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AN EPIDEMIOLOGICAL–INDUSTRIAL HYGIENE STUDY OF TALC WORKERS

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Abstract—Two-hundred and ninety-nine (299) miners and millers exposed to talc from Montana, Texas and North Carolina were examined in a cross-sectional study of respiratory systems, lung function and chest X-rays. Work histories were taken from personnel records. Personal respirable dust samples were collected for all jobs. Cumulative exposure was calculated by summing the products of the estimated exposure for each job and the length of time worked in that job. The average time worked was 7, 6, and 10 yr and the average exposure (cumulative exposure/total time worked) was 1.2, 2.6, and 0.3 mg m^{-3} in Montana, Texas, and North Carolina respectively. Free silica content of bulk samples was low (below the limit of detection in Montana, 1.5% in North Carolina, and 2.2% in Texas). No fibres were observed under the light microscope. Under the transmission electron microscope, tremolite and antigorite fibres (0.5–3 μm length) were observed on the Texas talc, acicular particles (aspect ratios 5–100 to 1 and some diameters less than 0.1 μm) in North Carolina talc, and no fibres in the Montana talc. The differences in age-corrected symptom prevalences (cough, phlegm, and dyspnea) between regions, when compared by both smoking categories and exposure groups were not statistically significant. None of the symptoms showed any consistent association with years worked or cumulative exposure. Symptom prevalence was not elevated compared with blue collar workers and potash miners. There were two cases (less than 1%) of grade 1 small rounded opacities. The prevalence of bilateral pleural thickening among workers 40 yr or older was 7, 16, and 14% in Montana, Texas, and North Carolina, and 0, 0, and 10% in those less than 40 yr of age. No non-smoker had bilateral pleural thickening and there was a slight tendency for the prevalence to increase with exposure. Workers with bilateral pleural thickening had lung function 10–20% below workers with no pleural thickening. They had also worked twice as long (13 yr) and an average of 13 yr between beginning exposure to talc and the time of the X-ray. The prevalence of bilateral pleural thickening was elevated in workers 40 yr or older compared with blue collar workers and potash miners. There also were no demonstrated differences in prevalence when the subjects in this study were compared with workers exposed to New York talc which contains tremolite and anthophyllite. For the entire study population no association of reduced lung function with exposure was demonstrated. After adjustments for age, height, and smoking, FEV_1 and FVC were not detectably different compared with potash miners and blue collar workers; however, flow rates at low lung volumes were reduced 4–19%. There was little difference among these three populations in age coefficients for FEV_1, FVC, and flow rates by smoking category. Predicted pulmonary function of the study population was elevated compared with New York talc workers.

There were no significant increases in symptoms or pneumoconiosis among the study group of talc workers nor significant reductions in lung function; however, the average amount of time worked by the study group was short. Bilateral pleural thickening was significantly increased and was associated with decreased pulmonary function. The prognostic significance of the pleural thickening awaits prospective evaluation.

INTRODUCTION

TALC is a mineral with a wide variety of uses in paint, paper, ceramics, cosmetics, roofing products, textile material, rubber, lubricants, corrosion proofing compositions, fire extinguishing powders, cereal polishing, water filtration, insecticides, to name a few. Pure talc is a hydrated magnesium silicate, but the talc found in nature has a quite variable chemical composition. The mineral contaminant in talc of most concern is asbestos. Such contaminated talc can produce a clinical condition resembling that seen on exposure to asbestos. The hazard from exposure to 'pure' talc free of asbestos contamination is less well documented. The purpose of this study was to ascertain the effects on the respiratory system (symptoms, lung function, radiographic) of exposure to talc dust thought to contain no asbestos.

Talc workers in seven mines and eight mills in Montana, Texas and North Carolina were studied in this cross-sectional study. The mines in Montana and Texas were typical open pit operations, while the underground mine in North Carolina employed square set timbers and stopes. In each mine examined, typical mucking techniques were employed. ANFO (ammonium nitrate and fuel oil) was the most common type of explosive used.

Following extraction of the ore, the talc was hand sorted to remove extraneous material, as in Montana, or went directly from the mine to the primary crusher. Froth flotation and heavy metal separation techniques were not used in any facility examined. Following initial crushing, the talc might be calcined, as in the case of ceramic grade talcs, before being ground using dry grinding methods into the final product. Once the talc was ground to the appropriate mesh size, it was sterilized as in the case of pharmaceutical grade talc and then shipped in bags or bulk.

The specific questions being addressed in this paper are: (1) What is the prevalence of symptoms and abnormal radiographic findings by exposure categories within each region? What is the association of exposure with reduced lung function? (2) After adjustment for confounding variables, how does the study population compare with other mining and non-mining populations in the prevalence of symptoms, abnormal radiographic findings and mean lung function?

METHODS

The study of population consisted of workers who mined and milled talc from three regions of the United States: Montana, Texas and North Carolina. Although several different companies may be involved, the results for each region were combined and analysed. Since there were no demonstrated differences among the regions by age, smoking and exposure groups, the combined results of all regions are presented in this paper. Over 90% of the workers participated in the study.

The industrial hygiene portion of the study took place in every facility in which the morbidity data were collected. Personal respirable breathing zone samples were collected utilizing a Model G MSA* pump and a 10 mm nylon cyclone. These samples were analysed for respirable dust and percent quartz and cristobalite. The quartz and cristobalite analysis was done by X-ray diffraction (NIOSH, 1977). Time weighted averages (TWA) were obtained for each job classification at each facility. General area dust samples were collected on open face cellulose acetate filters and were analysed by atomic absorption for iron, manganese, calcium, aluminium, zinc and nickel (NIOSH, 1977).

From each ore body airborne dust samples were collected on open face cellulose acetate filters and analysed by phase contrast microscopy for the presence of fibres

* Mention of brand names does not constitute endorsement by the USPHS.

(NIOSH). Analysis for fibrous tremolite and anthophyllite was done on bulk and airborne dust samples utilizing analytical electron microscopy (NIOSH, undated). Bulk samples from each ore body were analysed for calcite and dolomite by X-ray diffraction (NIOSH, 1977).

