ERJ Express. Published on December 23, 2010 as doi: 10.1183/09031936.00050210

Lung Function, Radiologic Changes and Exposure: Analysis of ATSDR Data from Libby, Montana

David Weill[1], Gundeep Dhillon[1], Laurie Freyder[2], John Lefante[3], and Henry Glindmeyer[2]

[1] Division of Pulmonary and Critical Medicine, Stanford University Medical Center

[2] Section of Pulmonary, Critical Care & Environmental Medicine, Department of Medicine, Tulane Medical School

[3] Department of Biostatics, Tulane School of Public Health

Corresponding Author:

David Weill, M.D.

300 Pasteur Drive, H3143

Stanford, CA 94305-5236

dweill@stanford.edu

Fax 650-725-5489

Phone 650-725-7329

Running Head: Analysis of the Libby ATSDR Data

Funding: The analysis was funded by W.R. Grace & Company, but the data upon which the analyses were based were independently collected by the Agency for Toxic Substances and Disease Registry (ATSDR), an agency of the U.S. Department of Health and Human Services.

ABSTRACT

Objectives: In 2000, the Agency for Toxic Substances and Disease Registry investigated lung disease in those exposed to the tremolite contaminated vermiculite mine in Libby, Montana. Previously unreported, spirometric results are presented here in relation to exposure and radiographic findings.

Methods: 4524 study participants were assigned to one of 7 mutually exclusive exposure categories. Associations among radiographic findings, spirometric results and exposure were investigated, along with the effect of a reduction in exposure potential when production was moved to a wet process mill in the mid 1970's.

Results: Spirometry for the total population by smoking status and age were within normal range. Prevalence of pleural plaque increased with age, but was lowest in the environmentally exposed group (0.42% to 12.74%) and greatest in the mineworkers (20% to 45.68%). For men, there was a significant (4.5%) effect of pleural plaques on FVC. For Grace workers and household contacts, a reduction in plaque (0.11% v 1.64%) and in diffuse pleural thickening or costophrenic angle obliteration (1.94% and 0.13%) was noted for those exposed after 1976.

Conclusions: These analyses do not support a clinically important reduction in spirometry of this cohort. The 1976 reductions in exposure have led to decrease in radiographic changes.

INTRODUCTION

Since the 1970s, governmental and non-governmental researchers have studied the respiratory health effects associated with the vermiculite mine in Libby, Montana. The Agency for Toxic Substances and Disease Registry (ATSDR), in cooperation with the Montana Department of Public Health and Human Services (MDPHHS), released several reports [1-6] revealing important findings about lung disease in the mineworkers that was associated with exposure to vermiculite contaminated with tremolite asbestos. As their primary finding, the ATSDR reported that, in the 20 year period from 1979 to 1998, the mortality in Libby from asbestosis was 40 to 80 times higher than expected, and that lung cancer mortality was 20 to 30 percent greater than expected, when compared to the mortality statistics from the United States and the state of Montana. Mesothelioma mortality was more difficult to assess, due to the inability to have adequate comparison data because of the rarity of this type of cancer. Through these findings, the scientific community alerted the interested parties to health risks associated with working in the Libby mine, resulting in the closing of the mining operation in 1990.

In 2000, the ATSDR initiated a community-based study (Libby Community Environmental Health Project) to investigate reports of respiratory illness and any possible associations with tremolite contaminated vermiculite exposure. Eligible participants included former W.R. Grace workers from Libby and anyone who lived, worked, or played in the Libby area for at least 6 months before December 31, 1990. The medical screening program consisted of a respiratory health and cigarette smoking questionnaire, simple spirometry, and a three-view (EPA, left and right oblique) chest radiographic examination. The exposure history included inquiries about potential exposure to asbestos or vermiculite, either through having worked for W.R. Grace or at other occupations with a potential for asbestos exposure. Other questions

addressed household contacts with Grace Workers and/or exposure potentials associated with recreational activities, or domestic use including vermiculite used as loose-fill insulation.

A primary result of the ATSDR report was that 17.8% of those with radiographs had pleural abnormalities and 0.9% had interstitial infiltrates [6]. The ATSDR also administered pulmonary function tests (spirometry) to these same individuals, but to our knowledge, these spirometric results have not been previously published. However, concerns over reduced lung function in the Libby population have been presented by Whitehouse [7] in 2004 who concluded that pleural changes in his patient population were associated with progressive lung function loss due to vermiculite exposure.

