ORIGINAL ARTICLE

Long term effects of exposure to automobile exhaust on the pulmonary function of female adults in Tokyo, Japan

K Sekine, M Shima, Y Nitta, M Adachi

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See end of article for authors' affiliations

Correspondence to:
Dr M Shima, Department
of Public Health, Graduate
School of Medicine, Chiba
University, 1-8-1 Inohana,
Chuo-ku, Chiba 260-
8670, Japan; shima-m@
faculty.chiba-u.jp

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Aims: To investigate the chronic effects of air pollution caused mainly by automobiles in healthy adult females.

Methods: Respiratory symptoms were investigated in 5682 adult females who had lived in the Tokyo metropolitan area for three years or more in 1987; 733 of them were subjected to pulmonary function tests over eight years from 1987 to 1994. The subjects were divided into three groups by the level of air pollution they were exposed to during the study period. The concentrations of nitrogen dioxide and suspended particulate matter were the highest in group 1, and the lowest in group 3.

Results: The prevalence rates of respiratory symptoms in group 1 were higher than those in groups 2 and 3, except for wheezing. Multiple logistic regression analysis showed significant differences in persistent phlegm and breathlessness. The subjects selected for the analysis of pulmonary function were 94, 210, and 102 females in groups 1, 2, and 3, respectively. The annual mean change of FEV₁ in group 1 was the largest (–0.020 l/y), followed by that in group 2 (–0.015 l/y), and that in group 3 (–0.009 l/y). Testing for trends showed a significant larger decrease of FEV₁ with the increase in the level of air pollution.

Conclusions: The subjects living in areas with high levels of air pollution showed higher prevalence rates of respiratory symptoms and a larger decrease of FEV₁ compared with those living in areas with low levels of air pollution. Since the traffic density is larger in areas with high air pollution, the differences among the groups may reflect the effect of air pollution attributable to particulate matter found in automobile exhaust.

Nowadays, people cannot evade the global problem of environmental pollution caused by automobile exhaust so long as they live in urban areas. In Japan, along with the concentration of the population and production in large cities, air pollution in the districts along trunk roads is now causing a serious problem. The major components of air pollution in urban districts in Japan are nitrogen dioxide (NO₂) and suspended particulate matter (SPM) emitted mainly by automobiles.^{1–3} Air pollution in the districts along main roads has shown hardly any sign of improvement. In particular, the exhaust from diesel engines is considered substantial in this regard. Larger sized diesel engines emit 2–30 times more nitric oxide and 30–100 times more SPM than gasoline engines.^{4–6} Therefore, diesel engines constitute a major cause of air pollution attributable to NO₂ and SPM. It is reported that Tokyo, the capital of Japan, has the largest number of vehicles (2 690 000 in 1990), and the annual mean concentrations of NO₂ and SPM in the air in Tokyo are 0.030 ppm and 52 µg/m³, respectively; that is, higher than the national means of 0.016 ppm and 37 µg/m³, respectively.

There have been many studies on the influence of air pollution on children's pulmonary function, and it has been reported that in areas of high concentration of nitric oxide, the values of children's pulmonary function parameters are low and their growth is comparatively delayed.^{7–10} However, there is little data on the effects of air pollution on pulmonary function in adults. In traffic workers, several studies have shown an association between exposure to automobile exhaust and adverse effects on respiratory symptoms and pulmonary function,^{11–13} whereas others failed to find such an association.^{14–15} In this way, the results of studies on the effects of air pollution are not conclusive. Hardly any community based research has been conducted to investigate the long term effects of air pollution on pulmonary function.

We carried out a cross-sectional study to investigate respiratory symptoms in adult females who lived in the Tokyo metropolitan area, and performed a longitudinal study of annual pulmonary function tests for eight years from 1987 to 1994. Based on these studies, we evaluated the long term influence of air pollutants, mainly automobile exhaust, on pulmonary function.

SUBJECTS AND METHODS

Study areas and subjects

We covered almost the whole Tokyo metropolitan area by investigating the nine districts shown in fig 1 (Chuo ward, Ohta ward, Shibuya ward, Itabashi ward, Hachioji City, Tachikawa City, Ome City, Machida City, Tanashi City). The daytime average traffic density of trunk roads in these districts¹⁶ was 8000–32 000 vehicles every 12 hours in 1990 (table 1).

