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Longitudinal analyses of chest radiographs from the European Carbon Black Respiratory Morbidity Study

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ABSTRACT: High levels of exposure to carbon black have been linked with an increased prevalence of chest radiograph abnormalities. However, it is unclear to what extent current levels of exposure in the carbon black manufacturing industry are associated with new cases of and progression in small opacities.

Longitudinal analyses were carried out on data from workers in the European carbon black manufacturing industry who provided three full-size chest radiographs sequentially between 1987–1995. All chest radiographs were independently read by three experienced readers according to the International Labour Organisation (ILO) classification.

After exclusion of participants with previous lung diseases or injuries, females, unreadable chest radiographs and from factories with a low participation rate, data from 675 workers were available for the longitudinal analyses. An association was observed between cumulative carbon black exposure and new cases of chest radiograph abnormalities (ILO category ⩾1/0) and progression in small opacities. These associations were mainly related to changes in chest radiographs from workers at one factory. A large percentage of workers with chest radiograph abnormalities reversed to normal chest films; however, after adjusting for other factors, this was not associated with levels of exposure to carbon black dust.

In conclusion, the results show that exposure to carbon black is associated with increased risk of chest radiographic abnormalities, which may be reversible after reduction or cessation of exposure.

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Carbon black is a very fine powdered form of elemental carbon and is manufactured by the controlled vapour phase pyrolysis of liquid or gaseous hydrocarbons [1]. Currently, the oil-furnace process accounts for >95% of world production, with most of the carbon black being used in the production of automotive tyres [2, 3].

Concern about health effects following inhalation of carbon black has given rise to a number of occupational respiratory morbidity and mortality studies, with equivocal results [2, 4–12]. Although the primary particles of carbon black (10–500 nm) readily aggregate and agglomerate to larger particles, these are still submicron in aerodynamic diameter, and therefore small enough to reach the distal airways and alveoli.

A detailed review of the literature of the respiratory health effects of occupational exposure to carbon black has been published previously, suggesting that most of these studies have either methodological shortcomings or lack the necessary detail for confident interpretation of the results [2]. Most of these studies suggest that long-term exposure to carbon black can lead to some form of pneumoconiotic changes [4, 8, 9, 13–20]. However, most of these studies were small, ranging from autopsy studies and case reports to populations of ~30–150 workers. There have been four large investigations into the prevalence of pneumoconiotic abnormalities amongst workers in the carbon black manufacturing industry, each utilising ostensibly the same (European) population and involving between ~1,000 and 2,000 workers. The first of these [4] found only six workers (out of 935, <1%) with chest radiograph abnormalities (International Labour Organisation (ILO) category ⩾0/1). Three linked cross-sectional investigations in the European carbon black industry have been reported [5] (I. Saez-Llorett, Institute of Occupational Health, University of Birmingham, Birmingham, UK; personal communication). These studies found considerably higher prevalences of small opacities (between 10–20% ILO category ⩾1/0). The prevalence of small opacities was associated with indices of personal dust exposure in each of the three, linked, cross-sectional surveys [5], although the prevalence had declined at the time of the last cross-sectional phase. In addition, a sharp reduction in exposure was observed, predominantly between the first and second survey, concurrent with a decline in smoking habits.

The studies referenced in the previous section were of a cross-sectional nature and therefore could not investigate longitudinal changes in the chest radiographs. By combining the three cross-sectional studies [5], a longitudinal cohort was established. The main aim of this paper is to investigate if current levels of exposure to carbon black are related to progressive changes in chest radiographs using the longitudinal component of these three cross-sectional studies, which covers a period of ~8 yrs. In addition, the relationship between exposure to carbon black and new cases of small opacities in Phase III will be studied. Finally, as exposure levels have dropped substantially since the first cross-sectional study [21, 22], this paper will investigate if the radiological changes found in the cross-sectional studies are reversible and if this is associated with exposure.