The purpose of the current study was to investigate the respiratory health of the ATSDR cohort in terms of their pulmonary function results, radiographic findings and exposure pathways. It should be noted that the following analyses were based on ATSDR X-ray interpretations, lung function measures, and questionnaires.

METHODS

The ATSDR database from the Libby Community Environmental Health Project was produced to W.R. Grace in *U.S. v. W.R. Grace*, No. CR-05-07-M-DWM (D. Mont.). This data, absent all personal identifiers, was produced pursuant to a subpoena without any restrictions on use and/or privacy and included nine SAS datasets. Eligibility criteria are noted above, and our study included all surveyed individuals between 25 to 90 years of age.

A total of 7,307 current and former Libby residents participated in the program, of who 6,668 received chest radiographs. To focus on exposure from tremolite-contaminated

vermiculite, we excluded subjects (n = 1,327) with occupations or activities likely associated with exposure to traditional, non-vermiculite asbestos containing materials (hereafter called "traditional asbestos occupations"). This included anyone responding yes to any of the following ATSDR queries: worked as a pipe fitter or steam fitter; brake repair person; insulator; in a job mixing, cutting, or spraying asbestos material; in any job exposed to asbestos; or had asbestos exposure in military. Of the remaining subjects, 4,524 were 25 to 90 years of age and had spirometric test results **(Figure 1).** Of these, 4,397 had a consensus (2 of 3 B-readers in agreement) frontal posterior anterior [5] chest X-ray reading according to the 1980 International Labour Organization (ILO) classification, cigarette smoking data, and sufficient information, based on the specific ATSDR exposure pathways queries, to allow them to be placed into the following seven mutually-exclusive exposure categories.

- **Grace Worker (N = 255):** "No" to any traditional asbestos occupations, but "yes" to ever worked for WR Grace/Zonolite.
- **Other Vermiculite Occupation (N=664):** "No" to any traditional asbestos occupations, a non-Grace/Zonolite worker, "no" to Household, but "yes" to living with Grace/Zonolite worker (hereafter called Household), and "yes" to either of the following (hereafter called Other Vermiculite Occupations): ever worked as a secondary contractor to the mining or processing facilities (for example, as a truck driver, delivery person, or janitorial worker, etc); or ever had jobs in which you may have been exposed to vermiculite (for example, insulation installer, logger near the mine, etc).
- **Other Dusty Occupation (N=831)**: "No" to any traditional asbestos, a non-Grace/Zonolite worker, "no" to Household, "no" to Other Vermiculite Occupations, but "yes" to any of the following (hereafter called Other Dusty Occupations): any dust exposure at other jobs; or

worked as a plumber, dry wall finisher, carpenter, roofer, electrician, or welder; or worked in a shipyard, in ship construction or repair, in the military, or on any kind of ship.

- **Household With Other Vermiculite Occupation (N = 114):** "No" to any traditional asbestos occupations, and a non-Grace/Zonolite worker, but "yes" to living with Grace/Zonolite worker (hereafter called Household), and "yes" to Other Vermiculite Occupations.
- **Household With Other Dusty Occupation (N=172): "Yes" t**o Household, "no" to any traditional asbestos occupations, a non-Grace/Zonolite worker, "no" to Other Vermiculite Occupations, but "yes" to Other Dusty Occupatio**ns.**
- **Household Without Dusty Occupation (N=594): "Y**es" to Household, "no" to any traditional asbestos occupations, a non-Grace/Zonolite worker, and "no" to Other Vermiculite Occupations **or Other Dusty Occupations.**
- **Environmental (N = 1,894):** "No" to any traditional asbestos, a non-Grace/Zonolite worker, and "no" to Household, Other Vermiculite Occupations and Other Dusty Occupations.

It should be noted that the goal of the above qualitative exposure categories was to develop distinct mutually exclusive categories based on the available information.