In each district, the area close to the edge of a trunk road ("roadside area"; within 20 m from the road) and the hind land ("area behind the road", >20 m–<150 m) were investigated. The subjects, 500 females, 30–59 years old, were randomly selected from the inhabitants register of each area, and the respiratory symptoms were investigated in those who had lived in a given area for three years or more. One hundred females who did not smoke and who did not have a history of respiratory diseases were then randomly selected from among the females in each district, and subjected to pulmonary function tests. The objective and

Abbreviations: DEP, diesel exhaust particle; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; NO₂, nitrogen dioxide; PM₁₀, particulate matter less than 10 µg in diameter; SPM, suspended particulate matter

Main messages

- The prevalence of respiratory symptoms and the longitudinal changes of pulmonary function among adult females were investigated relative to air pollution caused mainly by automobiles.
- The prevalence rates of respiratory symptoms were high among the subjects living in areas with high levels of air pollution.
- The annual mean changes of FEV₁ were significantly greater in females living in areas with higher levels of air pollution.

method of this study were fully explained to the subjects, and informed consent was obtained from them before the study.

Air monitoring

Air environment measurement devices were installed at 0 m and 20 m from the edge of trunk roads, and the concentration of air pollutants was measured every month for three consecutive days. NO₂ concentrations were measured using the PTIO method.¹⁷ For measurement of SPM, particulate matter less than 10 µm in diameter was collected by a low volume air sampler for 72 hours.

Respiratory symptoms

The questionnaire employed was a modified Japanese version of ATS-DLD-78.¹⁸ It was sent by mail to each subject between July and August 1987. They were collected after about 1–2 weeks by the staff engaged in the investigation who visited each home and verified that the questionnaires had been filled in properly.

Pulmonary function tests

Skilled staff conducted the pulmonary function tests in the community centre in each area once a year (August–November) using an electronic spirometer (DISCOM-21, Chest Inc., Tokyo, Japan). Prior to each test the device was calibrated using a 3-litre syringe. After sufficient explanation on the method, the subjects were repeatedly tested, with a short interval, until more than three forced expiratory curves that were reproducible had been obtained (maximum eight times). A nose clip was applied to each subject, and subjects were in the standing position during the tests.

Table 1 Daytime average traffic density of the trunk roads in study areas

Area	Trunk roads	Traffic density (1990)	
		All (vehicles/ 12 hours)	Heavy vehicles (vehicles/ 12 hours)
Chuo ward	Kiyosumi avenue	24100	5724
Ohta ward	Route 131	24172	6612
Shibuya ward	Yamate avenue	32881	4152
Itabashi ward	Route 17	30884	6949
Tanashi City	Shinome street	28821	5018
Hachioji City	Route 20 bypass	20397	2681
Tachikawa City	Tachikawa avenue	10216	1730
Machida City	Machida street	13816	1742
Ome City	Okutama street	8641	1690

Policy implications

- The differences in respiratory symptoms and pulmonary function among the areas may reflect the effect of air pollution attributable to particulate matter found in automobile exhaust.
- The chronic effects of air pollution on the respiratory health of people living in urban areas should be further clarified.

Data analysis

Classification by degree of air pollution

The roadside areas and the areas behind the roads (18 areas in total) in nine districts were classified into the following three groups by the level of air pollution (mean NO₂ and mean SPM concentrations) during the study period (table 2). Since NO₂ concentrations showed a smaller standard deviation and range to the SPM concentrations, and reflected the differences among areas quite well, the classification was mainly based on the NO₂ concentration, with consideration of the SPM concentration.

- Group 1: This group consisted of roadside areas in five districts (Chuo ward, Ohta ward, Shibuya ward, Itabashi ward, Tanashi City) where both NO₂ (mean 0.047–0.056 ppm) and SPM (mean 48–62 µg/m³) concentrations were high. The daytime average traffic density (in 1990) exceeded 20 000 vehicles including 4000 large vehicles in each of these districts.
- Group 2: This group consisted of roadside areas in three districts (Hachioji City, Tachikawa City, Machida City) where both NO₂ (mean 0.038–0.046 ppm) and SPM (mean 38–46 µg/m³) concentrations were moderate and the areas behind the roads in the five districts of group 1. The traffic density in the roadside areas was 10 000–20 000 vehicles, including <3000 large vehicles.
- Group 3: This group consisted of areas close to the roads and those behind the roads in one district (Ome City)

Figure 1 Location of the study areas.

