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Descriptive analysis of the respiratory health status of persons exposed to Libby amphibole asbestos

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ABSTRACT

Objective: Describe respiratory health and quality of life in persons exposed to Libby amphibole asbestos (LAA) contaminated vermiculite.

Design: Cross-sectional descriptive.

Setting: Asbestos-related disease clinic in Libby, Montana USA.

Participants: 329 individuals exposed to LAA; mostly men, married, between 50 and 69 years; two-thirds lived in the surrounding county; one-third lived elsewhere in the state and USA.

Primary outcome measures: Chest radiograph (CXR), pulmonary function data and the St George Respiratory Questionnaire (SGRQ).

Results: Exposure categories included vermiculite workers=7.6%; family/household contact of vermiculite worker=32%; and environmental exposure only=60%. Of the participants, 55% had only pleural abnormalities; 5.4% had only interstitial abnormalities; nearly 21% had both abnormalities and 18% had no lung abnormality on chest x-ray. Mean forced vital capacity (FVC) 95.3% (SD=18.7); forced expiratory volume (FEV_1) mean 87% (SD=20.2); ratio of $FEV1_1$/FVC 95.5% (SD=12.0); and diffusing capacity (DLCO) of 83% (SD=21.7) of the percent predicted. The mean total SGRQ (38.5; SD=22.1) indicated a lower quality of life than healthy persons and persons with other chronic conditions. SGRQ subscale means were Symptoms 52.1 (SD=24.9), activity 49.4 (SD=26.9) and impacts 27.5 (SD=21.9). Participants with normal CXR differed significantly from those with both interstitial and pleural abnormalities on total, activity and impacts scores. For activity alone, subjects with normal CXR differed significantly from those with pleural disease; no differences were found for those with interstitial disease. Significant findings were found for smoking history across all pulmonary measures, and for exposure status, radiographic findings, age and gender for select pulmonary parameters. Subjects with any smoking history had significantly worse average total and subscale scores on the SGRQ.

Conclusions: Of 329 persons exposed to LAA, the majority (182) had pleural abnormalities identified on CXR. SGRQ scores for persons with abnormalities (pleural, interstitial or both) (269) differed significantly from those with a normal CXR.

ARTICLE SUMMARY

Article focus

- Overall health and respiratory quality of life in persons exposed to Libby amphibole asbestos (LAA) using clinical data and the St George Respiratory Questionnaire (SGRQ).

Key messages

- In 329 participants where 60% had only environmental exposure to LAA, 55% had pleural abnormalities alone, 5.4% had only interstitial abnormalities 18% had no abnormalities noted on chest x-ray, and overall quality of life was poorer than in healthy persons and persons with chronic obstructive pulmonary disease.
- For participants with evidence of both interstitial and pleural abnormalities, FVC, FEV_1 and DL_{CO}, differed significantly from those participants with normal chest radiograph (CXR) diagnostics.
- Poorer SGRQ scores and findings of pleural and interstitial abnormalities and diminished pulmonary function in persons with low lifetime cumulative amphibole asbestos exposure is important given the widespread distribution and use of LAA-contaminated material in private and commercial applications.

Strengths and limitations of this study

- Only study to describe the health status and respiratory quality of life in persons exposed to LAA.
- Only study to use the SGRQ with persons exposed to LAA.
- Cross-sectional design.
- Real-time quality-of-life data and the most recent pulmonary data.
- Significant lack of sensitivity of standard CXR in the detection and characterisation of significant asbestos-related pleural and parenchymal fibrosis.
- Participants were at varying stages of health and illness and given that ARD is a progressive disease that evolves over 10-plus years, the results of the study provide a snapshot in time of the pulmonary and quality-of-life status of participants.

INTRODUCTION

Asbestosis is one of several chronic illnesses commonly linked to exposure to microscopic asbestos fibres. Pleural fibrosis, lung cancer, mesothelioma, a rare cancer of the chest lining and other cancers are also caused by exposure to asbestos.[1] The physical properties of asbestos are instrumental in causing asbestos-related diseases (ARDs). Amphibole fibres are characteristically straight, rigid and needle-like. These fine (<5 µm in diameter), straight and short fibres (5–20 µm long) are less likely to be cleared from the airways than are thick, longer fibres and can cause intense inflammation and fibrotic changes in the lung interstitium.[2] Once exposed, it can take 10 or more years before respiratory compromise is noted.[3 4] The pleura are particularly sensitive to the effects of the fibres, causing pleural plaques to develop after low, intermittent exposure. Pleural effusions are often the earliest manifestation of ARD.[5] Shortness of breath (dyspnoea) often accompanied by rales (crackles) or cough is common.[6 7] Deficits occur in pulmonary function variables such as forced expiratory volume in 1 s (FEV_1), forced vital capacity (FVC), total lung capacity (TLC) and diffusing capacity (DLCO).[8–12]