Consensus X-ray findings were based on 2 of the 3 ATSDR B-readers agreement using only the frontal [5] view, as required by the 1980 ILO guidelines. The following radiographic findings were investigated:

i. **Profusion ≥ 1/0**: Any 2 readers reporting any profusion ≥ 1/0.

ii. **Any Plaque**: Any 2 readers reporting any diaphragm or wall or other site plaques, even if the readers did not agree on specifics.

iii. **Any Diffuse pleural thickening (DPT) or Costophrenic angle obliteration (CAO)**: Any 2 readers reporting any diffuse pleural thickening or costophrenic angle obliteration, even if the readers did not agree on specifics.

Percent predicted FEV_1, FVC and FEV_1/FVC were computed using the observed values reported by the ATSDR and applying the normative equations developed by Knudson [8].

Statistical analysis: The continuous variables were compared using student t test and categorical variables were compared using chi-square test. Multiple linear regression was used to assess statistical associations between radiographic findings, spirometric test results and exposure categories. All analyses were performed using SAS

RESULTS

Spirometric results were investigated for the following age quartiles (25-40, 41-50, 51-60 and 61-90). The results of all age quartiles are reported in **Table 1**, excluding subjects with either evidence of non-tremolite asbestos exposure or individuals in whom exposure could not be determined. These results are presented by cigarette smoking (ever vs. never) status. For all quartiles, reductions in percent predicted FEV_1 and FEV_1/FVC were noted among ever cigarette smokers, as compared to never-smokers, but the lung function for both ever- and never- smokers were within the normal range on average. Further, even higher values were observed in the younger quartiles, usually over 100 percent predicted on average.

Also assessed were the presence of radiographic findings in each of the 7 exposure categories within each age quartile. The percent prevalence for profusion of small opacities (greater than 1/0), plaques with or without calcification, and/or the presence of DPT and/or CAO, based on the ATSDR ILO consensus PA readings, are shown in **Table 2**. The three

household exposure groups have been combined, as the overall numbers in each group were small and the percent prevalence of radiographic findings were similar. As expected, the prevalence of all radiographic abnormalities in the Grace Worker population was higher than in the other exposure groups, and it increased with age. In addition to the Grace Worker group, the prevalence of pleural changes was increased in all of the Household exposure groups and some of the older subjects in other exposure categories.

The effect of specific radiographic findings on percent predicted FVC was also assessed. **Table 3** shows the effect on average lung function based on specific chest radiograph findings. In this analysis, a comparison of lung function was made between those with following specific x-ray findings:

i. consensus pleural disease other than DPT or CAO (with or without calcification) and no consensus profusion ≥ 1/0
ii. consensus DPT with consensus CAO, but no consensus profusion ≥ 1/0
iii. consensus profusion ≥ 1/0 where plaque, DPT, CAO or calcification may be present
iv. no consensus findings of profusion ≥ 1/0, plaque, DPT, CAO, calcification or effusions

Here we excluded subjects who had evidence of non-tremolite asbestos. These data show a loss of lung function in subjects with DPT/CAO and in those with evidence of parenchymal lung disease. Those with pleural findings other than DPT/CAO or who had no radiographic findings had lung function well within the normal range.

We also investigated what degree of diffuse pleural thickening would predict loss of lung function. For this purpose, participants with consensus DPT with CAO were identified. Those with consensus profusion ≥ 1/0 and those with consensus effusion were removed, while those with other non-tremolite asbestos exposure were retained. The 2000 ILO guidelines were used for classifying diffuse pleural thickening by extent and width of the thickening. According to the Guidelines, thickening involving greater than 25% of the length of the chest wall was designated as extent '2'. A width greater than 3mm was classified as width 'a'. Using these two parameters which indicated more than minimal diffuse pleural thickening, the average lung function was measured after dividing the population into two groups: one group had an extent greater than or equal to '2' and had an extent greater than or equal to 'a' and the second group did not meet these criteria. As shown in **Table 4**, the group that met these criteria had a significantly lower FVC than the group not meeting the criteria

Next statistically significant effects on percent predicted FVC were investigated for: specific radiographic findings, cigarette smoking (ever or never), gender, age, Body Mass Index (BMI), exposure category, and interactions between all of the above. Again, significant interactions were noted between radiographic findings and both cigarette smoking and gender, so individual models were developed for the following categories: never smoking men, never smoking women, ever smoking men, and ever smoking women.