Table 2 Air pollution average concentration of the sampled areas

Area	Distance from roadway	NO ₂ concentration (ppb)*				SPM concentration (μg/m ³)†				Group
		n	Mean	SD	Range	n	Mean	SD	Range	
Chuo ward	0 m	51	51.6	7.8	33–65	87	47.6	16.8	19.2–99.8	1
	20 m	32	44.0	9.0	27–64	87	43.3	18.0	16.3–95.8	2
Ohta ward	0 m	51	52.0	12.1	27–83	87	51.6	18.6	12.1–102.3	1
	20 m	51	45.7	10.3	25–75	87	46.4	16.8	21.1–100.8	2
Shibuya ward	0 m	51	56.1	10.1	33–77	87	61.8	21.7	30.2–131.0	1
	20 m	51	42.6	10.2	24–75	85	38.8	15.7	10.6–94.8	2
Itabashi ward	0 m	51	53.6	12.0	30–80	87	59.2	23.0	22.5–140.6	1
	20 m	32	44.0	10.6	24–67	87	45.7	19.8	9.9–112.2	2
Tanashi City	0 m	47	47.2	9.7	29–65	85	56.8	23.9	11.1–135.5	1
	20 m	26	37.8	9.2	23–54	83	46.0	22.3	7.3–108.2	2
Hachioji City	0 m	51	38.7	8.2	24–57	85	44.3	15.5	16.8–82.2	2
	20 m	32	32.8	6.6	21–43	87	39.4	13.7	10.5–82.5	3
Tachikawa City	0 m	50	41.8	9.8	24–59	75	45.1	17.4	15.4–88.6	2
	20 m	32	33.9	8.2	19–46	75	38.9	14.4	11.0–77.1	3
Machida City	0 m	51	40.1	9.0	23–56	87	43.1	17.9	11.1–108.1	2
	20 m	31	35.6	8.2	22–51	82	33.9	15.8	5.0–74.7	3
Ome City	0 m	51	29.0	6.0	18–49	87	34.5	14.7	7.3–89.2	3
	20 m	32	23.5	5.4	14–33	87	28.1	13.8	3.4–69.7	3

*The average concentration of the five-year period (1990–94) measured at ambient air monitoring.

†The average concentration of the eight-year period (1987–94) measured at ambient air monitoring.
SD, standard deviation.

where both NO₂ (mean 0.024–0.036 ppm) and SPM (mean 28–39 μg/m³) concentrations were low, as well as the areas behind the roads in districts of group 2. The traffic density in the roadside areas in Ome City was 8641 vehicles, which was smaller than the density observed in other districts.

Investigation of respiratory symptoms

Six items (age, years of residence in the area, job status, smoking habit, type of heater, and housing structure) were compared among the three groups. Significance was evaluated by the χ^2 test.

- The prevalence of respiratory symptoms was compared among the three groups. Respiratory symptoms were determined from questionnaire responses defined as follows: (1) persistent cough: for ≥ 3 months a year, cough almost every day; (2) persistent phlegm: for ≥ 3 months a year, phlegm almost every day; (3) wheeze: twice or more times in the past two years, wheezing or rattling when the subject had a cold or even when she did not have a cold; (4) asthma: diagnosed by a physician and history of ≥ 2 attacks accompanied with respiratory difficulty in the past, and an attack or treatment for asthma in the past two years; (5) breathlessness: breathing difficulty in walking a flat road and not catching up with people of the same generation.
- We used multiple logistic regression analysis (adjusted for age, years of residence in the area, etc) to calculate odds ratios for the above five symptoms compared with the status in group 3. We also evaluated the trend of the hypothesis group 1 > group 2 > group 3. The LOGIST procedure of the SAS statistics package was employed for the calculation.¹⁹

Pulmonary function tests

Those who provided valid data on four or more of the eight tests performed in addition to the valid data in the initial test were subjected to pulmonary function tests. Their age, height, forced vital capacity (FVC), forced expiratory volume in 1 second (FEV₁), and respiratory symptoms at the time of the initial test were compared between the subjects included in

the analysis of pulmonary function tests and those excluded from the analysis.