Methods

Population

Data were collected in 19 factories during three cross-sectional surveys [5, 12]. Data for the first survey were collected between September 1987 and April 1989; for the second survey between May 1991 and April 1992; and for the third survey between April 1994 and June 1995. Persons of either sex and in full-time employment for >1 month were eligible to participate in the study. All participants completed self-administered questionnaires on respiratory symptoms [23], occupational history, previous occupational exposures, smoking habits and previous lung illnesses, injuries or operations.

In the first survey, 2,879 subjects participated, with chest radiographs being available for 1,942 workers. Of these, chest radiographs were available in all three surveys for 952 workers (49%).

Readings of radiographs

Full sized chest radiographs (40×40 cm) were taken and evaluated independently by three experienced readers using the ILO 1980 International Classification of Radiographs of Pneumoconiosis [24]. As the chest films from the first survey were evaluated initially by a different team of readers and to reduce potential reader bias over time, all chest radiographs from the first and second surveys from participants in the longitudinal study were reread simultaneously with the films from the third survey.

The films were sent to the readers in random order, but with the three films for each participant read closely together in time. The readers were blind to all factors including the sequence in which the radiographs were taken. All readers used recording clerks to ensure that each reading was complete and in accordance with the classification. Trigger films were included at random throughout each batch, and immediately after reading a trigger film, the recording clerk would inform the reader of the agreed trigger reading [25]. The readers also recorded the technical quality of the chest radiograph on a scale from 1 (good) to 4 (unacceptable). In cases where readers disagreed, the median was determined by ordering the three readings for each feature of the ILO classification and taking the middle reading.

Exposure assessment

Exposure estimates were obtained from three extensive assessment surveys that ran concurrently with the three cross-sectional studies [1, 21, 22, 26]. In total, 8,015 personal inhalable dust measurements were taken, using the Institute of Occupational Medicine sampling head with a flow rate of 2 $L \cdot min^{-1}$ [27]. Individual exposure estimates were obtained by calculating the arithmetic mean (AM) exposure for each combination of factory and job category. Individual cumulative exposure was calculated by multiplying the number of months employed with the exposure estimate (AM) for that job category taking into account the changes in levels of exposure since the first survey and work history.

Statistical analyses

In total, 2,856 full sized chest radiographs from 952 workers were available for analyses. All workers with previous lung injuries or operations, pleurisy, pulmonary tuberculosis and/or bronchial asthma were excluded, as were all workers from factories with participation rates in the first survey of <60%. In addition, all females were excluded as their number was small and most were administrative workers, hence, they were not exposed. Finally, workers with at least one unreadable chest radiograph were excluded.

Presence of small opacities was defined as a chest radiograph with a median reading of small opacity profusion of category 1/0 or higher, using the ILO International Classification of Radiographs of Pneumoconiosis [24]. For the longitudinal analyses, progression in small opacities was defined as an increase of ⩾two ILO subcategories between the first and the third survey (*e.g.* from 0/1 to 1/1). Participants with normal chest radiographs in the first phase (*i.e.* 0/0 or 0/1) but with small opacities in the third survey (⩾1/0) were defined as new cases with small opacities. Regression in small opacities was defined as a decrease of ⩾two ILO subcategories, whilst reversion was defined as changing from an abnormal chest radiograph in the first phase to a normal chest radiograph in the third survey.

Cumulative inhalable dust exposure between the first and third survey was entered into the models as a categorical variable (high, medium or low). These exposure groups were created by ranking the workers according to exposure and choosing cut-off points so that each group contained more or less equal numbers of workers (*i.e.* tertiles). Other exposure metrics were also considered, but these were either highly correlated with cumulative exposure between the surveys

Table 1. – Comparison of the cross-sectional (n=1,942) and longitudinal (n=952) populations with chest radiographs