National mortality surveillance of occupation-related respiratory diseases designated asbestosis as the leading pneumoconiosis recorded on death certificates from 1982 to 2000.[13] While death rates decreased for other previously dominant occupational lung diseases, American deaths attributed to asbestosis steadily increased from 77 deaths in 1968 to 1493 in 2000.[14] Deaths due to asbestosis continued to rise in older individuals aged 75–84 years until 2005 and then levelled off while deaths in younger individuals aged 45–74 years peaked earlier,[15] a trend consistent with a legacy of past exposures and a downward trend in asbestos usage.

A significant source of exposure to amphibole asbestos in the USA came from contaminated vermiculite ore mined and processed in rural Libby, Montana from the early 1920s until 1990 when the mine closed. The raw ore, which is estimated to have contained as much as 26% amphibole asbestos[16] was distributed to over 250 regional processing plants then shipped to nearly every state in the USA. Vermiculite is widely used in consumer products, such as attic insulation, lawn and garden products and fireproofing material.[5] In the years of operation, millions of tons of vermiculite were produced at the mine, providing nearly 80% of the world's supply.

Air sampling in Libby in the 1980s identified asbestos fibres in excess of occupational limits of 0.1 fibre/cm^3 over 8 h set by the Occupational Safety and Health Administration.[17 18] As early as 1986, a cohort study (1963–1983) detected increased death rates among Libby vermiculite mine workers.[19] In addition to the occupational exposure associated with vermiculite mining and handling, household members of vermiculite workers and residents of Libby without connections to the mining operations were exposed when the product was distributed throughout town and used for gardening, insulation, driveways and a school baseball field.[20]

Increasing national attention focused on Libby, Montana in November 1999 when increasing numbers of local residents were diagnosed with ARD. From 1979 to 1998 asbestosis mortality in Libby was 40–80 times higher than expected for Montana and the USA, respectively.[21] In 2000 and 2001, medical screenings of more than 6668 current and former Libby residents were conducted. Pleural abnormalities were observed on chest x-ray in 18% of participants and interstitial abnormalities in <1% of participants who were screened.[20 22] Fifty-one per cent of the former vermiculite workers who were x-rayed and 26% of household contacts of workers had pleural abnormalities. By comparison, the rate of pleural abnormalities in non-asbestos exposed groups in the USA ranges from 0.2% to 2.3%.[16]

In February of 2002, after extensive review, the US Environmental Protection Agency (EPA) placed Libby on the National Priorities List and the area became a Superfund asbestos cleanup and removal site. In June of 2008,[23] updated asbestosis mortality statistics were released for 1995–2004. Lincoln County Montana where Libby is located had the highest age-adjusted asbestosis death rate per million population in the USA for residents age 15 and older. In 2009, 7 years after the Superfund designation, the EPA declared a public health emergency in Libby, the first such determination under the Comprehensive Environmental Response, Compensation, and Liability Act (Libby Public Health Emergency, http://www.epa.gov/region8/superfund/libby/phe.html). The declaration constitutes formal recognition of the serious health impacts from asbestos contamination in the Libby community.

The association between specific exposure pathways and radiographic abnormalities has been reported[19 20 24–26] Scant information has been published on overall responses to exposure, for example, access to healthcare[27] and psychosocial ramifications[28] in this population. The quality of life of persons exposed to Libby amphibole asbestos (LAA) has not been described.

PURPOSE

The purpose of this paper is to describe the respiratory health status (aim 1) and respiratory health-related quality of life (aim 2) of a cohort of persons exposed to LAA.

METHODS

Study design

A descriptive cross-sectional design was used for the study. Participants were patients of the Center for Asbestos Related Disease (CARD) in Libby, Montana. CARD provides long-term health screening, monitoring, ARD diagnosis, specialised asbestos healthcare and counselling to people affected by exposure to LAA. Clinical records and the results of chest radiographs

(CXR) and pulmonary function tests (PFT) were examined to determine the severity of respiratory illness. Results from the St George Respiratory Questionnaire (SGRQ) were used to determine respiratory health-related quality of life and demographic information was used to describe the cohort.