FVC and FEV₁ were used as indices of pulmonary function. The age and height adjusted mean levels were obtained and annual mean changes were compared among the three groups. The mean levels of these indices were obtained from each group after adjusting them for age, square of age, height, years of residence in the area, housing structure, job status, and type of heater; the results were compared with those of group 3 in which the air pollution level was the lowest.

There seemed to be an autocorrelation of individual pulmonary function levels between the years investigated. Accordingly, the annual mean changes of FVC and FEV₁ were analysed in a two stage analysis. First, based on the progressive decrease of FVC and FEV₁ over the follow up years in each subject, the regression coefficient was assumed as the individual annual mean changes. Then, with this annual mean change as the dependent variable, covariance analysis was carried out using a general linear model (GLM procedure of SAS).²⁰ The factors analysed were the group, pulmonary function at the initial test, age and height at the time of the initial test, number of years investigated, years of residence in the area, type of heater, housing structure, and job status. Using the above mentioned model, the adjusted annual mean change was obtained for each of the three groups, and the hypothesis of group 1 > group 2 > group 3 was evaluated.

RESULTS

Investigation of respiratory symptoms

The number of questionnaires recovered was 6760 (the recovery rate was 73.3% in group 1, 77.5% in group 2, and 75.8% in group 3). Since those who lived less than three years in an area (n=478) and those whose answers to the questions used for the analysis were inaccurate (n=600) were excluded, data from 5682 subjects (1147 in group 1, 2695 in group 2, and 1840 in group 3) were analysed. The percentage of subjects analysed was 84.1% of the total number of people who answered the questionnaire, and 63.8% of the initially included subjects.

Table 3 shows the prevalence of relevant factors by group. Significant differences among the three groups were observed in age, years of residence in the area, job status, smoking

Table 3 Characteristics of the subjects who answered the questionnaire, by area

	Group 1 (n = 1147)		Group 2 (n = 2695)		Group 3 (n = 1840)		p value
	n	%	n	%	n	%	
Age (y)							0.001
30–39	363	31.6	730	27.1	580	31.5	
40–49	388	33.8	909	33.7	628	34.1	
50–59	396	34.5	1056	39.2	632	34.3	
Years of residence in the area							<0.001
3–9	431	37.6	713	26.5	620	33.7	
10+	716	62.4	1982	73.5	1220	66.3	
Job status							<0.001
Currently employed	721	62.9	1479	54.9	1000	54.3	
Past employed	222	19.4	635	23.6	480	26.1	
Never employed	204	17.8	581	21.6	360	19.6	
Smoking habits							0.004
Current smoker	241	21.0	443	16.4	312	17.0	
Past smoker	52	4.5	106	3.9	64	3.5	
Never smoked	854	74.5	2146	79.6	1464	79.6	
Type of heaters							0.053
Unvented	526	45.9	1345	49.9	876	47.6	
Others or none	621	54.1	1350	50.1	964	52.4	
House structures							<0.001
Wooden with wooden window frames	190	16.6	595	22.1	381	20.7	
Wooden with aluminium window frames	367	32.0	1484	55.1	1037	56.4	
Reinforced concrete	590	51.4	616	22.9	422	22.9	

The χ^2 test was used to test the differences among rates for statistical significance.

habit, and housing structure. With regard to age, those in their 50s accounted for the highest percentage in group 2. With regard to years of residence in the area, those who lived in the area in question for 10 years or more accounted for 60% or more in each group, but those in groups 2 and 3 lived longer in the areas in question than those in group 1. With regard to occupation, 62.9% of the subjects in group 1 had jobs and the proportion was higher than that in the remaining two groups; 79% of them were engaged in clerical jobs, sales, and service jobs, and few subjects were engaged in the dust work. With regard to smoking status, the proportion of those who smoked in group 1 was higher than that in the remaining two groups. With regard to housing structure, the proportion of those who lived in airtight reinforced concrete buildings in group 1 was the highest among the three groups. With regard to heaters, the proportion of those who used vented heaters was the highest in each group and there were no significant differences among the three groups.

