

Coalworkers' pneumoconiosis: correlation between opacity profusion and number and type of dust lesions with special reference to opacity type

JUNE M FERNIE, V ANNE RUCKLEY

From the Institute of Occupational Medicine, Edinburgh EH8 9SU, UK

ABSTRACT The relation between the profusion and predominant type of small rounded opacities on chest radiographs taken within four years of death and the postmortem counts of dust lesions in four classes (macules, "pinhead" fibrotic nodules, nodules 1-3 mm, and nodules >3-9 mm in diameter) has been examined for 71 coalworkers without progressive massive fibrosis. The radiographs were categorised by four readers independently, according to the ILO classification. For subjects considered by each reader to present predominantly p type opacities, increasing opacity profusion was exclusively and significantly associated with an increase in the number of pinhead fibrotic nodules. Numbers of nodules measuring 1-3 mm and >3-9 mm in diameter both showed significant linear associations with opacity profusion category in subjects presenting predominantly q opacities, the closer association being observed with the smaller lesions. These observations held true for all readers. Opacities of type r were rarely considered to be the predominant type. For the reader who recorded the maximum number of such cases, opacity profusion was not significantly related to the numbers of dust lesions in any of the lesion classes. Nevertheless, the closest association was observed with nodules measuring >3-9 mm in diameter. An overall significant linear association between total lung dust content and opacity profusion was found to be due mainly to subjects presenting predominantly p type opacities and to a lesser extent to those with predominantly q opacities.

Radiological pathological correlations are of particular importance in coalworkers' pneumoconiosis because they are the only means of establishing how reliable the radiological classification is in assessing the extent and severity of the disease. They also provide data which may allow the visualisation of what is present in the lung when a certain radiological category is read. Although several studies of this nature have been carried out,¹⁻⁴ the emphasis has been on determining how the profusion of small rounded opacities relates to the number and character of dust lesions within the lung, opacity type being largely ignored.

In a recent study of "pure" opacity types we showed that the three types of small rounded opacity, p, q, and r, present somewhat different pathological features with regard to dust lesion size, shape, and extent of fibrosis.⁵ On the basis of these results it

seemed logical to suppose that in coalworkers the relation between profusion of opacities and the number and character of dust lesions might vary according to the type of opacity. This we have investigated in the present study. We also report the results of preliminary analyses in which we considered the two factors, profusion and type of opacity, separately.

Lastly, we have included data on the content and composition of lung dust in our study subjects; we thought that these data would help in the interpretation of our findings in view of the relation between the content and composition of lung dust and radiological category.^{4 6 7}

Materials and methods

SUBJECTS

Seventy one coalworkers were included in this study, these being a subgroup of the 261 coalworkers on whom our earlier radiographic study⁵ was based. All the men had been employed at collieries included in

the Pneumoconiosis Field Research of the National Coal Board and in most instances their lungs were obtained from the pneumoconiosis medical panels. Selection for our previous radiographic study⁵ was dependent on the availability of a chest radiograph taken within four years of death; the additional selection criteria applied in the present study were the absence of progressive massive fibrosis as confirmed pathologically (no lesions ≥ 1 cm in diameter), the presence of at least one smaller fibrotic lesion, and the availability of detailed dust lesion counts.

SOURCE AND CLASSIFICATION OF RADIOGRAPHS

Radiographs were obtained from the pneumoconiosis medical panels or from hospitals, or were those taken during the Pneumoconiosis Field Research surveys. All 71 radiographs were read independently by four experienced National Coal Board medical officers.

The classification used was the 1971 ILO U/C classification⁸ in which the profusion of small rounded opacities is recorded on a 12 point incremental scale and opacity type is recorded using two characters, the first denoting the predominant type of opacity seen.

DUST LESION COUNTS AND CLASSIFICATION

The lungs were sliced at 1 cm intervals in the sagittal plane and a representative slice (usually the mid-sagittal) chosen for assessment. The dust lesions present on that slice were recorded in four size/type classes using fixed calipers to define size boundaries. The classes were: macules, "pinhead" fibrotic nodules < 1 mm, nodules 1-3 mm, and nodules > 3-9 mm in diameter, a nodule being defined as circumscribed dusted tissue which offered resistance to needle palpation. Where counts were available for both left and right lungs the average was used; otherwise counts from a single lung were taken to represent that subject.

