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Key terms: chest X-ray; coal miner; pleura; pneumoconiosis; radiological pleural change; silica exposure

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Radiologically recognized pleural changes in nonpneumoconiotic silica-exposed coal miners

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Objectives Whether nonpneumoconiotic silica-exposed coal miners develop radiologically recognizable pleural changes was studied.

Methods In a retrospective follow-up study, the oldest and the most recent chest X-rays of 765 workers with a profusion category lower than 1/0 according to the International Labour Office were read.

Results Altogether 720 (94.1%) workers had no abnormalities, and 45 (5.9%) showed some pleural alteration in the first X-ray. In 43 (6%) of the 720 with no initial abnormalities, some pleural change was detected in the last X-ray. There was a statistical difference (P=0.022) according to silica exposure category [low: 5 (2.4%); medium: 8 (6%); high: 30 (8%)]. The relative risk for any pleural alteration was significantly increased in relation to the silica-exposed group [medium: odds ratio (OR) 5.72, 95% confidence interval (95% CI) 1.4–23.5, P=0.016; high: OR 7.62, 95% CI 2.1–27.2, P=0.002] and to rib alterations (OR 3.74, 95% CI 1.4–9.7, P=0.007). In 19 (2.6%) workers with no alterations initially, a costophrenic sinus alteration was detected later. Again the silica exposure categories [low: 1 (0.5%); medium: 3 (2.2%); high: 15 (4.2%)] differed significantly (P=0.033). The relative risk of costophrenic sinus obliteration was significantly increased in relation to the silica-exposed group [medium: OR 8.59, 95% CI 0.7–113, P=0.102; high: OR 16.44, 95% CI 1.5–177, P=0.021]. The appearance of two costophrenic sinus obliterations and the disappearance of four were detected in the last chest X-ray of the 45 workers with some pleural alteration initially.

Conclusions Costophrenic sinus obliteration can be found in nonpneumoconiotic silica-exposed coal miners and seems to be associated with silica exposure intensity.

Key terms chest X-ray; pleura; pneumoconiosis.

Coal workers' pneumoconiosis and silicosis are pneumoconioses associated with coal mining. In coal workers' pneumoconiosis the pleura is pathologically thickened if subpleural nodules or progressive massive fibrosis are present (1). In silicosis, pleural surfaces of the lungs often reveal focal fibrosis and silicotic nodules forming, on occasions, what is called candle-wax lesions (2). Radiologically recognizable pleural thickening, in accordance with this pathological background, has been observed in both diseases (2, 3). Coal mine dust, derived in large measure from the rock strata where the mine is located, may have a complex and high mineral content (1). Exposure to different types of minerals, some of which are found in coal mine dust, may produce benign pleural changes without concomitant lung involvement (4–8). These pleural changes, basically pathological and radiological findings, rarely cause significant symptoms (5) and may consequently go unnoticed. To our knowledge, no studies have been directed towards showing radiological pleural alterations in coal workers without pneumoconiosis.

The aim of this study was to ascertain whether nonpneumoconiotic coal miners exposed to silica develop pleural changes.

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Study population and methods

Study population and design

A retrospective follow-up study was conducted among all workers of an anthracite coal mine in Asturias (Spain) who attended the Respiratory Service of the Instituto Nacional de Silicosis. This institute is a national referral center for occupational respiratory diseases in the public health system in Spain, covering the entire population (in this region there are no alternative health providers). It evaluates legal disabilities and conducts regular respiratory check-ups on the coal-mining population. Between 1978 and 1993, 765 workers visited this service for a routine check-up. They completed a minimum of two chest X-rays, separated by at least 1 year, with a negative profile for the diagnosis of pneumoconiosis [profusion category lower than 1/0 according to the International Labour Office (ILO) (9)]. Among the 765 workers, representing approximately 50% of the total work force, 545 worked underground for at least some part of their workday, and 220 worked only in surface services. All the workers studied were men, with a mean age of 39.7 (SD 5.7) years.