Table 4 shows the prevalence rates of respiratory symptoms by group. The rates in group 1 were higher than that in groups 2 and 3 except for wheezing. According to testing for the trend, significant differences were found in persistent phlegm (7.7%, 5.9%, and 5.1% in groups 1, 2, and 3, respectively) and breathlessness (3.1%, 1.0%, and 1.3% in groups 1, 2, and 3, respectively), among the groups.

Multiple logistic regression analysis was employed to adjust the relevant six factors including age and years of residence in the area. Table 5 shows the adjusted odds ratios relative to group 3. The odds ratios were significantly higher

than 1 for persistent phlegm (group 1: OR = 1.78, 95% CI 1.26 to 2.53; group 2: OR = 1.52, 95% CI 1.11 to 2.04) and breathlessness (group 1: OR = 2.70, 95% CI 1.48 to 4.91). Although the odds ratio of asthma was larger than 1, it was not significant in group 1 (OR = 2.66, 95% CI 0.98 to 7.19) and group 2 (OR = 1.99, 95% CI 0.82 to 4.83). The trend test revealed significant relationships of breathlessness and persistent phlegm with the level of air pollution ($p = 0.001$ for both).

Pulmonary function tests

A total of 733 females were subjected to the pulmonary function tests the first time (179, 358, and 196 in groups 1, 2, and 3, respectively). Of them, 406 (94 (52.5%), 210 (58.7%), and 102 (52.0%) in groups 1, 2, and 3, respectively) who provided valid data on four or more tests during the investigation period were subjected to the analysis (table 6).

Table 7 compares the characteristics of subjects included in the analysis of each group with those of people excluded from the analysis. The subjects in all three groups were significantly older than those excluded from the analysis but there was no difference in height. Although FVC and FEV₁ were slightly higher in the analysis group, there was no significant difference. Since those without a history of respiratory diseases were selected, the proportion of those having respiratory symptoms was extremely low in subjects both included and excluded, and there was no significant difference between them (data not shown).

Table 4 Prevalence of respiratory symptoms among female adults, by area

	Group 1 (n = 1147)		Group 2 (n = 2695)		Group 3 (n = 1840)		χ^2 test p value	Cochran-Armitage test p value
	n	%	n	%	n	%		
Persistent cough	36	3.1	79	2.9	56	3.0	0.937	0.926
Persistent phlegm	88	7.7	160	5.9	94	5.1	0.016	0.005
Asthma	12	1.0	24	0.9	11	0.6	0.371	0.168
Wheeze	42	3.7	105	3.9	53	2.9	0.182	0.177
Breathlessness	35	3.1	28	1.0	24	1.3	<0.001	0.001

Table 5 Results of multiple logistic regression analysis for respiratory symptoms

	Group	OR	95% CI	p value (trend test)
Persistent cough	Group 3	1.00		0.788
	Group 2	1.02	0.70 to 1.48	
	Group 1	1.07	0.67 to 1.70	
Persistent phlegm	Group 3	1.00		0.001
	Group 2	1.51	1.11 to 2.04	
	Group 1	1.78	1.26 to 2.53	
Asthma	Group 3	1.00		0.052
	Group 2	1.99	0.82 to 4.83	
	Group 1	2.66	0.98 to 7.19	
Wheeze	Group 3	1.00		0.186
	Group 2	1.39	0.95 to 2.01	
	Group 1	1.34	0.85 to 2.11	
Breathlessness	Group 3	1.00		0.001
	Group 2	0.84	0.47 to 1.50	
	Group 1	2.70	1.48 to 4.91	

OR, odds ratio; CI, confidence interval.

Odds ratios were adjusted for age, years of residence in the area, job status, smoking habit, type of heater used in home, and housing structure.

Figure 2 compares the changes in mean values adjusted for age and height in each group. Although FVC did not show a consistent trend among the groups by the year of investigation, FEV₁ in group 1 was the lowest every year.

Figure 3 shows the comparison of adjusted mean values of FVC and FEV₁ of females in group 1 and group 2 with those in group 3, who had been living in areas with the lowest level of air pollution. FVC did not show any specific relation among the groups. Although there was no difference in FEV₁ among the groups in the first year, the level started to decrease in group 1 in comparison with group 3, and the difference between the two groups tended to increase with time.

