Exposure to Biogenic Silica Fibers and Respiratory Health in Hawaii Sugarcane Workers

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We conducted a cross-sectional environmental and medical survey of 355 male sugarcane workers in Hawaii to determine whether exposure to biogenic silica fibers (BSF) affected their respiratory health. Exposures to BSF ranged from nondetectable to more than 0.700 BSF/mL and varied by job and department. Respiratory symptoms, chest radiograph findings, and pulmonary function were not associated with BSF exposures. Cigarette smoking was associated with respiratory symptoms and pulmonary obstruction. Fifteen workers had pleural thickening or pleural plaques and 3 of these workers were exposed to BSF for more than 10 years. BSF exposure does not appear to influence the respiratory health of sugarcane workers; however, further study is warranted.

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Sugarcane, like many plant species, has been shown to contain insoluble, amorphous (noncrystalline) opaline silica in fibrous form.[1] These biogenic silica fibers (BSF) are highly respirable, ranging in size from 0.25 to 2.0 μm in diameter and from 5 to 80 μm in length.[2] A report of a series of mesothelioma cases among sugarcane workers[3] living in an agricultural region of India, where there was no (reported) opportunity for asbestos exposure, led to speculation that exposure to BSF could cause mesothelioma.[4] An excess of mesothelioma among Swedish sugar refining workers[5,6] and an association between lung cancer and sugarcane farming in Louisiana[7] have also been reported. The occurrence of mesothelioma in Swedish sugar refinery workers has been attributed to asbestos exposure. Based on this information, we theorized that exposure to BSF might result in a complex of diseases similar to asbestos exposure (ie, mesothelioma, lung cancer, and pulmonary fibrosis).

In January 1988, the National Institute for Occupational Safety and Health received a request to evaluate sugarcane workers' health in relation to their exposures to the burning of sugarcane before harvesting. We conducted a feasibility study[2] in March 1988 and confirmed that harvesting workers were exposed to BSF. We also reviewed random medical records of active and retired sugarcane workers. We found that 98 of 170 sugarcane workers had a routine chest radiograph. The radiologists' interpretation of these chest radiographs were found in the medical record and 26 included descriptive terms that were compatible with, but not specific for, pneumoconiosis. We describe in this paper two of our research goals: to define exposures to BSF and asbestos throughout the Hawaii sugarcane industry and to determine whether these exposures affect the respiratory health of workers. The results of a case-control study to determine whether BSF exposure is related to the development of mesothelioma is described elsewhere.[8]

Materials and Methods

In August 1989, environmental sampling and medical examinations of selected workers were conducted at two Hawaii sugar plantations: one located on the island of Maui, and the second located on the island of Hawaii. These two plantations were selected because of their large work forces and proximity to local medical facilities.

Environmental Assessment

Personal breathing zone air samples for BSF and asbestos were collected by sampling workers engaged in representative jobs within all departments (planting, burning, harvesting, milling). Analytic methods included transmission electron microscopy for counting and sizing fibers, energy dispersive x-ray analysis for determining fiber type, and electron diffraction to determine crystallinity. Phase-contrast microscopy was not used to count fibers.

A BSF job-exposure matrix was developed and is described in detail elsewhere.[8] We placed each job into one of four BSF-exposure categories based on sampling results and our understanding of the sugarcane farming and milling process: (1) harvest rake operator; (2) all other field work; (3) truck driver, those involved in cleaning or unloading cane, and work in the bagasse or power houses; and (4) all other workers. Analysis of variance, with after tests to determine the difference between means, was used to test the difference between the group mean fiber concentrations.[9] We considered the time exposed to BSF as the duration of employment in any BSF-exposure category where the mean exposure was measured at greater than 0.050 fibers/mL. According to these criteria, harvest rake operator was the only job category considered exposed. We used the worker's detailed job history card to cumulate the number of days assigned as a harvest rake operator.

Assessment of asbestos exposure was based on our environmental sampling data and an industrial hygienist's opinion of jobs involving asbestos exposure. Each job was classified as probably or probably not exposed to asbestos.

Medical Evaluation

Male workers were selected on the basis of age, work status, job category, and total years employed. We included those workers (current and retired) with the longest duration of employment in harvesting jobs. One hundred workers with 9 or more years experience in harvesting related jobs were chosen from each plantation. Category matching[10] was used to select randomly an equal number of nonharvesting workers by plantation, age, and duration of employment strata. Workers who were not available or were not willing to participate were replaced by randomly selected workers with similar work histories to maintain sample size.