	Cross-sectional survey I	Longitudinal cohort
Age yrs	42	38
Duration of employment months	178.0	162.2
% Females	6.9	6.5
% Smokers	50.6	51.2
% Exsmokers	27.0	25.9
Current inhalable mg·m^{-3}	1.6	1.6
Cumulative inhalable mg·month·m^{-3}	299.1	279.0
Small opacities#	12.5	10.4
Cough %	17.8	15.1
Sputum %	17.2	17.2
Cough with sputum %	10.1	9.2
Wheezing	8.5	8.1
Dyspnoea 2+	3.4	1.9
Breathlessness with wheezing	3.4	3.2
Chronic bronchitis	4.9	4.5
FVC % pred	108.8	110.9
FEV_1 % pred	104.1	105.9
FEF_{25-75} % pred	85.6	87.3
FEV_1:FVC % pred	91.4	91.8

FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; FEF_{25-75}: forced midexpiratory flow. #: prevalence of small opacities (International Labour Organisation category ⩾1/0) given here is based upon the original survey readings.

(such as mean exposure level over the three surveys or exposure level at the first or third survey) or were thought to be estimated with unacceptable error (such as cumulative exposure prior to the first survey).

Multivariate logistic regression analyses were carried out to test if progression, regression, new cases and reversion of small opacities were related to cumulative carbon black exposure whilst adjusting for potential confounders such as smoking habits and age. For the analyses on new cases, only those workers with normal chest radiographs (ILO category 0/0 or 0/1) in the first survey were used. For the analyses on regression in and reversion of small opacities, only those with chest radiograph abnormalities (ILO category ⩾1/0) in the first survey were used.

Results

Population

The average age in the first survey of participants with chest radiographs in all three surveys (*i.e.* the longitudinal cohort) was 38 yrs and 51% were current smokers (table 1). The average age of the longitudinal cohort was somewhat lower than that of the total population for which chest radiographs were available in the first cross-sectional survey, whilst there was little difference in smoking habits. Some minor differences were observed in prevalence of small opacities, prevalence of respiratory symptoms and average value of the lung function parameters (table 1).

After excluding all participants with previous lung injuries or operations, pleurisy, pulmonary tuberculosis and/or bronchial asthma (n=129); all workers from factories with participation rates in the first survey of >60% (n=90); all females (n=55); and workers with at least one unreadable chest radiograph (n=4); data from 675 workers with three chest radiographs were available for the longitudinal analyses. The average age of this group was 38 yrs (range 18–59 yrs) in the first survey, with an average duration of employment of ~13 yrs (mean 157 months, range 2–409 months) (table 2). In the first survey, 54% of the workers were current smokers and 25% exsmokers; the percentage of current smokers dropped to 49% in the second and 46% in third survey.

Dust exposure

Mean inhalable dust exposure dropped significantly from 1.5 mg·m^{-3} in the first to 0.9 mg·m^{-3} in the second and 0.6 mg·m^{-3} in the third survey. The mean cumulative inhalable dust exposure between the first and the third survey was 70.1 mg·month·m^{-3}, with a range of 11.1–564.8 mg·month·m^{-3}. All workers were grouped into one of three cumulative inhalable dust exposure groups. There was little difference in average age and duration of employment between the

Table 2. – Population characteristics categorised by cumulative inhalable dust exposure between the first and third survey

		Cumulative inhalable dust exposure between phase I and III		
	All	Low	Medium	High
Subjects n	675	225	232	218
Age	38 (9)	38 (9)	39 (8)	37 (9)
Duration of employment	13.1 (8.1)	13.1 (8.7)	14.2 (7.8)	11.7 (7.6)
Smokers in phase I %	53.6	43.3	57.1	60.4
Smokers in phase III %	46.2	33.3	57.1	53.0
Cumulative dust exposure mg·month·m^{-3} (range)	70.1 (11.1–564.9)	20.4 (11.1–30.6)	54.8 (31.5–79.1)	137.8 (82.1–564.9)

Data are presented as mean (SD) unless otherwise stated.