The study was conducted under the auspices of the Institutional Review Board at Montana State University. Written informed consent was obtained from all participants prior to data collection. Each participant was assigned a unique study code number and deidentified data were used in the analysis.

Participants

Because this was a cross-sectional descriptive study, a large sample was sought. Primary data were collected on 485 CARD patients but the final sample yielded a total of 329 participants based on incomplete secondary clinical data from chart review. Eligible participants were patients of the CARD clinic with a history of exposure to LAA, 21 years of age or older, with the ability to speak, read and write English. To publicise the study, descriptive posters and brochures that described the study's intent to examine overall health status of persons exposed to LAA were available in the CARD clinic waiting room. On an individual basis, each client presenting to the CARD for their annual examination were approached and invited to participate. Those who met the inclusion criteria and consented completed either an electronic or paper version of the SGRQ and demographic questionnaire during their clinic visit. CARD clients, who lived outside the Libby area in Montana or elsewhere in the USA, also were invited to participate in the study by including a letter describing the study, consent form and a paper copy of the study questionnaire with normal annual correspondence. Although it is not known if enrolled patients of the CARD clinic differ from those not enrolled in this study, staff report very few clients that were approached declined to participate. CXR and PFT results along with other clinical data were extracted from each participant's medical record by a CARD staff member and provided to the research team. Data were collected from February to December 2007.

Measures

The measures used to describe the respiratory health status included results from the annual or most recent CXR and PFT, two tests routinely used to monitor respiratory status in CARD patients. Chest films consisted of anterior/posterior and lateral views interpreted by a single community-based radiologist. Chest x-rays are an insensitive method of diagnosing asbestos-related disease in this population. The International Labour Organization (ILO) classification was not utilised; rather, readers experienced in asbestos-related disease, specifically pleural disease were utilised. Data collected for the study included the radiologist's reading of the participants' latest CXR, recorded as no abnormality, pleural abnormality, interstitial abnormality, or both pleural and interstitial abnormalities.

PFT is a generic term used to indicate a battery of tests performed using standardised equipment to measure lung function.[29] PFT testing at the CARD clinic was performed by trained respiratory therapy staff using Medgraphics Platinum Elite Series Plethysmograph, (model Elite DL) and following standard testing procedures.[30] Results obtained were based on standardised reference values adjusted for height, age and gender reported by Knudson *et al*[31] The most recent results of the FVC, FEV in 1 s (FEV_1), forced FEV_1/FEV_1 ratio and diffusing capacity of carbon dioxide (DL_{CO}) were evaluated for this study.

Participants' perceptions of respiratory health-related quality of life (HRQOL) were measured using the SGRQ, an instrument routinely used by the CARD clinic to monitor clients' perceptions of their respiratory health status. The SGRQ is a 76-item standardised questionnaire for measuring impaired health and perceived HRQOL in airway disease. Impairment is measured in terms of 'symptoms' (frequency and severity of respiratory symptoms), 'activity' (activities that cause or are limited by breathlessness), 'impacts' (social functioning and psychological disturbances related to respiratory problems) and a total score (sums and weights of above components).[32] Potential SGRQ scores range from 0 (no impairment) to 100 (the worst impairment) for each subscale, with higher scores indicating greater distress and worse HRQOL. Previous studies showed good reliability, cross-sectional and longitudinal validity of the SGRQ.[33–36] Cronbach's α-coefficients for this study were 0.887 (total), 0.713 (symptoms), 0.913 (activity) and 0.908 (impacts). The total score and scores for the subscales were collected for this study as a measure of respiratory HRQOL.

Data management

Survey data collected electronically were transmitted directly and electronically to a protected database at the research office at Montana State University through a secure Internet connection. The paper/pencil questionnaire data and the deidentified medical record data were entered into an electronic file by the CARD research team members and sent directly and electronically to the research office. All data were exported into SPSS (V.16, 2001) on an ongoing basis. Summary results from the SGRQ for individual participants were reported to the CARD clinic on a weekly basis using the unique study number as they had a potential impact on the individual's plan of care. Ultimately, all questionnaire data became a part of the client's health record at the CARD clinic. To address the research questions posed in this study a one-way analysis of variance (ANOVA) was used to examine group differences in pulmonary function and respiratory related quality of life based on gender, age, smoking status, exposure source and radiographic

findings. Significant omnibus tests of differences were followed by appropriate post hoc analysis to identify specific group differences.

