Asbestos Fibers in the General Population[1-3]

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SUMMARY

We isolated uncoated asbestos fibers from the lungs of 21 urban dwellers who had fewer than 100 asbestos bodies/gram of lung, a level shown previously to be associated with environmental rather than occupational exposure to asbestos. Lack of occupational history was confirmed in 20 of the 21 patients; history of probable exposure was obtained for 1 patient. Fibers were counted, measured, and identified using a combination of electron optical morphology, diffraction, and energy dispersive x-ray spectroscopy. Eighty per cent of the fibers were chrysotile (mean 130×10^3, range 12×10^3 to 680×10^3 fibers/gram wet lung) and 90% of the chrysotile was less than 5 μ long. Total amphiboles had a mean of 25×10^3 and ranged from 1.3×10^3 to 75×10^3 fibers/g; 95% were noncommercial amphiboles and two thirds were less than 5 μ long. However, 20% of the commercial fibers, amosite/crocidolite, and 20% of the anthophyllite were longer than 10 μ, a finding in accord with the types of fibers seen in asbestos bodies in these patients. Short (<5 μ) chrysotile was preferentially deposited subpleurally; similar but not statistically significant accumulation was seen for the other types and lengths of asbestos fiber. We conclude that: (*1*) Substantial amounts of asbestos, mainly chrysotile and noncommercial amphiboles, are present in the average lung in an urban environment; (*2*) Most of these fibers are too small to form asbestos bodies or to be visible by light microscopy; (*3*) Asbestos bodies may serve as some indication of exposure to long amphiboles, but offer no information about the bulk of fibers present; and (*4*) It is probable that most of these fibers reflect general environmental contamination.

Introduction

There is extensive evidence that many persons in an urban population are exposed to asbestos fibers. Such exposure has been surmised from the finding of asbestos fibers in urban air and water supplies, in beverages, parenteral drugs, and home construction and repair products (1). Asbestos bodies, fibers of asbestos covered with an iron-protein coat, may be found in the lungs of almost everyone if suitable examination techniques are employed (2). Whether exposures of this magnitude (many times smaller than the exposure of asbestos workers) may lead to either pulmonary fibrosis or pulmonary malignancy is an important and unanswered question.

We have recently demonstrated in men that most asbestos bodies contain the commercial amphibole fibers amosite and crocidolite, whereas asbestos bodies in women may also frequently be formed on the noncommercial amphibole fiber, anthophyllite. However, the bulk (90%) of asbestos mined in the world and used in this country is the serpentine mineral chrysotile, and chrysotile is the fiber most often demonstrated as an environmental contaminant (3). It seemed likely, therefore, that asbestos bodies are only a partial indicator of pulmonary asbestos burden, and that examination of uncoated asbestos fibers is necessary to determine the magnitude and nature of that burden.

In this study we examined the asbestos fiber content of lungs from 21 subjects who had fewer than 100 asbestos bodies/g of lung, a concentration that we have shown previously is commonly

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found in women and white collar men, and that appears to be associated with environmental rather than occupational exposure to asbestos (2).

Methods

Subject selection. Subjects were selected from the autopsy service of the University of California, San Francisco, if they were 40 years of age or older at the time of death and had fewer than 100 asbestos bodies/g of wet lung. In addition, a detailed occupational, residential, and smoking history had to be available for each subject; this information was obtained by a telephone interview with relatives of the patients using a standard questionnaire, as previously described (4). Interviews were conducted by investigators who had no knowledge of asbestos counts. The nature of the underlying disease was determined by review of the subject's chart and histologic slides.

Preparation of tissue for light and electron microscopic study. Because chrysotile asbestos is a common contaminant of water supplies, air, and various chemicals, all solutions including the formalin fixative were prefiltered through 0.45 μ pore size membrane filters (Millipore Co., Bedford, MA). In addition, blank filters were prepared for each subject as described subsequently, but omitting tissue; the number of asbestos fibers found in the blanks was subtracted from the test values.

Asbestos bodies were isolated using methods previously described (2); briefly these consisted of dissolving formalin-fixed lung tissue in bleach, washing the sediment with a mixture of chloroform and ethanol to remove carbonaceous debris, and collecting the bodies on a membrane filter. The filter was dried, cleared, and mounted on a slide for light microscopic examination.