MEASUREMENT OF LUNG DUST CONTENT

Dust was recovered from representative samples of dried lung⁹ and ashed to constant weight. Coal content was calculated from weight loss during ashing and the residual ash was analysed for quartz, kaolin,

and mica by infrared spectrophotometry.¹⁰ The dust content of a pair of lungs was calculated by multiplying the measured weight in one lung by the corrective factors of 2.16 or 1.86 depending on whether the left or right lung was analysed.¹¹

Results

RELATION BETWEEN PROFUSION OF OPACITIES AND COUNTS OF DUST LESIONS

Initially, the profusion scores for small rounded opacities were reduced from a 12 to a four point scale giving categories 0 (0/-, 0/0, 0/1), 1 (1/0, 1/1, 1/2) 2 (2/1, 2/2, 2/3), and 3 (3/2, 3/3, 3/4). Mean numbers of dust lesions within each of the four classes were then calculated for subjects assigned to categories 0, 1, 2, and 3. Table 1 illustrates the values obtained for reader 1; similar trends were evident for the other three readers. It may be seen from table 1 that from category 0 to 3 there is an overall increase in the total number of dust foci present within the lung, which is accounted for by an increased number of pinhead fibrotic nodules and also nodules measuring 1-3 mm and > 3-9 mm in diameter.

Regression of opacity profusion score (on a 12 point scale) against numbers of dust lesions within each of the four classes, and also total number of dust lesions, showed that for all four readers rising profusion category was most closely associated with an increase in the number of fibrotic nodules measuring 1-3 mm in diameter. This linear association, however, was significant for only one reader (reader 1, $p < 0.05$).

The total lung dust content showed a closer positive linear association with radiographic opacity profusion than did the counts of any of the dust lesion classes ($r = 0.54 - 0.62$, $p < 0.02 - < 0.001$ for the four readers). This result is not illustrated.

RELATIONSHIP BETWEEN TYPE OF OPACITY AND COUNTS OF DUST LESIONS

For each reader the mean numbers of dust lesions within each of the four classes were calculated for subjects considered to present no small rounded opacities or predominantly type p, q, or r. The mean values obtained for reader 3 (taken as an example) are

Table 1 Mean (standard deviations) numbers of dust lesions within each lesion class for subjects read as category 0, 1, 2, or 3 by reader 1

SRO profusion	Macules	Pinheads	Nodules (1-3 mm)	Nodules (>3-9 mm)	All foci
0 (n = 43)	78.3 (56.7)	22.5 (29.2)	11.9 (11.8)	2.4 (3.3)	114.2 (77.8)
1 (n = 18)	92.4 (63.5)	39.1 (68.7)	26.3 (15.2)	5.2 (6.5)	170.0 (104.0)
2 (n = 8)	97.2 (46.2)	40.5 (29.7)	36.7 (35.6)	5.3 (6.0)	180.5 (42.5)
3 (n = 2)	42.5 (34.6)	64.5 (30.4)	64.5 (74.2)	12.0 (14.1)	183.5 (92.6)

Table 2 Mean (standard deviations) number of dust lesions within each lesion class for subjects considered by reader 3 to show no small rounded opacities or predominantly type p, q, or r. The table also shows the mean profusion category, lung dust content, and percentage composition for subjects in these four opacity type groups

	Opacity type			
	o (n = 13)	p (n = 8)	q (n = 44)	r (n = 6)
Macules	60.0 (31.6)	112.6 (67.2)	88.0 (59.9)	40.5 (19.5)
Pinheads	21.8 (41.8)	54.5 (29.0)	30.4 (47.1)	11.2 (8.5)
Nodules (1-3 mm)	7.2 (9.0)	14.1 (9.4)	20.9 (21.1)	47.5 (35.0)
Nodules (> 3-9 mm)	1.6 (3.4)	0.5 (0.8)	4.1 (5.7)	9.0 (3.1)
Opacity profusion	—	2/2	2/1	2/1
Lung dust content (g)	8.8 (7.4)	28.9 (11.7)	15.2 (8.0)	17.3 (4.1)
Percentage ash	39.1 (17.9)	20.1 (7.5)	38.9 (18.8)	56.4 (23.5)

shown in table 2, together with the mean values for opacity profusion and lung dust content and composition (percentage ash). Several points emerge from table 2. Firstly, the lungs of subjects read as category O may contain several pinhead fibrotic lesions; they may also contain fibrotic lesions measuring 1-3 mm and even > 3 mm in diameter. Secondly, the lungs of subjects presenting predominantly p radiographic opacities contained more macules and pinhead fibrotic nodules than those of subjects presenting q or r opacities; the latter group showed the smallest numbers of these two classes of dust lesion. With regard to the larger fibrotic lesions, there was an increase in the mean numbers of both those measuring 1-3 mm and those measuring > 3-9 mm in diameter moving from the p through the q to the r group.