RESULTS

Of the 329 study participants, two-thirds lived in Lincoln County (local patients) and one-third lived elsewhere in Montana and throughout the USA (distant patients). More men than woman participated, most were married, had a history of smoking and 70% were between 50 and 69 years of age (see table 1).

Aim 1 of this study explored respiratory morbidity among this cohort by measured pulmonary function. Means and SDs for measures of pulmonary function are included in table 2A,B (analysed as percent predicted). For the total sample of 329 persons exposed to LAA, the mean FVC was 95.3% (SD=18.7), FEV_1 87.0% (SD=20.2), ratio of FEV_1/FVC 95.5% (SD=12.0) and DL_{CO} 83.0% (SD=21.7).

A one-way ANOVA was used to examine differences in pulmonary function including FVC, FEV_1, FEV_1/FVC ratio and DL_{CO} according to gender, age, smoking history, exposure status and findings from CXR. The ANOVA summary table 2A,B indicate that omnibus differences were found based on smoking history and findings for FVC; age, smoking history and findings for FEV_1; smoking history alone for FEV_1/FVC; and gender, age, smoking and findings for DL_{CO}. ANOVA findings examining differences in PFT's based on radiographic findings were confirmed with a follow-up Kruskal-Wallis test due to violations in distributional assumptions. Post hoc analyses using the Tukey HSD test indicated that for FVC, FEV_1 and DL_{CO}, participants with a normal CXR had better pulmonary function from those with evidence of both interstitial and pleural abnormalities. For FVC alone, those with pleural or interstitial abnormalities scored similarly although only the difference between normal CXR and CXR showing pleural abnormalities was detected by the ANOVA, likely as a result of increasing variability when sample size dropped to only 18 persons in the interstitial only group. A similar finding can be seen for FEV_1 as results indicated that participants scored similarly from both the pleural and interstitial group although only the difference with the interstitial group was detected. Post hoc analysis for DL_{CO} showed that the youngest age group (20–49) scored significantly better than the other three groups, and as expected, the oldest age group of persons (over 70 years) fared the worst.

Table 1 Sample characteristics (n=329)

	Subjects (n=329)	Sample (%)
Age		
20–49	39	11.9
50–59	112	34.0
60–69	120	36.5
70+	58	17.6
Marital status		
Married	239	72.6
Single	27	8.2
Widow(er)	30	9.1
Divorced	29	8.8
Separated	4	1.2
Insurance status (not exclusive)		
HNA	204	62.0
LAMP screening	124	37.7
LAMP supplemental	179	54.4
Other	167	50.8
Gender		
Men	187	56.8
Women	142	43.2
Location		
Local	219	66.6
Distant	110	33.4
Exposure route		
Worker	25	7.6
Household member/contact	106	30.2
Other	198	62.2

Aim 2 of this study was to explore respiratory related quality of life among this cohort using results from the SGRQ. Means and SDs for the entire SGRQ scale and each of the three subscales (symptoms, activity and impacts) are included in table 3A,B. The overall score of the total scale among this cohort was 38.5 (SD=22.1) and means for the subscales were 52.1 (SD=24.9), 49.4 (SD=26.9) and 27.5 (SD=21.9) for symptoms, activity and impacts, respectively.

Subgroup analysis was conducted to evaluate potential differences within this sample identical to the PFT analysis. A one-way ANOVA was used to examine differences in respiratory health-related quality of life (SGRQ total, symptoms, activity and impacts) according to gender, age, smoking history, exposure status and radiographic findings. The ANOVA summary table 3A,B indicated that omnibus differences were found based on smoking history and radiographic findings for SGRQ total; smoking history for symptoms; smoking history and radiographic findings for activity; and smoking history, and radiographic findings for impacts.

ANOVA findings examining differences in PFT's based on radiographic findings were confirmed with a follow-up Kruskal-Wallis test due to violations in distributional assumptions. Post hoc analyses using the Tukey HSD test indicated that participants scored significantly higher for activity limitations if they had any evidence of abnormality on CXR and were more significantly affected if they had either pleural abnormalities or both pleural and interstitial abnormalities. In addition, for the total score on the SGRQ, those subjects with either pleural abnormalities or evidence of both pleural and interstitial abnormalities appeared to score worse. Those subjects with any smoking history had significantly worse average scores overall and on the three subscales of the SGRQ.

