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AIR POLLUTION AND PULMONARY FUNCTION OF ADOLESCENTS

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ABSTRACT

Five hundred and ninety-five healthy Caucasian teenagers (315 females, 280 males) between the ages of 13 and 19 participated in a community pulmonary function survey in Illinois. Of the total, 293 attended Granite City High School South (highly industrialized and polluted area). On the average, this teenage population has smaller lung volumes (15% in males, 14% in females) and flow rates (14% in males, 12% in females) than the predicted normal population. There was also a statistical difference between high school subgroups, with both the North High School male and female students demonstrating significantly larger pulmonary functions than their South High School counterparts. When the relation between air flow rates and smoking was examined by High School subgroups, evidence was found for a synergistic effect between smoking and air pollution.

INTRODUCTION

This study reports the effects of air pollution on pulmonary health of adolescents. The site of the study is Granite City, Illinois, a highly industrialized city which has been identified as one of the air pollution "hot spots" in the nation. Its total suspended particulate (TSP) concentrations rank as the highest in the state.[1,2,3] A 1977 study of industrial emissions in communities east of the metropolitan St. Louis area ranked Granite City first for TSP, first for total hydrocarbon, first for carbon monoxide, fifth for sulfur dioxide, and fifth for nitrogen oxides.[1] Data available from the Illinois Department of Public Health indicate that hospitalization for pulmonary diseases, such as lung cancer, tuberculosis, bronchitis, histoplasmosis, pneumonia and chronic obstructive pulmonary disease, occurs with a combined annual incidence of 25-30 per thousand of the Granite City population.

The population studied in this report is a group of healthy caucasian teenagers from each of the two high schools in the city. Granite City High School South is located in the older, highly industrialized section of the city, while North High School is on the outskirts of the city in a non-industrialized area. In general, the area of the city feeding into North High School appears to have less outdoor air pollution than the section of the city from which South High School draws its students.

MATERIALS AND METHODS

During a two month period, 595 healthy, normal caucasian teenagers between the ages of 13 and 19 were studied as part of a community respiratory disease survey. The teenagers were members of the two high schools in the community: 293 from South High School and 302 from North High School, representing 15 and 20 percent of the respective school populations.

The parents of the students completed a written questionnaire, and a written informed consent. Smoking history of the students was determined in a confidential interview just prior to the conducting of pulmonary function measurements.

Ventilatory function was assessed by using a Vanguard DS 512 Digital Electronic Spirometer. The parameters measured include the forced vital capacity (FVC), the forced expiratory volume in one second (FEV_1), the ratio of FEV_1 to FVC, and forced expiratory flow during the mid-portion of the FVC curve (FEF_{25-75}). All pulmonary function parameters are automatically corrected to Body Temperature, Pressure, Saturated (BTPS) by the microprocessor. This system meets or exceeds all American Thoracic Society accuracy and performance standards.[4] Predicted normal equations based on age, height and sex are internally programmed. Teenager predicted values are automatically extrapolated from the regression equations of Morris *et al.*[5] The percent predicted for the measured values is automatically generated at the completion of the study.

The North High School students were studied first, followed at a later date by the South High School students. Each student was carefully coached as to the proper method for performing an acceptable FVC curve and the procedure was demonstrated.[6] Each student then performed three or more FVC maneuvers, until at least two FVC curves were acceptable. Each curve was recorded on the graphic recorder and a permanent alphanumeric record was produced. The curve with the best FVC for each subject was used in the statistical analysis.

RESULTS

Only those pulmonary function measurements of students without any history of chronic pulmonary disorders or allergies, as determined from the questionnaires completed by the parents or guardians, were used in the statistical analysis. Teenagers with current respiratory infections were excluded from the analysis. Means, standard deviations and correlation coefficients were calculated; two-tailed t-tests and chi square distributions were used to evaluate population relations.

In an attempt to differentiate the effects of cigarette smoking and environmental location on pulmonary function, we subdivided the students by high school and smoking history. The term 'nonsmoker' refers to those who have not smoked regularly. Table 1 describes the pulmonary function measurements of the students arranged by school. Although the mean ages are the same, the North High School males are significantly taller than the South High School males. In addition, the air flow parameters, FEV_1, FEV_1/FVC and $FED_{25\text{-}75}$, are significantly higher in the North males than in those from the South.