Personal samples for respirable coal-mine dust were collected using 37-mm cyclones operated at 2 l/min (10) by inspectors of the Instituto Nacional de Silicosis. The silica content of the dust from the mine and the possible existence of fibers were studied in more than 1000 recordings obtained in high- and medium-exposure jobs over four consecutive years of study. Gravimetric analysis (11) and infrared absorption spectrophotometry (12) showed that the mine had a high mean silica content [coal-mine dust: 7.4 (SD 6.1) and 2.3 (SD 3.4) mg/m^3, respectively; quartz percentage: 5.2 (SD 6.8) and 3.1 (SD 3.4), respectively]. These quartz contents are approximately 7 and 4 times higher than the exposure limit recommended for respirable quartz by the National Institute for Occupational Safety and Health (NIOSH) in the United States (3, 13). Fibers were not detected using optical microscopy under phase-contrast conditions (14). An additional two samples collected every 3 months using the same procedures, at the same sites and during the same study period were used for microanalysis. At least 20 particles of each sample, including all those which, by scanning electron microscopy, could be morphologically different were identified by energy dispersive X-ray analysis (15). Many carbon and quartz particles were found. Clays, feldspars, and other silicates were also detected. However, only two isolated particles of mica, but no other pleural alteration-related silicates (5–8) were found. Calcium carbonate and pyrite were also observed.

Detailed clinical and employment records, including job title description, were obtained for all the workers. With the aid of a hygienist, each job title was classified as follows: high dust exposure: all manual jobs predominantly concerned with the mining or initial transport of rock from the face; medium dust exposure: skilled jobs mainly or partly underground, based away from the rock face and not involved with the initial transport of rock from the face; low dust exposure: mine surface jobs. Since the workers could have worked in jobs with different exposure intensities, they were classified into the following three groups: (i) low silica-exposed group: workers who had only worked in low-dust exposure occupations; (ii) medium silica-exposed group: those who had never carried out high-dust exposure occupations but who had performed medium-dust exposure tasks; (iii) high silica-exposed group: those who had carried out high-dust exposure occupations, although they had, at some time, had another type of occupation.

Diagnosis of pleural changes

The diagnosis of pleural changes was made with the use of a chest X-ray. The frontal projection of the oldest chest X-ray available and the most recent was read for each worker. Twenty-nine (1.89%) radiographs were considered to be of poor quality and were replaced by the following one in the case of the first or the previous one in the case of the most recent. The mean time elapsed between the two radiographic controls was 9.6 (SD 4.6) years.

Each X-ray was read separately by two chest physicians with experience with the pleura and occupational diseases and specially trained in the interpretation of X-rays of patients with pneumoconiosis, in no predetermined order, and unaware of the silica-exposed group to which each individual belonged. Of the 1530 radiographs read, pleural reading discrepancies arose between the two readers in 119 cases, which represented a kappa concordance index of 0.61. In cases of disagreement, the radiograph was read by a third reader, who broke the tie. The readings were made according to the 1980 guidelines of the International Labour Office (9).

Analyzed variables

Pleural alterations as a whole, and obliteration of the costophrenic sinus in particular, were analyzed as dependent variables. The independent variables analyzed were age, smoking, total time worked (time elapsed from the start of the job to the date of the last radiological control), time between X-rays, lung parenchyma alterations (any lesion except those corresponding to the profusion pattern), chest wall alterations (rib fractures or calluses), cumulative exposure [dust-exposure job score (high = 2, medium = 1, low = 0) by number of years worked in each job), and degree of intensity of the exposure of the group to which the workers belonged.

Statistical analysis

An analysis of the association between pleural lesion and exposure, adjusting for other variables such as smoking and age, was undertaken with the standard method of logistic regression. The association was measured with the maximum likelihood estimation of the odds ratio (OR). The analysis was carried out with the EGRET (Serc and Cytel Corporation, Seattle, WA, USA) statistical program.

