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ASBESTOS IN DRINKING WATER AND CANCER IN THE SAN FRANCISCO BAY AREA: 1969–1974 INCIDENCE*

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Abstract—The relationship between ingested asbestos (through drinking water) and cancer of various body sites was examined. This study was a follow-up to another article that investigated this relationship. Age-adjusted, sex and race specific 1969–1974 cancer incidence ratios for 410 census tract groupings ('super tracts') of the San Francisco–Oakland Standard Metropolitan Statistical Area were compared with measured chrysotile asbestos counts in drinking waters of super tracts. The earlier article analyzed cancer data for the 3 yr period, 1969–1971. The present study used that data and an added set of cancer cases for 1972–1974. The water supplies serving the area have varying contact with naturally occurring serpentine. The *t*-test for multiple regression coefficients and the *t*-test for correlation coefficients showed significant ($p < 0.01$) relationships between chrysotile asbestos content of super tract drinking water and white male digestive tract, esophageal, stomach and pancreatic cancers. For white females, significant ($p < 0.01$) relationships on these tests were found for esophageal, stomach, digestive related organs, and pancreatic cancers. These associations appeared to be independent of income, education, asbestos occupation, marital status and mobility.

INTRODUCTION

THIS STUDY was an extension of the investigation of the possible relationship between the presence of asbestos fibers in drinking water and the incidence of selected cancers in the population served by such water supplies. The original study used a 3 yr data set of cancer incidence (1969–1971) [1]. The present study combined this 3 yr data set with another 3 yr of cancer incidence (1972–1974). The 3 yr data base (1969–1971) included 25,256 cancer incidence cases while the 6 yr data base included 51,314 incidence cases. Reanalysis using this larger data set was imperative because of the suggestive findings for cancers of low incidence, such as pleura and peritoneum, in the 1969–1971 incidence study.

The occurrence of asbestos fibers in drinking water supplies became a subject of concern in 1973 when 1–74 million asbestos-like fibers per liter (f/l) were reported in the Duluth, Minnesota drinking water supply [2, 3]. The question of possible increased cancers in the general population resulting from long-term ingestion of asbestos fibers in drinking waters is of importance because of the well-documented relationships between occupational asbestos exposures and increased respiratory and digestive cancers in exposed workers [4, 5].

California has some of the richest deposits in the U.S. of the mineral serpentine, from which comes chrysotile asbestos. In fact, serpentine is the official state rock of California [6]. Several drinking water supplies in the San Francisco Bay Area come from aquifers

*This work was supported by U.S. Environmental Protection Agency Grant No. 804366. Abbreviations: f/l—fibers per liter; RCE—San Francisco Bay Area Resource for Cancer Epidemiology; SIR—Standard Incidence Ratio; SMSA—Standard Metropolitan Statistical Area; TNCS—Third National Cancer Survey.

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or are stored in reservoirs that are exposed to serpentine. The San Francisco–Oakland Standard Metropolitan Statistical Area (SMSA) was selected as the location for the study since there are several distinct water sources serving the SMSA, with differing amounts of asbestos in the drinking waters. The overall study design was that of a geographic correlation study. "Super tracts" (groupings of census tracts that yield geographical boundary parity between censuses, in this case 1970 and 1960), with differing chrysotile asbestos counts in drinking water, were compared for cancer incidence while controlling for potentially confounding factors. The San Francisco–Oakland SMSA contains five countries: Alameda, Contra Costa, Marin, San Francisco and San Mateo. The SMSA was divided into 722 census tracts for 1970, 410 super tracts with respect to 1970 and 1960 censuses, and had a 1970 population of slightly over 3 million.

MATERIALS AND METHODS

Asbestos analysis

A water sampling program was designed to determine the levels of chrysotile asbestos within the distribution systems. Analyses were made on raw and finished water at treatment plants and on samples taken from various sites within a given distribution system: the latter analyses were made in order to determine the continuity of values throughout the distribution area. Most of the samples were taken from household taps. Stored emergency waters, some dating back to 1908, were also analyzed. These samples yielded historical background data on the presence of asbestos in Bay Area water.

The present study used the 353 water samples collected in the original study along with an additional 19 samples. The assignment of asbestos values to the super tracts was made by calculating the arithmetic mean of finished and tap water samples from a given water distribution area and assigning that value to all super tracts in that service area. Where possible, each water district was subdivided by source, treatment process, and/or pressure zone. Concentrations of chrysotile asbestos were recorded in fibers per liter (f/l) and ranged from below detectable limit of the analysis (usually 10^6 f/l) to 3.6×10^7 f/l of finished drinking water. When the sample result was below detectable limit, the lowest detectable limit of the analysis was used as the sample count in calculating the mean. The analysis involved the filtration of each sample through a 0.45 μm pore size Millipore filter for examination and counting by transmission electron microscopy. The procedures and precision of the measurement techniques are described elsewhere [7].