All workers were administered either a Spanish or English version of the British Medical Research Council respiratory questionnaire by trained interviewers. Non-talc work histories were obtained in the interviews; work experiences at the talc facility were obtained from company records. Standard postero-anterior chest radiograms were read by three 'B' readers using the ILO U/C 1971 scheme. The films were read independently without knowledge of age, occupation or smoking history. The median of the three readings (i.e. the middle number) was used for analysis. Flow volume curves from a minimum of five forced expiratory manoeuvres were obtained and recorded on magnetic tape using an Ohio 800* rolling seal spirometer. Values from the maximum envelope were used for analysis. Sputums were collected on workers ≥35 yr of age. Personal environmental samples were collected on day shift workers and were used to estimate talc dust exposure for each job. This estimate was then used to calculate cumulative talc dust exposure by multiplying job exposure by time and adding the results. The association of lung function and exposure (cumulative exposure and years worked) was analysed by multiple regression. Years worked was divided into < 5, 5–9, and ≥ 10 yr worked categories for analysis of symptoms and pleural thickening. Cumulative exposure was the estimate of total exposure to respirable particulate over all years employed and was divided into low ($<2\ \mathrm{mg\ m^{-3}} \times$ years), medium (2–$6\ \mathrm{mg\ m^{-3}} \times$ years) and high ($>6\ \mathrm{mg\ m^{-3}} \times$ years) exposure groups for analysis of symptoms and pleural thickening. Differences by region and department (classified according to whether the majority of work was done in the mine, mill, crayon plant or other) were also estimated.

The prevalences of selected symptoms and pleural thickening were compared with mining and non-mining populations after indirect adjustment for smoking and using the age distribution of all populations (FLEISS, 1973). Prediction equations were calculated for each smoking category of the comparison populations. The observed lung function of each worker from the study population was compared with the predicted of the appropriate smoking category of the comparison population. The percent predicted lung function from all smoking categories and regions were then combined. Female prediction equations were available for only the blue collar comparison populations. Percent predicted lung function comparisons with the mining populations are therefore for males only.

RESULTS

Environmental results

Respirable dust exposure was highest in Texas and lowest in North Carolina, and mill dust levels were higher than mine dust levels in all regions (Table 1).

Montana talc had the lowest concentrations of trace metals of the three regions examined. Concentrations were slightly higher in North Carolina. Texas talc differed

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TABLE 1. DEMOGRAPHIC CHARACTERISTICS OF THE TALC WORKER POPULATIONS BY REGION

		Montana	Texas	North Carolina
n		177	71	51
Age	(SD)	34.9 (11.5)	38.0 (13.7)	43.1 (12.6)
Height (cm)	(SD)	175.5 (8.8)	173.0 (6.9)	172.5 (8.3)
Years worked	(SD)	6.6 (6.3)	5.5 (5.7)	10.1 (8.6)
Cumulative exposure [(mg m^{-3}) × years]	(SD)	5.9 (7.6)	11.3 (45.1)	3.0 (4.8)
Average exposure (mg m^{-3})	(SD)	1.21 (0.94)	2.64 (7.12)	0.28 (0.33)
Geometric mean of current respirable dust samples (mg m^{-3})	(GSD)	0.86 (0.77)	1.08 (0.72)	0.21 (0.86)
Mine (95% CI)		0.66 (0.85–1.41)	0.45 (0.18–0.75)	0.14 (0.07–0.31)
Mill (95% CI)		1.1 (0.47–0.92)	1.56 (0.96–2.54)	0.26 (0.13–0.51)
Non-smokers	(%)	33	20	21
Ex-smokers	(%)	21	27	17
pack years	(SD)	15.7 (17.9)	13.3 (20.7)	18.2 (16.5)
cigarettes/day	(SD)	23.0 (15.0)	12.0 (14.0)	21.4 (15.7)
Smokers	(%)	45	54	62
pack years	(SD)	17.9 (16.9)	14.3 (19.7)	23.7 (21.8)
cigarettes/day	(SD)	20.4 (11.0)	14.5 (11.1)	20.4 (10.0)

most significantly from the other regions by its extremely large concentration of calcium, as indicated by a much larger percentage of dolomite (13 compared with 3 and 1%) and a slightly larger percentage of calcite (1 compared with <1 and 0%) than the other two regions. Silica content of bulk samples of Montana talc was below the limit of detection (<0.8%), 1.45% in North Carolina and 2.23% in Texas. Respirable dust samples revealed the silica content in Montana and North Carolina to be generally below the limit of detection (0.04 mg m^{-3}). The Texas talc had slightly higher levels of respirable silica (0.09 mg m^{-3}) (Table 2).

No fibres were detected in any of the regions by light microscopy utilizing phase contrast techniques. Analysis of bulk samples from each region utilizing analytical transmission electron microscopy revealed no fibres in any samples of Montana talc. Two fibrous minerals were identified in the Texas talc: tremolite and antigorite. Antigorite, a serpentine mineral, was the main constituent. The fibres of both minerals ranged from 0.5 to 3.0 μm in dia. and 4 to 30 μm in length. The morphology of the North Carolina talc was identified as acicular. The acicular particles had aspect ratios ranging from 5–1 to 100–1, with some dia. <0.1 μm, and may have resulted from mechanical destruction of talc plates.

Demographic characteristics

All Texas talc workers were male, while about 20% of the Montana and North Carolina workers were female. The North Carolina population had the highest proportion of smokers (62%) and lowest proportion of ex-smokers (17%). The highest proportion of non-smokers (33%) and lowest proportion of smokers (46%) were in Montana. Pack years ranged from 13 to 24 and cigarettes smoked/day from 12 to 23 in the three regions. Montana workers were on average 8 yr younger, 3 cm taller, had worked 3.5 yr less and had 2.9 mg m^{-3} yr more cumulative exposure than the workers

TABLE 2. METAL AND MINERAL COMPOSITION OF BULK SAMPLES BY REGION

	Montana	Texas	North Carolina
$mg\ m^{-3}$			
Iron	0.05	0.5	0.05
LOD*	0.01	0.1	0.02
Manganese	<0.01	<0.08	<0.02
LOD	0.01	0.08	0.02
Calcium	0.05	8.0	0.05
LOD	0.03	0.2	0.02
Aluminium	0.2	0.4	0.2
LOD	0.1	0.2	0.04
Zinc	<0.01	0.03	<0.02
LOD	0.01	0.08	0.02
Nickel	<0.01	<0.08	<0.02
LOD	0.01	0.08	0.02
Percent			
Calcite	<1	1	0
(range)	(0–0.8)	(0–3)	0
Dolomite	1	13	3
(range)	(0–3)	(7–20)	(1–4)

* LOD = Limit of Detection.

in North Carolina. Mean values for these parameters in Texas were not demonstrably different from those for Montana and North Carolina. Average exposure (cumulative exposure divided by years worked) was less in North Carolina than in the other two regions (Table 1).

