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Effects of air pollution on children's pulmonary health

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ABSTRACT

Introduction: Many reports regarding the effects of air pollution on children's respiratory health have appeared in the scientific literature. Some investigators found increases in persistent cough and phlegm, bronchitis, and early respiratory infections in communities with poor air quality. The purpose of this survey was to compare the pulmonary function of children living in urban area of Tirana city with children living in suburban area of the city.
Material and methods: This survey is carried out during 2004–2005 period on 238 children living in urban area and in 72 children living in suburban area, measuring dynamic pulmonary function. A questionnaire was used to collect data on sex, current respiratory symptoms, allergy diagnosed by the physician, parent education and smoking habit of parents, presence of animals, synthetic carpets and moulds in their houses. The selection of schools, and children included in this survey was done by randomized method. Also, we have measured and classic air pollutants.
Results: Comparing the results of values of pulmonary function of two groups of children, we have shown that differences were significant (p 0.001), whereas comparing symptoms were for cough (p 0.011) and for phlegm (p 0.032). The level of particulate matter (PM10) and total suspended matter (TSP) were over the recommended limit values, whereas the levels of other pollutants have resulted within recommended levels of World Health Organization (WHO)
Conclusions: The results of this survey suggest that air pollution is associated with respiratory health of children causing a slight decrease in values of pulmonary function in children of urban area compared with those of suburban area.

1. Introduction

Outdoor air pollution is also a major problem in developing countries. The World Health Organization found that the air quality in large cities in many developing countries is remarkably poor and that very large numbers of people in those countries are exposed to ambient concentrations of air pollutants well above the World Health Organization guidelines for air quality (WHO, 1999, 2006). Scientific understanding of the health effects of air pollution, including effects on children, has increased in the last decade.

Children have increased exposure to many air pollutants compared with adults because of higher minute ventilation and higher levels of physical activity (Plunkett et al., 1992). Because children spend more time outdoors than do adults, they have increased exposure to outdoor air pollution (Wiley et al., 1991a,b).

Air pollutants (ozone, sulfur dioxide, particulate matter, nitrogen dioxide) have respiratory effects in children and adults, including increased respiratory tract illness, asthma exacerbations, and decreased lung function (American Thoracic Society, 1996a,b; Ostro et al., 2001; Yu et al., 2000; Leonardi and Houthuijs, 2002; Hajat et al., 1999; Jedruchovski et al., 2000; Oftedal et al., 2008). In adults, particulate air pollution is associated with respiratory and cardiovascular hospitalizations, cardiovascular mortality (Dockery, 2001) and lung cancer (Pope et al., 2002). Air pollution also has effects on indirect health indicators such as health care utilization and school absences (American Thoracic Society, 1996a,b; Bates, 1995; Timonen et al., 2002; Avol et al., 2001).

Tirana is a city that sustains a rapidly growing population and it has serious air pollution problems, especially by particulate matter, which results from motor vehicle traffic, the development of construction industry and the dense population. The purpose of this survey was to compare the pulmonary function of children living and attending schools in urban area of Tirana city, with children living and attending schools in suburban area of the city.

Studies examining associations between adverse respiratory tract health and traffic have been reviewed (Delfino, 2002). Increased respiratory tract complications in children (e.g., wheezing,

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chronic productive cough, and asthma hospitalizations) have been associated with residence near areas of high traffic density (Delfino, 2002; Edwards et al., 1994; van Vliet et al., 1997; Brunekreef et al., 1997; Ciccone et al., 1998). Other investigators have linked various childhood cancers to proximity to traffic (Feychting et al., 1998; Pearson et al., 2000; Raaschou-Nielsen et al., 2001).