For enumeration of uncoated asbestos fibers, lung tissue was dissolved in bleach (5% sodium hypochlorite) and centrifuged once at 1,000 *g* for 20 min. The sediment was treated with 30% H_2O_2 for 4 h at 60° C. The latter step rendered much of the remaining carbonaceous debris relatively electron lucent. Several drops of dilute Tween® 80 were added to prevent agglutination of debris. An aliquot of the peroxide mixture was collected on a membrane filter (Millipore Co.), with a pore size of 0.45 μ; pieces of the filter were cut out and placed on formvar-carbon coated, 300 mesh, nickel electron microscope grids. The filter was dissolved by placing the grids on acetone-impregnated, polyurethane foam sponges, leaving the fibrous material on the support films.

Tissue sampling. Samples were obtained from 4 sites for each lung: peripheral upper lobe, peripheral lower lobe, central upper lobe, and central lower lobe. The peripheral sample included pleura and parenchyma to a depth of 5 mm. Central samples were taken more than 5 mm from the pleura, avoiding large bronchovascular structures and focal lesions. One to four g of wet lung were used for each sample. A sample adjacent to the upper lobe sample was weighed and dried to constant weight in order to relate counts/wet weight to dry weight. The ratio of dry weight to wet weight varied from 6% to 13% (average, 9%).

Enumeration of fibers. The number of asbestos bodies was determined by counting the bodies in 2 perpendicular diameters of the Millipore filter and multiplying by an appropriate factor to obtain the number of bodies/g of lung (2). On the basis of our previous studies, we counted all ferruginous bodies with transparent, colorless cores as asbestos bodies (5).

Uncoated asbestos fibers were identified in the electron microscope using a combination of morphology, electron diffraction, and electron microprobe analysis. Studies were performed on a JEOL 100 CX scanning/transmission microscope equipped with a Kevex energy dispersive x-ray spectrometer. Nickel rather than copper specimen grids were used to minimize production of copper L peaks, which interfere with sodium analysis. All microprobe analyses were performed at 100 KV with a collection time of 100 s. Elemental compositions were determined using the thin film approximation (6), and expressed as elemental weight percentages. For comparison with the test fibers, diffraction patterns and microprobe spectra were obtained from the UICC Standard Reference Asbestos Samples, from the University of Chicago Tremolite sample No. 1611 and from samples of glaucophane (kindly supplied by Dr. Jean Smith of the California Academy of Sciences) and actinolite (San Bernardino Co., Ca.). For purposes of this paper we did not separate amosite and crocidolite.

For each sampling site, fibers were located, measured (length and width), and examined by diffraction and microprobe analysis from a minimum of 100 grid squares, scanned sequentially. The number of fibers of each asbestos type/g of wet lung was obtained by use of an appropriate factor-converting area examined to grams of lung. Only fibers longer than 1 μ were counted.

Because the counts of the number of fibers/g were not normally distributed, nonparametric tests were done using Wilcoxon's signed rank test for paired and unpaired data and Spearman's rank correlation test (7).

Results

Fiber types, sizes, and distribution. Asbestos body counts for the 21 subjects ranged from 2 to 84 (mean, 33) per gram of wet lung (table 1). Uncoated chrysotile and amphibole fibers were found in all 21 subjects. The number of chrysotile fibers ranged from 12×10^3 to 680×10^3 (mean, 130×10^3), whereas amphiboles varied from 1.3×10^3 to 75×10^3 fibers/g of wet lung (mean, 25×10^3). Chrysotile and amphibole values for each subject are shown in table 1; there was no correlation between the amount of the 2 types of fiber in the 21 subjects. Chrysotile fibers outnumbered amphibole in 19 of the 21 subjects; the ratio of total chrysotile to total amphibole fibers ranged from 0.62 to 77 (mean, 12). Ratios of various types of fiber to the number of asbestos bodies are shown in table 2. This ratio varied from a mean of 170 for anthophyllite to 9,700 for chrysotile.

The number of fibers classified by mineralogic type and by size distribution are shown in table 3

TABLE 1

CLINICAL AND FIBER DATA ON 21 SUBJECTS (11 MEN AND 10 WOMEN)