Results

The results of the study are summarized in figure 1. No pleural alterations were observed in the first radiologic control for 720 (94.1%) workers. For 43 (6%) of these workers, some pleural change was evident in the last chest X-ray. The time from the first exposure to the time of its detection was 16.5 (SD 5.7) years. Changes were located in the costophrenic sinus in 19 (2.6%) workers, for whom normal spirometric values were verified (16). Other changes were located in the apical cap in 13 (1.8%), the lateral wall in 13 (1.8%), the diaphragmatic zone in 6 (0.8%), and the image was diffuse for 1 (0.1%). More than one pleural alteration was detected for several workers.

Significant differences were found in this group of workers according to the intensity exposure group to which they belonged when both the pleural alterations as a whole and the change in the costophrenic sinus were analyzed. The incidence rates were also calculated (table 1).

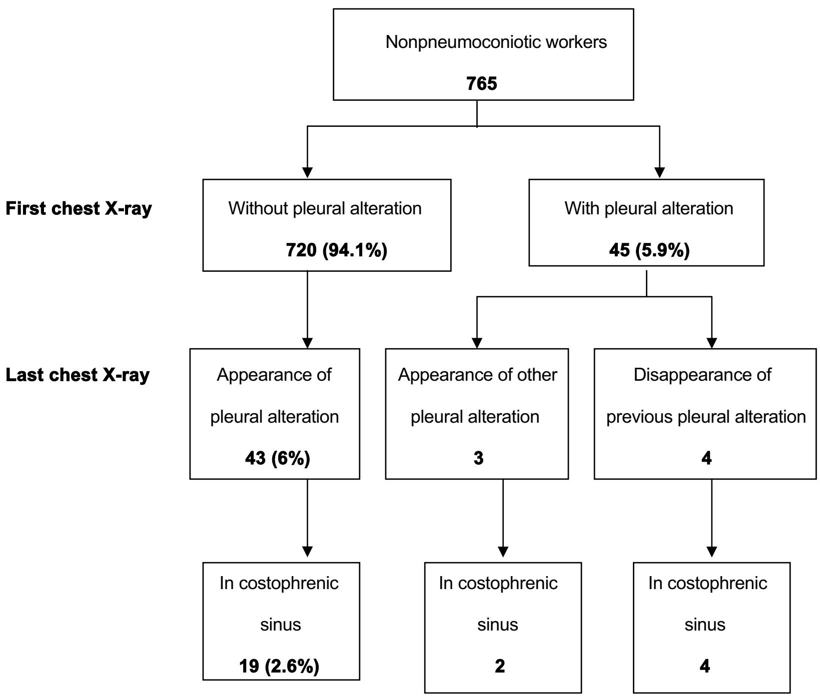

Figure 1. Division of the initial population according to the finding or not of pleural alteration in first chest X-ray. The incidence of pleural alterations and costophrenic sinus obliteration is shown.

Table 1. Location of radiological pleural alterations according to the intensity of silica exposure among 720 workers without an initial pleural lesion in the first chest X-ray.

Location of pleural alteration	Silica exposure											P-value
	Low (N=211)			Medium (N=134)			High (N=375)			Total		
	N [a]	%	Incidence (1000/ year)	N [a]	%	Incidence (1000/ year)	N [a]	%	Incidence (1000/ year)	N [a]	Incidence (1000/ year)	
Any pleural alteration	5	2.4	2.5	8	6	6.2	30	8	8.3	43	6.2	0.022
Costophrenic sinus	1	0.5	0.5	3	2.2	2.3	15	4.2	4.2	19	2.7	0.036
Apical cap	2	0.9	1	1	0.7	0.8	10	2.6	2.8	13	1.9	0.192
Lateral wall	2	0.9	1	4	3	3.1	7	1.8	1.9	13	1.9	0.380
Diaphragm	1	0.5	0.5	2	1.5	1.5	3	0.8	0.8	6	0.9	0.594
Diffuse	–	0	0	–	0	0	1	0.3	0.3	1	0.1	0.630

[a] Pleural lesions were detected in more than one site in several workers.