2. Material and methods

This survey was carried out during 2004–2005 period on 238 children living in urban area and in 72 children living in suburban area, measuring pulmonary function, forced vital capacity (FVC), forced expiratory volume in the first second after full inspiration (FEV_1), FEV_1/FVC ratio, peak expiratory flow rate (PEF), forced expiratory flow (FEF_{25-75}), and vital capacity (VC). Each subject produced at least three acceptable FVC curves based on ATS standards (Standardization of spirometry, 1995). Testing was preceded and followed by flow calibrations done with a 3-L volumetric syringe (Standardization of spirometry, 1995). A questionnaire was used to collect data on sex, current respiratory symptoms, allergy diagnosed by the physician, parent education, parental history of atopy, environmental tobacco smoke at home, use of gas, wood or electricity for heating and cooking, home dampness, visible indoor moulds, and the keeping of pets (Jedrychowski et al., 1998). The selection of schools, and children included in this survey was done by randomized method. Also, we have measured air pollutants, for particulate matter, sulfur dioxide, nitrogen oxides, ozone and total suspended matter. Air samples were collected in five stationary points allocated in the city and are analyzed for total suspended matter (TSP), particulate matter (PM_{10}) by gravimetric cascade impact method, sulfur dioxide (SO_2), nitrogen oxides (NOx), and ozone (O_3) (James and Lodge, 1988)

Statistical processing of the data was carried out using Statistical Package for Social Science (SPSS 15). Multiples regression is used to analyze the correlation between variables.

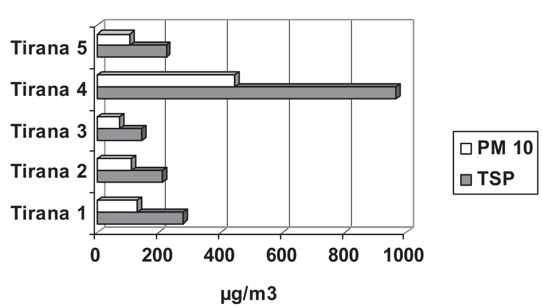
3. Results

A summary of 2004 average air pollution levels for PM_{10}, O_3, NO_2, SO_2 and TSP appears in Graphs 1 and 2.

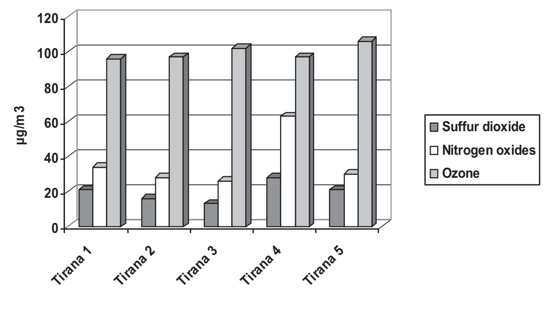
Data on urban–suburban comparison of pulmonary function are presented in Table 1.

4. Discussion

Air pollution in Tirana originates mostly from motor vehicle traffic exhausts (especially diesel exhausts), road dust and construction industry. As a result, concentrations of airborne particles are generally high, as well as some other pollutants.



Graph 1.



Graph 2.

The most important ambient air pollutants associated with adverse health effects are particulate matter, ozone, oxides of nitrogen and sulfur dioxide Motor vehicles pollute the air through tailpipe exhaust emissions and fuel evaporation, contributing to carbon monoxide, $PM_{2.5}$, nitrogen oxides, hydrocarbons, other hazardous air pollutants (HAPs), and ozone formation. Motor vehicles represent the principal source of air pollution in many communities, and concentrations of traffic pollutants are greater near major roads (Zhu et al., 2002). Recently, investigators have found increased adverse health effects among those living near busy roads.

Particles less than 1 μm in diameter can easily enter into the distal portions of the lung and the systemic circulation. Moreover they act as vehicles transporting toxic chemicals into the human respiratory system (Zhiqiang et al., 2000).

Total airborne dust concentrations in air of urban area of city oscillated from 146–964 $\mu g\, m^{-3}$. Respirable dust concentration varied from 73–445 $\mu g\, m^{-3}$ (Graph 1). The averages of these data on air pollution exceed threshold limits values (WHO, 1999, 2006).