Subject No.	Age/ Sex	Smoking	Occupation/Hobbies/Other Possible Asbestos Exposure	Underlying Disease	Asbestos Bodies /g of Lung	Chrysotile Fibers/g of Lung	Amphibole Fibers/g of Lung
78-275	56/M	None	Draftsman. Supervised work in sawmills and construction sites.	ASCVD	22	180×10^3	35×10^3
95-78	83/M	34 pk yr	2yrs ship boiler room; office worker.	Ca lung	69	33×10^3	15×10^3
96-78	68/M	60 pk yr	Clerical. Mined gold as hobby.	Ca lung	57	35×10^3	7×10^3
103-78	50/M	60 pk yr	20yrs cotton mill; steel mill construction.	Hepatocellular Ca	34	12×10^3	14×10^3
112-78	81/M	Smoker	Detective. Exposed to dust in rubber factory.	Ca pancreas	34	52×10^3	23×10^3
120-78	56/M	50 pk yr	Contractor, Insulated own home.	GI bleed	2	140×10^3	24×10^3
92-78	63/M	180 pk yr	Office worker.	Cirrhosis	9	62×10^3	4×10^3
111-78	47/M	66 pk yr	Printer. May have insulated home.	Ca pancreas	33	200×10^3	20×10^3
118-78	70/M	100 pk yr	Sold building supplies. Drove trucks to construction sites.	Ca colon	37	73×10^3	6×10^3
94-78	78/M	60 pk yr	Pilot. 1yr merchant seaman.	M I	19	100×10^3	1.3×10^3
78-214	55/M	130 pk yr	Truck driver. Probably insulated home.	Ca lung	35	400×10^3	7.6×10^3
Mean ± SD for the men						(120×10^3 ± 110×10^3)	(14×10^3 ± 10×10^3)
79-23	95/F	None	Teacher, housewife. Husband worked on railroad.	Ca cervix	27	75×10^3	74×10^3
79-68	73/F	None	Wholesale furniture store. Father worked in shipyard; brought clothes home.	CVA	21	120×10^3	8×10^3
79-85	63/F	None	Social worker.	Ca colon	30	130×10^3	13×10^3
79-117	64/F	None	Clerk.	Ca stomach/ lymphocytic interstitial pneumonia	30	59×10^3	34×10^3
78-202	67/F	20 pk yr	Dry cleaning business, 20 yr.	MI	36	61×10^3	14×10^3
78-242	60/F	40 pk yr	6 wk making sheetrock for shipyards/ 20 yr waitress, beautician.	Ca lung	36	680×10^3	75×10^3
79-27	64/F	25 pk yr	10 yr in factory, exact details unknown; installed home insulation.	Pancreatic abcess/ sepsis	9	80×10^3	15×10^3
79-24	43/F	20 pk yr	Beautician, restaurant work.	Ca cervix	2	92×10^3	4×10^3
79-209	62/F	Smoker	Housewife.	Pneumonia	64	58×10^3	93×10^3
78-205	54/F	100 pk yr	Housewife.	Renal cell ca	84	35×10^3	28×10^3
Mean ± SD for the women						(140×10^3 ± 190×10^3)	(36×10^3 ± 33×10^3)

Definition of abbreviations: ASCVD = arteriosclerotic cardiovascular disease; MI = myocardial infarction; CVA = cerebrovascular accident; Ca = cancer.

and figure 1. The amphiboles have been subdivided into the noncommercial forms tremolite, actinolite, anthophyllite, and glaucophane, and the commercial forms amosite/crocidolite. The serpentine mineral, antigorite, which is chemically similar to chrysotile, but forms acicular crystals rather than the hollow tubes of chrysotile, was also listed. Of the amphiboles, only tremolite and anthophyllite were found in most of the subjects; the commerically used fibers, amosite and crocidolite, were seen in only 11 of the 21 subjects. Tremolite was the most frequently encountered amphibole; it was present in all cases, and its concentration ranged from 3 to 14 times that of the other amphiboles. The average concentration of amosite/crocidolite (1,100 fibers/g) was the smallest of any of the amphiboles.

Measurements of fiber size showed that the bulk of the fibers were less than 5 μ long. However, the size distribution was quite different for chrysotile and the amphiboles (table 3, figure 2). Almost 90% of chrysotile fibers were less than 5 μ long, whereas approximately 60% of the noncommercial amphibole and only 25% of the commercial amphibole fibers were shorter than 5 μ. When fibers longer than 10 μ were evaluated, it was found that only 1.9% of chrysotile exceeded this length, compared with 7.4% of noncommercial amphiboles and 20.6% of commercial amphiboles. Of interest is the fact that 22% of anthophyllite fibers also exceeded 10 μ in length; fibers of anthophyllite and amosite/crocidolite appeared to be involved in forming asbestos bodies (4, 8) (see Discussion).