The variables contributing to the explanation of the pleural alterations as a whole were exposure group (OR 5.7 for medium silica exposure; OR 7.6 for high silica exposure) and rib alterations (OR 3.7) (table 2). However, only the intensity of the exposure group contributed to accounting for an obliterated costophrenic sinus (OR 8.9% for medium silica-exposure; OR 16.44 for high silica exposure) (table 3). There was no association between the presence of either a pleural alteration or an obliterated costophrenic sinus with cumulative exposure (P>0.1).

At least one pleural alteration was detected in the first radiological control of 45 (5.9%) workers. Altogether 30 (3.9%) showed obliteration of the costophrenic sinus, 10 (1.3%) had an apical cap, 7 (0.9%) revealed a diaphragmatic pleural alteration, and 5 (0.6%) had thickening of the lateral wall. More than one pleural alteration was detected in several workers. A radiological change was detected in the last radiological control for 7 of these workers, none of whom belonged to the low exposure group. In 2 of the 7, a new obliteration of the costophrenic sinus was detected. In another worker new involvement of the lateral wall appeared, and no obliteration of the costophrenic sinus, which was present in the first radiological control, was detected for the remaining 4. The other alterations observed remained unchanged.

Table 2. Adjusted association [measured as the odds ratio (OR)] between pleural alteration and the study variables. The OR and 95% confidence interval (95% CI) were obtained in a single multivariate model including all the variables in the table.

Variable	Workers with pleural alterations (N=43)		Workers without pleural alterations (N=677)		OR	95% CI	P-value
	N	%	N	%			
Silica-exposed group [a]							
Low	5	2.4	206	97.6	1	·	·
Medium	8	6	126	94	5.72	1.4–23.5	0.016
High	30	8	345	92	7.62	2.1–27.2	0.002
Smoking							
0 cigarettes/day	15	5.9	240	94.1	1	·	·
1–10 cigarettes/day	9	5.7	149	94.3	0.96	0.4–2.3	0.937
11–20 cigarettes/day	13	5.4	227	94.6	0.99	0.4–2.2	0.996
>20 cigarettes/day	6	9	61	91	2.13	0.7–6.0	0.154
Time worked [b]							
<11 years	8	7	106	93	1	·	·
11–20 years	25	5.3	446	94.7	0.78	0.3–2.0	0.604
>20 years	10	7.4	125	92.6	0.64	0.2–2.3	0.506
Alterations in parenchyma							
Yes	2	10	18	90	2.56	0.5–11.9	0.233
No	41	5.9	659	94.1	·	·	·
Rib alterations							
Yes	7	20	28	80	3.74	1.4–9.7	0.007
No	36	5.3	649	94.7	·	·	·

[a] Age: 40.1 years (6.5 %) for workers with pleural alterations and 39.8 years (5.7 %) for workers without pleural alterations, OR 1.01, 95% CI 0.9–1.1, P-value 0.779.

[b] Time between X-rays: 9.4 years (3.6 %) for workers with pleural alterations and 9.6 years (4.7 %) for workers without pleural alterations, OR 1.14, 95% CI 1.00–1.22, P-value 0.056.

Table 3. Adjusted association [measured as the odds ratio (OR)] between costophrenic sinus and the study variables. The OR and 95% confidence interval (95% CI) were obtained in a single multivariate model including all the variables in the table.