Table 2 Pulmonary function of Libby ARD cohort

Panel A	N	FVC* Mean (SD)	F	p Value	Pair differences†	$FEV1_1$ mean (SD)	F	p Value	Pair differences
Total	329	95.3 (18.7)	–	–	–	87.0 (20.2)	–	–	–
Gender									
Male	187	95.7 (19.3)	0.19	0.66	NA	87.3 (19.7)	0.10	0.76	NA
Female	142	94.7 (18.0)				86.6 (20.8)			
Age									
20–49 (0)	39	100.1 (14.8)	1.43	0.23	NA	96.5 (14.3)	3.79	0.01	0 vs 2
50–59 (1)	112	95.0 (21.6)				87.9 (23.0)			0 vs 3
60–69(2)	120	94.2 (18.7)				85.1 (19.4)			
70+(3)	58	94.0 (14.4)				83.3 (17.8)			
Smoker									
Yes (ever)	215	93.8 (20.1)	3.63	0.05	NA	84.1 (20.6)	13.30	0.00	NA
No	114	98.0 (15.5)				92.5 (18.1)			
Exposure									
Worker	25	95.2 (17.9)	0.84	0.43	NA	89.0 (18.9)	0.39	0.68	NA
Family/contact	106	93.4 (17.1)				85.7 (19.8)			
Other	198	96.3 (19.7)				87.5 (20.6)			
Radiographic findings									
Normal (0)	60	103.8 (15.0)	7.40	0.00	0 vs 1	92.8 (21.8)	4.33	0.00	0 vs 3
Pleural abnormalities (1)	182	94.9 (20.2)			0 vs 3	87.7 (20.0)			1 vs 3
Interstitial abnormalities (2)	18	95.6 (12.0)				86.4 (16.5)			
Both (3)	69	88.8 (16.3)				80.4 (18.6)			

Panel B	n	$FEV1_1$/ FVC_1 Mean (SD)	F	p Value	Pair differences†	DLCO* Mean (SD)	F	p Value	Pair differences
Total	329	95.5 (12.0)	–	–	–	83.0 (21.7)	–	–	–
Gender									
Male	187	96.1 (11.9)	1.02	0.31	NA	86.3 (21.7)	10.13	0.00	NA
Female	142	94.8 (12.2)				78.7 (21.0)			
Age									
20–49 (0)	39	98.4 (8.5)	1.22	0.30	NA	91.5 (18.6)	9.31	0.00	0 vs 2
50–59 (1)	112	95.5 (13.3)				87.6 (22.2)			0 vs 3
60–69 (2)	120	95.6 (10.9)				81.1 (19.9)			1 vs 3
70+ (3)	58	93.6 (13.4)				72.3 (21.8)			2 vs 3
Smoker									
Yes (ever)	215	93.3 (13.2)	23.4	0.00	NA	78.5 (21.9)	29.00	0.00	NA
No	114	99.8 (7.6)				91.5 (18.5)			
Exposure									
Worker	25	99.0 (9.3)	1.15	0.32	NA	89.8 (19.2)	2.10	0.13	NA
Family/contact	106	95.5 (11.6)				80.4 (19.4)			
Other	198	95.1 (12.5)				83.6 (23.0)			
Radiographic									
Findings	60	94.8 (13.6)	0.16	0.92	NA	90.2 (19.5)	11.10	0.00	0 vs 2
Normal (0)	182	95.85 (10.8)				85.7 (20.1)			0 vs 3
Pleural abnormalities (1)	18	94.7 (12.6)				68.1 (24.5)			1 vs 2
Interstitial abnormalities (2)	69	95.6 (13.5)				73.7 (22.4)			1 vs 3
Both (3)									

*Tukey HSD used for paired differences.
†FVC, FEV_1, FEV_1/FVC and DLCO analysed as percent predicted.
ARD, asbestos related disease; FEV, forced expiratory volume; FVC, forced vital capacity.

Table 4 compares the Libby SGRQ mean scores with scores obtained from a representative population sample. Ferrer *et al*[45] examined SGRQ results from a subset of the 'IBERPOC (epidemiological study of chronic obstructive disease in Spain)' (p 406) to establish population norms for a respiratory-specific health-related quality-of-life tool. Table 5 compares the Libby cohort SGRQ results with the general population norms based on gender, age, and the category 'never smoked'.