Table 3. – Median International Labour Organisation (ILO) profusion category by phase and the percentage of radiographs with a median ILO category of ⩾1/0 (males only)

	Phase I		Phase II		Phase III	
	n	%	n	%	n	%
0/0	372	55.1	353	52.3	328	48.6
0/1	209	31.0	188	27.9	214	31.7
1/0	56	8.3	86	12.7	79	11.7
1/1	35	5.2	42	6.2	45	6.7
1/2	1	0.1	4	0.6	4	0.6
2/1	1	0.1			3	0.4
2/2	1	0.1	2	0.3	2	0.3
⩾1/0	94	13.9	134	19.9	133	19.7

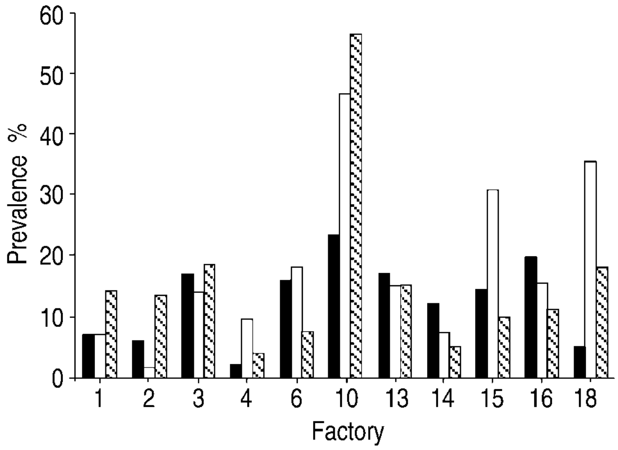

Fig. 1. – Prevalence with small opacities of International Labour Organisation ⩾1/0 by survey and factory. ■: survey I; □: survey II; ▧: survey III.

exposure groups, but there were fewer smokers in the low exposed group (table 2).

Prevalence of small opacities

The majority of the film quality of these chest radiographs was classified as acceptable (film quality 2), whilst the percentage of poor films (film quality 3) increased from 3.5% in the first to 6.9% in the third survey. The prevalence of small opacities (ILO category ⩾1/0) was 13.9% in the first survey, rising to 19.9% in the second and 19.7% in the third survey (table 3); with the majority of the opacities being irregular in all three surveys (predominant shape/size was t (small irregular opacities with a width 1.5–3 mm)). The number of workers with small opacities of ILO category ⩾1/2 increased from three in the first survey to nine in the third survey. Of these nine workers, one had a forced vital capacity (FVC) which was <90% of predicted when using the equations derived from the European Coal and Steel Community [28], and one could not produce a valid spirometry trace according to the criteria of the American Thoracic Society [29]. Five of these nine workers reported working with asbestos in either their current or previous jobs.

The majority of the increase in prevalence of small opacities was found in participants from factory 10 (fig. 1). In fact, if this factory was excluded from the analyses, the prevalence of small opacities would have been relatively stable across the three surveys (11.7%, 13.6% and 11.0%, respectively).

Progression and new cases of small opacities

Progression of at least two ILO subcategories between the first and third survey was observed in 43 workers (6.4%). The majority of progression (90%) was from ILO subcategory 0/0 to 1/0 or from 0/1 to 1/1. Only four cases of existing chest radiograph abnormalities progressed to higher ILO categories; two from 1/0 to 1/2 and two from 1/1 to 2/2.

Significant differences were found in progression of small opacities between cumulative inhalable dust exposure groups (Chi-squared 9.2; p=0.010) (table 4). Smoking status also appeared to be a significant predictor of progression in small opacities, with 2.1% in the nonsmokers, 4.0% in the exsmokers and 9.9% in the current smokers (Chi-squared 12.9; p=0.002). No significant differences in progression of small opacities were found for self-reported asbestos exposure, previous dusty occupations, birth decades, or for median chest radiograph reading in the first survey. However, significant differences were found between the film quality, with 16.7% of those workers with a poor quality chest radiograph having progression of ⩾two ILO subcategories. Chi-squared tests showed that factory was a strong predictor of progression in small opacities (Chi-squared 81.7; p<0.001), with the majority of subjects with progression coming from factory 10 (23% of workers in factory 10, compared with 2% in the remaining factories).