There are no anthropometric differences between the females of the two schools. With the exception of the $FEF_{25\text{-}75}$ being significantly greater for the North females, all other pulmonary function parameters are similar. However, there is a significant difference between male and female air flow parameters within each school. The South female % Pred. FEV_1 and % Pred. $FEF_{25\text{-}75}$ are significantly larger than the South male values. The North female % Pred. $FEF_{25\text{-}75}$ is significantly larger than the North male air flow.

Table 2 shows the pulmonary function measurements on the basis of both high school and smoking history. The lower air flow rates for smokers as compared to nonsmokers are clearly evident as is the fact that female students of each high school, both smokers and nonsmokers, have significantly larger air flow rates than their male counterparts. It is also noteworthy that the male nonsmokers of North High School are significantly taller than the South nonsmoking males.

Although there are significant differences between the pulmonary function parameters within the various student subgroups, all mean values are within normal limits.[7] Examination of Table 2 shows, however, that the means for the percent predicted values are at the lower limits of normal. This teenage population displays smaller pulmonary function parameters than have been seen in other students.[8,9,10] Because of this difference, regression equations were derived for this population of teenagers. (Table 3) The correlation coefficients noted are all significant at the p 0.05 level.

Further statistical analysis was used to relate years of residence in the community to % Pred. FVC and % Pred. $FEF_{25\text{-}75}$. Years of residence in the community was evaluated in terms of sex of the teenager. Although the females show no significant variations in their pulmonary functions, the male population does. Those males who have lived in the community for five years or less have a significantly lower mean value for % Pred. FVC and a slightly lower mean value for % Pred. $FEF_{25\text{-}75}$ than do those males who have lived in the community longer than five years. (Table 4)

A breakdown of data by high schools also shows a trend. Those males who attend North High School and have lived less than five years in the community show a significantly lower mean % Pred. $FEF_{25\text{-}75}$ than those with more than five years residence. The difference for % Pred. FVC is not significant. South High School males show a small difference in % Pred. FVC but no difference in % Pred. $FEF_{25\text{-}75}$. A slight variation in % Pred. FVC is also noted for South High School females, but the lower value occurs for females who have lived in the community for more than five years.

DISCUSSION

It is well known that pulmonary function in normal, healthy children is closely related to growth and development.[9] It has been previously shown that the rate of pulmonary development increases at adolescence and marked absolute differences are noted between boys and girls.[10] Our data show a mean absolute difference in FVC between boys and girls of 936 mL, a mean difference in FEV_1 of 960 mL and a mean difference in FEF_{25-75} of 0.67 L/sec.

When % Pred. values are examined, it is noted that the girls demonstrate the larger relative values for volume and flow. This agrees with earlier studies which demonstrate that maturity of pulmonary functions is reached earlier in girls than in boys.[11] It appears that girls reach their functional plateau by around age 14 while boys must develop until age 18 to reach this plateau.

It is observed that the average individual in this teenage population has smaller lung volumes and flow rates than the predicted normal population. The males average 15.3% less in lung volume, 14.4% less in FEV_1 and 11% less in FEF_{25-75}. The females average 14.3% less in lung volume, 12% less in FEV_1 and 5% less in FEF_{25-75}.

Although within normal limits, these marked reductions in average pulmonary function parameters compared to normal predicted values could be an early response to environmental exposure.[12] The respiratory system has an obvious and continuous contact with the environment; and the lungs are thus exposed intensely and on a prolonged basis to any injurious substances which might be offered by the environment.[13]

It has been shown in England that episodes of increased sulfur dioxide and particulate pollution result in an increased morbidity and mortality among those with chronic lung disease.[14] The FEV_1 has been shown to be significantly less in men in England exposed to higher pollution levels than in men in less polluted areas. Furthermore, pulmonary function parameters in school children in grossly polluted regions are measurably less as compared with those in children in low polluted regions.[15]

Ventilatory function in children is a particularly useful measure of air pollution effects because cigarette smoking, occupational exposures, and frequent changes of residence do not generally play a role in the observed effect.[16] In nearly all reported studies, children residing in more polluted communities of the sulfur dioxide/particulate category both in the United States and in other countries, have shown diminished ventilatory function when compared to their counterparts living in less polluted areas.[15,16,17] It has been observed that four major factors — childhood smoking, air pollution, social class and past history of respiratory diseases — can have independent effects on ventilatory function.[18] Although smoking and air pollution apparently have the greatest influence, all four factors appear to exert their effects additively. In this particular study, however, social class does not appear to be a determining influence.

