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Long-Term Exposure to Ambient Air Pollution in Childhood-Adolescence and Lung Function in Adulthood

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Abstract

The aim of the study was to evaluate the effect of air pollution in the dwelling place during childhood-adolescence on respiratory function in early adulthood. The study was conducted in 220 female and 160 male university undergraduates in the cities of Cracow and Wroclaw in Poland and consisted of spirometry to assess lung function. The subjects' exposure to pollution during childhood-adolescence was assessed from the data acquired by the Polish Chief Inspectorate for Environmental Protection. We found differences in all spirometry variables depending on benz[a]piren exposure, in FVC% and FEV_1/%FVC depending on $PM_{2.5}$ content, and in FVC% depending on NO_2 content. Statistically significant differences in spirometry variables were also found in relation to the degree of urbanization of the place of living during the early life period in question. The higher the urbanization, the higher is FEV_1% and FCV%, and the lower FEV_1/%FVC. Additionally, undergraduates of Cracow University had worse lung function compared to those of Wroclaw University. In conclusion, air pollution in the dwelling place during childhood-adolescence has an impact on lung function in early adulthood, independently of the current exposure to pollutants.

Keywords

Adolescence · Adulthood · Air pollution · Lung function · Particular matters · Spirometry · Urbanization

1 Introduction

Chronic respiratory diseases are among the most common health problems. Such diseases reduce lung capacity and respiratory ability, impairing functions of other systems and leading to comorbid conditions. According to WHO (2014), hundreds of millions of people suffer every day from respiratory diseases. An important part of the diagnostics is spirometry tests that enable the early detection of a lung function decrement. Forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC) are the two essential variables in the objective assessment of respiratory health. These variables are considered the

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early indicators of respiratory inflammation and also relate with cardiovascular diseases.

Air pollution is one of the most important environmental determinants of pulmonary function. According to a report by the European Environment Agency (2015), the most harmful substances detected in the air include suspended particulate matter, ozone, nitrogen dioxide, and benzo[a]pyrene; the last being a chemical compound present mainly in Eastern Europe. Poland is listed among countries where most pollutants exceed acceptable limits.

Acute respiratory health effects of worsening air quality are well established (Nkosi et al. 2016; Anderson et al. 2012; Sunyer 2009; Dominici et al. 2006). Numerous studies have evaluated the effects of long-term exposure to air pollution, which affects mostly children and adolescents as these populations are particularly sensitive to environmental factors (Perera et al. 2012; Wang et al. 2009; Calderón-Garcidueñas et al. 2008; Dales et al. 2008; Suglia et al. 2008). Children are more likely than adults to spend time outdoors, where the concentration of pollutants is greater, and their respiratory system is not yet fully developed. A greater ventilation rate and mouth-breathing may pull air pollutants deeper into the children's lungs, thereby making clearance slower and more difficult (Bateson and Schwartz 2007). Their immune system also is immature, which promotes respiratory infections.

Both longitudinal and cross-sectional studies show that long-term exposure to air pollution in childhood is associated with a retardation of the respiratory system development (Gauderman et al. 2002, 2004; Horak et al. 2002). However, some authors have failed to confirm such a relationship (Hoek et al. 2012; Nicolai et al. 2003). A Greek study has demonstrated that particulate air pollution has a significant impact on the development of nasal, but not lung, respiratory function (Spyratosa et al. 2015). Nonetheless, most studies point to a relation between long-term exposure to air pollution and respiratory health. Specifically, changes in spirometry variables and the intensity of respiratory symptoms are reported in the context of the atmospheric air quality. Pollutant emissions cause a deterioration of respiratory function in children and adolescents (Rice et al. 2016; Schultz et al. 2016), while a reduction in the emissions improves the function (Gauderman et al. 2015). A detrimental effect of pollutants on respiratory health may be present even when their content is below the current permissible limits (Moshammer et al. 2006).

Notwithstanding the respiratory detriment of air pollution in childhood above outlined, the adulthood consequences of the pollution are not fully documented; permanent lung damage or retardation in lung development is a possibility. Therefore, the present study seeks to examine the respiratory function in early adulthood in relation to air pollution in the current dwelling place and the dwelling place during childhood-adolescence of the same subjects.

2 Methods

2.1 Study Subjects

The study protocol was approved by a local Ethics Committee of the Jagiellonian University in Cracow, Poland. Data were collected following the ethical principles as stated in the Declaration of Helsinki for Human Research. The measurements were taken in March 2016 and January 2017. The study included 220 women and 160 men of the mean age of 20.5 ± 1.2 (SD) years, with the median of 20 years of age. There were 250 undergraduates of the Jagiellonian University in Cracow and 130 undergraduates of the University of Environmental and Life Sciences in Wroclaw, Poland. All participating subjects were free of chronic diseases other than possible food allergy and allergic rhinitis. All lived in the respective cities for at least one year.

