J Occup Health 2009; 51: 164–168

Short Communication

The Dose-Response Relationship between Pulmonary Function Injury and Cumulative Dose of Tobacco Dust Exposure among Tobacco Processing Workers

Yongxing Zhang, Juan Wang and Jiezhi Lou

Department of Preventive Medicine, Medical College of Xiamen University, China

Key words: Dose-response relationship, Pulmonary function, Tobacco workers

In China, the tobacco-processing industry is one of the nation's largest industries. Tobacco dust can cause respiratory symptoms and a decline in pulmonary function[1, 2]. Viegi *et al.*[3] reported that respiratory or nasal symptoms in cigar and cigarette-making workers were significantly higher than controls. Mustjbegovic *et al.* [4] showed that tobacco workers tended to have lower forced vital capacity (FVC), forced expiratory volume in 1 sec ($FEV_{1.0}$), FEF_{50}, and FEF_{25}. In no studies[5, 6] have authors documented the relationship between dose of exposure to tobacco dust and respiratory system injury, as measured by pulmonary function. We completed an industrial hygiene investigation and conducted pulmonary function tests on workers employed in a tobacco-processing factory to determine whether there was a dose-response relationship between the cumulative dose of tobacco dust exposure and respiratory system injury, as measured by pulmonary function. We also discussed whether the current exposure limit for tobacco dust of 3 mg/m^3 set in China could protect workers' health.

Subjects and Methods

The subjects consisted of 302 workers (informed consent was obtained from each subject) of the tobacco-processing factory participating in this study. They were composed of 135 male workers (105 smokers, 30 nonsmokers) whose mean ages were 34.0 ± 14.9 yr old, average intake of drugs of smokers was 6,1762.5 yr·day·(ramus/day), and 167 female workers (nonsmokers) whose mean ages were 37.0 ± 18.2 yr old. Another 323 workers (informed consent was obtained from each subject) with similar labor intensity and no exposure to dust or toxicants in a machine factory in the same county were selected as controls. They were composed of 159 male workers (107 smokers, 52 nonsmokers) who were 35.0 ± 19.9 yr old on average, average drug dosage of smokers was 61,425.164 yr·day·(ramus/day), and 164 females (nonsmokers) who were 38.0 ± 17.4 yr old on average. (Noties: 1. yr·day·(ramus/day): year is the length of smoking years, day means 365 days, and (ramus/day) stands for rami of drugs for each day. 2. There were no female smokers in the investigation.)

Pulmonary function test

Following 2 days of rest and prior to the first day of work spirometries were performed on all subjects with a ST-300 spiro analyzer in December 1990 (Fukuda Sangyo Co., Ltd, [Tokyo Japan]). The subjects performed the maximum expiratory flow-volume curve test and repeated the performance until at least 3 acceptable curves were obtained. Subjects who failed to produce acceptable curves were excluded from the study. For each subject, we used the curve with the highest value in the data analysis, plus values for FVC, $FEV_{1.0}$, MMF, forced expiratory flow at 50% vital capacity (V_{50}), and forced expiratory flow at 25% vital capacity (V_{25}). Measurements were converted to body temperature and pressure saturated with water (BTPS) Standard Units. Linear regression models to predict the above-listed pulmonary function parameters were developed using data gathered from non-smoking controls Variables in the regression equations included age, height, and body weight. Separate equations were developed for men and women for each parameter. Predicted pulmonary values were then calculated for each worker using these gender-specific equations. The lower limits of the abnormal values were 80% for the predicted FVC or $FEV_{1.0}$, and were 70% for the predicted MMF, V_{50} or V_{25}.