The additional information presented in table 2 indicates that the mean profusion scores were similar for the three small rounded opacity groups. The mean lung dust content, however, was highest for subjects in the p group whereas the retained dust of subjects in the r group contained the highest proportion of ash.

The results obtained for readers 1, 2, and 4 followed trends similar to those illustrated for reader 3.

RELATION BETWEEN PROFUSION OF OPACITIES AND COUNTS OF DUST LESIONS, WITH REFERENCE TO TYPE OF OPACITY

For each reader, subjects were subdivided by predominant type of radiographic opacity seen and, for the groups p, q, and r, opacity profusion (on a 12 point scale) was regressed against the number of dust lesions within each dust lesion class.

P OPACITIES

For all four readers, increasing opacity profusion was most closely associated with an increase in the number of pinhead fibrotic nodules ($r = 0.49-0.79$), and for three readers (1, 3, and 4) this association was significant ($p < 0.05-p < 0.01$). Figure 1 illustrates the relation observed for reader 3. No significant correlations were observed between p opacity profusion and any of the other dust lesion classes. For

three of the readers (1, 2 and 4), however, the variable which correlated best with p opacity profusion was total lung dust content ($r = 0.61-0.67$, $p < 0.05-p < 0.001$).

Q OPACITIES

In subjects presenting predominantly q opacities profusion category correlated with numbers of dust lesions in two classes, nodules 1-3 mm and nodules > 3-9 mm in diameter; these associations were significant for all four readers. For three readers (1, 2, and 3) the closest association was observed with the smaller nodule class ($r = 0.52-0.70$, $p < 0.001$). This association is illustrated for reader 1 in fig 2. Counts of macules and pinheads were unrelated to profusion category.

In general, the association between opacity profusion and lung dust content was weaker in subjects presenting q compared with p opacities ($r = 0.07-0.57$, $p > 0.05-p < 0.001$ for the four readers), and for only one reader (3) did the association better than observed with the nodule counts.

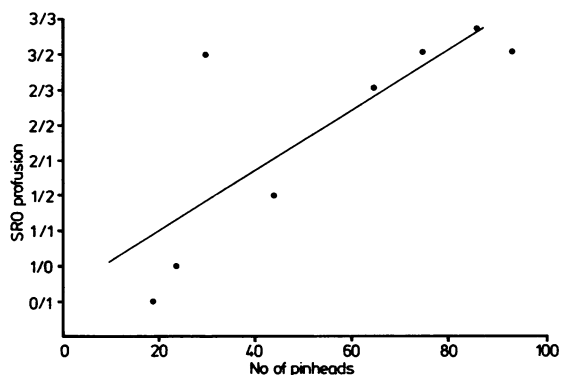


Fig 1 Relation between opacity profusion and number of pinhead nodules for subjects considered to present predominantly p opacities by reader 3.

Line of best fit $y = 1.31 + 0.084x$, $n = 8$, $r = 0.79$, $p < 0.02$.

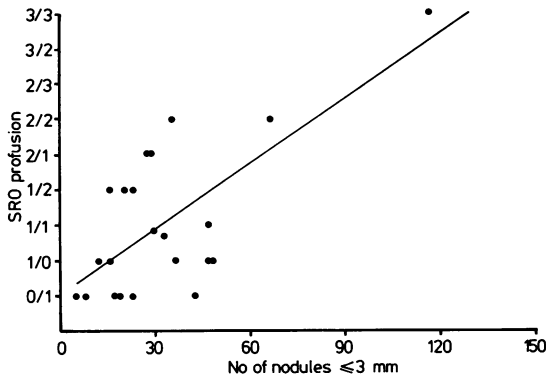


Fig 2 Relation between opacity profusion and number of nodules 1–3 mm in diameter for subjects considered to present predominantly q opacities by reader 1.

