF25–75 as a screening-level indicator. Particularly among adolescents, the application of this parameter enables the identification of early-stage respiratory alterations and facilitates timely implementation of preventive measures.

From a statistical standpoint, the identified categorical differences ($p < 0.05$) confirm that small airway dysfunction is not a random phenomenon. At the same time, the observed high dispersion suggests a potential role of individual environmental and lifestyle factors. Variables such as passive smoking exposure, low physical activity, and subjective perception of air quality may act as determinants influencing small airway function. However, the elucidation of these associations requires larger-scale cohort studies.

The findings of this study have important implications for clinical practice. Even when conventional spirometric parameters are within normal ranges, small airway pathology cannot be excluded. Therefore, the broader application of the FEF25–75 parameter—particularly among adolescents living in environmentally high-risk areas—should be considered an essential component of diagnostic algorithms. Such an approach may play a critical role in the early detection of respiratory diseases and in preventing their progression.

It is important to acknowledge the limitations of the present study. The relatively small sample size limits statistical power and reduces the generalizability of the findings. In addition, exposure factors were not measured objectively, which precludes definitive conclusions regarding causal relationships. Nevertheless, the identified trends are consistent with existing scientific evidence and provide a basis for future large-scale investigations.

Overall, the findings confirm the high diagnostic value of the FEF25–75 parameter in detecting early stages of small airway dysfunction and highlight the need for a revised

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approach to respiratory health assessment among adolescents living in urban environments.

Conclusion

The results of this study indicate that subclinical dysfunction of small airways is widely prevalent among adolescents living in urban settings and can be detected even when conventional spirometric parameters remain within normal ranges. A reduction in FEF25–75 serves as an important indicator of early pathological changes at the level of distal bronchi.

Urban environmental factors, particularly exposure to PM2.5, emerge as key pathogenic contributors to this process. The integration of small airway function assessment into clinical and preventive practice is therefore essential for preserving respiratory health in adolescent populations.

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