Industrial hygiene investigation

Tobacco is processed in the following steps: reeling off, steaming, unpacking, hanging and wrapping. The total dust concentration was measured by area sampling, and 2–6 locations for each tobacco processing procedure were selected for sampling by means of a FCY-3T dust sampler (Jiangsu Jianhu Xinyu Analysis Apparatus Factory). Four samples were collected during the entire 8-h shift, and sampling was continued for 2 days in each location. One hundred eleven dust samples were collected from 5 locations in December 1990. The geometric means of dust concentrations in all of the processes were calculated according to the data obtained in the surveys. The gravimetric method was carried out to analyze the silica content and the dust dispersity was measured by dissolving filter membrane.

Cumulative dose of dust exposure (mg·yr·h)

There were in total 2,894 monitoring samples collected

Received Jun 6, 2008; Accepted Nov 14, 2008
Published online in J-STAGE Jan 30, 2009
Correspondence to: Y. Zhang, Department of Preventive Medicine, Medical College of Xiamen University, Room 512, No.168, Daxue Road, Xiamen City, Fujian Prov 361005, China
(e-mail: z63y94x@163.com)

Table 1. Dust concentrations and silica contents in the Tobacco-Processing Factory Processes

Process	Dust concentration (mg/m^3)				Silica
	Number	Maximum	Minimum	Geometric means (GM ± GSD)	(%)
Reeling off	22	43.5	9.3	23.85 ± 11.28	10.78
Steaming	24	31.0	6.7	19.78 ± 9.14	2.69
Unpacking	20	52.8	6.4	22.75 ± 15.36	7.27
Hanging	22	88.0	6.7	20.9 ± 18.62	7.15
Wrapping	23	35.6	3.7	12.78 ± 13.67	2.42

Table 2. Cut-off level of tobacco dust in the Tobacco-Processing Factory Processes (%)

μm	Reeling off	Steaming	Unpacking	Hanging	Wrapping
<2	62.5	81.0	61.5	74.5	72.5
2 –	17.5	16.0	19.0	18.5	19.5
5 –	13.5	1.5	14.5	4.5	7.0
10–	6.5	1.5	5.0	2.5	1.0

from 1974 to 1990. Determining demand: according to size of every post to select 2–6 sampling points, the dust concentration (mg/m^3) and free SiO_2 content (%) of the dust sample, which were gathered at the height of the breathing zone, were determined by the gravimetric method. The dust levels used in this study are the geometric means for the sampling locations used for each processing procedure step-by-time period. We defined cumulative dose (mg·yr·h) of dust exposure as $\Sigma Ci \cdot Ti \cdot Hr$[5, 6], where Ci represents the average dust concentration for each procedure to which a worker was exposed, and Ti is the time (yr) each worker spent engaged in that specific procedure, and Hr is the average time (h) workers were exposed to the different procedures each day.

Statistical analysis

We used analysis of variance (ANOVA) to examine differences in pulmonary function indices between groups that were stratified by various characteristics. We used chi-squared tests to examine differences in the prevalence of abnormal %FVC, %$FEV_{1.0}$, %MMF, %V_{50}, %V_{25} values between groups, stratified by various characteristics. We used a life-table[5, 6] to calculate the cumulative prevalence of abnormal %$FEV_{1.0}$ values. Statistical significance was set at $p<0.05$. We used SPSS 13.0 for windows (SPSS Inc, ISBN 0-13-154242-7) to conduct statistical analyses.

Results

Dust concentrations and free silica contents

In total, 111 samples of the dust were collected in the tobacco processing workshops. The average dust concentrations ranged from 12.78 to 23.85 mg/m^3, which were above the national health limit of China, 3 mg/m^3. Sandy soil was the source of the silica in the tobacco dust, which was attached to the tobacco leaves. Silica content ranged from 2.42% to 10.87% (Table 1). Most of the particles, 80%–97%, were under 5 μm, and most of tobacco dusts were respirable (Table 2).