Fiber compositions as determined by energy dispersive x-ray spectroscopy are shown in table 4. For the amphiboles, the variation in composition among fibers of any given category was remarkably small, particularly considering that they were derived from many different subjects who presumably had been exposed to different sources. Comparison of the test and reference standard compositions for the amphiboles also showed generally good agreement; the major exception was in the tremolite group. We found that fibers that produce diffraction patterns consistent with amphiboles in these lungs and had chemistries consistent with either tremolite or anthophyllite tended to show a continuous range of calcium concentration from that typical of tremolite (14% calcium) down to no calcium. We arbitrarily classified fibers containing 4% or more of calcium as tremolite, and those with less (provided the other elemental concentrations were appropriate) as anthophyllite. This distinction appeared to be valid, since the size distribution of fibers classified in this way was quite different (table 3). However, using this separation, the mean observed weight percentage for calcium in tremolite was 9 rather than 14.

By contrast, the chrysotile fibers almost invariably showed leaching of magnesium; almost no fibers demonstrated the magnesium/silicon ratio seen in freshly prepared samples of UICC chrysotile. A small number of fibers had magnesium/silicon ratios as low as 1 to 9; these fibers were not included in the data for table 4. The well-formed hollow tube structure of

TABLE 2

RATIOS OF UNCOATED FIBERS TO ASBESTOS BODIES

Fiber Type	Mean	Range
Chrysotile	9,700	350–70,000
All amphiboles	1,400	68–12,000
Anthophyllite	170	0–1,400
Amosite/crocidolite	311	0–5,500

TABLE 3

TYPE, NUMBER, AND SIZE OF FIBERS IN 21 SUBJECTS

Fiber Type	Number of cases containing	Average Fibers/g of Wet Lung ($\times 10^3$)	Range ($\times 10^3$)	SD ($\times 10^3$)	% of Fibers 1–4.9 μ	5–9.9 μ	10 + μ
Chrysotile	21	130	12–680	150	89.7	8.4	1.9
Antigorite	7	2.5	0–15	5	ND*	ND	ND
Noncommercial amphibole							
Tremolite	21	15	0.5–20	20	65.8	27.5	6.7
Actinolite	10	5.1	0–46	12	86.1	13.9	0.0
Anthophyllite	15	3.7	0–39	8.7	18.8	59.0	22.2
Glaucophane	8	2.7	0–12	4.4	76.0	19.1	4.9
Commercial amphibole							
Amosite and crocidolite	11	1.1	0–6	2	25.5	53.9	20.6

* ND = Not done.

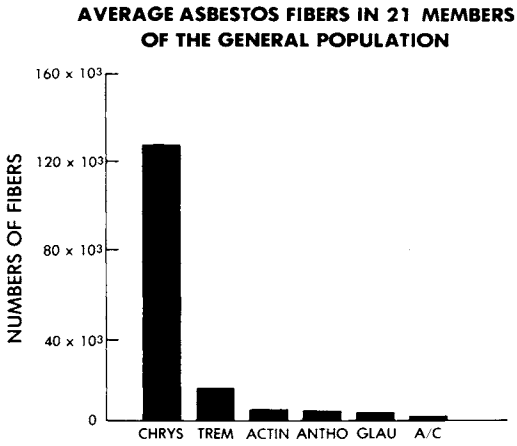

Fig. 1. Average number of chrysotile (chrys), tremolite (trem), actinolite (actin), anthophyllite (antho), glaucophane (glauc), and amosite/crocidolite (A/C) fibers/g of lung.

chrysotile was encountered with less frequency than the various degraded structures illustrated by Langer and associates (9). We were not able to correlate the appearance with the degree of magnesium leaching. Small amounts of short (1 to 2 μ) chrysotile fibers were sometimes found in the blanks. These fibers generally showed less magnesium leaching than those from the lungs, but were morphologically similar.

Aspect ratios by fiber type and size are shown in table 5 and figure 3. For the noncommercial amphiboles, mean aspect ratios were in the range of 18 to 30, and increased only modestly with increasing fiber length. Amosite/crocidolite and chrysotile had much higher mean aspect ratios (30 to 340), and these increased dramatically with length. Mean diameters are also shown in table 6. The chrysotile fibers had a mean diameter of 0.04 μ, the noncommercial amphiboles ranged from 0.3 to 0.8 μ, whereas the commercial fibers were all approximately 0.2 μ in diameter.