There was one case each in Texas and Montana of grade 1 small rounded opacities. This number is too small to analyse further. There were no other radiographic interpretations of pneumoconiosis. Cytology on sputums collected from workers 35 yr of age or older were read as follows: 20% unsatisfactory, 60% normal cytology or regular metaplastic cells, 20% atypical.

Symptoms and radiography (*internal comparisons*)

Tables 3–6 summarize the prevalence of cough, phlegm, shortness of breath and pleural thickening by age, smoking and exposure. Regions were combined for presentation of these results as there were generally no statistically significant differences among the regions. If differences were observed they are noted in the text.

The overall prevalence of cough was 19%. The prevalence tended to increase with age and smoking (only the difference between non-smokers and smokers was significant). There was no apparent association with either exposure variable (Table 3).

The overall prevalence of phlegm was 23%. There was no consistent increase with age. Overall, smokers had a higher prevalence of phlegm than non-smokers. There was no apparent association with exposure (Table 4).

The overall prevalence of dyspnea was 5%. Prevalence increased with age in all regions and smoking categories, but the increase with age was significant for only the total population. There was no apparent association with smoking or exposure (Table 5).

TABLE 3. PREVALENCE (%) OF COUGH* AMONG ALL TALC WORKERS BY AGE, SMOKING AND EXPOSURE (ALL REGIONS COMBINED)

	Age <40 % (95% CI)	Age ≥40 % (95% CI)	Total % (95% CI)
Non-smoker	7 (2–16)	15 (5–32)	10 (5–20)
Ex-smoker	7 (1–21)	19 (9–34)	13 (6–24)
Smoker	26 (18–35)	30 (18–45)	27 (20–35)
Total	21 (15–29)	23 (15–32)	19
Years worked			
<5			19 (14–25)
5–9			19 (10–31)
≥10			21 (10–36)
Cumulative exposure			
Low			14 (8–23)
Medium			25 (17–35)
High			16 (9–26)

Summary: (i) No demonstration difference among regions by age, smoking or exposure. (ii) Tendency to increase with age except among smokers. (iii) Higher prevalence in smokers. (iv) No demonstrated association with exposure.

* Cough = Answering yes to the question: 'Do you usually cough on most days for as much as 3 months each year?'

TABLE 4. PREVALENCE (%) OF PHLEGM* AMONG ALL TALC WORKERS BY AGE, SMOKING AND EXPOSURE

	Age <40 % (95% CI)	Age ≥40 % (95% CI)	Total % (95% CI)
Non-smoker	12 (5–24)	7 (1–22)	11 (5–20)†
Ex-smoker	13 (5–29)	27 (14–43)	21 (12–33)
Smoker	33 (24–43)	26 (15–40)	31 (24–39)†
Total	23 (16–30)	22 (15–31)	23
Years worked			
<5			19 (14–25)
5–9			16 (8–26)
≥10			25 (14–39)
Cumulative exposure			
Low			13 (7–21)
Medium			24 (16–34)
High			19 (11–30)

Summary: (i) No demonstrated difference among regions by age, smoking or exposure. (ii) Smokers had highest prevalence. (iii) No demonstrated association with age or exposure.

* Phlegm = Answering yes to the question: 'Do you usually bring up phlegm from your chest for as much as 3 months each year?'

†95% CI do not overlap.

TABLE 5. PREVALENCE OF DYSPNEA* AMONG ALL TALC WORKERS BY AGE, SMOKING AND EXPOSURE

	Age <40 % (95% CI)	≥40 % (95% CI)	Total % (95% CI)
Non-smoker	4 (1–13)	11 (3–27)	6 (2–14)
Ex-smoker	3 (0–16)	16 (1–18)	10 (4–20)
Smoker	1 (0–5)	6 (0–13)	3 (1–7)
Total	2 (0–5)†	10 (5–18)†	5
Years worked			
<5			6 (3–10)
5–9			0 (0–6)
≥10			8 (2–20)
Cumulative exposure			
Low			5 (2–11)
Medium			3 (1–8)
High			7 (2–14)

Summary: (i) No demonstration differences among regions by age, smoking or exposure. (ii) Increased prevalence with increased age. (iii) No demonstrated association with smoking or exposure.

* Dyspnea = Answering yes to the question: 'Do you get short of breath walking with people your own age on level ground?'

† 95% CI do not overlap.

TABLE 6. PREVALENCE OF BILATERAL PLEURAL THICKENING AMONG ALL TALC WORKERS BY AGE, SMOKING AND EXPOSURE

	Age <40 % (95% CI)	≥40 % (95% CI)	Total % (95% CI)
Non-smoker	0 (0–7)	0 (0–11)	0 (0–6)
Ex-smoker	6 (0–24)	3 (0–15)	4 (0–14)
Smoker	2 (0–7)*	22 (11–36)*	9 (5–15)
Total	2 (0–6)	11 (5–18)	5
Years worked			
<5			2 (0–5)‡
5–9			3 (0–10)*
≥10			23 (12–38)*‡
Cumulative exposure			
Low			4 (1–10)†
Medium			5 (1–12)
High			8 (3–17)†

Summary: (i) No demonstrated differences among regions by age, smoking or exposure, except medium cumulative exposure group in North Carolina had higher prevalence than in Montana. (ii) Tendency to increase with age (significant among smokers). (iii) No bilateral pleural thickening among non-smokers. (iv) Increasing prevalence with increasing years worked. (v) No demonstrated association with cumulative exposure.

*‡ 95%Confidence intervals do not overlap.

† 1 with extent 2 pleural thickening.