Figure 4 shows the annual mean changes of FVC and FEV₁ by group. With regard to FVC, group 1 showed the highest rate of decrease (0.006 l/year) followed by group 2 (0.002 l/year) and group 3 (0.000 l/year). However, the result of the trend test was not significant ($p=0.162$). With regard to FEV₁, group 1 showed the highest rate of decrease (0.020 l/year), followed by group 2 (0.015 l/year) and group 3 (0.009 l/year). The trend test revealed that the higher the level of air pollution, the more significantly the FEV₁ was reduced ($p < 0.001$).

DISCUSSION

To clarify the chronic effects of air pollution caused mainly by automobiles, on health, pulmonary function tests were conducted for eight years in adult females who lived in various areas of the Tokyo metropolitan area. The decrease in pulmonary function was larger in females who lived in areas close to the trunk roads where the daytime traffic density exceeded 20 000 vehicles, than in the other groups.

Compared with agricultural and rural regions, the levels of air pollution are higher in larger cities. The level of air

pollution around trunk roads is reportedly the highest in roadside areas, but the farther from the roads an area is, the lower the level of pollution it has. Laxen and Noordally²¹ measured the NO₂ concentration, which is a major pollutant arising from automobile exhaust, in the roadside areas in England. They reported that the level rapidly decreased in the areas 10–15 m away from the road and that the level became almost constant when the distance from the road exceeded 30 m. The results of air monitoring in this study also indicated that the highest NO₂ and SPM concentrations were in the roadside areas, but the levels gradually decreased with the distance from the road. Although the level also depends on the environmental conditions around an area, including topography and climate,²² the distance from the road is clearly the most important factor influencing the level of air pollution in a given area.

Ono and colleagues²³ measured NO₂ and SPM concentrations in areas close to the trunk roads in Tokyo as well as inside the houses in Tokyo. They reported that, the nearer a house was to a road, the higher the indoor NO₂ concentration if an unvented heater was not used, and that the influence of unvented heaters was greater during the winter time. Nakai and colleagues²⁴ reported that the personal levels of exposure to NO₂ also decreased with the distance from the roads. According to the results of this survey, the type of heaters used was similar among the groups. Even if indoor pollution caused by heaters was considered, those who lived in roadside areas seemed to have been exposed to a higher concentration of pollutants in comparison with those who lived farther from the roadside.

Several reports on the effect of automobile exhaust on health have been published. According to these reports, respiratory symptoms, including chronic cough and phlegm, asthma, and allergic rhinitis were observed at a high rate in

Table 6 The number of subjects according to the times of pulmonary function tests

		The times of pulmonary function tests								Subjects excluded from the analysis (1–3 times)	Subjects included in the analysis (4–8 times)
		1	2	3	4	5	6	7	8		
Group 1 (n = 179)	n	40	30	15	21	18	12	23	20	85	94
	%	22.3	16.8	8.4	11.7	10.1	6.7	12.8	11.2	47.5	52.5
Group 2 (n = 358)	n	77	35	36	36	31	51	47	45	148	210
	%	21.5	9.8	10.1	10.1	8.7	14.2	13.1	12.6	41.3	58.7
Group 3 (n = 196)	n	48	24	22	14	9	33	25	21	94	102
	%	24.5	12.2	11.2	7.1	4.6	16.8	12.8	10.7	48.0	52.0

Table 7 Characteristics of subjects included and excluded from the analyses of pulmonary function

	n	Age (y)			Height (cm)		FVC (l)		FEV ₁ (l)	
		Mean	SD		Mean	SD	Mean	SD	Mean	SD
Group 1										
Subjects included	94	47.3	7.4	*	153.2	4.8	2.71	0.31	2.33	0.26
Subjects excluded	85	44.0	7.7	*	154.2	5.1	2.67	0.35	2.30	0.28
Group 2										
Subjects included	210	47.6	7.8	†	153.6	4.9	2.72	0.33	2.34	0.28
Subjects excluded	148	43.8	8.4	†	154.3	5.4	2.67	0.32	2.29	0.27
Group 3										
Subjects included	102	46.1	8.4	*	153.2	4.6	2.67	0.30	2.33	0.23
Subjects excluded	94	43.5	8.6	*	154.1	4.9	2.63	0.30	2.28	0.28

SD, standard deviation.