2.2 Pulmonary Function, Dwelling Place, and Air Pollution

FEV_1 and FVC were measured, taking into consideration the best of three forced maneuvers. Data were expressed in the percentage of predicted values (%pred). In addition, the ratio of FEV_1/% FVC was calculated. Lung function was tested using a portable MIR Spirolab III device (Medical International Research; Rome, Italy).

The information on the number of years spent in the current dwelling place and the dwelling place during childhood-adolescence was collected by means of a questionnaire. The subject's dwelling place before entering a university was specified in categories defined according to the air pollution level (1. area of low air pollution; 2. area of average air pollution; and 3. area of high air pollution) and the degree of urbanization (1. city – over 100,000 inhabitants; 2. town – less than 100,000 inhabitants; and 3. village).

The subject's dwelling place during the childhood years also was stratified into three categories, taking into account the air quality to which the area in question was classified during a period of no less than 10 years. Class 1 refers to the zones below the lower cut-off limit; Class 2 – zones between the lower and upper cut-off limits; and Class 3 – zones above the upper cut-off limit. The annual lower and upper cut-off limits were as follows: for NO_2 30 and 40 μg/m^3, for benz[a] piren 4 and 5 μg/m^3, and for CO, for which no area qualified to Class 3, these limits were 0.5 and 1.0 mg/m^3, respectively. Concerning the $PM_{2.5}$ and PM_{10} particulate matter, all zones qualified to Class 3, i.e., the annual mean values exceeded 15 and 30 μg/m^3, respectively. The PM-related stratification considered three categories: moderate (<20 μg/m^3 for $PM_{2.5}$ and <40 μg/m^3 for PM_{10}), high (≥21 <25 μg/m^3 for $PM_{2.5}$ and ≥41 <50 μg/m^3 for PM_{10}), and very high level (>25 μg/m^3 for $PM_{2.5}$ and >50 μg/m^3 for PM_{10}). It was based on the measurements made over the last 16 years and expressed medians and tertiles.

A division into areas with different pollution levels was made on the basis of data acquired by the Chief Inspectorate for Environmental Protection in Poland between the years 2000 and 2016 (http//:www.gios.gov.pl).

2.3 Statistical Elaboration

Data were presented as means ± SD. Distribution of quantitative data was checked using the Shapiro-Wilk test. A *t*-test was used to evaluate differences in spirometry variables in relation to gender and the current dwelling place (Cracow or Wroclaw). Multivariate analysis of variance MANOVA was used to evaluate differences in lung function depending on air quality and the degree of urbanization of the dwelling place during childhood-adolescence and to verify the interactions between these variables. A p-value of <0.05 defined the statistically significant differences.

3 Results

Spirometry results, separately for women and men, are presented in Table 1. The results were slightly, albeit insignificantly, greater in men, both in the absolute values and in reference to standards. Further evaluation was thus performed for the whole group, regardless of gender.

Current residents of Cracow had a significantly lower FEV_1% and FVC%, while displaying a higher FEV_1/%FVC ratio than those living in Wroclaw (Table 2). Of note, both cities are characterized by a high level of air pollution and classified as air quality Class 3 in 2015–2016, taking into consideration $PM_{2.5}$, $PM_{10,}$ benz[a]piren and NO_2. In case of CO, Wroclaw was classified as Class 1 and Cracow as Class 2. In case of benz[a] piren Wroclaw was classified as Class 2, while Cracow as Class 3. Overall, greater average annual content of the above-mentioned pollutants was observed in Cracow than in Wroclaw. This study was, in part, conducted in January of 2017 when Cracow was shrouded in smog for several days, which, in all likelihood, influenced the results, as the spirometry variables were appreciably worse compared with the same period a year before.

The degree of urbanization of the dwelling place during childhood-adolescence was significantly associated with spirometry variables. A greater FEV_1 and FCV, and a lower FEV_1/FVC were noted among the undergraduates from rural areas than among those from urban areas (Table 3). In addition, the degree of urbanization significantly altered the relationship between the level of air pollutants and respiratory function. Variations in respiratory function across areas with different pollution were greater in large cities than in villages (Table 4).