Variable	Workers with costophrenic sinus obliteration (N=43)		Workers without costophrenic sinus obliteration (N=677)		OR	95% CI	P-value
	N	%	N	%			
Silica-exposed group [a]							
Low	1	0.5	210	99.5	1	·	·
Medium	3	2.2	131	97.8	8.59	0.7–113	0.102
High	15	4	360	96	16.44	1.5–177	0.021
Smoking							
0 cigarettes/day	6	2.4	249	97.6	1	·	·
1–10 cigarettes/day	3	1.9	155	98.1	0.69	0.2–2.9	0.620
11–20 cigarettes/day	7	2.9	233	97.1	1.27	0.4–3.9	0.676
>20 cigarettes/day	3	4.5	64	95.5	3.16	0.7–13.1	0.113
Time worked [b]							
<11 years	6	5.3	108	94.7	1	·	·
11–20 years	102.12.2		461	97.9	0.49	0.2–1.5	0.216
>20 years	3		132	97.8	0.35	0.1–1.6	0.172
Alterations in parenchyma							
Yes	1	5	19	95	2.54	0.3–21.7	0.393
No	18	2.6	682	97.4	·	·	·
Rib alterations							
Yes	2	5.7	33	94.3	1.88	0.4–9.1	0.431
No	17	2.5	668	97.5	·	·	·

[a] Age: 39.1 years (6.7 %) for workers with costophrenic sinus obliteration and 39.8 years (5.7 %) for workers without costophrenic sinus obliteration, OR 1.00, 95% CI 1.0–1.0, P-value 0.260.

[b] Time between X-rays: 8.4 years (3.9 %) for workers with pleural alterations and 9.7 years (4.7 %)for workers without pleural alterations, OR 1.08, 95% CI 0.92–1.26, P-value 0.353.

With the exception of 1 worker, none of those studied had a clinical history of chest pain, dyspnea, or any other clinical event that would lead to a suspicion of pleural lesion. The symptomatic worker belonged to the high-exposure group, and no pleural alteration had been detected in his first radiological control. Ten years after the first exposure, he experienced chest pain, and pleural effusion was found after costophrenic sinus obliteration had been detected. An exhaustive study, including thoracocentesis, pleural biopsy and thoracoscopy, yielded no specific diagnosis.

Discussion

A silica-exposed coal-mining workforce with profusion of less than 1/0 in a chest X-ray according to the ILO classification (9) was studied. For this population, our results showed the appearance of some pleural change, as a whole, in a chest X-ray to be related to the degree of silica exposure intensity and rib alterations, while costophrenic sinus obliteration was linked only to silica exposure intensity. Independent randomized reading has been advocated in serial film readings owing to the bias that may occur in side-by-side readings (17). In our study, the kappa concordance index between readers for pleural alterations was 0.61, whereas, in the literature, the highest reported index is 0.58 (18). The readers in our study, chest physicians with experience with the pleura and with occupational diseases, were specially trained in the use of the ILO classification, which may explain the relatively low interobserver variability. Although the studied workers represented approximately 50% of the total workforce, we do not believe that self-selection of the workers spuriously increased the differences in pleural alterations according to silica exposure. These pleural X-ray changes were, in general, nonsymptomatic and therefore probably unrelated to health service attendance.

An idiopathic apical cap has been identified in 6% of people under 45 years of age and consists of nonspecific fibrosis of apical lung parenchyma that merges with the visceral pleura (19). Normal companion shadows in the chest wall, such as the serratus anterior muscle (20) and subpleural fat pads (21), may generate confusion by resembling localized, especially in the lateral chest wall, or generalized pleural thickening. Thus some of the pleural alterations found in our study may not have been significant. However, obliteration of the costophrenic sinus was the only pleural alteration associated with silica exposure intensity, and therefore it was probably not a casual finding. Moreover, obliteration of the costophrenic sinus is usually considered secondary to pleural effusion or a sequela of previous pleural effusions (22) and not to other causes.