The prevalence of pleural thickening was 4, 13 and 18% in Montana, Texas and North Carolina respectively, and was significantly less in Montana after adjustment for age or years worked. The number of those with unilateral pleural thickening was one of six, five of nine, and three of nine in the three regions. There were no radiographic interpretations of pleural calcification.

The overall prevalence of bilateral thickening was 5%. The prevalence among the medium exposure group was 30% in North Carolina and 0% in Montana. There were no other demonstrable regional differences. Prevalence increased with age, but only among smokers. Prevalence was highest among smokers, and no non-smokers had bilateral pleural thickening, but none of the differences were significant. The prevalence was greater (23%) in the group working 10 yr or more, compared with 2.5% in those working less than 10 yr, but was about the same in the low, medium and high cumulative exposure groups (Table 6).

Table 7 compares workers with and without pleural thickening. Those with any pleural thickening were about 10 yr older than those without. Workers with bilateral pleural thickening on average weighed more (11–15 kg), had worked longer (6 yr) and had higher average and cumulative exposures than those with unilateral or no pleural thickening. All pulmonary function values of those with bilateral pleural thickening

TABLE 7. COMPARISON OF WORKERS WITH AND WITHOUT PLEURAL THICKENING (REGIONS COMBINED)

	No PT	Unilateral	Bilateral
n	255	9	15
Frequency (95% CI)			
Cough (%)	18 (14–23)	22 (4–56)	33 (14–63)
Phlegm (%)	18 (14–23)	22 (4–56)	33 (14–63)
Dyspnea (≥Grade 2)	5 (3–8)	11 (0–44)	7 (0–30)
Obliteration of costophrenic angle			
Unilateral	2 (0–5)	11 (0–44)	13 (2–37)
Bilateral	<1 (0–1)	0 (0–29)	0 (0–19)
*Means (SE)			
Age	36.4 (0.8)	46.7 (3.4)	47.7 (2.2)
Height (cm)	174.0 (0.5)	170.1 (2.1)	175.3 (2.0)
Weight (kg)	76.6 (0.8)	80.5 (4.9)	91.9 (4.3)
Years worked	6.7 (0.4)	6.9 (2.2)	13.4 (2.3)
Cumulative exposure [(mg m^{-3}) × years)]	5.1 (0.4)	2.4 (0.7)	34.1 24.6)
Average exposure (mg m^{-3})	1.1 (0.1)	0.9 (0.3)	3.2 (2.5)
'Latency' years	—	4.50 (1.4)	13.1 (2.3)
†$FEV_1/FVC \times 100$	77.10 (0.7)	80.20 (2.7)	72.50 (2.2)
†FEV_1 (L)	3.56 (0.05)	3.47 (0.19)	3.08 (0.16)
†FVC (L)	4.61 (0.06)	4.29 (0.22)	4.19 (0.18)
†Peak flow (L s^{-1})	8.37 (0.15)	7.62 (0.56)	7.02 (0.45)
FEF_{50}	4.10 (0.13)	4.19 (0.49)	3.30 (0.40)
FEF_{75}	1.40 (0.06)	1.43 (0.21)	1.24 (0.18)

* Lung function least square means adjusted for differences in sex, age, height, weight and smoking status.

† Pleural thickening is a significant variable in the linear regression model.

were reduced compared with those without pleural thickening. Those with unilateral pleural thickening generally had intermediate lung function values. The prevalences of cough and phlegm were not statistically significant and were not adjusted for age and smoking.

Symptoms and radiography (external comparisons)

Table 8 summarizes the characteristics of the comparison populations. The potash mines were part of the MSHA/NIOSH epidemiological–industrial hygiene study of metal and non-metal underground miners (ATTFIELD, 1979; SUTTON *et al.*, 1979). White male miners from six potash mines were used for comparison. All of the potash mines used diesel engines and had high dust exposures. The New York talc miners and millers were exposed to tremolite and anthophyllite (GAMBLE *et al.*, 1979a; DEMENT and ZUMWALDE, 1979; DEMENT *et al.*, 1980). The blue collar comparison population was part of a NIOSH blue collar control study and included male and female workers from North Carolina in such industries as electronics, synthetic textiles, bakeries and bottling plants (PETERSEN, personal communication). The workers in the comparison populations had generally worked longer in their current industry than had the Montana and Texas talc populations. The mining populations generally were heavier smokers than the study populations and the blue collar workers. The mining comparison groups had occupational exposures in the form of diesel fumes and 'potash' (primarily sylvite, a mixture of KCl and NaCl, and langbeinite or $K_2Mg_2(SO_4)_3$) and talc containing asbestiform fibres.

Table 9 summarizes the age and smoking adjusted prevalence of cough, phlegm, dyspnea and pleural thickening of the study and comparison populations. There was no demonstrated difference in the prevalence of cough between the study population and the potash or blue collar workers. New York talc workers had an elevated

TABLE 8. CHARACTERISTICS OF COMPARISON POPULATIONS

	New York talc	Blue collar‡ Male	Blue collar‡ Female	Potash
n	121	843	597	875
Age (SD)	39 (12)	38 (14)	40 (13)	41 (13)
Height (cm) (SD)	176 (6)	173 (7)	162 (6)	176 (6)
Years worked (SD)	11 (9)	12 (12)	11 (10)	16 (13)
Non-smokers (%)	21	25	49	20
Ex-smokers (%)	31	23	10	28
Mean pack years (SD)	26 (28)	21 (23)	9 (10)	23 (20)
Mean cigarettes/day (SD)	28 (19)	23 (15)	16 (12)	25 (14)
Smokers (%)	48	54	42	52
Mean pack years (SD)	26 (17)	23 (19)	17 (13)	28 (23)
Mean cigarettes/day (SD)	27 (11)	23 (11)	19 (9)	25 (12)
Current dust levels ($mg\ m^{-3}$)	*0.77 (Mine) *0.87 (Mill)	NA	NA	†3.45
Fibres > 5 $\mu m\ cc^{-1}$	*5.40 (Mine) *4.80 (Mill)	NA	NA	NA

NA = Not Available.
* Personal samples of respirable dust and light microscope fibre counts from DEMENT *et al.* (1980).
† Personal samples of total dust from ATTFIELD (1979) and SUTTON *et al.* (1979).
‡ Unpublished data from Martin Petersen.