To determine the variability of asbestos levels within a distribution system that would indicate the representativeness of a one-time sample in characterizing an area's asbestos fiber count, a census tract was selected for detailed random sampling. Ten blocks were randomly selected from within a San Francisco census tract and one address was randomly sampled on each block. Chrysotile fiber counts ranged from 1.3×10^7 to 5.8×10^7 f/l with a mean of 2.8×10^7 f/l and a standard deviation of 1.66×10^7 f/l. This was considered to be a small range in variability.

A second test of variability within a distribution system compared finished asbestos values from the treatment plant with tap water samples. Duplicate morning samples, taken during a high use period, were collected at a filter plant and were followed by ten samples throughout the plant's distribution system. Mean chrysotile counts were 4×10^5 f/l for the finished water samples and 3.5×10^5 f/l for the tap water samples. The standard deviation for the 10 tap water samples was 2.38×10^5 f/l. Two evening samples were also collected during a high use period. Asbestos counts in the evening samples were slightly lower than their morning counterparts. The variability in this case was also considered to be negligible.

Tumor incidence

The dependent variable for this study was the Standard Incidence Ratio (SIR), that is, the ratio of the observed to the expected number of cancer cases. In order to obtain the

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necessary SIR's. cancer incidence case data for 1969–1974 as well as population data from the 1960 and 1970 censuses were employed in an indirect age-adjustment procedure using standard rates. which in this case were calculated rates for the whole SMSA.

The cancer incidence case data for 1969–1974 were obtained from the San Francisco Bay Area Resource for Cancer Epidemiology (RCE) that is located in the State of California Department of Health Services. The data for 1969–1971 were collected as part of the Third National Cancer Survey (TNCS). The TNCS collected medical and other data on the incidence of all newly diagnosed malignancies during the 3 yr period. 1969–1971. for nine areas of the U.S. The areas included two entire states (Iowa and Colorado) and seven metropolitan areas including the San Francisco–Oakland SMSA. The design and operations of the TNCS are detailed in a 1975 TNCS Monograph [8].

Cutler *et al.* [9] in 1974 described the salient attributes of the data collected in the TNCS. The tumor site and type were coded according to the 1968 Manual of Tumor Nomenclature and Coding [10]. Over 90% of the cancers were microscopically confirmed [9]. A noteworthy feature of this survey was the classification by morphologic type of tumor (sometimes called histologic type). This classification defined over 200 pathologically different cell types of malignancy [9]. For each case. there were codes for age. sex. race. body site of the malignancy, histologic cell type. diagnosis date. hospital. method of diagnosis and census tract.

The cancer incidence case data for 1972–1974 were collected as part of the Cancer Incidence Survey conducted by the RCE [11]. This survey was designed to collect data comparable to that of the TNCS.

Basically. all major sites were analyzed except skin and bone. For purposes of analysis. some sites were combined into logical groupings. Examples of these combination categories include the digestive tract and the urinary system. In total. 35 individual sites and groupings were prepared for analysis. See Table 1 for a listing of these sites with both their RCE and Eighth Revision International Classification of Diseases codes [12].

A major difference between the earlier and present study was the use of extrapolated population figures in the calculation of incidence rates. In the 1969–1971 incidence study. population figures were taken directly from the 1970 census. As stated previously. the present study is based on the six year period. 1969–1974. The mid-point of this period is January 1. 1972. The 1960 and 1970 censuses of population were used to extrapolate population figures for January 1. 1972. The actual date of the 1970 census was April 1. 1970: thus. the extrapolation was over a 21 month interval and was calculated as follows:

$$P_{1/1/72} = (P_{1970} - P_{1960})\frac{21}{120} + P_{1970}.$$

where:

$P_{1/1/72}$ was the estimated population at January 1. 1972,
P_{1970} was the census population for 1970. and
P_{1960} was the census population for 1960.

The extrapolation was performed for each age. race and sex grouping to yield population figures used in the indirect age-adjustment procedure.

Census tracts in 1960 and 1970 were not in one-to-one correspondence. Census tract groupings (super tracts) were developed that had corresponding geographical boundaries between censuses. In many instances. there were one-to-one correspondences between 1960 and 1970 tracts. while certain other 1960 tracts were subdivided into as many as fifteen 1970 tracts. In the earlier study. there were 722 census tracts. The present study had 410 super tracts.

Age-adjustment was performed by the indirect method. The observed numbers of cases for a site were compiled for 5 yr age groups in each super tract for each race and sex group and the expected numbers of cases were calculated by applying the SMSA age. race. sex and site-specific rates as standard rates to the age. race and sex population distribution of each super tract. The race categories used were white. non-white and total population.