*Difference significant at $p=0.05$.

†Difference significant at $p=0.01$.

areas close to the roads with a high traffic level in comparison with the areas away from the roads.^{25, 26} The prevalence rate of respiratory symptoms in group 1 was higher than that in groups 2 and 3, except for wheezing. The rates of these respiratory symptoms were higher in the areas with high air pollution. The trend test indicated a significant difference in persistent phlegm and breathlessness. Among the three groups, there were differences in age, years of residence in the area, job status, smoking habit, and housing structure. The results of logistic regression analysis arranging these factors showed a significant relation of persistent phlegm and breathlessness with the level of air pollution. The influences of outing hours in daily life and type of occupation should also be considered. Among the subjects of this study, there

were many who worked, and in most cases their jobs were clerical jobs, sales, and light work. It was also confirmed that more than 70% of them stayed at home 18 hours or longer, daily. Thus, the influence of outing hours may not be too large.

Concerning the relation between respiratory symptoms and pulmonary function, Sherman and colleagues²⁷ reported that chronic cough and phlegm affected pulmonary function but that persistent wheezing and breathlessness did not show any relation in this regard. On the other hand, Kauffmann and colleagues²⁸ conducted a 12-year follow up study and reported that respiratory symptoms, including cough, phlegm and dyspnoea, observed at the initial test were related to a lower initial level of FEV₁, but that those symptoms were not

Figure 2 Mean levels of FVC (A) and FEV₁ (B) in each group at the examination, adjusted for age and height.

Figure 3 Mean levels of FVC (A) and FEV₁ (B) in each group at the examination, adjusted for age, square of age, height, years of residence in the area, housing structure, job status, and type of heater. The values in group 3 are subtracted from those in group 1 or group 2.

Figure 4 Annual mean change rates (l/y) of FVC (A) and FEV₁ (B) in the three groups. All values are mean (SEM), adjusted for group, pulmonary function test value in the initial test, age and height at the time of the initial test, number of years investigated, years of residence in the area, type of heater, housing structure, and job status.

related to subsequent decreases in pulmonary function. Since the major purpose of this study was to evaluate the influences of air pollution on long term changes in pulmonary function, we examined respiratory symptoms of subjects only at the initial test. Therefore, the incidence of respiratory symptoms during the follow up period remains unclear. However, we limited the number of females subjected to pulmonary function tests to healthy non-smokers who had no history of respiratory diseases, thus the influence of respiratory symptoms on the changes in pulmonary function may not be too large.

Since FVC and FEV₁ are often clinically used to assess longitudinal changes, these parameters were selected as the indices of pulmonary function in this study. Ackermann-Lieblich *et al* investigated the effects of air pollution on pulmonary function in eight districts in Switzerland.²⁹ They reported that an increase of 10 µg/m³ in particulate matter less than 10 µm in diameter (PM₁₀) resulted in a decrease of 3.4% in FVC and of 1.6% in FEV₁ in healthy non-smokers. Chestnut *et al*³⁰ reported that an increase of 34 µg/m³ in total suspended particles was related to a decrease of 2.25% in FVC and that the change in FEV₁ was significant even though the change was small. Speizer³¹ showed that the effect of air pollution on respiratory health in adults was not clear because smoking and other interactive factors such as occupation and environmental exposure were also involved. To avoid uncontrollable variations in pulmonary function due to individual differences such as smoking history, we selected only healthy non-smoking adult females without a history of respiratory diseases as the subjects of this study. Furthermore, to evaluate the changes of pulmonary function values during the study period, we performed a longitudinal analysis over eight years. As a result, the influence of

interactive factors such as exposure to air pollution in the past was considered small in our subjects. When a survey lasts a long time, a substantial number of subjects are inevitably lost to follow up due to change of address, etc. According to Tashkin and colleagues,³² change of address was the major reason for not receiving the second test, and the respiratory symptoms accounted for less than 1% of the reasons for drop-out. A considerable number of drop-outs also occurred during the follow up period in our study. Among those subjected to the initial pulmonary function test, the number of those included in the analysis of longitudinal changes and the number of those lost to follow up were compared. The results indicated that those analysed were significantly older in all three groups, indicating that those who were older had a stronger sense of participation in the study. However, considering that there was not much difference in the respiratory symptoms and initial level of pulmonary function between those analysed and the drop-outs, the influence of drop-outs seemed to be small.