With all seven-exposure groups combined, significant effects were found for ever-smoking women and for both ever and never smoking men. DPT and/or CAO had significant adverse effect on FVC in all smoking and gender combination groups, except in never-smoking women. The reductions in percent predicted were 6.73% for ever-smoking women; 9.77% for ever-smoking men; and 23.77% for never-smoking men. On the other hand, presence of pleural

plaques led to a small reduction in FVC in the men only (4.2-4.4%), and on average an FVC that was still near 100% predicted. These results are summarized in **Table 5.** We also conducted a similar analysis where we excluded the Grace workers and the Household with Vermiculite Occupation group, because preliminary analyses indicated that, of all the exposure categories, only these two were sometimes significantly different from the Non – occupational/non – household contact group in terms of their effect on FVC. However, the results were similar and the same significant radiographic effects were observed.

Also investigated was the effect on prevalence of radiographic findings in the general population due to the closing of the old dry and wet mills in 1974. This resulted in a reduction in the mining operation exposure estimates that sometimes exceeded 100 fibers ^{4}/cc prior to 1975 to less than 1/f/cc after 1976, based on 8-hr time weighted average job exposure estimates [9]. We again included all individuals over 25 years of age, excluding only those with any reported non-tremolite asbestos exposure, Grace workers and those with Household exposures from living with an active Grace worker. Therefore, the following individuals were retained:

- Those with only environmental exposure
- Those reporting "yes" to any dust exposure at other jobs; or worked as a plumber, dry wall finisher, carpenter, roofer, electrician, or welder; or worked in a shipyard, in ship construction or repair, in the military, or on any kind of ship.
- Those with other occupation with potential vermiculite exposure who reported "yes" to ever worked as a secondary contractor to the mining or processing facilities, for example, as a truck driver, delivery person, or janitorial worker, etc.; and
- Those that ever had jobs in which they may have been exposed to vermiculite, but not as a direct employee of W.R. Grace.

This population was divided into those that had any residential (first year moved into Libby area or Koontenai valley) or occupational (first year started in any of the types of occupations noted above) exposure prior to 1976, and those that had residential or occupational exposure only after 1976. **Table 6** shows the percent prevalence of profusion, any plaque (diaphragm or wall), and any DPT or CAO, by pre-post-1976 exposure potential and by age category. Those shown as DK (don't know) had insufficient X-ray findings to determine a consensus. Also reported is the percent of men, smokers, those reporting to have played in piles of vermiculite, and the percent predicted FVC. For the oldest age group, 61-90 year olds, the reductions were still almost 4-fold for plaque, with no consensus readings of DPT or CAO post-1976. It should be noted that 33.44% of the individuals in the pre-1976 category reported that they had played in piles of vermiculite, compared to 12.39% in the post-1976 group, introducing the possibility of selection bias. Regardless, the percent predicted FVC values were greater than100%, on average, with similar results noted pre and post-1976. All participants had a minimum 10-year latency between the time they entered the Libby area and the date of their X-ray.

Overall, a more than 6-fold reduction in plaque (percent prevalence reduced from 10.11 to 1.64), and an almost 15-fold reduction in DPT or CAO (percent prevalence reduced from 1.94 to 0.13) is noted pre-post 1976, respectively. These data are shown in **Figure 2**.

DISCUSSION

Our study focuses on the previously unreported pulmonary function findings of the ATSDR x-ray screening study. Concerns over reduced lung function in the Libby population have been reported by Whitehouse [7] in 2004 who concluded that pleural changes in his patient

population were associated with progressive loss in pulmonary function due to exposure to Libby tremolite and that his patient population was "representative of the population of Libby, Montana." On closer inspection, his population of 123 patients consisted of 70% (N=86) former W.R. Grace employees, which was not a representative sample of the population of Libby. Whitehouse also reported that the average annual percent predicted loss of lung function was 3.2% for FVC, 2.3% for TLC and 3.0% for DLCO, but this was based on only 2 data points over about 3 years on average, of which 19.5% and 42.3% of the subjects had 1 and 2 years or less follow-up, respectively.

Our review of the ATSDR data does not support the conclusion that pleural changes are associated with clinically significant reduced lung function. According to Peipins (5), 1183 participants over 25 years of age were categorized as having any pleural abnormality. However, in a more focused analysis, our review of the lung function in the group (N=482) that had pleural plaques but no other radiographic abnormalities indicated that mean percent predicted FVC was 95.63% on average.