Fiber distribution for chrysotile is shown in figure 4. Short (< 5 μ) fibers of chrysotile appeared in greater numbers in the 2 subpleural samples when compared with the 2 central samples; the overall ratio of subpleural to central fibers was 2.9. When the actual number of fibers in the peripheral and central samples was compared for upper and lower lobes using Wilcoxon's signed rank test for paired data, the increased number of fibers in the subpleural zone was found to be significant ($p < 0.03$, upper lobe; $p < 0.02$, lower lobe). For chrysotile fibers longer than 5 μ, the ratio of peripheral to central fibers was 1.7 (P = NS). Similarly, although the amphiboles tended to have more fibers in the peripheral zones, the differences were not significant for either short or long fibers.

Short amphibole fibers were found to be concentrated in the upper lobe; the ratio of upper to lower was 2.3 ($p < 0.02$); amphiboles longer than 5 μ were not significantly increased in the upper lobe. Chrysotile fibers did not show any differences in concentration between upper and lower lobes.

Correlations with subject data. Subject data are shown in table 1. There were 10 women and 11 men. Their ages at time of death ranged from 43 to 95 (mean, 64). Ten of the men and 6 of the women had been cigarette smokers. The average number of chrysotile fibers in the women's lungs (140×10^3) was not significantly different from the number in the men's lungs (120 ± 10^3), nor was the number of amphibole fibers in the women's lungs (36×10^3) significantly higher than that in the men's lungs (14×10^3). No differences were found for chrysotile (110×10^3) and amphibole (33×10^3) for the 5 nonsmokers compared with the values (130×10^3 and 22×10^3, respectively) for the 16 smokers. There was no correlation between total asbestos fibers and age.

Occupations and other possible sources of asbestos are shown in Table 1. One subject (No. 78-242) was considered to have definite occupational exposure (6 wk making sheet rock for shipyards during World War II); this conclusion was corroborated by the finding of pleural

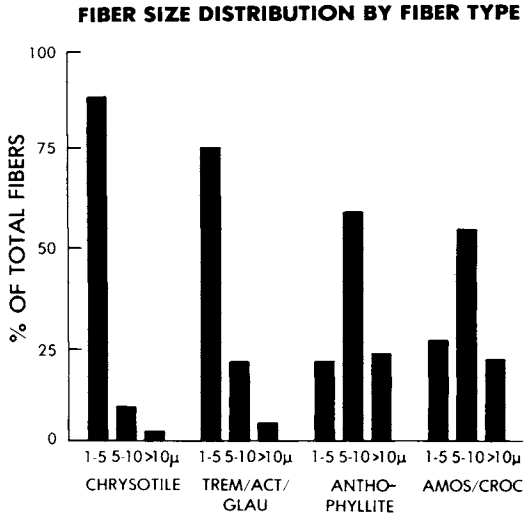

Fig. 2. Fiber types are as follows: chrysotile, tremolite (trem), actinolite (act), glaucophane (glau), anthophyllite, amosite (amos)/crocidolite (croc).

TABLE 4
COMPOSITION DATA FOR ASBESTOS FIBERS RECOVERED FROM LUNG

	Reference Standard		Fibers From 21 Subjects	
Fiber Type	Element	Mean Wt% (SD)	Element	Mean Wt% (SD)
Chrysotile	Mg	55 ± 2.4	Mg	46 ± 8.7
	Si	45 ± 2.4	Si	54 ± 8.7
Antigorite	Mg	55 ± 2.4	Mg	46 ± 7.4
	Si	45 ± 2.4	Si	54 ± 7.4
Tremolite	Na	1 ± 2.0	Na	2 ± 3.0
	Mg	30 ± 1.6	Mg	29 ± 3.7
	Al	0 ± 0	Al	0 ± 1.0
	Si	54 ± 0.9	Si	57 ± 3.3
	Ca	14 ± 1.0	Ca	9 ± 2.6
	Fe	0 ± 0	Fe	3 ± 2.7
Actinolite	Na	0 ± 0	Na	0 ± 1.0
	Mg	25 ± 1.5	Mg	21 ± 5.7
	Al	1 ± 1.5	Al	2 ± 2.3
	Si	52 ± 3.0	Si	50 ± 4.2
	Ca	10 ± 0.8	Ca	9 ± 1.4
	Fe	12 ± 1.1	Fe	19 ± 6.5
Anthophyllite	Na	0 ± 0	Na	1 ± 2.1
	Mg	35 ± 2.5	Mg	35 ± 5.0
	Al	0 ± 0	Al	0 ± 0
	Si	52 ± 2.0	Si	58 ± 4.1
	Ca	1 ± 1.7	Ca	1 ± 1.1
	Fe	12 ± 3.1	Fe	4 ± 3.9
Glaucophane	Na	8 ± 1.8	Na	9 ± 3.8
	Mg	9 ± 1.1	Mg	6 ± 3.4
	Al	7 ± 1.2	Al	6 ± 2.7
	Si	51 ± 2.2	Si	49 ± 4.4
	Ca	2 ± 0.8	Ca	1 ± 1.4
	Fe	23 ± 2.9	Fe	29 ± 6.7
Amosite and crocidolite	Na	4 ± 4.3	Na	4 ± 3.8
	Mg	5 ± 2.7	Mg	5 ± 3.3
	Al	0 ± 0	Al	0 ± 0.0
	Si	41 ± 1.7	Si	40 ± 3.4
	Ca	0 ± 0	Ca	1 ± 1.0
	Fe	51 ± 3.1	Fe	52 ± 3.6