TABLE 9. COMPARATIVE RATES OF COUGH, PHLEGM, DYSPNEA AND BILATERAL PLEURAL THICKENING AMONG ALL TALC WORKERS COMPARED WITH NEW YORK TALC WORKERS, BLUE COLLAR WORKERS AND POTASH MINERS (INDIRECTLY ADJUSTED FOR AGE AND SMOKING)

	Study population (combined) % (95% CI)	Comparison group New York talc % (95% CI)	Potash miners % (95% CI)	Blue collar workers % (95% CI)
Cough	20.3 (16–25)	36.1 (28–45)	24.1 (20–27)	16.7 (14–20)
Phlegm	20.3 (16–25)	35.5 (27–45)	29.5 (27–34)	17.3 (14–21)
Dyspnea	5.8 (4–10)	12.3 (7–19)	8.4 (6–11)	7.5 (6–10)
Bilateral pleural thickening	6.3 (3–9)	7.9 (4–15)	0.2 (0–0.5)	0.4 (0–1)

Summary: (i) Cough: Study population less than New York talc, no different from potash and blue collar. (ii) Phlegm: Study population less than New York talc and potash, no different from blue collar workers. (iii) Dyspnea: No difference among study and comparison populations. (iv) Bilateral Pleural Thickening: Study population and New York talc workers greater than potash and blue collar workers. (Difference indicated by non-overlap of confidence intervals)

prevalence of cough compared with other populations. There was no apparent difference in the prevalence of phlegm among the study population and blue collar workers, and the prevalence in both these populations was less than the potash and New York populations. There were no demonstrated differences in the prevalence of dyspnea among the study and comparison populations. The prevalence of bilateral pleural thickening was higher in both talc (study and New York) populations compared with the potash and blue collar populations.

Pulmonary function

Table 10 summarizes the results of multiple regression models of pulmonary function with the predictor variables race, sex, age, height, smoking status. Region, department, years worked and cumulative exposure were tested for association with lung function. Age and height were significant for all parameters. Race, department, years worked and cumulative exposure were not significant for any of the lung function tests. Sex was not significant for FEF_{50} and FEF_{75}. FVC was reduced in Texas compared with Montana and North Carolina. The effect of smoking was generally as expected.

Table 11 summarizes the mean percent predicted pulmonary function of the study population compared with potash, blue collar workers (male and female) and New York talc workers. Flow rates (peak flow, FEF_{50}, FEF_{75}) of the talc workers were reduced compared with the potash and blue collar workers, but there were no significant differences in FEV_1 and FVC. Compared with New York talc workers, all pulmonary function parameters were elevated except percent predicted peak flow.

TABLE 10. SUMMARY OF MULTIPLE REGRESSION MODEL* FOR LUNG FUNCTION AND SELECTED MEANS ADJUSTED FOR SEX, AGE, HEIGHT, SMOKING STATUS, REGION AND EXPOSURE

	Lung function parameter				
	FEV_1	FVC	Peak flow	FEF_{50}	FEF_{75}
Department	NS	NS	NS	NS	NS
Years exposure	NS	NS	NS	NS	NS
Cumulative exposure	NS	NS	NS	NS	NS
Region	NS	†	NS	NS	NS
Montana	3.58 (0.06)	4.65 (0.06)	8.51 (0.16)	4.07 (0.13)	1.41 (0.06)
Texas	3.51 (0.10)	4.39 (0.11)	8.46 (0.27)	4.63 (0.23)	1.48 (0.10)
North Carolina	3.71 (0.10)	4.62 (0.11)	7.87 (0.28)	4.48 (0.24)	1.55 (0.11)
Smoking status	†	NS	‡	†	†
Non-smokers	3.71 (0.08)	4.62 (0.09)	8.31 (0.23)	4.55 (0.19)	1.63 (0.09)
Ex-smokers	3.58 (0.09)	4.51 (0.10)	8.60 (0.25)	4.52 (0.21)	1.44 (0.10)
Smokers	3.51 (0.07)	4.53 (0.08)	7.93 (0.20)	4.12 (0.17)	1.37 (0.08)

* Regression model: Lung function $= \alpha + \beta_1$ (race) $+ \beta_2$ (sex) $+ \beta_3$ (age) $+ \beta_4$ (height) $+ \beta_5$ (smoking status) $+ \beta_6$ (region) $+ \beta_7$ (department) $+ \beta_8$ (years exposure) $+ \beta_9$ (cumulative exposure).

NS $= P > 0.05$.

† $P < 0.05 > 0.01$.

‡ $P < 0.01$.

Summary: (i) Age and height were always significant; sex was significant for FEV_1, FVC and Peak Flow. (ii) No exposure variable was significant. Region was significant for FVC (Texas was reduced). (iii) Cumulative exposure was significant for FVC ($P = 0.02$) in model lung function $= \alpha + \beta_1$ (sex) $+ \beta_2$ (age) $+ \beta_3$ (height) $+ \beta_4$ (weight) $+ \beta_5$ (smoking status) $+ \beta_6$ (cumulative exposure) $\beta_6 = -4(4)$.

Comparison of age coefficients by smoking categories showed little difference among the four populations. The New York and blue collar populations showed a greater effect of age than did the study and potash populations (Table 12).

DISCUSSION

Interpretation of the data from this study has the inherent problems of all cross-sectional prevalence studies. The workers examined in this study comprise only those currently working. While there are few studies that have examined ex-workers to determine the effects of selection, significant disease has been observed among older ex-hemp workers (BOUHUYS *et al.*, 1969) and progressive massive fibrosis among ex-workers in two silica flour mills (BANKS *et al.*, 1981). In both of these studies there was significant disease among the currently employed workers. The consequences of not examining ex-workers in this study are unknown.

The reasons for using several comparison populations are that no comparison population is ideal, and several may help in interpretation of the data. Factors that may affect the morbidity of a study population (in addition to work exposure) but are not measured include region, socio-economic status and type of employment (for example, mining). These may affect morbidity by selection of particular kinds of individuals, but it is unlikely that all the comparison populations will have biases in the same direction relative to the study population (although the biases in the study group still cannot be estimated).