Table 3 Respiratory quality of life

Panel A	n	SGRQ total Mean (SD)	F	p Value	Pair differences*	Symptoms Mean (SD)	F	p Value	Pair differences
Total	329	38.5 (22.1)	–	–	–	52.1 (24.9)	–	–	–
Gender									
Male	187	35.3 (22.1)	0.03	0.86	NA	52.1 (24.5)	0.00	0.99	NA
Female	142	38.8 (22.3)				52.0 (25.4)			
Age									
20–49	39	32.3 (20.3)	1.43	0.23	NA	52.0 (21.4)	0.76	0.51	NA
50–59	112	40.1 (23.3)				54.1 (25.4)			
60–69	120	40.0 (21.8)				52.1 (25.4)			
70+	58	37.1 (21.3)				48.0 (25.1)			
Smoker									
Yes (ever)	215	40.1 (22.1)	7.10	0.00	NA	54.0 (25.4)	3.80	0.05	NA
No	114	34.0 (21.5)				48.4 (23.4)			
Exposure									
Worker	25	35.2 (25.0)	0.63	0.53	NA	49.1 (31.0)	0.20	0.82	NA
Family/Contact	106	40.2 (22.0)				52.5 (23.4)			
Other	198	38.1 (21.9)				52.2 (25.0)			
Radiographic Findings									
Normal (0)	60	29.8 (20.8)	4.76	0.00	0 vs 1	47.1 (24.2)	1.54	0.20	NA
Pleural abnormalities (1)	182	39.1 (22.5)			0 vs 3	51.8 (25.1)			
Interstitial abnormalities (2)	18	41.3 (21.5)				54.5 (27.0)			
Both(3)	69	43.8 (20.4)				56.3 (23.8)			

Panel B	n	Activity Mean (SD)	F	p Value	Pair differences*	Impacts Mean (SD)	F	p Value	Pair differences
Total	329	49.4 (26.9)	–	–	–	27.5 (21.9)	–	–	–
Gender									
Male	187	47.8 (27.1)	1.40	0.23	NA	28.2 (21.6)	0.42	0.51	NA
Female	142	51.4 (26.7)				26.6 (22.3)			
Age									
20–49	39	39.2 (28.5)	2.30	0.07	NA	21.8 (18.5)	1.98	0.13	NA
50–59	112	49.4 (28.5)				30.1 (22.5)			
60–69	120	51.3 (25.1)				28.6 (22.4)			
70+	58	52.2 (25.4)				24.3 (21.1)			
Smoker									
Yes (ever)	215	52.1 (26.3)	6.70	0.01	NA	30.0 (22.1)	6.38	0.01	NA
No	114	44.2 (27.4)				23.4 (21.0)			
Exposure									
Worker	25	45.0 (30.0)	1.20	0.30	NA	24.8 (24.1)	0.34	0.71	NA
Family/Contact	106	52.5 (25.8)				28.7 (22.8)			
Other	198	48.3 (27.1)				27.3 (21.2)			
Radiographic Findings									
Normal(0)	60	36.5 (26.8)	7.41	0.00	0 vs 1	20.1 (19.2)			0 vs 1
Pleural abnormalities (1)	182	49.9 (27.4)			0 vs 2	28.4 (21.2)	3.22	0.02	0 vs 3
Interstitial abnormalities (2)	18	54.6 (22.3)			0 vs 3	28.5 (23.4)			
Both(3)	69	57.7 (23.0)				31.4 (21.8)			

*Tukey HSD used for paired differences.

DISCUSSION

In 2002, Libby Montana was placed on the EPA priorities list and work began to clean up the amphibole asbestos contaminating the community. Seven years later, the EPA formally recognised the serious health implications of asbestos contamination in Libby by declaring a public health emergency. The study reported here was conducted between the time the clean-up began and the health emergency was declared.