Out of 581 workers with a normal chest radiograph in the first survey, 77 workers (13.3%) had chest radiograph abnormalities (⩾1/0) in the third survey. Again, the majority of these came from factory 10 (45% of workers in factory 10, compared with 6.7% in the remaining factories) (Chi-squared 113.4; p<0.001). Chi-squared tests showed statistical significant associations between new cases of small opacities and cumulative inhalable dust exposure (Chi-squared 24.3; p<0.001), smoking status in the third survey (Chi-squared 16.1; p<0.001), ILO-category in first survey (Chi-squared 35.3; p<0.001) and film quality in the first survey (Chi-squared 21.1; p<0.001) (table 4). For the cumulative exposure groups, new cases of small opacities occurred in 4.3% in the low, 16.4% in the medium and 20.5% in the high exposed group, respectively.

Table 5 shows the results of multiple logistic regression analyses for progression in ILO subcategory and new cases of small opacities. Smoking and cumulative inhalable dust exposure were statistically significantly associated with progression of ⩾two ILO subcategories, whilst film quality was of borderline statistical significance (p=0.067). The odds ratio (OR) for the highest cumulative exposure group was 3.1 (p=0.017) and for the medium exposure group 2.1 (p=0.141).

Table 4. – Results of univariate analyses on progression of ⩾2 International Labour Organisation (ILO) categories on chest radiographs or new cases of small opacities for various exposure indices

	Progression				New cases			
	n	%	χ^2	p-value	n	%	χ^2	p-value
Cum. Inh. survey I–III								
Low (<31 mg·month·m^{-3})	225	2.7			210	4.3		
Medium (31–80 mg·month·m^{-3})	232	6.9	9.2	0.010	195	16.4	24.3	<0.001
High (>80 mg·month·m^{-3})	218	9.6			176	20.5		
Duration of employment#								
Low (<103 months)	226	5.8			205	13.7		
Medium (103–205 months)	225	8.0	1.5	0.465	190	15.8	2.6	0.274
High (>205 months)	224	5.4			186	10.2		
Smoking survey III								
Never	140	2.1			129	5.4		
Ex	223	4.0	12.9	0.002	191	10.5	16.1	<0.001
Current	312	9.9			261	19.2		
Year of birth								
<1940	120	6.7			104	12.5		
1940–1949	250	7.2	0.7	0.862	201	14.9	1.1	0.770
1950–1959	192	5.2			168	11.3		
>1959	113	6.2			108	13.9		
Asbestos exposure (self-reported)								
No	466	6.2	0.1	0.815	409	12.7	0.3	0.555
Yes	209	6.7			172	14.5		
Dust exposure (self-reported)								
No	473	6.1	0.2	0.697	413	12.3	1.0	0.313
Yes	202	6.9			168	15.5		
ILO reading in survey I								
0/0, 0/1	581	6.7	0.8	0.365				
⩾1/0	94	4.3						
ILO reading in survey I								
0/0					372	7.0	35.3	<0.001
0/1					209	24.4		
Film quality survey I								
Good	65	0.0			64	0.0		
Acceptable	586	6.7	8.8	0.012	496	13.9	21.2	<0.001
Poor	24	16.7			21	38.1		

χ^2: Chi-squared test; Cum. Inh. survey I–III: cumulative inhalable dust exposure between the first and third survey. #: duration of employment in the first survey.