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TABLE 1. CANCER SITES ANALYZED IN ASBESTOS STUDY OF SAN FRANCISCO BAY AREA INCIDENCE, 1969–1974

Site No.	Name	RCE site No.*	ICD 8th rev. site Nos†
1	All sites	010–940	
2	All digestive	500–590	150–159
3	Digestive tract	500–549	150–154
4	Esophagus	500–509	150
5	Stomach	510–519	151
6	Small intestine	520–529	152
7	Colon	530–539	153
8	Rectum	540–549	154
9	Digestive related organs	550–589	155–158
10	Liver	550–551	155
11	Gall bladder	560–569	156
12	Pancreas	570–579	157
13	Retroperitoneum	580–589	158
14	Digestive organ NOS‡	590	159
15	All respiratory	619–639	161–163
16	Larynx	619	161
17	Trachea, bronchus, lung	620–621	162
18	Pleura	630	163.0
19	Mediastinum	631	163.1
20	Breast	700–709	174
21	Female reproductive	710–759	180–183
22	Cervix uteri	710	180
23	Corpus uteri	720	182.0
24	Ovary	750	183.0
25	Prostate	770	185
26	Urinary	800–810	188–189
27	Kidney	800–804	189
28	Bladder	810	188
29	Brain	930	191
30	Thyroid	940	193
31	Hodgkin's disease	010	201
32	Leukemia	040–049	204–208
33	Lung small cell carcinoma	621 RCE-hist 804	
34	Lung squamous	621 RCE-hist 807	
35	Lung adenocarcinoma NOS‡	621 RCE-hist 814	

*Manual of Tumor Nomenclature and Coding.
†Eighth Revision International Classification of Diseases, 1968.
‡Not otherwise specified.

Other variables

Other variables were organized by super tracts for inclusion in the analysis. These variables were picked because of their possible influence in confounding a relationship between asbestos levels in drinking water and cancer incidence.

Socioeconomic status is well known to be related to cancer rates. For instance, stomach and lung cancers are associated with low socioeconomic status and colon cancer is associated with high socioeconomic status. The 1970 census data on median family income and median school years completed for each super tract were used as indicators of socioeconomic status in the analysis. Similarly, marital status is well known to be related to disease rates in general. Married persons have lower disease rates than unmarried persons. To account for this disparity, an indicator of marital status for each super tract was formed by dividing the number of unmarried persons 14 yr old and over in 1970 by the super tract total population 14 yr old and over in 1970.

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TABLE 2. NUMBER OF SUPER TRACTS IN TRACT GROUPINGS BY CHRYSOTILE ASBESTOS FIBER COUNTS

	Chrysotile asbestos fibers liter				
	25,000–305,812	310,000–330,000	350,000–19,542,843	20,000,000–36,000,000	Total
Number of super tracts	92	110	107	101	410

A variable was prepared to estimate the numbers of workers in each super tract who were employed in industries that might have exposed workers to asbestos. For each super tract, the number of construction, electrical and textile workers in 1970 was divided by the total working population in 1970.

Data on residence stability and year moved into unit were also organized by super tract. They were both made into proportions to serve as indices of stability of the tract. It was hoped that this variable would account for population mobility in the analysis. The number of persons in each mover group was divided by the total super tract population for 1970.

RESULTS

Tract groupings by asbestos count

The first step in the analysis involved dividing the super tracts into groups according to their chrysotile asbestos count and then calculating the SIR for these groups. The object of this step was to determine if these observed to expected cancer ratios for each site showed a dose–response relationship with the assigned asbestos values. These groupings were made prior to the analysis and were based on emergent gaps in the distribution of fiber counts across super tracts. Since many tracts had common water systems and therefore had identical fiber counts, there emerged four groups each containing super tracts that were considered relatively homogeneous with respect to asbestos fiber counts. This division yielded approximately equal numbers of super tracts in each grouping. The fiber count boundaries were a compromise between having similar numbers of tracts in each grouping and having sufficient differences in the fiber counts between groups. Table 2 delineates the number of super tracts in each grouping by fiber counts.

The SIR's were tested for statistical significance using chi-square procedures as described by Fleiss [13]. The SMSA race and sex specific crude rate for each cancer site was multiplied by the corresponding observed to expected ratio for each of the tract groupings. This resulted in indirect age-adjusted rates. Total, slope and linearity chi-square tests were performed for each set of age-adjusted rates. The total chi-square equals the sum of the chi-square linearity and the chi-square slope. The total chi-square determines the statistical significance of the differences among the cancer rates. The slope chi-square determines the significance of increasing or decreasing cancer rates from low to high asbestos groupings. The linearity chi-square shows whether or not increasing or decreasing SIR's form a linear relationship.