In this cross-sectional, descriptive study, 18% of the study cohort (n=60) had a normal CXR, a finding slightly higher than the 10–15% previously reported for persons with ARD.[3] A small number of participants exhibited interstitial abnormalities (5.4%) alone on CXR while the majority had pleural abnormalities (55%) or both pleural and interstitial disease (20.9%). These findings support studies showing that exposure to amphibole asbestos can lead to increased risk of structural changes

Table 4 Libby comparison with general population norms on the St George Respiratory Questionnaire

Study Group	Symptoms	Activity	Impacts	Total
Libby (n=329)	52.1 (24.9)	49.4 (26.9)	27.5 (21.9)	38.5 (22.1)
General population (n=862)	9.67 (13.24)	13.40 (17.63)	4.73 (9.92)	8.41 (11.33)

Data are presented as mean and (SD) for the Libby cohort and the general population norms (Ferrer *et al*).[45]

in the pleura alone.[4 20] Nearly one-third of participants with pulmonary abnormalities were family or household contacts of vermiculite workers and 60% reported only environmental exposure to LAA. This important finding of environmental exposure alone, for example, non-vermiculite worker or household member of vermiculite worker provides support for studies which demonstrated that pleural and interstitial changes can occur at low lifetime cumulative amphibole fibre exposure levels.[20 37–40] With the widespread distribution of the Libby vermiculite, pulmonary changes due to low-level exposure have significant public health implications.

The pulmonary function indicators showed low normal mean values for the total cohort for $FEV1_1$ (87%) and DL_{CO} (83.0%) (normal >80% of predicted value). Significant differences were found in $FEV1_1$ based on age, smoking history and radiographic findings, while smoking history alone was related to significant changes in $FEV1_1$/FVC ratio. Analysis of correlates with these lung function parameters is complicated by the clinical observation by the study authors that adult-onset obstructive airway disease (no history of smoking, asthma) frequently occurs in the Libby cohort in association with the development of asbestos-related pleural +/− parenchymal disease. A diagnosis of adult onset asthma is commonly present in individuals presenting to CARD for screening who have evidence of ARD. Although the American Thoracic Society Statement[41] addresses the relationship of chronic airway obstruction to asbestos exposure, the frequency and severity have been observed to be greater in the Libby cohort. Thus, contributions to significant airway obstruction decreased FEV_1 and/or low FEV_1/FVC could arise from asbestos[42] as well as smoking. Differences in DL_{CO} were associated with gender, age, smoking history and radiographic findings. Lower FEV_1 and DL_{CO} are consistent with restrictive lung disease (eg, respiratory fibrosis) and conditions caused by fibrogenic dusts (eg, asbestos) and smoking.[29] Ross[3] reported that DL_{CO} can be reduced in approximately 80–90% of persons with asbestosis.

Mean FVC value for the cohort was 95.3%. Differences in FVC were found based on exposure status, smoking and radiographic findings although significant differences between groups were not identified. Pleural thickening has been shown to impair lung function measured by pulmonary function testing and diffuse pleural scarring is associated with reduced FVC and DL_{CO}.[43 44] This finding is clinically significant as it strongly suggests that pleural abnormalities on radiograph correlate with relative restrictive changes across this population and could be associated with dyspnoea on exertion resulting from the more diffuse pleural abnormalities.

The Libby cohort demonstrated a total SGRQ score of 38.5 on a scale of 0–100 with a higher score indicating worse HRQOL. Subjects with any smoking history had significantly worse average total scores and on the three subscales of the SGRQ. For activity alone, subjects with normal radiographic findings differed significantly from those with pleural evidence of disease but no differences were found for those with interstitial evidence. When compared with persons with chronic obstructive pulmonary disease (COPD) and interstitial lung disease, the Libby cohort's HRQOL total scores were worse. However, when comparing the Libby cohort to the general population (tables 4 and 5), the findings indicated significantly worse quality of life.[45] Small changes in scores are meaningful; a difference of four points is considered clinically significant.[46] Interestingly, as with the Libby cohort, the general population of women was higher than men on the activity scale but lower than men on impacts. As expected, the general population symptoms, activity and impact scores increased with age while the Libby cohort symptoms and impact scores actually decreased possibly related to accommodation of the chronic condition. Libby individuals noting 'no or never smoked' compared with the general population

Table 5 St George Respiratory Questionnaire Libby and general population comparison based on characteristics

	Symptoms		Activity		Impact		Total	
	Libby	General	Libby	General	Libby	General	Libby	General
Gender								
Male	52.1	11.62	47.8	12.17	28.2	5.23	35.3	8.60
Female	52.0	7.82	51.4	14.58	26.6	4.26	38.8	8.23
Age								
50–59	54.1	8.74	49.4	13.48	30.1	4.55	40.1	8.19
60–69	52.1	12.54	51.3	17.95	28.6	7.23	40.0	11.61
Never smoked	48.4	7.49	44.2	13.63	23.4	4.16	34.0	

indicate a significantly lower quality of life related to asbestos-related disease despite smoking status.