Results of our survey showed that sulfur dioxide and nitrogen oxides levels (Graph 2) are within limits of WHO (WHO, 1999, 2006), whereas the levels of ozone has the tendency to increase.

The results of our study indicate that spirometric lung-function measurements of urban children were consistently lower than those of suburban children. Application of Levine's test, as is presented in Table 1 revealed that this difference was significant $P < 0.001$ level for FVC, FEV_1 and PEF. The average percentage predicted FVC and FEV_1 in the urban area were 12.2% and 8.1% less than those of the suburban area, respectively. This difference could not be explained by urban-suburban variations in (a) anthropometric measurements of the children; (b) exposures to potential sources of indoor air pollutants (e.g., cooking and heating fuels); (c) parental smoking patterns; or (d) socioeconomic status. The decrements in lung function were, however, associated with differences in ambient levels of PM_{10} between areas.

To assess whether other variables contributed to the lower lung function of the urban children, we explored nutritional status (Table 2) indoor air quality (Table 3), and socioeconomic status (Table 4). We examined three potential sources of indoor pollutants: cooking and heating sources, and tobacco smoke.

We categorized cooking and heating sources (e.g., fuel oil, kerosene, wood) on the basis of their fume-generating capability as

Table 1
Urban–suburban comparison of pulmonary function.

	Urban group	Suburban group	*P*
FVC	2085.294 ± 668.3199	2412.708 ± 761.3831	0.0010
FEV_1	2073.197 ± 657.828	2412.861 ± 761.3831	0.0007
PEF	4823.227 ± 1274.764	5518.167 ± 1500.794	0.0001

Table 2
Urban–suburban comparison of anthropomorphic data.

	Urban		Suburban		Urban vs. Suburban
	Arit. mean	SD	Arit. mean	SD	*P*
Age	13.76	0.67	13.54	0.62	0.014
Height	160.18	11.31	162.27	27.83	0.529
Weight	51.80	9.78	50.59	9.82	0.362
BMI	20.23	4.65	19.23	5.02	0.184

fume-generating sources, Suburban households used more fume-generating cooking and heating sources, (p 0.032) than urban homes. Regarding smoking habits of parents, we did not obtain significant differences between two groups (p 0.093).

Socioeconomic status is a risk factor for respiratory disease. The indices we used to assess socioeconomic status in this study were size of household, rooms in the house, and education level of parents. The number of rooms per household and the number of people in the household did not differ significantly between the suburban and urban areas (p 0.329). Regarding parental educations, according this survey there are significant differences in maternal educations between two groups (p 0.045), whereas for paternal education no significant differences were observed (p 0.234).

The respiratory symptoms we investigated in the questionnaire were coughing, phlegm, and wheezing. In addition, we assessed the prevalence of physician-diagnosed asthma. A summary of the frequency of reported respiratory symptoms is presented in Table 5.

Regarding the symptoms we found significant differences between two groups of children for wheezing during physical activity (p 0.022), cough with cold (p 0.011) and phlegm with cold (p 0.036), whereas for asthma diagnosed by physician we didn't notice any significant difference (p 0.208). Also, for other symptoms like cough for three consecutive months and phlegm for three consecutive months we didn't ascertain any significant differences, (p 0. 45 and p 0.0650) respectively.

The most significant air pollutant in Tirana that has consistently exceeded established air-quality guidelines are TSP and PM_{10}. The findings of lower FEV_1 and FVC in the more polluted urban environment are in agreement with the current literature, and recently, results of several studies have pointed to particulates as the main factor in morbidity and mortality associated with air-pollution episodes (Edwards et al., 1994; van Vliet et al., 1997; Brunekreef et al., 1997; Ciccone et al., 1998; Feychting et al., 1998; Pearson et al., 2000; Raaschou-Nielsen et al., 2001), as well as for decrements in pulmonary function associated with air pollution. The association between decrements in pulmonary function and TSP/PM_{10} levels suggested in this study has also been documented in other international studies (American Thoracic Society, 1996a,b; Ostro et al., 2001; Yu et al., 2000; Leonardi and Houthuijs, 2002; Hajat et al., 1999; Jedruchovski et al., 2000; Oftedal et al., 2008).