plaques at autopsy. She had the highest number of both chrysotile and amphibole fibers seen in any of the subjects. Several of the other subjects had highly suggestive histories; for example, work in a ship's boiler room, but we were unable to correlate the numbers of fibers found with the putative exposure.

Underlying diseases are shown in table 1. Four subjects had cancer of the lung; two of them had the highest chrysotile counts found in this study (680×10^3 and 400×10^3 fibers/g) whereas the other 2 had the lowest (33×10^3 and 35×10^3 fibers/g). One of these subjects (No. 78-242) also had the highest amphibole count observed, 75×10^3 fibers/g, whereas the other 3 were quite low. Fibrous parietal pleural plaques were present in Subject No. 78-242.

Histologic sections were reviewed to confirm the diagnoses and to assess fibrosis in the lung. All subjects except 3 had none or very minimal interstitial fibrosis; the 3 with marked fibrosis all had clinical reasons for the finding; for example, old tuberculosis.

Discussion

In this study we demonstrated that lungs from a series of subjects who had fewer than 100 asbestos bodies per gram of lung, a value that appears to be associated with environmental rather than occupational exposure (2), nonetheless contained substantial amounts of asbestos. The bulk of this asbestos (approximately 80% of fibers) was chrysotile; whereas the rest was largely the noncommercial type of amphibole. On the average, commercial forms accounted for only about 4% of the amphibole fibers. Eighty-five per cent of

TABLE 5

ASPECT RATIOS FOR ASBESTOS FIBERS IN THE LUNGS OF 21 SUBJECTS

Fiber Type	1–4.9 μ (Mean ± SD)	5–9.9 μ (Mean ± SD)	10+ μ (Mean ± SD)
Chrysotile	61 ± 33	200 ± 100	340 ± 150
Noncommercial amphibole	18 ± 17	25 ± 24	30 ± 26
Commercial amphibole, amosite/crocidolite	32 ± 25	68 ± 59	160 ± 120

the total fibers examined were less than 5 μ in length, and only 3% were longer than 10 μ. Differences in fiber size and distribution were seen between chrysotile, for which 90% of the fibers were shorter than 5 μ, and the amphiboles, which showed a shift toward longer fibers. In particular, 20 to 25% of the anthophyllite fibers and the fibers of amosite/crocidolite were longer than 10 μ.

The dangers of pulmonary malignancy and pulmonary fibrosis from exposure to relatively small amounts of asbestos are unknown. Establishment of a dose-response relationship can be approached epidemiologically by comparing incidence rates of various diseases in persons whose exposure has been quantified by measurements of ambient asbestos concentrations; such studies have led to the current permitted standard of 2 fibers greater than 5 μ long/ml of air during any 8-h period. However, studies of ambient dust concentrations do not measure what is in the lung, and they are not applicable to other than a few carefully monitored industries. An alternate approach is to count asbestos fibers in the lung itself. The published literature on this topic for persons with minimal or no known exposure is scanty. In general, 3 approaches have been used: (*1*) counting of asbestos bodies, (*2*) counting of uncoated asbestos fibers with the light microscope, and (*3*) counting of fibers with the electron microscope.

Counting of asbestos bodies with a light microscope has the advantage of being a relatively quick and easy procedure. Although animal experiments have suggested that structures identical to asbestos bodies might be formed on nonasbestos fibers such as fiberglass (10), bodies obtained from humans in the general population have almost invariably been formed on asbestos fibers (4, 8). More than 50 articles have been published demonstrating the presence of asbestos bodies in the lungs of urban dwellers in several continents (11).