A questionnaire sought basic demographic information, work history, medical history, active medical problems, and current symptoms (especially respiratory complaints). The questionnaire incorporated pertinent parts of the American Thoracic Society questionnaire[11,12] and was self-administered in the presence of trained personnel, who reviewed it for accuracy after completion. Filipino translators assisted workers born in the Philippine Islands. Using self-reported symptoms and standardized definitions,[11] we determined the prevalence of chronic cough, chronic bronchitis, grades 1 and 2 shortness of breath, wheezing, and wheezing with shortness of breath.

Pulmonary function testing was performed using procedures that conformed to the American Thoracic Society's criteria for screening spirometry.[13,14] All participants who attempted spirometry were included in the analyses. A forced vital capacity (FVC) of less than 80% of predicted, with a forced expiratory volume in 1 second (FEV_1) to FVC ratio of 70% or more was considered a restrictive pattern. A FEV_1/FVC ratio less than 70% was considered an obstructive pattern. Predicted values for FEV_1 and FVC were calculated using the Knudson regression equations as described by Hankinson.[14] Predicted values were not adjusted for differences in race or ethnicity. Ethnicity was considered as a potential confounder in the analysis of the data. Chest roentgenograms were initially read by two B-readers trained in the use of the International Labor Organization's standardized interpretation and classification of radiographs for pneumoconiosis.[15] Two additional B-readers reviewed the films if the reports of the original readers were not in agreement. A case of possible interstitial fibrosis (parenchymal opacities with a score of 1/0 or greater) or pleural abnormalities (pleural thickening or pleural plaques) depended upon agreement between any two readers.

Pulmonary function and chest radiograph results were reported back to the individual participants and their physicians. We did not obtain results of follow-up medical examinations that may have been conducted by private physicians. We tested the associations between the health status measurements (respiratory symptoms, pulmonary function, and chest radiograph results) and age, race, smoking, employment status, and years of employment in BSF-exposed or probable asbestos-exposed jobs. Analyses of categorical data used χ^2 tests. Tests for the difference between means involved Student's t test and analysis of variance.

Results

Environmental Assessment

A total of 147 personal breathing zone samples were submitted for analysis. BSF concentrations ranged from nondetectable to 0.712 BSF/mL. BSF averaged 17.7 μm in length (median = 12.2 μm; range, 1.5 to 83.5 μm) and 1.2 μm in diameter (median = 1.0 μm; range, 0.15 to 10.5 μm). Eighty-four percent of the fibers were greater than 2 μm in length and between 0.15 and 2 μm in diameter.

Summary statistics of BSF concentrations by departments, activity, and plantation are presented in Table 1. We found a qualitative difference in exposure to BSF concentrations between each of the four exposure categories (F_{3df} = 34.0, $P < .001$; after tests indicated that each mean differed from each other mean). The harvest rake operator category was the only category with a mean BSF concentration that exceeded 0.050 BSF/mL (35 samples, mean = 0.089 BSF/mL). BSF exposures for all other workers were substantially lower (all other field workers, 57 samples, mean = .016 BSF/mL; truck drivers, cleaning and unloading cane, bagasse and power house workers, 38 samples, mean = .003; all other workers combined, 17 samples, mean < .001 BSF/mL).

Ten samples had asbestos fibers and the asbestos fiber concentrations ranged from .001 to .774 fibers/mL. As expected, most asbestos-exposed workers were machinists or mechanics. Two workers operating planting machinery (one from each plantation) had low airborne concentrations (.017 and .018 fibers/mL) of asbestos. A bagasse tractor driver had a single asbestos airborne concentration of 0.774 fibers/mL. The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL)[16] is 0.200 fibers/mL when phase-contrast microscopy is used to count fibers. Two additional samples on this same worker, taken sequentially on the same day, found no detectable asbestos fibers and no source could be identified.

Medical Evaluation

A total of 486 workers were selected for the study and 355 participated in at least some part. The study group included 213 (61%) current and 130 (37%) retired workers, as well as 12 (2%) workers on disability leave or with an unknown work status (Table 2). The average participant was 54 years old, began working in the sugarcane industry at 22 years of age, had worked in the industry for 30 years, and had completed 9 years of education. Filipinos represented the largest ethnic group (42%), followed by Japanese (23%), whites (18%), and Pacific Islanders (16%). Workers from the Hawaii plantation were more likely than workers from Maui to be current workers (rate ratio [RR] = 1.5; 95% Confidence Interval [CI] = 1.3 to 1.8) or Pacific Islanders (RR = 2.8; 95% CI = 1.6 to 4.9).