The chi-square total had three degrees of freedom; the chi-square linearity had two degrees of freedom; and the chi-square slope had one degree of freedom.

Table 3 lists the sites with significant chi-square slope results ($p < 0.05$). It must be remembered that significant chi-square slope results can be obtained whether the gradient being tested is positive or negative with respect to asbestos. For instance, significant chi-square results were obtained for female reproductive cancer (site No. 21), but the SIR gradient in relation to asbestos was negative. The white and total populations had almost identical results due to the fact that the Bay Area population was

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TABLE 3. ONE-TAILED, CHI-SQUARE SIGNIFICANCE LEVELS FOR SLOPE BY SITE, SEX, AND ASBESTOS LEVEL, 1969–1974

Site No.	Name	White male	White female
1	All sites	<0.000001	
2	All digestive	<0.000001	<0.001
3	Digestive tract	<0.00001	<0.001
4	Esophagus	<0.05	<0.001
5	Stomach	<0.001	
6	Small intesine		
7	Colon	<0.05	<0.05
8	Rectum		
9	Digestive related organs	<0.05	
10	Liver		
11	Gall bladder		
12	Pancreas		
13	Retroperitoneum		<0.05
14	Digestive organ NOS†		
15	All respiratory	<0.01	
16	Larynx		
17	Trachea, bronchus, lung	<0.01	
18	Pleura		
19	Mediastinum		
20	Breast		
21	Female reproductive		<0.000001*
22	Cervix uteri		
23	Corpus uteri		<0.000001*
24	Ovary		
25	Prostate		
26	Urinary		
27	Kidney		
28	Bladder		
29	Brain		
30	Thyroid		
31	Hodgkin's disease		
32	Leukemia		
33	Lung small cell carcinoma		
34	Lung squamous		
35	Lung adenocarcinoma NOS*		

*Slope is negative.
†Not otherwise specified.

predominantly white. Therefore, the data for only the white population were included in the results.

Table 3 shows that site Nos 1, 2, and 3 (all sites, all digestive and digestive tract) are highly significant ($p < 0.00001$) for white males, whereas site Nos 21 and 23 (female reproductive and corpus uteri) are highly significant ($p < 0.00001$) for white females. Note that these results for males are positive gradients (low cancer rates associated with low asbestos levels and high cancer rates associated with high asbestos levels) while those for females are negative gradients (low cancer rates associated with high asbestos levels and high cancer rates associated with low asbestos levels). There were significant ($p < 0.05$) positive gradients for both sexes on site Nos 2, 3, 4 and 7 (all digestive, digestive tract, esophagus and colon).

Effect of socioeconomic status

The effect of socioeconomic status was separated from that of asbestos by cross-classifying the super tracts into groups using these two variables. Thus, using three

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asbestos categories and three socioeconomic status indicator levels, the tracts were divided into nine groups. The SIR's were then calculated for each of the nine groups of tracts for each site and sex. This was done using the two indicators of socioeconomic status, median school years completed and median family income. In this case, three levels of asbestos fiber counts were used instead of the four that were used in the above analysis because the stratification of the previous four asbestos fiber count groupings by socioeconomic status yielded a cross-classification with an unequal distribution of super tracts. The cross-classification based on three levels of asbestos and three levels of socioeconomic status had nearly equal numbers of tracts across the nine groupings. The asbestos levels and socioeconomic levels were chosen prior to the analysis to provide meaningful categories which contained nearly equal numbers of tracts.

Tables 4 and 5 display the results of this cross-classification procedure for the body sites that showed significant ($p < 0.01$) chi-square slope results with positive gradients in Table 3. These results show that the apparent effect of asbestos exposure on the cancer rates in the previous section is maintained here irrespective of the effect of the socioeconomic status indicators. For example, for white male lung cancer (site No. 17), there appears to be a strong negative effect of socioeconomic status which is well known in the literature. Low income and education groups show more lung cancer than high income and education groups. However, in each individual socioeconomic indicator category there appears to be higher cancer rates for higher asbestos levels. Other well known socioeconomic gradients that were substantiated in these results were negative gradients for site Nos 5 and 22 (stomach and cervix uteri) and a positive gradient for site No 20 (breast in females). It appears that the relationship of asbestos to cancer is consistently observed at each level of socioeconomic status.

Multiple regression and correlation coefficients

Multiple regression analysis procedures were used to examine the relationship between census tract asbestos fiber values and cancer incidence while taking into account other variables. A log-linear model was used since the theoretical construction of the probability of developing cancer by a certain time yields a function of the log form. The dependent variable was the super tract, sex and site specific SIR. The independent variables were median family income, median school years completed, marital status, asbestos industry workers and super tract asbestos value. The log-linear multiple regressions were performed using the Statistical Package for the Social Sciences [14] packaged computer program. The regressions were computed for white males and females. Table 6 lists the body sites with significant, positive asbestos regression coefficients.