LIMITATIONS

While this study provides important information about respiratory morbidity and quality of life among a unique population, results should be interpreted with caution due to the limitations of our cross-sectional design. It is not known for example how well our sample represents the population of those experiencing ARD as a result of exposures to LAA, or exactly how physical and quality-of-life changes occur during disease progression. As we have observed clinically, morbidity is often worse when a relative change occurs within the individual associated with an evolving disease process and single measurements despite apparent severity serve a less useful role. Future research will enable individual trends to be evaluated for respiratory morbidity and associated quality of life and provide a more complete prospective dataset that will allow greater statistical flexibility including multivariate analysis.

It is also important to note that the SGRQ data were collected from participants upon enrolment in the study while the pulmonary data (CXR and PFT) and exposure history represent the most recent data documented in the participant's health record and may not represent current pulmonary and exposure status. Also, although CXRs were read by the same radiologist, well recognised is the significant lack of sensitivity of standard CXR in the detection and characterisation of significant asbestos-related pleural and parenchymal fibrosis. This is especially true for non-calcified pleural thickening, where the anterior and posterior chest is poorly visualised. The Libby population exposed to the amphibole mixture predominately presents with non-calcified diffuse pleural thickening,[16 38 47] making CXR even less sensitive. In addition, subjects needed only to be patients of CARD with documented exposure to LAA to participate in the study resulting in a sample of participants at varying stages of health and illness. Given that ARD is a progressive disease that evolves over 10-plus years, the results of the study provide a snapshot in time of the pulmonary and HRQOL status of participants.

CONCLUSIONS

In this study of 329 persons exposed to LAA, pleural abnormalities alone were noted in 55% of participants; nearly 21% had both pleural and interstitial abnormalities, while only 18% of study participants had no documented lung abnormality on chest x-ray. Nearly 35% had never smoked. The mean FVC for the cohort was 95.3% (SD=18.7); FEV_1 87% (SD=20.2); ratio of FEV_1/FVC 95.5% (SD=12) and DL_{CO} was 83% (SD=21.7) of the per cent predicted. Significant findings were found based on smoking history across all pulmonary measures, and for exposure status, radiographic findings, age and gender for select pulmonary parameters. The mean total SGRQ for the cohort was 38.5 (SD=22.1) indicating a significantly lower HRQOL than is found in healthy persons and appreciably worse than some persons with COPD or interstitial lung disease. Means for the SGRQ subscales were 52.1 (SD=24.9), 49.4 (SD=26.9) and 27.5 (SD=21.9) for symptoms, activity and impacts, respectively. Subjects with normal CXR differed significantly from those with evidence of both interstitial and pleural abnormalities on total, activity and impacts scores. For activity alone, subjects with normal radiographic findings differed significantly (higher function) from those with pleural evidence of disease but no differences were found for those with interstitial evidence. Subjects with any smoking history had significantly worse average total scores and on the three subscales of the SGRQ.

The SGRQ findings in this cohort of subjects are noteworthy for clinicians. Furthermore, the finding of pleural and interstitial abnormalities and diminished pulmonary function in persons with low lifetime cumulative amphibole fibre exposure, for example, non-vermiculite worker or household member of a vermiculite worker, is important given the widespread distribution and use of vermiculite ore in private and commercial applications. Holistic healthcare that addresses the psychosocial and physiological aspects of health is an important consideration in persons exposed to or living with the health effects of LAA.[28] Routine screening of individuals at risk for ARD and those with pleural or interstitial abnormalities using tools like the SGRQ is essential to the provision of early psychosocial intervention and support for respiratory-related QOL issues. More research is needed to understand the psychosocial and physical costs of exposure to LAA.

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Contributors CAW was the principle investigator; WGH, SWK and CW were coinvestigators on the study. KR was engaged in data collection; TH provided case management for participants with needs resulting from participation and BB served as medical advisor for the study. Each member participated in the development and implementation of the study, analysis of the data, and dissemination of results. CAW, WGH, KR and BB drafted the manuscript and all co-authors critically revised the paper.

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