The prevalence of respiratory symptoms and their associations with cigarette smoking status, years worked in BSF-exposed jobs, and in potentially asbestos-exposed jobs are given in Table 3. Shortness of breath was the most common symptom (24% of all workers had grade 1 or higher), followed by wheezing (7%) and chronic cough (5%). As expected, respiratory symptoms were associated with cigarette smoking. Respiratory symptoms were not associated with years in BSF-exposed or asbestos-exposed jobs.

Three hundred and fifty-three workers attempted pulmonary function testing; the spirometry curves of 25 did not meet American Thoracic Society reproducibility criteria. Sixty-six workers had an obstructive pattern and 18 workers had a restrictive pattern (Table 3). As expected, obstruction was associated with cigarette smoking. Workers with an obstructive pattern averaged a 31.6 pack-year history compared with an 18.4 pack-year

TABLE 1

Biogenic Silica Fiber Exposures per Cubic Centimeter of Air Breathed for Hawaii Sugarcane Workers by Job Category and Plantation

	Maui Plantation					Hawaii Plantation				
	N*	Detect†	Mean	SD‡	Median	N	Detect	Mean	SD	Median
Planting										
Machinery	17	14	.016	.015	.011	14	11	.029	.099	.003
Field Work	9	6	.060	.006	.004	0				
Other	2	2	.018	.022	.018	3	2	.002	.003	.002
Harvesting										
Rake Op.	22	22	.045	.099	.011	13	12	.164	.210	.098
Others	6	6	.016	.019	.007	6	5	.007	.009	.004
Drivers	5	1	.001	.001	0	3	2	.006	.008	.002
Mill operations										
Unloading	8	8	.004	.005	.002	5	3	.002	.002	.002
Power house	7	2	.004	.007	0	10	4	.001	.002	0
Others	12	1	<.000	<.000	0	5	0	0	0	0
Total	88	62	.017	.052	.003	59	39	.045	.125	.002

* N, the number of personal breathing zone samples analyzed.
† Detected, the number of samples with detectable numbers of fibers.
‡ SD, standard deviation of the mean.

TABLE 2
Work Status and Demographic Characteristics of Hawaii Sugarcane Workers by Plantation and Having Worked in Harvesting-Related Jobs

	Maui Plantation				Hawaii Plantation			
	Harvesting		Non-harvesting		Harvesting		Non-harvesting	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Years of age, education, and duration of employment								
Age	56.7	13.2	55.9	13.3	51.9	11.4	53.4	9.3
Education	9.2	3.6	9.4	4.5	9.9	3.4	11.2	3.0
Employment	31.9	12.6	30.4	12.7	29.3	11.4	28.3	11.0
	N	%	N	%	N	%	N	%
Work status and ethnicity								
Work status								
Current	49	48	37	48	82	73	41	75
Retired	50	49	39	51	28	25	12	22
Other	3	3	1	1	2	2	2	4
Ethnicity								
Filipino	46	45	37	48	42	38	18	33
White	24	23	14	18	21	19	4	7
Japanese	21	21	21	27	18	16	22	40
Pacific Islander	11	11	4	5	29	26	10	18
Other	0	0	1	1	2	2	1	2
Total	102	100	77	100	112	100	55	100

history for workers without obstruction (Student's t test 3.8, $P < .01$). Neither an obstructive pattern nor a restrictive pattern was associated with duration of employment in BSF exposure or asbestos exposure, or with ethnic background.

A decrease in the FEV_1/FVC ratio was associated with pack-years of smoking and BSF exposure (Table 4). Workers in BSF-exposed jobs for fewer than 10 years had a better mean FEV_1/FVC ratio than unexposed workers and no dose-response relationship appears to exist. Adjustments for duration of employment, ethnicity, and asbestos exposure did not alter these associations. Adjustments for age did not alter the association between smoking and FEV_1/FVC ratio ($F = 6.91$, $P < .01$), but did alter the association between BSF exposure and FEV_1/FVC ratio ($F = 1.77$, $P < .17$). Pack-years of smoking and BSF exposure were not correlated with each other.

The percent of predicted FVC was not statistically associated with smoking, BSF exposure, or asbestos exposure (Table 4). We did note a trend in decreasing FVC with increasing BSF exposure and surprisingly, the workers with the longest employment in asbestos exposed jobs had the greatest mean percent predicted FVC. Neither relationship was statistically significant and both were probably the result of chance.

A total of 344 workers had chest radiographs. Seventy-one percent of the films were scored the highest quality rating, 23% were scored the second highest rating in quality, and 6% were considered of poor but readable quality. Two films were unreadable.