Relation between pulmonary function and exposure

We divided the exposed workers into 3 groups, by their cumulative dose of dust exposure (0–499 mg·yr·h, 500–999 mg·yr·h, and ≥1,000 mg·yr·h), in order to compare the levels of dust exposure with the predicted percentage of pulmonary function. As shown in Table 3, most of the %FVC, %$FEV_{1.0}$, %MMF, %V_{50} and %V_{25} values for the exposed groups were significantly lower than the respective values for the control group ($p<0.05$ or $p<0.01$). Generally, all pulmonary function indices decreased as the cumulative dose of dust exposure increased. Most of the percentages of predicted pulmonary function values of male smokers, male nonsmokers or female workers of the 500–999 mg·yr·h and ≥1,000 mg·yr·h groups were significantly lower than those of the 0–499 mg·yr·h groups ($p<0.05$ or $p<0.01$). Also, most of the percentages of predicted pulmonary function values of male smokers, male nonsmokers or female workers of the ≥1,000 mg·yr·h groups were significantly lower than those of the 500–999 mg·yr·h groups ($p<0.05$ or $p<0.01$). In the comparison of male smokers and female nonsmokers, the difference in the %V_{25} values of the 500–999 mg·yr·h groups were significant ($p<0.05$).The other indices showed no statistical significance.

Table 3. Percentage of predicted pulmonary function values by category of cumulative dose of dust exposure (mg·yr·h) in the exposed workers

Pulmonary function test	Control smokers	Exposed male smokers (n=105)			Control nonsmokers	Exposed male nonsmokers (n=30)		
	(n=107)	0–499 (n=35)	500–999 (n=51)	≥1,000 (n=19)	(n=52)	0–499 (n=18)	500–999 (n=8)	≥1,000 (n=4)
%FVC	99.34 ± 9.79	99.15 ± 13.61	92.1 ± 12.48*†	81.85 ± 14.58**††##	99.2 ± 12.39	98.79 ± 14.27	91.52 ± 11.16	74.35 ± 15.04**††##
%$FEV_{1.0}$	98.81 ± 18.68	95.5 ± 14.39	94.15 ± 17.91	78.47 ± 6.02**††#	99.56 ± 10.70	98.32 ± 18.89	86.68 ± 12.61**	64.42 ± 18.73**††#
%MMF	95.84 ± 10.90	96.27 ± 19.04	85.4 ± 21.03**†	81.47 ± 25.54**†	100.2 ± 15.00	95.39 ± 31.17	82.2 ± 25.22*	65.9 ± 14.60**†
%V_{50}	94.07 ± 18.93	94.94 ± 22.03	86.24 ± 31.63	75.23 ± 26.19**†	98.13 ± 22.22	96.38 ± 32.74	82.01 ± 25.37	62.4 ± 9.24**
%V_{25}	95.62 ± 24.24	99.03 ± 31.64	83.65 ± 30.40**†	78.16 ± 23.73**†	100.92 ± 31.62	97.83 ± 29.08	76.12 ± 23.61*	69.4 ± 19.71*†

	Control workers	Exposed female workers(n=167)		
	(n=164)	0–499 (n=64)	500–999 (n=59)	≥1,000 (n=44)
%FVC	102.93 ± 10.63	99.53 ± 15.04	92.47 ± 13.25**††	79.66 ± 17.43**††##
%$FEV_{1.0}$	98.34 ± 11.07	97.76 ± 15.29	91.1 ± 13.48**†	81.01 ± 19.50**††##
%MMF	99.64 ± 24.32	99.06 ± 23.02	89.27 ± 21.05**†	76.2 ± 26.24**††##
%V_{50}	99.74 ± 24.37	98.41 ± 22.20	86.89 ± 20.24**††	83.14 ± 26.92**††
%V_{25}	100.15 ± 33.04	98.14 ± 24.23	95.36 ± 19.96	85.12 ± 24.38**††#

Compared with control group *$p<0.05$, **$p<0.01$; compared with 0–499(mg.yr.h) †$p<0.05$, ††$p<0.01$; compared with 500–999(mg.yr.h) #$p<0.05$, ##$p<0.01$.