Workers with an ILO reading in the first survey of 0/1 were more than three times more likely to have abnormal chest radiographs in the third survey compared to those with a reading of 0/0 in the first survey (table 5). Again, smoking and cumulative inhalable dust exposure were statistically significant predictors of new small opacities. Compared to the low exposure group, the medium exposed group had an OR of 3.5 (p=0.002) and the high exposed group an OR of 4.6 (p<0.001).

Regression and reversion of small opacities

The analyses of regression in and reversion of small opacities were limited to those workers with a median ILO category in the first survey of ⩾1/0 (*i.e.* those who have the opportunity to regress) (n=94). Of these workers, 13 had median readings that were at least two ILO subcategories lower in the third compared to the first survey. Chi-squared tests revealed significant associations between regression and year of birth and film quality in the first survey, although the Chi-squared test may not be valid due to small numbers (*i.e.* <5) in some of the cells (table 6).

Of the 94 workers with abnormal chest radiographs in the first survey, 38 (40.4%) had normal chest films in the third survey. Chi-squared tests indicated that this reversal of chest radiograph abnormality was associated with cumulative dust exposure, smoking status and ILO reading in the first survey (table 6). Reversal of abnormality occurred in 73.3% of subjects in the low, 32.4% in the medium and 35.7% in the high exposed group (Chi-squared 8.1; p=0.017). These percentages were 72.7% for nonsmokers, 46.9% for exsmokers and 29.4% for current smokers, respectively (Chi-squared 7.9; p=0.019). For those with a median reading of 1/0 in the first survey, the probability of reversal in Phase III was 57.1% compared with 15.8% for those with median readings of ⩾1/1 (Chi-squared 16.1; p<0.001).

Results of multiple logistic regression analyses are presented in table 7. High ORs for regression and reversion were found for nonsmokers, young workers and for workers with an ILO subcategory in the first survey of 1/0 (compared with those with ILO

Table 5. – Results of multiple logistic regression models with progression of ⩾2 International Labour Organisation (ILO) categories or new cases of small opacities as dependent variables

	Progression		New cases	
	OR	CI	OR	CI
Smoking				
Non				
Ex	1.7	0.5–6.5	1.5	0.6–3.9
Current	4.1	1.2–13.9	2.6	1.1–7.0
Film quality in survey I				
Good/acceptable				
Poor	3.0	0.9–9.4	2.5	0.9–7.0
ILO category survey I				
0/0				
0/1			3.5	2.0–5.9
Cum. Inh. survey I–III				
Low (<31 mg·month·m^{-3})				
Medium (31–80 mg·month·m^{-3})	2.1	0.8–5.5	3.5	1.6–7.6
High (>80 mg·month·m^{-3})	3.1	1.2–8.0	4.6	2.1–10.0

OR: odds ratio; CI: 95% confidence interval; Cum. Inh. survey I–III: cumulative inhalable dust exposure between the first and third survey.

subcategory ⩾1/1). Elevated ORs for regression and reversion were also found for low exposed workers, but these were not statistically significantly different from unity (table 7).

Significant differences were found between the factories, with only two of the 30 subjects (6.7%) in factory 10 with chest radiograph abnormalities in the first survey reverting to normal; for the remaining factories this was 56%.

Discussion

This paper describes the results of longitudinal analyses of chest radiographs from a large study of workers in the carbon black manufacturing industry in Europe. Previously, statistically significant associations between occupational dust exposure in this industry and increased prevalence of small opacities have been reported [5]. However, these reports also showed that, after an initial increase, the prevalence of abnormal chest radiographs declined during the last two cross-sectional surveys, whilst exposure levels and smoking habits also decreased (I. Saez-Llorett; personal communication).