Two workers had bilateral, irregularly shaped opacities, 1.5 to 3.0 mm in diameter, throughout all lung fields consistent with pneumoconiosis. Neither had worked in a heavily BSF-exposed job.

Twelve workers had circumscribed pleural plaques (11 bilateral and 1 unilateral) and 3 had bilateral diffuse pleural thickening. The prevalence of pleural thickening or plaques was slightly greater for exsmokers and workers employed for more than 10 years in either BSF- or asbestos-exposed jobs. These observations were based on very few persons, and the increased prevalence was modest (Table 3). Workers with pleural thickening or plaques were slightly older than those without this condition (63 years vs 54 years; Students' t test, 3.7; $P < .01$). The presence of pleural plaques was associated with a decrease in the mean percent predicted FEV_1 (81.0% ± 29.7% compared with 101.9% ± 19.6%; Students' t test, −3.8; $P < .01$), and a decrease in the mean percent predicted FVC (92.6% ± 28.9% compared with 109.1% ± 17.1%; Students' t test, −3.4; $P < .01$).

Discussion

We confirmed that Hawaii sugarcane workers are exposed to BSF fibers, primarily during harvesting. More than 80% of the fibers we measured had physical dimensions that are thought to pose the greatest risk of asbestosis and lung cancer.[17] Even so, our results did not indicate any relationship between BSF fiber exposure and fibrotic lung disease. We did not evaluate the association between lung cancer and BSF exposure.

In general, the study participants appear to have been in good health. After adjusting for differences in smoking status, the prevalences of chronic cough, shortness of breath, and wheezing in this work force were lower than that in a study of blue collar workers not exposed to fibrogenic dusts.[18] We identified only 2 workers with signs of interstitial fibrosis and this is less than the 0.9% prevalence found in a study of 1422 nonexposed blue collar workers.[19] At the same time, we identified 17 workers with pleural thickening or pleural plaques, signs that have been associated with exposure to asbestos. Among workers with pleural thickening or pleural plaques, 5 reported respiratory symptoms and 8 had abnormal spirometry results. Eleven had a history of cigarette smoking, 2 reported occupational asbestos exposures outside of the sugarcane industry, 3 held BSF-exposed jobs for 10 or more years, and 5 worked in sugarcane industry jobs for 10 or more years that had potential for asbestos

TABLE 3
Prevalence of Respiratory Symptoms and Conditions in 340 Hawaii Sugarcane Workers by Exposure to Biogenic Silica Fibers (BSF), Exposure to Asbestos, and Smoking Status, 1989

	BSF Exposure: Years in Heavily Exposed Jobs		Asbestos Exposure: Work in Exposed Jobs		Smoking Status	
	1–9 y (N = 59)	10+ y (N = 37)	1–9 y (N = 34)	10+ y (N = 55)	Current (N = 106)	Exsmokers (N = 128)
Chronic cough (N = 16)	2	1	1	3	9	6
RR	0.6	0.5	0.6	1.1	8.8	4.9
95% CI	0.2, 2.7	0.1, 3.6	0.1, 4.6	0.4, 3.9	1.1, 68.5	0.6, 39.9
Shortness of breath, grade 1 (N = 83)	14	10	8	14	34	28
RR	1.0	1.1	1.0	1.0	1.6	1.1
95% CI	0.6, 1.7	0.6, 1.7	0.5, 1.8	0.6, 1.7	1.0, 2.6	0.6, 1.8
Shortness of breath, grade 2 (N = 31)	7	3	1	8	13	14
RR	1.4	0.9	0.3	1.6	3.2	2.8
95% CI	0.6, 3.2	0.3, 2.8	0.0, 2.4	0.8, 3.5	1.1, 9.5	1.0, 8.4
Wheeze (N = 23)	3	2	1	2	7	12
RR	0.7	0.7	0.4	0.4	1.7	2.4
95% CI	0.2, 2.3	0.2, 2.9	0.0, 2.6	0.1, 1.9	0.5, 5.7	0.8, 7.3
Restriction (N = 16)	5	1	4	2	9	4
RR	2.0	0.6	2.9	0.9	3.0	1.1
95% CI	0.7, 5.8	0.1, 5.0	1.0, 8.9	0.2, 4.1	0.8, 10.7	0.2, 4.8
Obstruction (N = 65)	9	10	3	12	25	26
RR	0.8	1.4	0.4	1.1	1.8	1.5
95% CI	0.4, 1.6	0.8, 2.5	0.2, 1.4	0.6, 1.9	1.0, 3.2	0.8, 2.7
Pleural plaques (N = 15)	0	3	0	5	2	9
RR	0.0	1.6	0.0	2.2	0.5	1.8
95% CI	–	0.5, 5.6	–	0.8, 6.2	0.1, 2.8	0.6, 5.8

The relative rates (RR) compare the years of work in exposed jobs (BSF and asbestos) to persons never working in exposed jobs and current and exsmokers with never smokers. Chronic bronchitis (N = 7), wheezing with shortness of breath (N = 11), and interstitial fibrosis (N = 2) are not included. The number of workers with complete job histories and readable chest radiographs was 331.