Table 4. Prevalence(%) of pulmonary function abnormalities by cumulative dose of dust exposure (mg·yr·h)

Pulmonary function test	Control male smokers	Exposed male smokers (n=105)			Control male nonsmokers	Exposed male nonsmokers (n=30)			Control female workers	Exposed female workers (n=167)		
		0–499	500–999	≥1,000		0–499	500–999	≥1,000		0–499	500–999	≥1,000
	(n=107)	(n=35)	(n=51)	(n=19)	(n=52)	(n=18)	(n=8)	(n=4)	(n=164)	(n=64)	(n=59)	(n=44)
%FVC	0.00	8.57**	7.84**	31.58**##	0.00	11.11**	12.50	50.00**	0.00	17.19**	22.03**	31.82**††
%$FEV_{1.0}$	6.54	14.28	17.65**	42.11**†#	3.85	11.11	25.00*	75.00**†	2.44	25.00**	20.34**	27.27**
%MMF	19.63	20.00	27.49	31.58	13.46	16.67	37.50	50.00	9.76	25.00**	25.42**	29.55**
%V_{50}	23.36	20.00	25.49	42.11*	11.54	16.67	50.00*	50.00	12.19	29.69**	25.42*	34.09**
%V_{25}	23.36	22.86	37.25**	42.11*	17.31	11.11	37.50	50.00	19.51	26.58	23.73	27.27

Compared with control group *$p<0.05$, **$p<0.01$; compared with 0–499(mg.yr.h) †$p<0.05$, ††$p<0.01$; compared with 500–999(mg.yr.h) #$p<0.05$, ##$p<0.01$.

Cumulative dust exposure and pulmonary function abnormalities

Most of the prevalences of pulmonary function abnormalities in the exposed groups were significantly higher than those in the control group (p<0.05 or p<0.01). Generally, the prevalences of pulmonary function abnormalities increased as the cumulative dose of dust exposure increased (Table 4). The prevalences of %$FEV_{1.0}$ pulmonary function abnormalities in male smokers and male nonsmokers the ≥1,000 mg·yr·h group were significantly higher than those of the 0–499 mg·yr·h group (p<0.05). The the prevalence of FVC pulmonary function abnormalities in female workers of the ≥1,000 mg·yr·h group were significantly higher than those of the 0–499 mg·yr·h group (p<0.01). The prevalences of FVC and %$FEV_{1.0}$ pulmonary function abnormalities in male smokers of the ≥1,000 mg·yr·h group were significantly higher than those of the 500–999 mg·yr·h group (p<0.01 or p<0.05).

On the basis of the relationship between the cumulative dose of dust exposure and prevalence of pulmonary function abnormality, we calculated the cumulative prevalence of %$FEV_{1.0}$ abnormality for different levels of the cumulative dose of dust exposure by the life-table method[5, 6] (Table 5). A linear-regression equation utilized the upper limit values of cumulative dose of dust exposure as dependent variables, and the Logit values converted from cumulative rates of %$FEV_{1.0}$ abnormality were the independent variables. The following linear-regression equation was obtained:

Y(cumulative dose of dust exposure) = 1070.7 + 254.1 × Logit Value
(F=158.882, r=0.9700) (1).

The prevalence of abnormal %$FEV_{1.0}$ values in the control group was 4.03% ([107 × 6.54% + 52 × 3.85% + 164 × 2.44%] / [107 + 52 + 164]) (Table 4). If the cumulative prevalence of abnormal %$FEV_{1.0}$ values for exposed workers is controlled at <3 times that of the control group, the cumulative prevalence of abnormality should be 12.09, corresponding to the 500–599 group in Table 5. The cumulative dose of dust exposure should be <571.14 (mg·yr·h) (calculated according to formula one). If the average time (h) of dust exposure is 6 h each day, and the average duration of dust exposure is 35 yr, the average dust level should be 2.72 mg/m^3. If the average duration of dust exposure is 40 yr, the average dust level should be 2.38 mg/m^3.