As noted, our consensus X-ray findings were based on 2 of the 3 ATSDR B-readers agreement using only the EPA view, as required by the 1980 ILO guidelines. This differs in a few significant ways from the method used by Peipins with regard to reporting pleural abnormalities associated with the ATSDR study. One of her stated objectives was to 'identify and quantify possible asbestos-related pleural and interstitial abnormalities. She classified study participants as "having a pleural abnormality if two out of three certified B-readers indicated:

a) any unilateral or bilateral pleural calcification on the diaphragm, chest wall or other site, or

b) any unilateral or bilateral pleural thickening or plaque on the chest wall, diaphragm, or costopherenic angle site, consistent with asbestos-related pleural disease, using the P-A view, the oblique views or a combination of those views."

The decision to use oblique views to arrive at judgments on ILO classification items can increase the prevalence of pleural abnormalities over those that would be found using only the PA view. Whether this would also increase the specificity for asbestos causation, as stated by Peipins, is uncertain. For example, more cases of pleural stripe widening due to subpleural fat (the mean BMI for those categorized as having pleural abnormalities was 30.4) or companion shadows will be found using obliques, unless the readers strictly adhere to the ILO 2000 Guidelines to indicate diffuse thickening only if it extends into the costophrenic angle. This was not a requirement in the 1980 ILO Guidelines that were used by the ATSDR readers, and a failure to apply the current standards could have led to an overestimation of pleural disease prevalence by abnormalities that have no relation to asbestos, or even to disease. This consideration notwithstanding, the use of oblique films in the Peipins study renders the results not comparable to published studies that comply with ILO 1980 and 2000 guidelines that support only using the PA view.

Irrespective of the above, Peipins' findings associated with the pleural abnormalities are worthy of careful consideration. Men had a much higher risk of developing pleural findings (odds ratio = 3.8) as compared to women (odds ratio = 1.0) [1-4,6]. Given the higher rate of occupational exposure to asbestos among men, these findings are not surprising and are further supported by the dose-response relationship described in the ATSDR study between exposure and the development of pleural plaques [2,4]. Both of these findings give further support to the premise that asbestos effects were found most strikingly in occupationally (as opposed to

environmental) exposed individuals. . Of note, subjects in "other dusty occupations" group may have had occupational exposure to asbestos, accounting for some of the noted pleural changes in that exposure group.

In our study of the ATSDR dataset, we investigated the associations between lung function, X-ray findings and exposure, resulting in the following conclusions:

1) The pulmonary function of the screened population as a whole is well within normal limits in all age groups, smoking categories, and exposure groups. There was an expected detrimental effect on lung function due to cigarette smoking.
2) In both women and men, and considering smokers and never-smokers, the prevalence of pleural plaques increased with age quartile. As expected, the prevalence of pleural plaques among all age groups was much less in the environmental exposure group (range, 0.42% to 12.74%), as compared to those that worked at the mine (range, 20% to 45.68%), or those who lived with a mine worker (range, 1.34% to 37.67%).
3) With regard to the effect of pleural plaques on FVC in men, there was a small, likely clinically insignificant reduction of less than 4.5%. There was no effect attributable to radiographic findings of plaque seen in women.
4) The closing of the old wet and dry mills at the facility appears to be associated with an overall post -1976 reduction in pleural abnormalities in the general population resulting in prevalence rates less than 2% for plaque and less than 0.2% for DPT or CAO.
5) Diffuse pleural thickening is associated with a reduction in FVC, particularly when found to be greater than extent '2' and width 'a'.