The prevalence of small opacities in the longitudinal

Table 6. – Results of univariate analyses on regression in International Labour Organisation (ILO) score of ⩾2 categories or on reversion on small opacities for various exposure indices

	Regression				Reversion			
	n	%	χ^2	p-value	n	%	χ^2	p-value
Cum. Inh. survey I–III								
Low (<31 mg·month·m^{-3})	15	26.7			15	73.3		
Medium (31–80 mg·month·m^{-3})	37	13.5	2.7	0.255	37	32.4	8.1	0.017
High (>80 mg·month·m^{-3})	42	9.5			42	35.7		
Duration of employment[#]								
Low (<103 months)	21	23.8			21	42.9		
Medium (103–205 months)	35	14.3	2.9	0.236[¶]	35	40.0	0.1	0.966
High (>205 months)	38	7.9			38	39.5		
Smoking status in survey III								
Never	11	27.3			11	72.7		
Ex	32	15.6	2.4	0.294[¶]	32	46.9	7.9	0.019
Current	51	9.8			51	29.4		
Year of birth								
<1950	29	20.7	9.5	0.023[¶]	16	25.0		
>1950	65	10.8			49	42.9	5.0	0.169[¶]
Asbestos exposure (self-reported)								
No	57	17.5	1.7	0.195[¶]	57	43.9	0.7	0.400
Yes	37	8.1			37	35.1		
Dust exposure (self-reported)								
No	60	10.0	2.0	0.153[¶]	60	38.3	0.3	0.583
Yes	34	20.6			34	44.1		
ILO reading in survey I								
1/0	56	12.5	0.2	0.650	56	57.1	16.1	<0.001
⩾1/1	38	15.8			38	15.8		
Film quality survey I								
Good	1	100.0			1	100.0		
Acceptable	90	13.3	6.7	0.035[¶]	90	38.9	2.4	0.298[¶]
Poor	3	0.0			3	66.7		

χ^2: Chi-squared test; Cum. Inh. survey I–III: cumulative inhalable dust exposure between the first and third survey. [#]: duration of employment in the first survey; [¶]: in some of the cells the expected number of observations is <5 and therefore the Chi-squared test may not be valid.

Table 7. – Results of multiple logistic regression models with regression of ⩾2 (International Labour Organisation) (ILO) categories or reversion of small opacities as dependent variables

	Regression		Reversion	
	OR	CI	OR	CI
Smoking status in survey I				
Non	4.5	0.7–29.5	11.3	1.7–75.5
Ex	2.3	0.5–10.4	2.0	0.7–5.8
Current				
Year of Birth				
<1940				
1940–1949	1.3	0.2–8.6	3.2	0.6–16.1
1950–1959	1.5	0.2–12.0	2.8	0.5–17.0
>1959	11.2	0.9–142.9	21.1	1.3–354.5
Asbestos exposure (self-reported)	0.6	0.1–3.0		
Dust exposure (self-reported)	2.3	0.6–8.5		
ILO category in survey I				
1/0			7.1	2.2–23.1
>1/0				
Cum. Inh. survey I–III				
Low (<31 mg·month·m^{-3})	1.7	0.4–7.6	1.6	0.5–5.6
Medium (31–80 mg·month·m^{-3})	0.7	0.1–5.3	1.4	0.4–4.9
High (>80 mg·month·m^{-3})				

OR: odds ratio; CI: 95% confidence interval; Cum. Inh. survey I–III: cumulative inhalable dust exposure between the first and third survey.

cohort varied between 14–20% over the study period. The predominant shape of the opacities was irregular, which is in contrast with the findings from GARDINER *et al.* [5] who reported that the predominant primary shape was rounded, and with the study by CROSBIE [4] who only reported rounded opacities. The prevalence of small opacities in the longitudinal cohort was somewhat higher than that reported for all participants in the first (9.9%) [5] and third cross-sectional survey (9.7%), but similar to the prevalence in the second survey (19.1%) (I. Saez-Llorett; personal communication). The differences are due partly to the fact that factory 10, which had a high prevalence of small opacities, was not included in the cross-sectional analyses of the first and third survey, as the participation rate in these surveys was <60% for this factory. However, shortly after completion of the first survey, additional chest radiographs were received from factory 10, which increased the participation rate to >60%, and therefore allowing for the inclusion of this factory in the longitudinal analyses (note: only the participation rate in the first cross-sectional survey was part of the inclusion criteria for the longitudinal study and not the participation rates in the subsequent cross-sectional surveys). In addition, the initial readings of the first cross-sectional survey cannot be compared directly with results presented here as all films from the first survey have been reread by different readers.