Discussion

Pulmonary function injury among tobacco workers has been reported by several authors. Lander and Gravesen[7] found the mean diurnal changes in peak expiratory flow time during 1 wk was 14.3% for tobacco workers compared with 9.8% for control subjects. In their study, tobacco workers had significantly lower FVC and $FEV_{1.0}$ values than control subjects. Kjaergaard *et al.*[8] reported a significant decrease of $FEV_{1.0}$ and FVC values in tobacco workers compared to referents. Uitti *et al.*[9] studied respiratory disease and allergic reactions in cigar factory workers exposed to raw tobacco and found that tobacco workers tended to have lower FVC, $FEV_{1.0}$, and FEF_{25}.

On the basis of the present study of tobacco dust, we conducted pulmonary function tests in workers employed in a tobacco-processing factory to determine whether there was a dose-response relationship between the cumulative dose of tobacco dust exposure. Our industrial hygiene investigation demonstrated that most of the average dust concentrations in tobacco-processing procedures ranged from 12.78 to 23.85 mg/m^3, which were above the national health limit of 3 mg/m^3. The concentration of SiO_2 was 2.42% to 10.87%, and it came from the soil attached to the tobacco leaves which fell off during the tobacco processing and accumulated on the ground and work benches. The reeling off process created the most SiO_2, 10.87%, followed by unpacking and hanging. The last process, wrapping, created the least concentration of 2.42%. Only a few workers engaged in reeling off were exposed to dust containing 10.87% silica, and most were exposed to tobacco dust that contained less than 10% silica. The measurement of dust dispersity showed that the dusts under 5 μm represented 80–97% of the total. Most exposed workers concentrated in the occupational circumstance of high dispersity. Tobacco-processing workers in our study had lower percentages of predicted pulmonary function than control workers. As the cumulative dose of dust exposure increased, average levels of pulmonary function declined. The prevalence of pulmonary function abnormalities also increased as the cumulative dose of dust exposure increased. These results demonstrate a dose-response relationship between dust exposure and pulmonary function injury in tobacco-processing workers. As is well-known, smoking can damage pulmonary function. We compared exposed male smokers and exposed female nonsmokers, but only the difference of the %V_{25} values of the 500–999 mg·yr·h group was statistically significant (p<0.05), and the other indices showed no statistical significant differences. This means smoking can damage pulmonary function but was not a leading factor, possibly because tobacco dust damages pulmonary function more than smoking. Therefore, the main factor influencing decrease of pulmonary function is tobacoo dust.

We used the life-table method to obtain a linear-regression equation between cumulative dose of dust exposure and cumulative rates of %$FEV_{1.0}$ abnormality. If the prevalence of abnormal %$FEV_{1.0}$ for exposed workers was set at 3 times[5, 6] that of the control group, and if the average duration of dust exposure of workers was 35–40 yr, the average dust level should not exceed 2.38–2.72 mg/m^3. The current implemented exposure limit for tobacco dust in China is 3 mg/m^3. From the

Table 5. Cumulative prevalence of %$FEV_{1.0}$ abnormality by cumulative dose of dust exposure (mg·yr·h)

Cumulative dose of dust exposure (mg·yr·h)	Observed number	Normal number	Abnormal number	Corrected observed number	Abnormal rate
100–199	302	41	5	281.5	0.018
200–299	256	18	4	247	0.016
300–399	234	18	6	225	0.027
400–499	210	17	8	201.5	0.040
500–599	185	23	5	173.5	0.029
600–699	157	27	4	143.5	0.028
700–799	126	11	6	120.5	0.050
800–899	109	10	1	104	0.010
900–999	98	24	7	86	0.081
1,000–1,099	67	19	7	57.5	0.122
1,100–1,199	41	6	3	38	0.079
≥1,200	32	19	13	22.5	0.578