As noted earlier, the pulmonary function data from this group of 595 Granite City teenagers appear to show a significant environmental response when compared to predicted normals. It is additionally possible to detect a statistical difference between high schools, based on differences in pollution levels within the city itself. Both the male and female students in the North High School demonstrate pulmonary function values slightly to significantly larger than their counterparts in South High School, located in the more polluted part of the city.

When smoking history is examined, both male and female smokers overall have significantly lower air flow rates than the nonsmokers. These findings are similar to previous studies which also showed that objective evidence of lung damage occurs in teenaged smokers.[19,20,21] When the relation between air flow rates and smoking is examined by high school subgroups, we find additional evidence which tends to confirm our concern over environmental exposure. Both the male and female smokers in South High School have lower air flow rates than their smoking counterparts in North High School. This tends to support the theory of additive effects of smoking and air pollution on pulmonary function changes in adolescents.

The importance of all these findings is that diminished repiratory function in childhood may well have long-term consequences, compromising respiratory health in later life. It has been suggested that the fact that air pollution exposure increases the risk in childhood of both reduced lung function and acute respiratory illness implies an increased risk for subsequent development of obstructive pulmonary disease in adulthood.[22] It has also been observed that a close relationship exists between a history of childhood respiratory disorders and prevalence of ventilatory impairment and obstructive airway disease in adults.[23] However, these data may be biased, as parents of children with respiratory diseases may have a better recall of childhood illness than do parents of children who are currently healthy.

There has been evidence that the effects of air pollution, or the combination of air pollution and smoking, are potentially reversible. Improvements in impaired pulmonary function in children living in polluted communities have been shown when air pollution concentration decreased.[24,25] Similar studies with adults also point to the conclusion that removal of air pollution at least slows the development of obstructive airway problems, and if removed early enough, results in a return to nearly normal functional status.[26,27]

Years of residence in a community would appear to be significant to pulmonary function, particularly in an area with as much air pollution as Granite City. The data for teenagers indicate considerably lower pulmonary function values for males who have lived in the community five years or less than for those who have lived in the city longer. The effect is similar for students of both high schools. Females do not show this effect. This pulmonary function change in males may be due to an acute reaction to the air pollution of Granite City. Female teenagers may not show this pronounced effect because their pulmonary functions develop earlier than those of males.[10,11,24]

CONCLUSION

In conclusion, our data provide statistical evidence for an adverse reaction in this group of teenagers to environmental exposure. Overall, the average lung volume and flow rates are reduced compared to normal predicted values. Individuals in the more polluted South High School area are more markedly affected than those in the North High School area. Those individuals with a history of cigarette smoking have an even greater decrease in air flow rates. There appears to be an additive effect between smoking and environmental exposure in this group.

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Table 1. Means and Standard Deviations of Pulmonary Function Measurements in Normal Caucasian Teenagers Arranged by High School.

	Males		Females	
Parameter	South High	North High	South High	North High
N	135	145	158	157
Age	15.30 ± 1.21	15.40 ± 1.24	16.06 ± 1.29	16.11 ± 1.11
Height (cm)	171.55 ± 5.13[b]	178.33 ± 4.34[b]	162.69 ± 6.22	163.37 ± 6.25
FVC (L)	4.44 ± 0.96	4.62 ± 0.83	3.54 ± 0.57	3.58 ± 0.61
% Pred. FVC	83.66 ± 13.27	85.66 ± 11.64	85.41 ± 11.39	86.01 ± 12.14
FEV_1 (L)	3.61 ± 0.85[b]	4.09 ± 0.63[b]	2.96 ± 0.57	3.04 ± 0.54
% Pred. FEV_1	81.75 ± 16.27[b]	89.25 ± 14.72[b]	87.33 ± 14.74[b]	88.84 ± 13.41
FEV_1/FVC (%)	81.83 ± 14.08[b]	88.12 ± 10.24[b]	83.88 ± 9.12	84.49 ± 7.92
FEV_{25-75} (L/sec)	4.34 ± 1.28[b]	4.52 ± 1.21[b]	3.68 ± 1.00[a]	3.84 ± 0.98[a]
% Pred. FEF_{25-75}	87.41 ± 13.83[b]	90.64 ± 13.43	93.78 ± 13.87[b]	97.02 ± 19.24[b]

[a]$p<0.05$; [b]$p<0.025$

Table 2a Means and Standard Deviations of Pulmonary Function Measurements in Female Teenagers Based on School and Smoking History.