In their study of adult pulmonary function in relation to TSP and SO_2 levels (Xu et al., 1991), also proposed that FVC may be a better indicator than FEV_1 for the assessment of effects of long-term cumulative exposure to air pollutants. In our survey, comparison of the spirometric lung function of urban children with suburban children revealed a similar trend (i.e., a larger decrement of FVC 12.2% than FEV_1 8.1%). This trend is consistent with the hypothesis (Xu et al., 1991; He et al., 1993) that changes in FVC may be more reflective of long-term, cumulative exposures than changes in FEV_1.

High levels of ambient air pollutants are associated with increased incidence or worsening of asthma and increased risk of developing allergic diseases, respiratory symptoms and respiratory tract infections. The underlying mechanism for the harmful effects is the generation of oxidative stress which induces a strong respiratory as well as systemic inflammatory response. Individuals with genetic defects in enzymes associated with antioxidant defenses seem to be particularly vulnerable to the harmful effects of air pollutants.

Children seem to be particularly susceptible to the harmful effects of ambient air pollution because their lungs are growing. Lung growth is guided by a complex and precisely timed sequence of chemical messages. Many ambient air pollutants are chemicals that have the potential to interfere with these signaling pathways (Trasande and Thurston, 2005).

Compared with adults, children have poor defenses against PM and gaseous air pollutants, have a differential ability to metabolize and detoxify environmental agents and have an airway epithelium that is more permeable to inhaled air pollutants (Schwartz, 2004). Also, children have a greater level of physical activity than adults (an average physical activity duration of 124 *versus* 21 min per day) (Salvi, 2007), hence the intake of air into the lungs is much greater than adults per day. Children spend more time outdoors than adults, particularly in the summer and in the late afternoon. Some of that time is spent in activities that increase ventilation rates.

Table 3
Urban – Suburban Comparison of Home Environmental Exposure

Source	Urban	Suburban	Urban vs. suburban
			P
Fume generating heating and cooking sources (gas liquid petrol + wood)			
No	78 (33.1)	15 (20.0)	0.032
Yes	158 (66.9)	60 (80.0)	
Smoking in home			
No	129 (54.2)	46 (63.89)	0.121
Yes	109 (45.8)	26 (36.11)	

Table 4
Urban–suburban comparison of socioeconomic status.

	Urban	Suburban	Urban vs. suburban
			P
Paternal education			
Primary school	42 (17.8)	20 (26.7)	0.234
High school	135 (57.2)	37 (49.3)	
College	59 (25.0)	18 (24.0)	
Maternal education			
Primary school	46 (19.5)	25 (33.3)	0.045
High school	145 (61.4)	38 (50.7)	
College	45 (19.1)	12 (16.0)	
Parent's allergy			
No	193 (81.43)	65 (91.55)	0.043
Yes	44 (18.57)	6 (8.45)	
People/room			
	1.33	1.21	0.329

Table 5
Urban–suburban comparison of respiratory symptoms.

	Number of children with respiratory symptoms		
	Urban	Suburban	*P* (urban vs suburban)
Wheezing during physical activity	28 (11.9)	15 (20.8)	0.022
Cough apart the cold	52 (22.0)	20 (27.8)	0.376
Cough with cold	41 (17.4)	23 (31.9)	0.011
Cough for 3 consecutive months	8 (3.4)	4 (5.3)	0.45
Phlegm apart the cold	13 (5.5)	8 (11.1)	0.128
Phlegm with cold	66 (28.0)	28 (38.9)	0.036
Phlegm for 3 consecutive months	5 (2.1)	5 (6.7)	0.065
Asthma	4 (1.7)	3 (4.16)	0.205

A recent study from Japan has demonstrated that intrauterine exposure to high levels of traffic-related air pollutants and/or such exposure soon after birth increases the risk of developing allergic disorders in infants (Miyake et al., 2010).