Multiple logistic regression analyses showed an association between recent cumulative dust exposure and new cases of chest radiograph abnormalities (ILO category ⩾1/0) and progression in small opacities. Estimates of cumulative inhalable dust rather than respirable dust were used in the longitudinal analyses, even though data on respirable dust were available. Due to the relatively low dust concentrations it was felt that inhalable dust exposure was assessed with more precision due to the collection of more material on the filters. In addition, inhalable and respirable dust concentrations were highly correlated in this industry.

Other factors associated with progression were smoking, chest radiograph reading in the first survey and quality of chest radiograph. Film quality could, through its link with obesity, be a marker for unhealthy lifestyle, which may explain the link with progression in small opacities. New cases of chest radiograph abnormalities and workers with progression in small opacities had significantly lower percentage of predicted forced expiratory volume in the first second of expiration (FEV1) in the third compared to the first survey. The FVC remained unchanged. Obstructive airflow disorders (*e.g.* chronic obstructive pulmonary disease) may be associated with decreased clearance and increased retention of carbon black and other particles as shown for other dusts. This may explain why FEV1 and not FVC appear to be related to progression.

Few cases of progression to higher ILO category opacities (⩾1/2) were observed during this study and it is unclear if the progression in these cases was due to carbon black exposure.

Reversion of chest radiograph abnormality occurred in 38% of all participants with small opacities in the first survey. This was associated with smoking status, year of birth and initial chest radiograph reading. After adjusting for these factors, no significant association was found with dust exposure. However, these analyses were of very limited power due to the small number of workers (n=94). Regression in small opacities or reversion of chest radiograph abnormalities did not have a statistically significant effect on the lung function parameters. Apart from environmental and lifestyle factors, the underlying cause of regression in the small opacities and reversion of chest radiograph could be a regression to the mean.

Large differences in longitudinal effects in the chest radiographs were observed between the factories. Significantly more progression and new cases of chest radiograph abnormalities were observed in factory 10 compared to the other factories. Factory 10 still exploits the lamp and channel black methods of production, which can give rise to relatively high exposures to airborne particulates of different size and physiochemical properties [30]. Exposure levels were significantly higher for the participants in factory 10 compared to the exposure levels from participants in other factories and more workers smoked in factory 10.

In addition, the difference between factory 10 and the other factories may be attributable in part to some selection bias in factory 10. Only 33% of the participants of the first phase from this factory were included in the longitudinal analyses compared with 53–82% from the other factories.

When observations from factory 10 were excluded from the analyses, no statistically significant associations were found between exposure and progression in or new cases of small opacities. However, this could be due simply to the limited power of the study with the loss of a large proportion of the subjects.

In conclusion, the longitudinal analyses presented in this paper show an association between the recent cumulative dust exposure and progression in small opacities and new cases of small opacities, although only a few cases of progression to higher International Labour Organisation categories were observed. It is unlikely that any shadowing on radiographs is simply deposited carbon black as phantom studies showed that a thickness of 2–3 cm was required before being evident on radiographic plates [31]. Workers in the carbon black industry with small opacities on the chest radiographs had lower lung function (forced vital capacity) than those with normal chest radiographs (I. Saez-Llorett; personal communication), raising the possibility of some tissue interaction. This interaction could be due to the ultrafine nature of the primary carbon black particles, as it has been shown that very fine carbon black particles have a greater potency to cause inflammatory reactions in lung tissue compared to larger particles sizes [32, 33]. However, it is unclear if this is also the case for airborne carbon black particles as the primary particles are generally agglomerated and aggregated in much larger particles.

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