	South High School		North High School	
Parameter	Nonsmoker	Smoker	Nonsmoker	Smoker
N	131	27	111	46
Age	16.11 ± 1.69	15.96 ± 0.98	16.25 ± 1.63	15.76 ± 1.16
Height (cm)	164.07 ± 6.04	162.46 ± 7.24	164.11 ± 6.12	161.57 ± 6.32
Pack-Years	0	4.25 ± 1.87	0	3.50 ± 0.42
FVC (L)	3.54 ± 0.56	3.58 ± 0.61	3.64 ± 0.67	3.48 ± 0.60
% Pred. FVC	85.32 ± 11.67	85.85 ± 10.11	86.07 ± 12.51	85.88 ± 11.62
FEV_1 (L)	3.01 ± 0.54	2.74 ± 0.68	3.10 ± 0.58	2.87 ± 0.40
% Pred. FEV_1	88.77 ± 14.28	80.33 ± 15.23	89.84 ± 13.44	86.43 ± 13.18
FEV_1/FVC (%)	85.15 ± 8.65	76.81 ± 13.11	85.54 ± 7.87	82.65 ± 8.99
$FEV_{25\text{-}75}$ (L/sec)	3.81 ± 0.95	3.04 ± 1.01	3.99 ± 1.00	3.48 ± 0.85
% Pred. $FEF_{25\text{-}75}$	97.31 ± 12.59	76.70 ± 22.84	100.20 ± 13.06	89.34 ± 22.08

Table 2b Means and Standard Deviations of Pulmonary Function Measurements in Male Teenagers Based on School and Smoking History.

	South High School		North High School	
Parameter	Nonsmoker	Smoker	Nonsmoker	Smoker
N	111	24	114	31
Age	15.24 ± 1.19	15.54 ± 1.32	15.32 ± 1.18	15.71 ± 1.42
Height (cm)	172.06 ± 7.01	169.24 ± 6.65	181.28 ± 5.84	172.14 ± 7.92
Pack-Years	0	4.76 ± 2.54	0	4.01 ± 2.66
FVC (L)	4.48 ± 0.99	4.23 ± 0.84	4.61 ± 0.71	4.66 ± 0.88
% Pred. FVC	84.30 ± 13.78	80.70 ± 12.60	85.52 ± 4.44	86.16 ± 12.55
FEV_1 (L)	3.68 ± 0.82	3.25 ± 0.94	4.15 ± 0.60	3.61 ± 0.77
% Pred. FEV_1	83.27 ± 14.99	74.75 ± 20.14	91.65 ± 6.71	80.52 ± 14.94
FEV_1/FVC (%)	83.44 ± 13.89	76.91 ± 14.11	89.94 ± 7.39	77.86 ± 13.13
FEV_{25-75} (L/sec)	4.43 ± 1.31	3.91 ± 1.06	4.69 ± 1.19	3.95 ± 1.11
% Pred. FEF_{25-75}	88.84 ± 12.24	80.79 ± 17.00	93.82 ± 12.96	78.94 ± 21.64

Table 3 Regression Equations Relating Pulmonary Function Variables to Age and Height in Normal Caucasian Teenagers in Granite City.

Parameter	Sex	Regression Equation	r	S.E.
FVC (L)	F	$y = 0.027A + 0.021H - 0.291$	0.88	0.412
	M	$y = 0.065A + 0.033H - 2.154$	0.84	0.463
FEV_1 (L)	F	$y = 0.034A + 0.024H - 1.505$	0.77	0.378
	M	$y = 0.041A + 0.026H - 1.246$	0.75	0.396
$FEF_{25\text{-}75}$ (L/sec)	F	$y = 0.015A + 0.031H - 1.63$	0.66	0.699
	M	$y = 0.025A + 0.014H - 1.41$	0.64	0.730

A = Age
H = Height in centimeters
r = Correlation Coefficient
S.E. = Standard Error of Estimate in liters

Table 4 Means and Standard Deviations of Pulmonary Function Measurements with Respect to Years of Residence in Granite City.

Parameter	South High Males <5 Years	South High Males >5 Years	North High Males <5 Years	North High Males >5 Years
N	16	117	15	128
% Pred. FVC	79.63 ± 9.96	84.26 ± 13.86	83.33 ± 9.17	86.05 ± 11.94
% Pred. $FEF_{25\text{-}75}$	88.69 ± 26.82	88.05 ± 25.60	77.47 ± 17.25	92.30 ± 23.01