A number of epidemiological studies have reported associations between residential and school proximity to busy roads as a surrogate for high levels of ambient air pollution, and a variety of adverse respiratory health outcomes in children, including presence of respiratory symptoms and worsening of asthma exacerbations (Wjst et al., 1993; Behrens et al., 2004; Gilliland, 2009; Sucharew et al., 2010; Brauer et al., 2007, 2002; Gehring et al., 2010).

A recent study from Cincinnati, OH, USA, revealed that children exposed to the highest tertile of traffic exhaust had a 45% increased risk of recurrent dry cough at night compared with children who were less exposed (Gauderman et al., 2004). In literature (Gauderman et al., 2000, 2002) are reported positive associations between markers of traffic-related air pollution and respiratory health outcomes, including asthma onset, incidence of wheeze, ear—nose—throat infections and serious colds or flu in a large cohort of children 4 yrs of age, effects that were first noted at the age of 2 years .

A growing number of studies also showed that children living in homes that are situated near roads with heavy truck traffic have an increased risk of new-onset asthma and asthma exacerbations accompanied by increased school absenteeism and asthma-related hospitalizations (Kinney et al., 1996; White et al., 1994).

More recently, a Dutch study has reported that ambient PM air pollution mainly arising from motor vehicular exhausts was significantly associated with increased incidence of asthma among schoolchildren (Gehring et al., 2010). The authors of a study that investigated the association between the prevalence of wheeze and allergic symptoms and truck traffic density in 13 and 14 yr old school children from Munster, Germany (Behrens et al., 2004), reported that compared with children who lived in 'never exposed to truck traffic areas', those children who lived in areas with rare, frequent and constant flow of truck traffic had a 29%, 58% and 57% increased prevalence of wheeze, respectively.

In a prospective study of 10-yr-old children that started with 1759 children and lasted for 8 yrs, (Gauderman et al., 2004) was found a significant association between lung function parameters FEV_1 and ambient levels of NO_2, acid vapor, $PM_{2.5}$ and elemental carbon, even after controlling for known confounding factors. Children who lived in areas with relatively higher ambient PM air pollution had a significant decrease in FEV1 values compared with children who lived in areas with lower PM air pollution levels. These effects were similar in males and females and remained significant even among children with no history of asthma. The magnitude of these effects was similar to those observed due to effects of maternal smoking reported in earlier studies (Gilliland, 2009; Sucharew et al., 2010; Brauer et al., 2007, 2002; Gehring et al., 2010).

Children in communities with higher levels of urban air pollution (acid vapor, nitrogen dioxide, particulate matter with a median aerodynamic diameter less than 2.5 μm ($PM_{2.5}$), and elemental carbon which is a component of diesel exhaust had decreased lung function growth, and children who spent more time outdoors had larger deficits in the growth rate of lung function (Gauderman et al., 2000, 2002).

Ozone is a powerful oxidant and respiratory tract irritant in adults and children, causing shortness of breath, chest pain when inhaling deeply, wheezing, and cough (Gauderman et al., 2000). Children have decreases in lung function, increased respiratory tract symptoms, and asthma exacerbations on days with higher levels of ambient ozone (Gauderman et al., 2002; Kinney et al., 1996; White et al., 1994; Thurston et al., 1997, 1994; Ostro et al., 1995; Tolbert et al., 2000). Increases in ambient ozone have been associated with respiratory or asthma hospitalizations, emergency department visits for asthma (McCreanor et al., 2007) and school absences for respiratory tract illness (Gilliland et al., 2001).