The site numbers that exhibited agreement between the sexes were Nos 1, 2, 4, 9 and 12 (all sites, all digestive, esophagus, digestive related organs and pancreas) at the $p < 0.05$ level of significance. The most highly significant ($p < 0.001$) results for males were site Nos 2, 9 and 12 (all digestive, digestive related organs and pancreas) and for females were site Nos 15 and 17 (all respiratory and trachea, bronchus lung).

The R squared value, the square of the multiple correlation coefficient, was low for these regression equations. It was always less than 0.172 and usually between 0.02 and 0.05. This means that only a small proportion of the total variation in cancer incidence was explained by the variables in the model. Because of the low multiple R, the regression data must be viewed with caution. Also, because as many as 210 regression equations were computed, the overall Type I error of the study cannot be considered to be the usual 0.05 or 0.01 unless individual p-values are considered significant only if they are considerably smaller than 0.05 or 0.01. However, the consistency of the relationship for certain sites across procedures reduces the concern for this issue.

Table 7 shows the product-moment correlation coefficients between asbestos values and cancer rates by site and sex for the white population. The t-statistic for testing the null hypothesis that the sample correlations were drawn from a population with zero correlation was computed in each case. Significant coefficients are noted for sites with p-values < 0.05. The results for correlation coefficients closely corresponded to those for

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TABLE 4. OBSERVED EXPECTED RATIOS FOR TRACTS GROUPED FOR ASBESTOS BY EDUCATION FOR CHI-SQUARE SLOPE SIGNIFICANT ($p < 0.01$) SITES. SAN FRANCISCO BAY AREA. INCIDENCE. 1969–1974

Tract distribution		Chrysotile fibers liter			
		25,000–310,000	319,348–3,700,000	4,600,000–36,000,000	
		Low	Med	High	Total tracts
Median school years completed	5.2–12.2 (low)	55	45	44	144
	12.3–12.6 (med)	36	50	45	131
	12.7–17.0 (high)	57	27	51	135
	Total tracts:	148	122	140	410

Site No.	Name		Asbestos Low	Med	High
White males					
1	All sites				
	Education	low	1.042	0.985	1.073
		med	0.959	0.974	1.127
		high	0.926	0.967	0.963
2	All digestive				
	Education	low	1.001	0.931	1.149
		med	0.953	0.986	1.175
		high	0.863	0.931	1.007
3	Digestive tract				
	Education	low	0.973	0.947	1.139
		med	0.958	0.981	1.175
		high	0.875	0.923	1.011
5	Stomach				
	Education	low	1.032	1.283	1.371
		med	0.960	0.868	1.303
		high	0.685	0.885	0.903
15	All respiratory				
	Education	low	1.230	1.206	1.109
		med	0.967	0.984	1.627
		high	0.784	0.913	0.882
17	Trachea, bronchus, lung				
	Education	low	1.232	1.209	1.107
		med	0.968	0.987	1.155
		high	0.784	0.907	0.891
White females					
2	All digestive				
	Education	low	1.024	0.941	1.071
		med	0.927	0.974	1.123
		high	0.878	1.000	1.019
3	Digestive tract				
	Education	low	1.027	0.961	1.025
		med	0.934	0.967	1.162
		high	0.868	0.985	1.024
4	Esophagus				
	Education	low	1.010	1.029	1.42
		med	0.543	0.872	1.476
		high	0.683	1.177	0.892

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TABLE 3. OBSERVED EXPECTED RATIOS FOR TRACTS GROUPED FOR ASBESTOS BY INCOME FOR CHI-SQUARE SLOPE SIGNIFICANT ($p < 0.01$) SITES, SAN FRANCISCO BAY AREA, INCIDENCE, 1969–1974

Tract distribution		Chrysotile fibers liter			
		25,000–310,000	319,348–3,700,000	4,600,000–36,000,000	
		Low	Med	High	Total tracts
Median family income	$0–10,304 (low)	63	36	56	148
	$10,316–12,799 (med)	39	53	51	122
	$12,813–34,530 (high)	46	33	33	140
	Total tracts:	148	122	140	410