The length of the study group's working history is a relatively short time for the development of occupationally related symptoms, radiographic changes and impaired

TABLE 11. MEAN PERCENT PREDICTED PULMONARY FUNCTION OF ALL TALC WORKERS COMPARED WITH POTASH MINERS AND BLUE COLLAR WORKERS AND ADJUSTED FOR AGE, HEIGHT AND SMOKING*

Percent predicted pulmonary function (SE)	New York talc (males only) $n=119$	Potash miners (males only) $n=251$	Blue collar workers (males and females) $n=292$
FEV_1	106.3 (1.3)‡	98.9 (1.0)	99.7 (1.0)
FVC	105.7 (1.1)‡	99.6 (0.8)	101.0 (0.8)
Peak Flow	95.2 (1.1)	93.2 (1.0)†	97.9 (1.0)
FEF_{50}	161.1 (39.8)	95.6 (2.1)†	94.1 (2.0)†
FEF_{75}	130.5 (4.7)‡	88.2 (3.1)†	84.5 (2.4)†

* Percent predicted pulmonary function = Σ(observed/expected) × 100.
† = >2 SE less than 100.
‡ = >2 SE greater than 100.
Summary: (i) FEV_1 and FVC were not demonstrably different from comparison potash and blue collar populations, but elevated compared with New York talc values. (ii) FEF_{50} and FEF_{75} reduced compared with potash and blue collar populations, but elevated compared with New York populations.

TABLE 12. AGE COEFFICIENTS OF MALE STUDY AND COMPARISON POPULATIONS (WITH SE)

	Study population	New York talc	Potash	Blue collar
FEV_1 (ml)				
Non-smokers	−24 (5)	−52 (9)	−28 (3)	−30 (3)
Ex-smokers	−35 (5)	−36 (11)	−32 (3)	−36 (3)
Smokers	−41 (5)	−54 (6)	−40 (2)	−39 (2)
FVC (ml)				
Non-smokers	−6 (5)	−55 (12)	−23 (3)	−24 (3)
Ex-smokers	−32 (6)	−42 (13)	−26 (4)	−25 (3)
Smokers	−27 (6)	−50 (8)	−32 (3)	−25 (2)
FEF_{50} (ml s^{-1})				
Non-smokers	−51 (11)	−66 (29)	−36 (7)	−43 (6)
Ex-smokers	−49 (15)	−21 (24)	−44 (8)	−58 (8)
Smokers	−73 (11)	−80 (14)	−63 (5)	−71 (5)
FEF_{75} (ml s^{-1})				
Non-smokers	−43 (7)	−40 (11)	−32 (4)	−38 (4)
Ex-smokers	−2 (10)	−22 (7)	−28 (3)	−40 (3)
Smokers	−44 (5)	−38 (5)	−41 (2)	−50 (2)
n				
Non-smokers	67	25	178	207
Ex-smokers	56	36	244	193
Smokers	128	58	451	442

lung function that might be caused by exposure to a mineral dust. Significant changes in FEV_1 and FVC due to exposure to respiratory irritants (such as cigarette smoke, for example) may not become noticeable until after 20–30 yr of smoking. Essentially the same time interval may be required for the development of pneumoconiosis (CHERNIACK and MCCARTHY, 1979). The mean ages of the study populations were around 40, and mean exposure to talc dust was less than 10 yr. Therefore, if talc dust was to adversely affect FEV_1 and FVC, the lung function results might not reflect that effect because of the short exposure times.

Estimating past exposure was a problem in this as in other studies where there was no environmental surveillance. Although dust levels were assumed not to have changed substantially with time, past exposures were probably higher than the calculated estimates and could obscure a true dose–response relation if it existed. Years worked is an exact time period, but it may be a less accurate measure of overall exposure than the calculated estimate of cumulative exposure. Often, years worked and exposure are highly correlated. This was not as true for Texas, but there was an association of years worked and cumulative exposure in Montana and North Carolina. Age was also correlated with exposure (years worked and cumulative exposure).

In this report, both internal comparisons (dose–response relations) and external comparisons were made with another talc population, another mining population and a 'non-exposed' blue collar population. For symptoms and pleural thickening the two comparisons supported each other. That is, for symptoms of cough, phlegm and dyspnea there was no dose–response relationship and no excess prevalence in the external comparison. For bilateral pleural thickening there was a dose–response relationship (association with years worked) and the prevalence was increased compared with both non-talc populations.

For pulmonary function there was also substantial agreement in the internal and external comparisons. Mean percent predicted pulmonary function after adjustment for age, height and smoking, and the age coefficients by smoking status taken from prediction equations were used for the external comparisons. Age coefficients are thought to be less subject to bias than predicted values (HANCOCK and ATTFIELD, 1980). The two methods were consistent in showing a tendency for the study population to have an elevated pulmonary function compared with New York talc workers, with no detectable differences in FEV_1 and FVC in the other comparisons. Mean flow rates were reduced in the study population compared with potash and blue collar workers, but the age coefficients did not reflect this deficiency.

Flow rates at low lung volumes (FEF_{50} and FEF_{75}) were slightly reduced compared with two of the control populations. FEF_{50} was better than 90% predicted, while FEF_{75} was between 80 and 90%. Air flow at low lung volumes is considered to be measuring changes occurring primarily in the small airways (HYATT *et al.*, 1979; MEAD, 1979). A current hypothesis of the pathophysiology of chronic air flow obstruction is that changes in the lung function seen in disease such as emphysema start in the region of the small airways (BECKLAKE and PERMUTT, 1979; MACKLEM, 1972). Tests such as FEF_{50} and FEF_{75} are of interest, because it is difficult to detect pathophysiological changes in the small airways that may be occurring for unknown time periods before they become evident in more routine tests such as FEF_1 and FVC. While existing data (such as the ability of FEF_{50} and FEF_{75} to detect differences in the young smokers and non-smokers) are compatible with the idea that air flow obstruction begins in the small airways, there are no available prospective data to prove it. Therefore, the significance of these reductions is only suggestive. Thus, the prognostic significance of reduced flow rates at low lung volumes is not proven and the evidence for reductions in the study population is not convincing.

Peak flow was reduced in the study population compared with potash and New

York talc workers but was no different from blue collar workers. Peak flow is most sensitive to changes in large airways, but is also most subject to technician differences and subject effort. The prognostic significance of reduced peak flow is also not known.