REFERENCES

1 Mortality in Libby, Montana, 1979-1998, Executive Summary,

2 Agency for Toxic Substances and Disease Registry. Year 2000 medical testing of individuals potentially exposed to asbestoform minerals associated with vermiculite in Libby, Montana: a report to the community. . In: Services. UDoHaH, ed. Atlanta, GA, August 23, 2001

3 Agency for Toxic Substances and Disease Registry. Health consultation on mortality from asbestosis in Libby, Montana for Libby Asbestos site. In: Services UDoHaH, ed. Atlanta, GA, December 12, 2000

4 Lybarger J LM, Miller A, Kess S (Agency for Toxic Substances and Disease Registry). Preliminary findings of medical testing of individuals potentially exposed to asbestoform minerals associated with vermiculite in Libby, Montana: an interim report for community health planning. In: Services UDoHaH, ed, February 2001

5 Muravov OI, Kaye WE, Lewin M, et al. The usefulness of computed tomography in detecting asbestos-related pleural abnormalities in people who had indeterminate chest radiographs: the Libby, MT, experience. Int J Hyg Environ Health 2005; 208:87-99

6 Peipins LA, Lewin M, Campolucci S, et al. Radiographic abnormalities and exposure to asbestos-contaminated vermiculite in the community of Libby, Montana, USA. Environ Health Perspect 2003; 111:1753-1759

7 Whitehouse AC. Asbestos-related pleural disease due to tremolite associated with progressive loss of lung function: serial observations in 123 miners, family members, and residents of Libby, Montana. Am J Ind Med 2004; 46:219-225

8 Knudson RJ, Lebowitz MD, Holberg CJ, et al. Changes in the normal maximal expiratory flow-volume curve with growth and aging. Am Rev Respir Dis 1983; 127:725-734

9 Amandus HE, Wheeler R, Jankovic J, et al. The morbidity and mortality of vermiculite miners and millers exposed to tremolite-actinolite: Part I. Exposure estimates. Am J Ind Med 1987; 11:1-14

Figure legends

FIGURE 1. Profile of the Study Population. CXR = Chest radiograph, HH = Household contact of a Grace worker, Verm = Vermiculite.

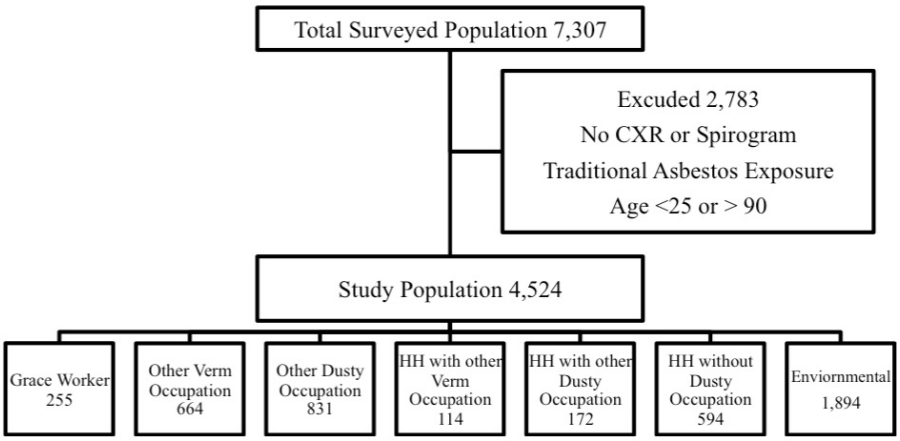

FIGURE 2. Plaque Prevalence by the Year of Initial Exposure.

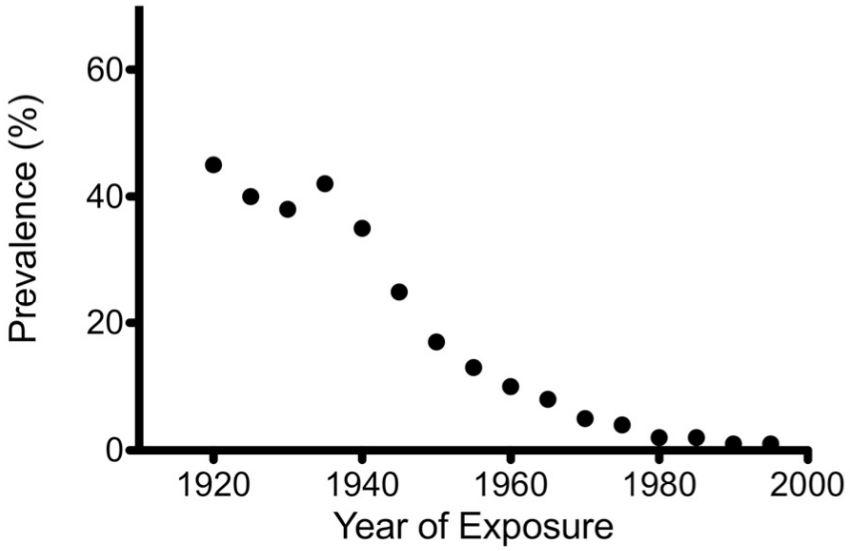
Prevalence (%)
60
40
20
0
1920
1940
1960
1980
2000
Year of Exposure