In asbestos workers, it has been found that asbestos bodies constitute only a portion (probably on the order of 10 to 30%) of the total fibers visible by light microscopy, and probably about 1% of the fibers visible by electron microscopy (12). In the present study, a similar relation was shown in subjects without occupational asbestos exposure. But the average proportion of asbestos bodies to total fibers was roughly 1 to 10,000, and there was no direct correlation between the number of bodies and the number of fibers.

Examination of the fiber types and sizes encountered in these subjects also indicated that asbestos bodies were not representative of the mineralogic forms of asbestos found in such lungs. We previously found that bodies are formed predominantly on long (30 to 40 μ) amosite/crocidolite fibers in men and also on anthophyllite fibers in women (4, 8). In the present report, amosite/crocidolite and anthophyllite account, on the average, for only 3% of fibers, and were not found in every subject. Although infrequent, a substantial portion of these fibers were larger than 10 μ and corresponded to the types of fibers we have found as cores of asbestos bodies.

The average number of fibers of amosite/

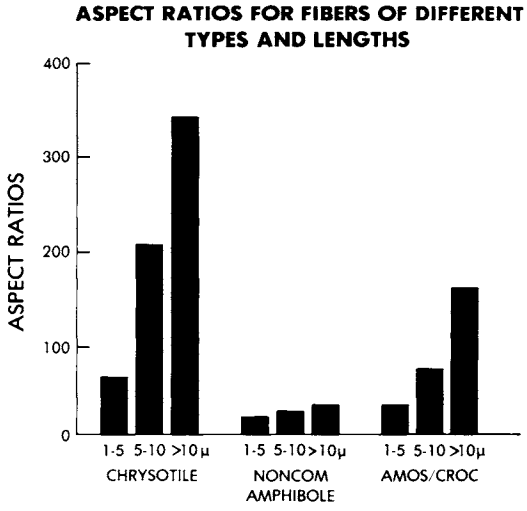

Fig. 3. Aspect ratios by length for chrysotile, noncommercial amphiboles (noncom amphibole) and amosite/crocidolite (amos/croc).

TABLE 6

MEAN DIAMETERS FOR ASBESTOS FIBERS IN THE LUNGS OF 21 SUBJECTS

Fiber Type	1-4.9 μ (Mean ± SD)	5-9.9 μ (Mean ± SD)	10+ μ (Mean ± SD)
Chrysotile	0.04 ± 0.03	0.04 ± 0.02	0.04 ± 0.01
Noncommercial amphibole; tremolite, actinolite, glaucophane, anthophyllite	0.34 ± 0.30	0.56 ± 0.50	0.75 ± 0.50
Commercial amphibole; amosite/crocidolite	0.20 ± 0.11	0.16 ± 0.11	0.23 ± 0.19

crocidolite and anthophyllite greater than 10 μ in our 21 subjects would be approximately 1,000/g; the number of fibers longer than 30 μ was much smaller, since the bulk of fibers we have observed do not exceed 20 μ. Assuming that 10% of such fibers were 30 μ or longer, we calculated that a typical lung would contain 100 such fibers/gram of lung, a reasonable approximation to the number of asbestos bodies. Similar estimations of the number of long chrysotile fibers indicated that the average lung should contain about 250 chrysotile fibers of optimal body-forming size. Because only about 2% of bodies recovered from such lungs in our previous studies (4) contained chrysotile, we concluded that long chrysotile fibers rapidly fragment in the body or, alternatively, that such fibers do not readily become coated. The relative infrequency of chrysotile cores in asbestos bodies has been noted by others (13).

Thus, counting of asbestos bodies, a rapid and inexpensive technique, cannot be used to document total lung asbestos burden. The bulk of asbestos in these lungs was short chrysotile, which does not form bodies. However, the data cited above, as well as the data presented on ratios of asbestos bodies to various types of asbestos fiber suggested that bodies may be a useful indicator of exposure to long asbestos fibers, and particularly an indicator of exposure to the commercial fibers amosite/crocidolite in men, and to anthophyllite in women.