We found no relationship between the radiological alterations observed in the lung parenchyma and pleural alterations; therefore, it seems unlikely that processes in lung parenchyma not due to pneumoconiosis, such as tuberculosis, could have been the cause of the alterations observed in our study. In fact, none of the workers had a clinical history of lung tuberculosis, and therefore the costophrenic sinus obliteration found was probably not a sequela of previous tuberculous pleuritis, since it is known that, during the 5 years after this process, 50–60% develop pulmonary or extrapulmonary tuberculosis (23). Furthermore, the risk of tuberculosis in nonpneumoconiotic miners exposed to silica dust is no greater than that of unexposed populations (24). The radiological rib lesions were related to those of the pleura, as a whole, but not with obliteration of the costophrenic sinus. It is known that rib fractures may produce pleural thickening secondary to regional hematoma in the fracture zone (25). On the other hand, the relative youth and intense physical activity of the study population may have helped to prevent some sequelae of post-traumatic pleural effusion in the costophrenic sinus, since pleural drainage is favored by both the indemnity of lymphatic capacity (22) and respiratory movements (26).

Coal is considered an inert material (27) and is therefore unlikely to be the cause of the pleural alterations observed. Furthermore, only nonspecific pathological pleural changes similar to those present in urban dwellers and cigarette smokers have been observed in non-pneumoconiotic coal miners (1). Several types of silicates (4–8), which may be present in variable amounts in coal mine dust, may produce different pleural diseases. Asbestos (5), zeolites (6), and wollastonite (7) are fiber-shaped silicates that have been related to radiological pleural alterations such as those found in our study. It seems unlikely, however, that these minerals could be the cause of the alterations observed in our study because neither fiber-shaped minerals nor asbestos, zeolites or wollastonite were found. Moreover, in the case of zeolites and wollastonite, the geological characteristics of the anthracite mine area render the presence of these minerals improbable (28). With the exception of mica (4), no other pleural alteration-related silicates (5–8) were found. However, for mica workers, only pleural calcifications have been described (4, 29, 30), but none of those found in the present study.

The existence of silica particles (31) has been reported for the pleura of nonpneumoconiotic persons exposed to silica. As occurs with asbestos, silica may cause edema of the mesothelial cell, alteration of microvillosities, separation of the basal lamina, exfoliation, exudative inflammation, and pleural effusion (32). Experimental studies with animals have shown that the intrapleural injection of quartz is invariably accompanied by a pleural effusion whose resolution is also in the form of pleural fibrosis (33). In fact, necropsic studies conducted on miners exposed to silica dust inhalation revealed pleural thickening and pleural collagenization (34), and even typical silicotic nodules (2), with no lung parenchyma involvement. However, little evidence exists that exposure to silica dust may cause radiological pleural alterations in nonpneumoconiotic persons. Over a period of 26 years, Cooper & Sargent (35) followed 473 employees of a diatomite mine. Pleural changes were found radiologically in 21 workers, only 11 of whom were diagnosed as silicosis according to the radiological findings. Denevik et al (36) found round atelectases in people exposed to silica dust without silicosis; this finding suggests that the irritative effect of silica in the pleura could be the cause. More recently, Zeren et al (37) reported a case of a silica-exposed patient without lung disease who had pleural thickening and chronic right pleural effusion attributed to the deposition of silica particles. This evidence and the results of our study suggest that silica may be the cause of costophrenic sinus obliteration in nonpneumoconiotic coal miners, although the possibility of other agents being implicated cannot be completely ruled out.

Lillis et al (38), on studying 2815 people in contact with asbestos, reported obliteration of the costophrenic sinus in 142 (5%) and a process consistent with benign pleural effusion in 20 (0.7%). Epler et al (39) showed that asbestos effusion was the most common within 10 years of first exposure; thereafter, effusion decreased in frequency and fibrosis increased. They also found that workers with high exposure had a greater incidence of effusions than those with a low exposure intensity. Although some of the obliterated costophrenic sinuses observed in the first chest X-ray control in our study were not detected later, most of the blunted costophrenic sinuses remained unchanged in the last control. It may be that, as in the case of asbestos (5), blunting of the angle often takes place between one routine examination and the next and is usually the sequela of a small asymptomatic undetected effusion. Similarly, the 16.5-year period elapsed from the time of the first exposure to the time of detection of the blunting angle and its relationship with exposure, more related to peak than to cumulative exposure, may be similar to those described for benign asbestos-related disease (39). However, more studies are required to confirm the findings of our study.

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