Table 1 Lung function of surveyed undergraduates

Variable	Total	Females	Males	p
FEV_1 (L)	3.17 ± 0.46	3.14 ± 0.44	3.20 ± 0.47	0.307
FEV_1 (%pred)	97.3 ± 13.2	95.2 ± 12.2	99.0 ± 14.1	0.519
FVC (L)	3.64 ± 0.53	3.58 ± 0.53	3.66 ± 0.53	0.409
FVC (%pred)	97.1 ± 13.0	95.4 ± 12.1	98.1 ± 14.1	0.813
FEV_1/%FVC	89.2 ± 10.3	87.1 ± 9.2	90.2 ± 9.3	0.813

Data are means ±SD; p-values concern inter-gender differences based on a *t*-test

Table 2 Spirometry variables depending on air quality in the dwelling place during childhood-adolescence

Factor	Category	n	FEV_1 (%pred)	FVC (%pred)	FEV_1/%FVC
Current dwelling place	Wroclaw	130	98.3 ± 13.1	99.1 ± 13.2	84.1 ± 8.0
	Cracow	250	91.4 ± 11.1	92.4 ± 14.0	88.7 ± 9.1
			p = 0.043	p = 0.042	p = 0.049
CO	Class 1	178	101.5 ± 10.7	104.3 ± 11.6	85.9 ± 7.4
	Class 2	202	94.2 ± 16.2	95.1 ± 14.2	89.0 ± 9.1
			p = 0.189	p = 0.110	p = 0.363
Benz[a]piren	Class 1	110	99.3 ± 16.3	103.2 ± 14.2	84.8 ± 6.9
	Class 2	156	95.4 ± 14.5	95.3 ± 13.4	87.6 ± 7.1
	Class 3	114	87.4 ± 0.18	88.4 ± 15.2	91.9 ± 11.0
			p = 0.049	p = 0.009	P = 0.043
NO_2	Class 1	165	99.1 ± 16.1	100.2 ± 14.1	84.9 ± 7.6
	Class 2	124	94.9 ± 14.3	94.4 ± 13.4	88.5 ± 8.2
	Class 3	91	92.1 ± 18.1	90.1 ± 15.0	90.2 ± 8.6
			p = 0.619	P = 0.072	p = 0.664
$PM_{2.5}$	1. moderate level	125	98.4 ± 12.3	102.1 ± 13.2	84.7 ± 7.3
	2. high level	128	95.6 ± 12.2	95.2 ± 12.2	88.5 ± 8.7
	3. very high level	127	93.5 ± 17.8	89.2 ± 16.1	91.5 ± 12.0
			p = 0.619	p = 0.010	p = 0.046
PM_{10}	1. moderate level	123	102.2 ± 12.3	103.1 ± 17.9	85.0 ± 8.5
	2. high level	130	95.4 ± 19.1	97.3 ± 16.4	87.1 ± 9.0
	3. very high level	127	93.3 ± 19.7	94.2 ± 18.0	88.9 ± 9.2
			p = 0.189	p = 0.110	p = 0.363

Data are means ±SD; p-values based on MANOVA

Table 3 Spirometry variables depending on the degree of urbanization of the dwelling place during childhood-adolescence

	n	FEV_1 (%pred)	FVC (% pred)	FEV_1/%FVC
Cities with ≥100,000 inhabitants	162	85.2 ± 18.9	87.3 ± 13.2	93.6 ± 9.0
Other cities and towns	75	96.4 ± 16.1	92.3 ± 15.2	87.3 ± 8.1
Villages	143	100.2 ± 17.2	104.2 ± 16.1	86.2 ± 7.1
		p = 0.048	p = 0.010	p = 0.036

Data are means ± SD; p-values based on MANOVA

Table 4 Differences in lung function depending on both degree of urbanization and air quality in the dwelling place during childhood-adolescence

Factor 1	Factor 2	FVC (% pred)		FEV_1 (% pred)		FEV1/% FVC	
		F	p	F	p	F	p
Urbanization of the dwelling place during childhood-adolescence	Current dwelling place	3.53	0.041	3.96	0.041	2.89	0.045
	CO	4.46	0.022	2.53	0.044	3.01	0.043
	Benzene	4.13	0.025	4.01	0.026	4.13	0.038
	NO_2	3.24	0.031	4.33	0.038	3.96	0.345
	$PM_{2.5}$	4.56	0.019	3.99	0.040	4.22	0.021
	PM_{10}	2.92	0.364	2.76	0.046	3.99	0.040

p-values based on MANOVA

4 Discussion

The findings of this study were that the presence of benz[a]piren in the dwelling place during childhood-adolescence had a significant impact on all spirometry variables investigated in the same subjects in adulthood. The $PM_{2.5}$ content influenced FVC, FEV_1/%FVC, and the NO_2 content influenced FVC. Adverse effects of air pollution on lung development in children are well-documented. Particulate matter, sulphur dioxide, carbon monoxide, carbon dioxide, and benz[a]piren pose the highest risk for respiratory health among substances suspended in the air. In the present study we set out to assess the effects on respiratory function of exposure to such substances during childhood-adolescence, delayed in time to early adulthood. Although not all the substances tested had a significant impact on spirometry variables, there was a clear tendency for FVC% and FEV_1% to decrease, and FEV_1/%FVC to increase in adulthood, with a greater content of pollutants in the dwelling place present during childhood-adolescence. The greatest changes in spirometry variables were noted in relation to the ambient concentration of benz[a]piren. We also observed that $PM_{2.5}$ had a greater effect on spirometry variables than that of PM_{10}. These findings are in line with other reports pointing to a more detrimental effect on respiratory health of the finer PM (Zwozdziak et al. 2016).