TABLE 1. Lung Function by Age and Smoking Status (Mean values and Standard Error)

Age Category (Years)	Smoking Status	N	Male (%)	BMI (kg/m^2)[+]	FEV_1, % predicted*,[+]	FVC, % predicted*,[+]	FEV_1/FVC, % predicted*,[+]
25-40	Ever	474	38.0	27.49 0.27	102.48 0.68	107.68 0.63	96.69 0.37
	Never	704	43.0	28.21 0.23	103.82 0.52	106.36 0.51	99.12 0.29
	Total	1178	41.0	27.92 0.17	103.28 0.41	106.89 0.39	98.14 0.23
41-50	Ever	634	41.6	28.79 0.24	96.60 0.67	103.00 0.58	94.92 0.41
	Never	655	42.1	28.80 0.24	103.72 0.53	106.07 0.53	99.65 0.27
	Total	1289	41.9	28.80 0.17	100.22 0.43	104.56 0.40	97.32 0.25
51-60	Ever	652	44.2	29.07 0.23	90.97 0.79	98.43 0.68	92.56 0.49
	Never	492	36.6	29.33 0.26	100.84 0.68	103.91 0.67	98.71 0.36
	Total	1144	40.9	29.18 0.17	95.22 0.55	100.79 0.49	95.21 0.33
61-90	Ever	744	51.3	28.75 0.20	82.70 0.83	91.74 0.74	88.58 0.54
	Never	487	27.9	29.20 0.25	97.40 0.83	97.63 0.81	98.61 0.39
	Total	1231	42.1	28.92 0.16	88.51 0.63	94.07 0.56	92.55 0.39
ALL	Ever	2504	44.5	28.60 0.12	92.12 0.41	99.35 0.36	92.76 0.25
	Never	2338	38.3	28.82 0.12	101.83 0.32	103.94 0.31	99.07 0.16
	Total	4842	41.5	28.71 0.08	96.80 0.27	101.57 0.24	95.81 0.16

[+] Mean and Standard Error, *Knudson, 1983 Predicted Equations. BMI = Body Mass Index.

TABLE 2. Prevalence (%) of Chest Radiograph Findings, by Age and Exposure Categories

Exposure Category	Age Category (Years)	N	Profusion ≥ 1/0	Plaque	DPT and/or CAO
Grace Worker	25-40	20	0	20	5
	41-50	80	0	26.2	5
	51-60	63	3.2	34.9	3.2
	61-90	81	11.1	45.7	8.6
Other Verm Occupation	25-40	122	0.8	0.8	0
	41-50	192	0.5	7.8	1
	51-60	160	0.6	13.7	0.6
	61-90	165	0.6	24.8	8.5
Other Dusty Occupation	25-40	237	0	3.8	0.4
	41-50	213	0	2.8	0.9
	51-60	175	0.6	12.6	0
	61-90	183	1.1	21.9	3.3
HH	25-40	224	0	2.2	0
	41-50	234	0	11.1	0.4
	51-60	194	1	20.1	1.5
	61-90	209	2.4	38.3	5.7
Environmental	25-40	472	0	0.4	0
	41-50	468	0	1.9	0.2
	51-60	442	0	7.7	0.9
	61-90	463	1.3	12.7	2.2

DPT = Diffuse pleural thickening, CAO = Costophrenic angle obliteration, HH = Household contacts of Grace workers, Verm = Vermiculite.