Pulmonary function tests were performed by the same method using the same spirometer throughout the study period. However, FVC and FEV₁ increased from 1993 to 1994, particularly in group 2. This may be due to a difference in the composition of the subjects examined or a difference in weather conditions, but the cause remains unclear. Many epidemiological studies have shown that exposure to air pollution for a short term was related to a decrease in pulmonary function.^{33–35} Tashkin and colleagues³² and van der Lende and colleagues³⁶ reported the chronic effects of air pollution on the annual changes of pulmonary function value for a long term. Tashkin and colleagues³² compared three districts in which the levels of air pollution differed from each other. After adjustment for interactive factors, FEV₁ decreased in females by 49.3 ml/year and 50.1 ml/year in two of the districts where air pollution levels were higher, but the decrease in the remaining district where the level was the lowest was 40.5 ml/year. According to our study, group 1 showed the highest decrease rate (0.020 l/year) of FEV₁ followed by group 2 (0.015 l/year) and group 3 (0.009 l/year). The annual change of FVC showed a similar pattern (group 1 > group 2 > group 3), but FVC did not change in group 3 during the follow up period. The change of FEV₁ was also smaller compared with the report by Tashkin and colleagues.³² As we obtained the annual mean respiratory volume change in each individual, the difference in the composition of the group examined may have not influenced the results. Since we selected only healthy non-smokers as the subjects of this study, the change of FVC might be too small to be detected. Furthermore, the difference in the method of investigation could also be responsible for the different results. To be more precise, we conducted a pulmonary function test every year and used those subjects whose data on four or more tests were available, while Tashkin and colleagues conducted only two tests with an interval of 5–6 years.³² In addition, it is necessary to take into consideration the ethnic difference as well as the differences in the device used for the pulmonary function tests, the air pollution level and quality, and the sensitivity of the subjects to air pollution. The increase in FEV₁, especially in group 2 in 1993, seemed to be partly responsible for the difference from the result reported by Tashkin and colleagues. However, the difference in the annual changes of FEV₁ between group 1 and group 3 was close to the difference between the area with the highest level of air pollution and that with the lowest level of air pollution in the study by Tashkin and colleagues.

Diesel exhaust particles (DEPs) are considered to account for about 30–50% of SPM, and most of DEPs consist of fine particles. Since fine particles reach the depth of lungs and precipitate there, they are expected to have a considerable

influence on the living body, including the respiratory system. However, the mechanism of action of these particles has yet to be established. Repeated exposure to NO₂ is known to induce inflammatory changes in the neutrophils in the lower airway, but reduction of pulmonary function is indicated to be temporary.³⁷⁻³⁸ On the other hand, inflammatory changes in the airway as well as in the whole body, and an increase in airway resistance were reported in humans experimentally exposed to diesel exhaust.³⁹⁻⁴⁰ These studies suggested that long term exposure to NO₂ and SPM was related to an increase in airway resistance and a chronic decrease in pulmonary function. The results of our study also show that the annual mean change of FEV₁ is larger than that of FVC, indicating the considerable influence on airflow obstruction, including increased airway resistance. In this study, those who had lived in an area along the trunk roads showed a high prevalence rate of respiratory symptoms and more decreased pulmonary function. However, in these areas, both the concentrations of NO₂ and SPM were high, so which pollutant had the most influence remains unclear. Hereafter, measurements of fine particles or diesel exhaust concentration may clarify the relation between air pollutants and pulmonary function.⁴¹

In summary, we investigated healthy adult females who lived in the Tokyo metropolitan area to clarify the chronic health effects of air pollution caused mainly by automobiles. According to our results, the subjects living in areas with high levels of air pollution showed higher prevalence rates of respiratory symptoms and a larger decrease of FEV₁ compared with those living in areas with low levels of air pollution. Considering the high traffic density in these areas, the effect of particulate matter found in automobile exhaust seems to be one of the factors responsible for the difference between other areas.

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Authors' affiliations

K Sekine, M Shima, Y Nitta, M Adachi, Department of Public Health, Graduate School of Medicine, Chiba University, Chiba, Japan

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