TABLE 4
Percent of Predicted Forced Vital Capacity (FVC %) and Forced Expiratory Volume in 1 s to FVC Ratio (FEV_1/FVC) by Exposure to Biogenic Silica Fibers (BSF), Asbestos, and Pack-Years of Cigarettes Smoked

	FVC %			FEV_1/FVC		
	Mean	SD	*P**	Mean	SD	*P**
BSF-exposed jobs						
0 y (N = 243)	109.2	18.1		75.4	8.4	
1–9 y (N = 59)	105.8	16.9		77.3†	8.3	
10+ y (N = 37)	103.3	17.5	.10	72.4†	13.0	.04
Asbestos-exposed jobs						
0 y (N = 250)	107.4	17.8		75.5	9.2	
1–9 y (N = 34)	105.3	18.5		77.8	6.2	
10+ y (N = 53)	112.5	17.7	.11	73.4	9.6	.08
Pack-years smoked						
0 (N = 109)	108.7	16.2		77.2	7.7	
1–15.2 y (N = 60)	110.8	17.1		77.4	9.4	
15.3–30.9 y (N = 84)	108.5	18.2		76.5	8.2	
>30.9 y (N = 83)	104.7	20.5	.22	70.9†	10.1	<.01

* *P* values calculated from *F* score based on 1-way analysis of variance.
† Means that differ statistically from each other.

exposure. We cannot attribute the presence of pleural abnormalities in this work force to any single factor.

There were several limitations to this study. Our assumptions about BSF and asbestos exposures may have resulted in some misclassification. We collected environmental samples during a 2-week period that may not have been representative of exposures during different seasons, weather conditions, or on different plantations. Harvesting methods have remained essentially unchanged in Hawaii for the past 40 years and it is unlikely that BSF exposures to workers have changed over time. However, the increased awareness of asbestos as a health hazard and active asbestos abatement in the Hawaii sugarcane mills probably has led to a decrease in asbestos exposures over time. Classification of asbestos exposure relied on a review of job titles and an industrial hygiene walk-through survey. A second limitation was the cross-sectional study design that prevented us from examining the risk of illness over time. In addition, we could not study workers who may have left employment before retirement or workers who had died, and this may have created a selection bias. Participation varied by job status and by type of work and this may have resulted in a slight bias in the study results. Finally, BSF concentrations may have been too low to have caused illness in this population.

The study had various strengths. Exposures to BSF were well documented. We used detailed job history records to identify all sugarcane jobs worked over the past 40 years. We included workers with the greatest potential for exposure who had worked in the industry for the longest period of time. A comparison group of other long-term workers allowed us to control for time-related factors such as age, duration of employment, and ethnicity. We presented an analysis where only the most heavily BSF-exposed jobs were considered as exposed. We have also analyzed these data by considering BSF exposures in all four BSF exposure categories. BSF/years was calculated by weighting each BSF exposure category by its mean BSF concentration, multiplying this weight by the duration of employment in each category, and summing across all four categories. Our results did not differ when we analyzed the data using this cumulative measurement of BSF exposure.

In summary, we noted that a slight decrease in the FEV_1/FVC ratio was associated with exposure to BSF for more than 10 years duration. This may be due to BSF exposure, to other factors related to harvesting burned sugarcane, or to chance. We also noted that several workers had pleural abnormalities, that these were associated with decreased pulmonary function, and that 3 workers with pleural abnormalities had worked in heavily exposed jobs for 10 or more years. However, most respiratory symptoms and conditions did not appear to be associated with BSF exposure. The finding of a moderate association between this exposure and a decreased FEV_1/FVC ratio and pleural plaques indicates that further study is warranted.

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Erratum

In the article "Multiple Chemical Sensitivity: A Clinical Perspective" in the July 1994 issue, there is a mistake in the references. In reference 40, pp 729–730, the quoted year of publication is 1987. The actual year of publication is 1991. The remainder of the citation is correct.