TABLE 3. Chest Radiograph Findings and Mean FVC (% predicted)

	Pleural abnormality excluding CAO, DPT or Profusion ≥ 1/0	DPT/ CAO excluding Profusion ≥ 1/0	Profusion ≥ 1/0	No pleural abnormality, no effusion and no Profusion ≥ 1/0
N	482	33	40	4065
Age, (years)[+]	60.07 0.53	66.73 1.85	67.50 1.73	49.12
BMI, (kg/m^2)[+]	30.30 0.24	30.79 1.25	28.04 0.97	28.48
Male (%)	63.50	66.70	70.00	37.60
Ever Smoker (%)	63.69	81.80	77.50	48.80
FVC, (% predicted)[+, *]	95.63 0.76	78.76 3.64	82.16 3.34	103.15 0.25

[+]Mean and Standard Error, *Knudson, 1983 Predicted Equations. DPT = Diffuse pleural thickening, CAO = Costophrenic angle obliteration, BMI = Body mass index.

TABLE 4: Diffuse Pleural Thickening and Mean FVC (% predicted)

DPT Characteristics *	N	FVC (% predicted)[+]
Extent ≥ 2 and Width ≥ a	30	76.26 ** 2.84
Extent < 2 and/or Width < a	23	91.98 3.63
Total	53	83.08 2.48

[+] Mean and Standard Error, * Based upon 2000 ILO guidelines. (Extent 2 = > 25% chest wall involvement; Width a = 3 mm). ** p-Value = 0.0006. DPT = Diffuse pleural thickening.

TABLE 5: Effect of Chest Radiograph Findings on FVC (% predicted), Adjusted for Age, Gender, Smoking Status and BMI.

Sex	Smoke	N, Coeff	Prof ≥1/0	Plaque wi/wo Calc	DPT and/or CAO
Women	Never Smokers	N	1233	1299	1234
		Intercept	133.11*	133.19*	133.14*
		X-ray	NS	NS	NS
		Age	-0.32*	-0.32*	-0.32*
		BMI	-0.41*	-0.41*	-0.41*
	Ever Smokers	N	1116	1196	1127
		Intercept	141.83*	142.03*	141.71*
		X-ray	NS	NS	-6.73*
		Age	-0.58*	-0.59*	-0.58*
		BMI	-0.37*	-0.37*	-0.37*
Men	Never Smokers	N	684	767	685
		Intercept	116.98*	117.25*	116.96*
		X-ray	NS	-4.28*	-23.77*
		Age	NS	NS	NS
		BMI	-0.46*	-0.47*	-0.46*
	Ever Smokers	N	692	848	699
		Intercept	119.92*	125.10*	124.73*
		X-ray	NS	-4.43*	-9.77*
		Age	NS	-0.13*	-0.10*
		BMI	-0.64*	-0.58*	-0.63*

* p-Value < 0.05. BMI = Body Mass Index. N = number.

TABLE 6: Prevalence of Chest Radiograph Findings by Timing of Exposure (Pre- or Post-1976)

	Age Category (Years)	N	Male (%)	Smoker (%)	Play in Piles (%)	FVC (% predicted)[+]	Profusion ≥ 1/0		Plaque		DPT or CAO	
							No	Yes	No	Yes	No	Yes
Pre - 1976	25 - 40	571	42.2	35.5	51.1	107.25 0.56	99.8	0.2	97	2	99.6	0.3
	41 - 50	582	43.8	47.6	43.5	103.82 0.59	99.1	0.2	94.8	4.8	99.1	0.9
	51 - 60	642	41.1	54.7	29.3	100.92 0.66	97.2	0.3	86.8	12.1	98.7	0.8
	61 - 90	777	42.3	57.3	16.3	94.62 0.72	92.5	1.3	78.8	18.3	93.2	4.9
	All	2572	42.4	49.6	33.4	101.08 0.34	96.8	0.5	88.4	10.1	97.4	1.9
Post - 1976	25 - 40	260	40.4	40.8	25	106.9 0.83	100	0	99.2	0.4	100	0
	41 - 50	293	39.2	47.4	7.8	106.1 0.74	99.7	0	97.9	1.4	100	0
	51 - 60	153	38.5	56.9	5.9	101.95 1.31	98	0	94.8	2.6	98.7	0.6
	61 - 90	85	36.5	63.5	1.2	97.31 2.13	96.5	1.2	94.1	4.7	100	0
	All	791	39.2	48.8	12.4	104.61 0.53	99.1	0.1	97.3	1.6	99.7	0.1

[+] Mean and Standard Error. Excluding non - tremolite asbestos exposed, Grace Workers, and Household contacts.
DPT = Diffuse pleural thickening, CAO = Costophrenic angle obliteration.