PM_{10} is small enough to reach the lower respiratory tract and has been associated with a wide range of serious health effects. PM_{10} is a heterogeneous mixture of small solid or liquid particles of varying composition found in the atmosphere. Fine particles ($PM_{2.5}$) are emitted from combustion processes (especially diesel-powered engines, power generation, and wood burning) and from some industrial activities. Coarse particles (diameter between 2.5 and 10 m) include windblown dust from dirt roads or soil and dust particles created by crushing and grinding operations. Toxicity of particles may vary with composition (Ghio et al., 2002; Pandya et al., 2002).

In children, particulate pollution affects lung function and lung growth (Oftedal et al., 2008; Brunekreef et al., 1997; Gauderman et al., 2004, 2000, 2002). In a prospective cohort of children living in southern California, children with asthma living in communities with increased levels of air pollution (especially particulates, nitrogen dioxide, and acid vapor) were more likely to have bronchitis symptoms. In this study, bronchitis symptoms refers to a parental report of "one or more episodes of 'bronchitis' in the past 12 months" or report that, "apart from colds, the child usually seems to be congested in the chest or able to bring up phlegm (Gauderman et al., 2004). The same mix of air pollutants was also associated with deficits in lung growth (as measured by lung function tests) (Gauderman et al., 2004).

The relative contribution of fine versus coarse particles to adverse health effects is being investigated. In studies of cities on the East Coast, fine particles seem to be important (Ostro et al., 2000). In other areas, coarse particles have a stronger or similar effect (Laden et al., 2000; Ozkaynak and Thurston, 1987). Several studies have found that fine particles from power plants and motor vehicles or industrial sources may be more closely associated with mortality (Woodruff et al., 1997).

Epidemiologic studies have reported relationships between increased ambient nitrogen dioxide and risks of respiratory tract symptoms) and asthma exacerbations (Ostro et al., 2001; Yu et al., 2000; Leonardi and Houthuijs, 2002; Hajat et al., 1999; Jedruchovski et al., 2000; Oftedal et al., 2008).

The epidemiologic studies of health effects associated with nitrogen dioxide should be interpreted with caution. Increased levels of ambient nitrogen dioxide may be a marker for exposure to traffic emissions or other combustion-related pollution. An independent role of nitrogen dioxide cannot be clearly established because of the high covariation between ambient nitrogen dioxide and other pollutants. Nonetheless, these studies illustrate that adverse respiratory tract effects are seen in urban areas where traffic is a dominant source of air pollution.

Public health interventions to improve air quality can improve health at the population level. A decrease in levels of air pollution in former East Germany after reunification was associated with improved lung function (Frye et al., 2003).

This survey has several strengths; it is the only published study of the effects of ambient air pollution on children's lung function in Albania. Other strengths is significant difference in pulmonary function between urban versus suburban group, good exposure data, a well-selected control group, and an extensive search for possible confounding variables.

We would like to mention and some weaknesses of our survey, as although, for the purposes of this analysis, the highest value of three efforts was defined as the child's peak flow value, there was wide variability within subjects. In contrast, there was far less within-subject variability in the lung-volume measurements. Another concern is that not all of the spirograms met the ATS criteria for reproducibility, indicating variable effort. Also, some of the total measured lung volumes were lower than expected for height and weight, indicating sub maximal effort; however, because this effort was observed in both urban and suburban spirograms and with similar frequency, there was no bias in urban-suburban comparisons.

As a conclusion, in an urban-suburban comparison of lung function and symptoms in Tirana, higher pollutant levels in the urban area were associated with lower lung function among children aged 14–15 years. This difference was not explained by indoor air quality, environmental tobacco smoke, differences in socioeconomic status, or by nutritional status. We believe that further research is needed because the pollutant levels and health effects measured are consistent with those in studies in other parts of the world and the levels and effects could indicate an important and potentially irreversible response to ambient pollutants.

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