Site No.	Name		Asbestos Low	Med	High
White males					
1	All sites				
		low	1.009	0.955	1.120
	Income	med	0.973	0.973	1.063
		high	0.924	0.982	0.964
2	All digestive				
		low	0.991	0.946	1.183
	Income	med	0.925	0.951	1.120
		high	0.886	0.958	1.003
3	Digestive tract				
		low	1.003	0.941	1.168
	Income	med	0.905	0.948	1.114
		high	0.876	0.959	1.022
5	Stomach				
		low	1.057	1.266	1.416
	Income	med	0.826	0.850	1.215
		high	0.699	0.971	0.858
15	All respiratory				
		low	1.128	1.182	1.217
	Income	med	1.005	1.001	1.075
		high	0.758	0.947	0.833
17	Trachea, bronchus, lung				
	Income	low	1.121	1.185	1.206
		med	1.010	1.002	1.081
		high	0.761	0.945	0.837
White females					
2	All digestive				
		low	0.939	0.904	1.094
	Income	med	0.934	0.970	1.096
		high	0.905	1.013	1.006
3	Digestive tract				
		low	0.946	0.925	1.073
	Income	med	0.914	0.959	1.123
		high	0.913	1.006	1.008
4	Esophagus				
		low	0.867	0.880	2.003
	Income	med	0.800	0.956	1.079
		high	0.529	1.144	0.736

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TABLE 6. SITES WITH SIGNIFICANT ($p < 0.05$) POSITIVE ASBESTOS REGRESSION COEFFICIENTS. SAN FRANCISCO BAY AREA, INCIDENCE, 1969–1974

Site No.	Name	p-value	R squared
White male			
1	All sites	0.05	0.062
2	All digestive	<0.001	0.039
3	Digestive tract	0.002	0.028
4	Esophagus	0.003	0.028
5	Stomach	0.002	0.038
7	Colon	0.011	0.114
9	Digestive related organs	<0.001	0.038
12	Pancreas	<0.001	0.058
25	Prostate	0.025	0.057
33	Lung small cell carcinoma	0.043	0.022
White female			
1	All sites	0.048	0.043
2	All digestive	0.038	0.047
4	Esophagus	0.007	0.040
5	Stomach	0.001	0.052
9	Digestive related organs	0.004	0.055
12	Pancreas	0.001	0.075
13	Retroperitoneum	0.036	0.023
15	All respiratory	<0.001	0.110
17	Trachea, bronchus, lung	<0.001	0.110
18	Pleura	0.027	0.018
20	Breast	0.005	0.171

multiple regression coefficients. For males, all significant sites under regression were significant under correlation coefficient testing except for site No. 33 (lung small cell carcinoma). Three additional sites for males were found to be significant under correlation coefficient testing: site Nos 15, 17 and 19 (all respiratory, trachea, bronchus, lung and mediastinum). For females, all significant sites under multiple regression were significant under correlation coefficient testing except for site Nos 1, 15, 17 and 20 (all sites, all respiratory, trachea, bronchus, lung and breast). Three additional sites for females were found to be significant under correlation coefficient testing: site Nos 8, 11 and 23 (rectum, gall bladder and corpus uteri). The additional significant sites for males and females under correlation coefficient testing may not have been significant in the regression due to the removal of the effects of covariables.

Population mobility

It was necessary to consider population mobility in this study. The movement of the population into, out of, and within the Bay Area could conceivably bias the data resulting in spurious results or obscuring real differences in cancer incidence associated with exposure to asbestos in drinking water. Population mobility is always a factor in studies comparing different geographical areas, but it could be especially important in cancer studies due to the long latent period between the initial exposure and onset of the disease.

Super tracts that were considered unstable with respect to the residence stability variable were removed in order to compare the regression on all super tracts with a regression using only 'stable' super tracts. Those super tracts with less than 47% of the population 5 yr old and over living in the same house in 1970 as in 1965 were removed, leaving 307 (of the original 410) so called 'high stability' super tracts. If the results of the analysis using only the most stable super tracts remained similar to the analysis that used all of the super tracts, then this would in some sense remove residence instability, and indirectly, population mobility as a potentially confounding factor.

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TABLE 7. PRODUCT-MOMENT CORRELATION COEFFICIENTS OF CANCER RATES BY ASBESTOS VALUES BY SITE, SEX FOR WHITE POPULATIONS, SAN FRANCISCO BAY AREA, INCIDENCE, 1969–1974