Cumulative dose of dust exposure (mg·yr·h)	Normal rate	Accumulative normal rate	Accumulative abnormal rate	Logit value
100–199	0.982	0.982	0.018	–4.011
200–299	0.984	0.966	0.034	–3.356
300–399	0.973	0.941	0.059	–2.761
400–499	0.960	0.903	0.097	–2.233
500–599	0.971	0.877	0.123	–1.966
600–699	0.972	0.853	0.147	–1.756
700–799	0.950	0.810	0.190	–1.452
800–899	0.990	0.802	0.198	–1.402
900–999	0.919	0.737	0.263	–1.031
1,000–1,099	0.878	0.647	0.353	–0.608
1,100–1,199	0.921	0.596	0.404	–0.390
≥1,200	0.422	0.252	0.748	1.089

Observed number is the number of people who were observed at first; Normal number is the number of people who were normal in the respective group; Abnormal number is the number of people who were abnormal in the respective group; Corrected observed number is the revised number calculated by the formula Corrected observed number=Observed number–0.5 × Normal number; the formula for the Abnormal rate was Abnormal rate=Abnormal number / Corrected observed number; the formula for the normal rate was 1– Abnormal rate; for the group of 100–199 Accumulative Normal rate equaled the Normal rate. The formula for the other Accumulative Normal rates was Accumulative normal rate=Normal rate of this group × Accumulative normal rate of last group. The formula for the Accumulative abnormal rate was 1– Accumulative Normal rate; The formula for the Logit value was Logit value=Ln (Accumulative abnormal rate / Accumulative normal rate).

aspect of protecting workers' pulmonary function, the exposure limit of 3 mg/m^3 for tobacco dust is practical. Furthermore, medical surveillance could be adopted to protect and treat workers with lung function injury.

In order to reduce the lung damage of workers exposed to tobacoo dust, the working conditions of tobacco exposed workers should be improved. In particular steps should be taken to decrease the leakage of tobacoo dust, and ventilation settings need to reduce the concentration of tobacoo dust in the workplace. Exposed workers should use individual protection such as a respirator, gloves and so on, for the purpose of protecting themselves form the health hazards of tobacco dust.

References

1) Mukthtar MSR, Rao GMM, Gamra NS, Afan AM, Zendah MI. Respiratory effects of occupational exposure to tobacco dust. Respiration 1991; 58: 271–6.
2) Zuskin E, Mustajbegovic J, Schachter EN, et al. Immunological and respiratory changes in tobacco workers. Am J Ind Med 2004; 45:76–83.
3) Viegi G, Paggiaro PL, Begliomini E, Vaghetti E, Paoletti P, Giuntini C. Respiratory effects of occupational exposure to tobacco dust. Br J Ind Med 1986; 43: 802–8.
4) Mustjbegovic J, Zuskin E, Schachter EN, et al. Respiratory findings in tobacco workers. Chest 2003; 123: 1740–8.
5) Chen J, Lou J, Liu Z. Pulmonary function in fur-processing workers: a dose-response relationship. Arch Environ Health 2003; 58: 37–41.
6) Chen J, Lou J, Guo X, Zhou C. Pulmonary function in jute dust-exposed workers: a dose-response relationship. J Occup Health 1997; 39: 313–8.
7) Lander F, Gravesen S. Respiratory disorders among tobacco workers. Br J Ind Med 1988; 45: 500–2.
8) Kjaergaard SK, Pedersen OF, Frydenberg M, Schonheyder H, Andersen P, Bonde GJ. Respiratory disease and lung function in a tobacco industry. Arch Environ Health 1989; 44: 164–70.
9) Uitti J, Nordman H, Huuskonen M, Roto P, Husman K, Reiman M. Respiratory health in cigar factory workers. Occup Environ Med 1998; 55: 834–9.