The most important finding in this study was the increased prevalence of pleural thickening. Asbestos (particularly anthophyllite) from either occupational or community exposure is believed to cause an increased prevalence of pleural thickening (SARGENT *et al.*, 1977) and in some instances, pleural changes have been more common than parenchymal changes (HURWITZ, 1961). Talc contaminated with asbestos (tremolite and anthophyllite) seen under the light and electron microscope has also been associated with an increased prevalence of pleural thickening (GAMBLE *et al.*, 1979b). But studies of workers exposed to talc without significant asbestos content have reported higher prevalence of pneumoconiosis than pleural changes (RUBINO *et al.*, 1977; DELAUDE, 1977; MESSITE *et al.*, 1959; FINE *et al.*, 1976; WEGMAN *et al.*, unpublished) and excessive mortality due to non-malignant respiratory disease (SELEVAN *et al.*, 1979). Radiographic evidence from these Vermont talc millers showed pneumoconiosis on 9 of 11 available chest roentgenograms. Although exposures were high, the talc was free of asbestos and free silica (BOUNDY *et al.*, 1979). Pneumoconiosis, however, was not significant in this study. Pleural abnormalities (unspecified) were found in 9% of Vermont talc workers (WEGMAN *et al.*, unpublished), compared with 9% with small irregular opacities and 12% with small rounded opacities. This is in contrast to this study where pleural thickening was observed in 9% of the population, but less than 1% had any signs of pneumoconiosis.

Pleural thickening is generally considered to take many years to develop. In a study of a Swedish population, mean latency for the development of bilateral pleural plaques after first exposure to asbestos was estimated at about 30 yr, which was consistent with other studies. Pleural plaques were rare before age 40 (HILLERDAHL, 1978). However, OCHS and SMITH (1976) reported on at least one case where as little a time interval of 1 yr was necessary for the appearance of bilateral pleural thickening in an individual without occupational asbestos exposure. In the study reported here, latency (time between first known talc exposure and date of the study) was 13 yr for workers with bilateral thickening and 4.5 yr in those with unilateral pleural thickening, a much shorter time than generally associated with pleural thickening from asbestos exposure. North Carolina also had an increased prevalence in workers less than 40 yr of age.

The association of pleural thickening and asbestos exposure may vary considerably in different populations. In a Swedish study about 1% of the men over 40 and less than 0.1% of men less than 40 had bilateral pleural plaques (HILLERDAHL, 1978). Almost 80% were current ex-smokers and had had some exposure to asbestos. Fibrosis was rare (4% of those with pleural thickening). Another community type study in Birmingham, England (BTTA and MRCPU, 1972) found that about 7% of those attending chest clinics had pleural plaques (10% of these were calcified). Unilateral obliteration of the costophrenic angle (not considered to be caused by asbestos) was observed in 36% of those with pleural plaques and there was a definite history of asbestos exposure in no more than 11% of the cases. Much of the pleural thickening was considered to be due to pleural disease (e.g., emphysema, severe chest wall injury, pleurisy). In the study of talc workers reported here, there was no apparent difference between those with and without pleural thickening in the exposure to asbestos or in chest disease.

In these two community studies the association of pleural thickening and asbestos exposure was quite different. The association of pleural thickening with asbestos may be coincidental, as the prevalence of pleural thickening is quite different in asbestos exposed workers. For example, prevalences of 17.5 and 35% have been reported in asbestos manufacturing plants and shipyard joiners (WEISS and THEODOS, 1978; FLETCHER, 1971). Two other studies of shipyard and dockyard workers reported prevalences of pleural thickening of around 5% (FLETCHER, 1972; reported in WEISS and THEODOS, 1978). It is possible that factors other than asbestos may account for these differences (e.g., age distribution, method of reading X-rays, oblique X-rays in addition to PA, different exposures and exposure times, smoking habits, readers, etc). Some of these factors could possibly account for the differences between study and comparison populations seen in this study.

Exposure to other dusts have also been associated with pleural abnormalities. SMITH (1952) reported finding a pleural calcification among 302 men making mica insulators, 6.3% among miners and millers of tremolitic talc, but zero among 261 asbestos workers. The common feature of exposure of all four groups was said to be exposure to talc/or mica.

No asbestos was seen in the NIOSH samples of Montana and North Carolina talc. MCCRONE (1975) analysed two samples from North Carolina and found 0.1–5% tremolite–actinolite by polarized light microscopy in one of the samples. Tremolite and actinolite have been reported in the Murphy talc deposits although the quantities were small (VAN HORN, 1948). GREXA and PARMENTIER (1979) report 0–5% anthophyllite in 'North Carolina' talc and no asbestos in Montana talc. Seven samples from Montana revealed no asbestos (MCCRONE, 1975) and antigorite was observed in some of the Texas samples (MCCRONE, 1975). While analysis of the talc from these three regions revealed little or no asbestos, the presence of asbestos as an impurity often occurs. It is not known whether very low levels of exposure to asbestos for short periods of time is sufficient to cause pleural thickening.

Thus, while pleural thickening is generally considered to be a signpost of asbestos exposure (SARGENT *et al.*, 1977), the possibility of other agents causing pleural thickening should be considered. The conclusion of MEURMAN (1966) that factors other than asbestos were either contributory or the sole cause of calcified plaques seems applicable to pleural thickening. The results of this study suggest that talc itself may produce pleural changes.

The clinical significance of pleural thickening, pleural plaques and pleural calcification as a result of asbestos exposure remains unclear, but is of concern because the pleural changes were considered to represent a significant exposure to asbestos and may be related to mesothelioma. However, there may be no association of mesotheliomas and pleural plaques even in the presence of asbestos, as no mesotheliomas associated with anthophyllite asbestos exposure have been observed in Finland (MEURMAN *et al.*, 1974). The suggestion that talc is carconogenic (BLEJER and ARLON, 1973) may be due to asbestos contamination of the talc. The characteristics of talc have been poorly reported in the past. Talc free of asbestos contamination does not appear to increase the risk of cancer, and mesothelioma has not been associated with talc exposure (KLEINFELD *et al.*, 1974; RUBINO *et al.*, 1976; WAGNER *et al.*, 1977; RCBTA and MRCPU, 1979; SELEVAN *et al.*, 1979). Risk of cancer in this study cannot be determined. Among those with bilateral pleural thickening, lung function was significantly reduced. The prognostic significance of these observations is unknown and deserves prospective evaluation.