Site No.	Name	White male		White Female	
		Correlation coefficient	p-value*	Correlation coefficient	p-value*
1	All sites	0.119	<0.01	0.015	
2	All digestive	0.111	<0.025	0.105	<0.05
3	Digestive tract	0.124	<0.01	0.050	
4	Esophagus	0.149	<0.005	0.188	<0.0005
5	Stomach	0.173	<0.0005	0.148	<0.005
6	Small intestine	0.004		−0.001	
7	Colon	0.086	<0.05	−0.005	
8	Rectum	0.043		0.090	<0.05
9	Digestive related organs	0.109	<0.05	0.132	<0.005
10	Liver	0.064		−0.003	
11	Gall bladder	0.038		0.091	<0.05
12	Pancreas	0.131	<0.005	0.154	<0.005
13	Retroperitoneum	0.002		0.124	<0.01
14	Digestive organ NOS†	0.015		−0.011	
15	All respiratory	0.112	<0.05	0.071	
16	Larynx	0.028		0.011	
17	Trachea, bronchus, lung	0.115	<0.025	0.065	
18	Pleura	−0.019		0.092	<0.05
19	Mediastinum	0.094	<0.05	0.025	
20	Breast	0.030		0.044	
21	Female reproductive	—		−0.059	
22	Cervix uteri	—		−0.036	
23	Corpus uteri	—		−0.098	<0.05
24	Ovary	—		0.028	
25	Prostate	0.098	<0.05	—	
26	Urinary	0.019		0.028	
27	Kidney	0.027		0.047	
28	Bladder	0.006		0.025	
29	Brain	−0.071		−0.037	
30	Thyroid	−0.043		0.046	
31	Hodgkin's disease	−0.032		0.003	
32	Leukemia	0.018		0.007	
33	Lung small cell carcinoma	0.056		−0.019	
34	Lung squamous	0.068		0.045	
35	Lung adenocarcinoma NOS†	−0.048		−0.010	

*p-value based on t-test for H: $\rho = 0$ $n = 410$ super tracts.
†Not otherwise specified.

Table 8 shows the results of this 'high stability' analysis for regression and correlation coefficient testing. There was close correspondence between the analysis on all of the super tracts and the analysis on the high stability super tracts. For males, there was overlap between analyses except for the inclusion of site Nos 1 and 33 (all sites and lung small cell CA) under regression analysis for all super tracts and the inclusion of site Nos 10, 26, and 28 (liver, urinary and bladder) under regression analysis for high stability super tracts. For males, under correlation coefficient testing, the same sites were significant under both analyses except for the inclusion of site Nos 15, 17 and 19 (all respiratory, trachea, bronchus, lung and mediastinum) under the analysis for all super tracts. For females, under regression analysis, site Nos 1, 2 and 20 (all sites, all digestive and breast) were found to be significant under the analysis on all super tracts, but not significant under the analysis on high stability super tracts; and site No. 8 (rectum) was found to be significant under the analysis on all super tracts. For females, under correlation coeffi-

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TABLE 8. HIGH STABILITY SUPER TRACTS: SITES WITH STATISTICALLY SIGNIFICANT ($p < 0.05$) ASBESTOS REGRESSION COEFFICIENTS AND CORRELATION COEFFICIENTS, SAN FRANCISCO BAY AREA, INCIDENCE, 1969–1974

White male				White female			
Site No.	Name	p-value*	R squared	Site No.	Name	p-value*	R squared
			Regression coefficients				
2	All digestive	<0.001	0.065	4	Esophagus	0.03	0.021
3	Digestive tract	<0.001	0.057	5	Stomach	0.005	0.060
4	Esophagus	0.004	0.039	8	Rectum	0.024	0.114
5	Stomach	0.001	0.072	9	Dig. rel. orgs	0.003	0.067
7	Colon	<0.001	0.172	12	Pancreas	<0.001	0.080
9	Dig. rel. orgs	0.001	0.041	13	Retroperitoneum	0.035	0.028
10	Liver	0.045	0.025	15	All respiratory	0.002	0.156
12	Pancreas	<0.001	0.058	17	Trach., bronchus	0.003	0.156
25	Prostate	0.004	0.142	18	Pleura	0.045	0.025
26	Urinary	0.017	0.133				
28	Bladder	0.022	0.125				
			Correlation coefficients				
1	All sites	<0.05		4	Esophagus	<0.025	
2	All digestive	<0.01		9	Dig. rel. orgs	<0.05	
3	Digestive tract	<0.005		12	Pancreas	<0.01	
4	Esophagus	<0.01		13	Retroperitoneum	<0.025	
5	Stomach	<0.005		21	Female repro.	<0.05†	
7	Colon	<0.05		22	Cervix uteri	<0.05†	
9	Dig. rel. orgs	<0.025					
12	Pancreas	<0.01					
25	Prostate	<0.05					

*p-value for correlation coefficients based on t-test for H: $\rho = 0$, $n = 307$ super tracts.
†Negative association.

cient testing, site Nos 2, 5, 8, 11, 18 and 23 (all digestive, stomach, rectum, gall bladder, pleura and corpus uteri) were found to be significant under the analysis on all super tracts, but not significant under the analysis on high stability super tracts; and site Nos 21 and 22 (female reproductive and cervix uteri) were found to be significant under the analysis on high stability super tracts but not significant under the analysis on all super tracts.

A summary of results across chi-square, regression and correlation testing showed that for white males and females site Nos 2 and 4 (all digestive and esophagus) were consistently, significantly, and positively related to asbestos. Also for males, site Nos 1, 3, 5, 7 and 9 (all sites, digestive tract, stomach, colon and digestive related organs) were consistently, significantly, and positively related to asbestos; as was site No. 13 (retroperitoneum) for females. These were the only sites that were found to be significant across all three tests. See Table 9 for these results.