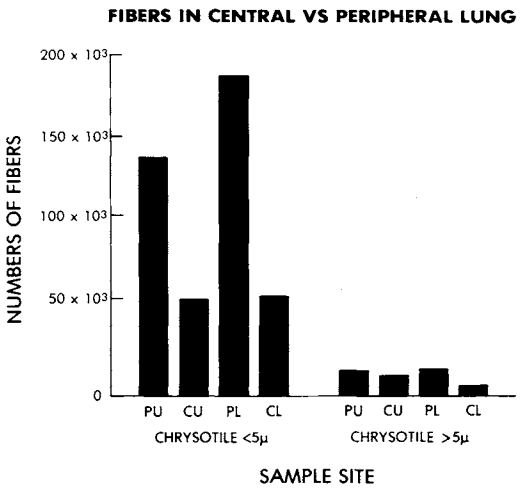

Fig. 4. Numbers of fibers in central versus peripheral lung. PU = peripheral upper lobe, 140 ± 190 (mean ± SD)/g of lung; CU = central upper lobe, 56 ± 85; PL = peripheral lower lobe, 190 ± 280; CL = central lower lobe, 58 ± 56. The difference between peripheral and central samples was significant ($p < 0.03$), Wilcoxon's signed rank test. See text for details of sampling procedure.

A few investigators have attempted to quantify asbestos fibers in lungs of exposed and nonexposed persons using light microscopy. Whitwell and co-workers (14) showed that 71% of lungs from patients without lung cancer or industrial asbestos exposure contained fewer than 20,000 fibers over 6 μ long/g of dried lung, when the fibers were counted by phase contrast microscopy. This number corresponded roughly to 2,000 fibers/g of wet lung, considerably smaller than the average of approximately 24,000 fibers greater than 5 μ/g of wet lung in our subjects.

In a group of 6 persons with modest occupational exposure, Sebastien and colleagues (15) found an average of 2,000 fibers/g of wet lung, and in a group of patients with a high degree of exposure and asbestosis, an average of 2,000,000 fibers. Ashcroft and Heppleston (12) found an average of 3,700,000 fibers/g of dry lung in 12 patients with heavy exposure but no asbestosis.

Examination of our fiber size and aspect ratio data indicated that in fact most fibers 5 μ and longer were too narrow to be observed by light microscopy; this was particularly true of chrysotile. Narrow fibers shorter than 5 μ were essentially undetectable. Furthermore, light microscopic methods made the assumption that fibers counted are indeed asbestos. We examined the nonasbestos fibers in this same group of subjects and found that there were 4 times as many as asbestos fibers (unpublished data).

Our findings in regard to fiber type and size distribution were similar to those reported elsewhere in patients with definite occupational ex-

posure. Using electron microscopy, Sebastien and colleagues (15) and Pooley and Clark (16) demonstrated that short chrysotile fibers predominated. More interesting in the report of Sebastien and colleagues (15) was their finding that chrysotile tended to accumulate under the pleura, a phenomenon that we have observed in our group of nonexposed subjects. Both chrysotile and amphibole have been shown to move to a subpleural location in experimental animals (17). Subpleural accumulation of asbestos may be important in the genesis of pleural plaques and mesothelioma. From a more practical standpoint, the fact that even in nonscarred lungs asbestos fiber distribution is uneven (we have shown previously that it is quite uneven in scarred lungs (18)), makes analysis of small biopsies hazardous.

Our findings with respect to the type of amphiboles present in these lungs was surprising. Most industrially used amphibole is amosite and crocidolite. However, in these subjects, commerical amphibole constituted less than 1% of the total fibers present and less than 4% of the amphiboles. The amphiboles that were found were generally encountered industrially or environmentally as contaminants of other minerals, for example, talc. We have suggested that cosmetic talc provides the source for the asbestos bodies formed on anthophyllite and tremolite in women (8). Another possibility in this group of subjects was that the fibers were derived from local rocks either because of natural weathering, or because of digging operations (19, 20). No matter what the source, the fairly constant finding of these different mineral types in subjects with a variety of residential locations and no obvious sources of occupational exposure suggested that this asbestos represented contamination of urban air.

It has been suggested that differences in the aspect ratios of fibrous minerals are a reflection of differences in origin as well as of differences in biological properties (21). Comparison of our present data with data from persons with high known occupational exposure may prove the validity of these assumptions.

We were unable to find any correlation with age, smoking, or occupational history and pulmonary asbestos content in these subjects. The one exception was Subject No. 78-242, who had a 6-wk exposure during World War II, and was found to have the greatest number of fibers of any of our subjects. In the remaining subjects, the histories of possible exposure did not correlate with the actual number of fibers found; in fact, although the men had much more suggestive histories (for example, work in a ship's boiler room), a greater number of amphibole fibers were seen in the women's lungs, and no differences between the sexes were observed for chrysotile. We believe that the range of chrysotile and amphibole fibers in these subjects represented the background inhaled from ambient air in the urban area; assessment of the correctness of this idea must await comparison with persons of known modest and high degrees of exposure.

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