CONCLUSIONS

In this cross-sectional study of 299 talc workers from Montana, Texas and North Carolina, there was no demonstrated association of symptoms (cough, phlegm, dyspnea) or reduced lung function with exposure. The prevalence of symptoms was not elevated and there was no demonstrable reduction in FEV_1 and FVC compared with the control populations. Thus, both internal and external comparisons were consistent in confirming the lack of association between morbidity and exposure variables. While there were no demonstrated differences in the symptom prevalences among the three talc regions (despite differences in exposure and talc composition), there were differences in the prevalence of cough and phlegm between the study population and the workers exposed to talc containing tremolite and anthophyllite.

The only significant effect observed in this study was related to the increased prevalence of bilateral pleural thickening. The excess was considerable in relation to the non-talc comparison populations, but the dose–response relationship was somewhat confounded with age. The comparable results among the talc populations, the lack of a consistent association of pleural thickening with asbestos exposure, and the lack of parenchymal changes in the talc exposed workers suggest talc as an etiological agent in the development of bilateral pleural thickening. While those with bilateral pleural thickening had reductions in lung function and a possible increase in symptoms, the long-term significance is unclear.

At least two warnings must be acknowledged. The mean number of years worked is relatively short. Therefore, more time may be needed to see exposure effects. The suggestion of reduced flow rates at low lung volumes supports this caution, as they may be early indicators of airways disease. The association of talc exposure with bilateral pleural thickening was relatively weak. However, latency was shorter than is commonly found in other studies and the excess is considerable compared with non-talc populations. A prospective study is necessary to answer the questions concerning prognostic significance.

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DISCUSSION*

J. C. MCDONALD: In addition to the pleural thickening you observed, was there any evidence of pleural calcification?

J. A. MERCHANT: May I answer that? I reviewed all the films with pleural thickening and there were no cases at all of pleural calcification. Most of the pleural thickening was grade 1, but there was one case where the thickening was considered grade 2. Two of the cases of pleural thickening were extent 2; the remainder extent 1.

J. WILLEMS: Do you have full information on the size-distribution of your talc dust particles?

Dr DEMENT: We do have some information that is not presented in this report. Of course, the respirable dust sampling attempted to simulate those particles which have the possibility of deep lung penetration. In general, the Montana talc had by far the largest particle size with much larger plates. In North Carolina there is a combination of the platy and acicular particles which were identified by electron diffraction and microchemical analysis as being talc with a rather unusual morphology.

S. F. MCCULLAGH: In this study (and several others) use is made of the standard respiratory questionnaire. Among other questions, workmen are asked if they get more short of breath walking on the level than other men of their own age. I have asked this question of thousands of workmen in Australia and at least half answer, 'Gee, Doc, I wouldn't know'. In the present study were the men forced to a decision, do you have a 'don't know' category or are American workers a great deal more intelligent than Australians?

Dr DEMENT: We try to administer the same questions to both our exposed and non-exposed populations and hope the level of intelligence is similar and better. The questionnaires are difficult to answer off-the-cuff, but we employ trained interviewers who are familiar with answering the questions and try to seek the answer in a polite manner. Very seldom does a worker answer, 'I don't know'. A very high percentage answer 'Yes' or 'No' and, if the answer is equivocal, the question is repeated with the admonition to answer 'Yes' or 'No'.

M. JACOBSEN: May I comment on Dr McCullagh's question. Whilst it is true that there are often ambiguous answers and strict protocols have to be used in order to maintain properly recorded answers useful for epidemiological studies, there is evidence from our studies that, if this is done rigorously and conscientiously, then the data obtained may be used sensibly for epidemiological purposes. Coal miners who have been asked these questions are no more or less intelligent than Dr McCullagh's patients. Their responses indicate very clearly that their mortality risk, particularly to the respiratory diseases, can be related to those responses to the questions particularly those relating to breathlessness and to cough and phlegm.

M. L. NEWHOUSE: I am surprised at the high prevalence of pleural thickening that you report. In a survey of 30–40 pharmaceutical workers exposed to a carefully specified, non-fibrous talc, we observed no more than one or two pleural thickenings.

* The paper was presented, and questions taken, by Dr J. M. DEMENT.

Dr DEMENT: There are several possible reasons for the difference. I think the possibility of contamination cannot be ruled out until we look at the talc composition in these facilities over a number of years. The possibility that pockets of fibre contamination exist in these operations also cannot be excluded.

F. D. K. LIDDELL: Tables 3–5 present the prevalence of cough, of phlegm and of dyspnea by years worked and by cumulative exposure, but for all three States combined. On the other hand, Table 1 reveals important associations between age, duration of employment and dust concentration in the three States. To what extent are the 'negative' findings of Tables 3–5 a masking of positive associations, within at least one State, by the interactions shown in Table 1?

Dr DEMENT: All the regions analysed were looked at separately. Admittedly the numbers were small within each region, but the only really significant finding in each of the regions was the pleural thickening.

J. C. GILSON: I would like to make two comments. The first concerns the recording of pleural thickening. The classification does provide a means of measuring the extent of this as well as the width, and I think it is important to make use of this information in order to deal with the kind of question that Dr Newhouse has raised.

My second point relates to the respiratory questionnaire. This questionnaire, as many of you know, was originally started here in S Wales by my colleague Dr Fletcher and, of course, it was applied to coal miners. Now coal miners do, by virtue of their job, have to walk together often underground under very adverse conditions. Also, in this particular area, the coal mines are in relatively steep valleys so miners were constantly walking with their colleagues. I have always thought the questions were particularly applicable in these circumstances and that they might well be inapplicable where people were walking on the level. If we had originally had coal mines in Norfolk this particular questionnaire would never have been developed.

J. C. MCDONALD: In our studies of Quebec asbestos workers, we found a very much higher prevalence of pleural thickening in one region than in the other, even allowing for exposure and other factors. This suggested to us that there might be something other than the asbestos involved, but we found no evidence for this. The same went for calcification.