Consequences of early life exposure to air pollution include diminished lung function and increased susceptibility to acute respiratory illness and asthma (Bateson and Schwartz 2007). The findings of several large cohort studies demonstrate a relationship between air quality and respiratory development. The Harvard 24 cities study, which covered more than 13,000 children aged 8–12, has demonstrated that the prevalence of abnormal lung function rises with increased pollution, especially with $PM_{2.5}$ level (Dockery et al. 1996; Raizenne et al. 1996). Likewise, longitudinal studies conducted over a 4-year period among children living in California have demonstrated a negative correlation between FVC and FEV1, and airborne $PM_{2.5}$ (Gauderman et al. 2002; Gauderman et al. 2000). Living in an environment of poor air quality is associated with lung development retardation. More recent research has confirmed that a long-term improvement in air quality has a positive effect on lung-function growth during adolescence, especially at ages 11 to 15 years (Gauderman et al. 2015). However, it is unknown whether exposure to high levels of pollutants during childhood leads to long-lasting effects, which would also be apparent in adulthood. The literature data fail to ascertain whether the differences in spirometry variables in adulthood are a consequence of a lower level of lung development in childhood-adolescence or an effect of the current exposure to air pollution (Ackermann-Liebrich et al. 1997).

Lung function gradually develops throughout the childhood-adolescence. In girls, respiratory development is completed around the age of 18; in boys about 2 years later (Burrows et al. 1983;

Wang et al. 1993). It is believed that exposure to adverse environmental factors during childhood-adolescence results in abnormal development. The findings of the Swedish birth cohort BAMSE study in 2278 children demonstrate that exposure to car traffic pollution in infancy may have a remote detrimental effect on respiratory function at 16 years of age (Schultz et al. 2016). Another study demonstrates that a reduction in car exhaust gas emissions, cannot much improve, if at all, diminished spirometry variables in otherwise healthy adults (Boogaard et al. 2013), although the issue is contentious as some other studies show that a reduction in PM_{10} may attenuate the decline in lung function related to airborne exposure to PM_{10} (Downs et al. 2007). Studies in animal models have largely confirmed that lung damage during a sensitive developmental period remodels the respiratory tract structure and, as a result, increases susceptibility to respiratory diseases in the future (Fanucchi et al. 2000, 2004).

On the other side, some studies are inclined to conclude that the impairment of lung function in adults results from the current exposure to pollutants. That is confirmed, *inter alia*, by a recent Swiss research that has shown that living in highly polluted areas leads to impairment of respiratory function. The data from the European Study of Cohorts for Air Pollution Effects (ESCAPE) covering more than 7,500,000 people has demonstrated a slight negative correlation between air pollution and long-term pulmonary function. In that study, poor air quality failed to cause a long-lasting downturn in spirometry variables, but increased NO_2 and/or PM_{10} levels did associate with slightly lower both FVC and FEV1 (Adam et al. 2015). It has been observed that spirometry variables can change relatively quickly as air quality varies in either direction in both children and adults, which particularly concerns airborne particulate matter (Boogaard et al. 2013; Cesaroni et al. 2012; Downs et al. 2007; Schikowski et al. 2005; Avol et al. 2001; Ackermann-Liebrich et al. 1997). That was confirmed in the present study as we found that individuals from Cracow tested during the smoggy period had evidently worse spirometry variables than those who had been tested one year earlier in the smog-free environment.

A limitation of this study was a broad definition of air pollution level during the period of subjects' growth and development, i.e., in childhood-adolescence. On the other side, the advantage of the study was a largely homogenous group of subjects who were age-matched and free of overt diseases. The study also spanned an extended period of 10 years. In addition, the participants were university undergraduates and were not exposed to substances posing respiratory hazard, other than ambient air pollution. Significant differences in air quality between city districts were controlled and taken into account in data evaluation. Thus, we believe the study has demonstrated that exposure to air pollution in the early stages of development has a long-term impact on lung function noticeable in adulthood.

In conclusion, this study suggests that the level of lung function in adulthood may have to do with both air pollution in the dwelling place during childhood-adolescence and the current exposure to pollutants. Poor air quality during the developmental age presumably retards lung growth, which is reflected in lower values of lung function variables in adulthood. Exposure to air pollution during childhood-adolescence has an impact on lung function in adulthood, independently of the current exposure. Lung function deterioration seems further augmented in adulthood due to the current pollution-related impact. Thus, pollution affects respiratory health irrespective of lung age, with the possible potentiating overlap of the early and late damage.

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Conflicts of Interest The authors declare no conflicts of interest in relation to this article.

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