DISCUSSION

The results of the analyses of the three and six year data certainly point to a statistical association between the incidence of certain cancers, particularly those of the digestive system and increasing amounts of asbestos in the domestic water supply of the San Francisco Bay Area. In order to further elucidate this observed relationship, more accurate information will be required to assess the effects of such activities as smoking, occupation and alcohol consumption upon the association of cancer with waterborne asbestos fibers. Such information can only be gained through a carefully designed case control study in which such activities can be effectively quantitated.

A characteristic of the study findings is the differential results by sex. The major differences by sex were positive relationships with chrysotile asbestos fiber counts in water for respiratory cancers in white males but not females, and negative relationships with chrysotile asbestos fiber counts in water for reproductive cancers in white females

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TABLE 9. SUMMARY OF STATISTICALLY SIGNIFICANT ($p < 0.05$) ASSOCIATIONS COMPARING ASBESTOS AND CANCER SITE, SAN FRANCISCO BAY AREA, INCIDENCE, 1969–1974

		p-value					
		White male statistical test*			White female statistical test*		
Site No.	Name	1	2	3	1	2	3
1	All sites	<0.01	<0.000001	0.05			0.048
2	All digestive	<0.025	<0.000001	<0.001	<0.05	<0.001	0.038
3	Digestive tract	<0.01	<0.00001	0.002		<0.001	
4	Esophagus	<0.005	<0.05	0.003	<0.0005	<0.001	0.007
5	Stomach	<0.0005	<0.001	0.002	<0.005		0.001
7	Colon	<0.05	<0.05	0.011		<0.05	
8	Rectum				<0.05		
9	Dig. rel. orgs	<0.05	<0.05	<0.001	<0.005		0.004
11	Gall bladder				<0.05		
12	Pancreas	<0.05		<0.001	<0.005		0.001
13	Retroperitoneum				<0.01	<0.05	0.036
15	All respiratory	<0.05	<0.01				<0.001
17	Trachea-lung	<0.025					<0.001
18	Pleura				<0.05		0.027
19	Mediastinum	<0.05					
20	Breast						0.005
21	Female repro.					<0.000001†	
23	Corpus uteri				<0.05†	<0.000001†	
25	Prostate	<0.05		0.025			
33	Lung small cell			0.043			

*Statistical test code: 1 = correlation coefficient, *t*-test for. 2 = chi-square slope. 3 = regression coefficient, *t*-test.
†Negative association.

but not males. The negative relationship for white female reproductive cancers is a bit troublesome, since this result is contrary to the hypothesis that asbestos in drinking water would be positively related to cancer. There is no obvious explanation for this result. As was suggested for the positive association between asbestos and digestive cancers, this negative association and the different results for males and females should be studied further to consider other factors.

One could speculate that a differential exposure to chrysotile asbestos by sex could possibly explain the different results for males and females. For instance, females could be more consistently exposed to asbestos fibers in drinking water at their place of residence perhaps because they are at home more than males. This study was based on place of residence and did not account for daily mobility factors, such as place of work. Another possible hypothesis would be based on differential susceptibility of the sexes to asbestos in water with respect to carcinogenesis. Thus, increased male but not female lung cancer, resulting from asbestos exposure via drinking water, would be a result of more male exposure to cigarettes and occupational carcinogens which might make males more susceptible than females to the carcinogenic potential of ingested asbestos fibers which migrate to the lungs via the blood or some other route.

Other organic and inorganic constituents of drinking water have been related to the occurrence of human cancer. For instance, chloroform has been associated with certain gastro-intestinal and urinary cancers in several studies [15], arsenic and skin cancer [16] and nitrates with stomach cancer [17]. There is no evidence of significant variation of these constituents between the different Bay Area drinking waters. In the future, it is hoped that further analyses of other water parameters such as pesticide content in Bay Area drinking waters would be conducted.

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A consequence of the results of this study is that it may be necessary to develop methods capable of removing asbestos fibers from public drinking water supplies with naturally occurring high asbestos fiber counts. 90% of amphibole asbestos fibers have been shown to be removed by ordinary rapid sand filtration [18]. There is evidence that the remaining 10% of the fibers may pass through the gastro-intestinal tract into the blood stream and could cause a health problem [19]. Currently, advanced treatment methods involving coagulation and mixed-media filtration which promise greater amphibole fiber removal efficiencies are being developed and tested [20, 21]. It is unknown at this time whether these techniques that were developed for removing amphibole asbestos fibers from drinking water will have similar removal efficiencies for chrysotile asbestos fibers.

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