Line of best fit $y = 0.98 + 0.062x$, $n = 22$, $r = 0.70$, $p < 0.001$.

R OPACITIES

In the study group r opacities were rarely considered to be the predominant type. For the reader who recorded six such cases, however, opacity profusion was most closely associated with nodules > 3–9 mm, albeit not significantly, and showed a poor correlation with lung dust content.

Additional data analyses taking account of all dust lesion classes using multiple regression techniques did not improve on the correlations described for the lesion classes considered individually.

Discussion

This study has established that the profusion of small rounded opacities observed on chest radiographs does relate to the number and type of dust lesions present in the lungs of coalworkers. To attempt to visualise what is present in the lungs when a certain radiological category is read, however, it is essential to consider the type of opacity and also dust composition.

Within these broad statements several points are worth discussion but perhaps initially it is pertinent to consider what factors might have directly affected the results obtained. For the pathological assessment only one sagittal slice of each lung was examined whereas the chest had been examined radiographically in the posterior/anterior plane. There is, however, no reason to suppose that dust lesions of whatever class are not randomly distributed in the horizontal plane of the lung and we have shown previously (internal report, Institute of Occupational Medicine) that one slice may be considered representative of the whole lung. With regard to the radio-

logical reading, subjects were grouped according to the predominant type of opacity observed; in fact the percentage of subjects read as "pure" opacity type—that is, pp, qq, or rr ranged from 65% to 83% for the four readers. The known variability between readers in the assessment of both opacity profusion and type might also have posed problems in the present study but all four readers showed a correlation between opacity profusion and dust lesion counts and furthermore the distinction between the opacity types remained in evidence.

We have found that the lungs of subjects read as category 0 may contain fibrotic lesions, sometimes in greater numbers than in lungs of subjects presenting opacities. This anomaly was not explicable in terms of dust composition because, on average, the category 0 lungs contained higher percentage of ash than, for example, the p lungs. It does, however, seem likely that the generally low total dust content of category 0 lungs is an important factor. Alternatively, the explanation may relate to the position of the fibrotic lesions within the lung and the properties of the structures surrounding them, factors thought to affect the visibility of lesions on chest films.¹² Although Caplan found that fibrotic nodules were absent from the lungs of his category 0 subjects,² most other workers have found that a surprising amount of disease is sometimes present when the radiographs show little or no abnormality,^{1 13} a finding with which we can agree.

If radiological pathological correlations are carried out without taking into account opacity type then one finds, as did Caplan,² for example, that the higher the radiological category the greater the likelihood that the lungs will show a large number of dust foci and in particular a higher prevalence of fibrotic nodules. We consider that these results are somewhat misleading and that the approach used obscures some rather interesting points. For instance, we have shown that in subjects presenting predominantly p opacities profusion category is related exclusively to the number of "pinhead" fibrotic lesions previously shown⁵ to be their pathological counterparts; these lesion types are usually present in considerable numbers. Other lesion types are usually also present; in addition to macules (which do not present as opacities) one would expect to see fibrotic lesions, notably those measuring 1–3 mm, albeit in small numbers.

The association between rising profusion category and increasing number of fibrotic nodules is evident only for subjects presenting either q or r opacities. With q opacities the stronger association was observed with the smaller lesion class (1–3 mm) whereas with r opacities the larger fibrotic lesions (> 3–9 mm) were those involved. These results are as one might expect given the size definitions of q and r

opacities in the radiological classification.⁸

Although it was disappointing that our study group included few subjects considered to present r opacities it was not unexpected. One of the criteria for inclusion in the study was the absence of progressive massive fibrosis (PMF) (which we thought might be a complicating factor), and most r subjects also show PMF.⁵ Because of the small numbers of subjects it is important to avoid over-interpretation, but our results suggest that for any particular radiological category, subjects presenting r opacities will usually have at least twice as many fibrotic lesions as subjects presenting q opacities. In studies of silicotic lungs some workers have found that the number of nodules at postmortem examination exceeds that predicted by radiography.^{14 15} Our experience, even with coalworkers presenting r opacities, is that the lungs will only rarely show a pronounced preponderance of fibrotic lesions. Caplan also found that none of the coalworkers in his study showed numerous fibrotic lesions.² This, coupled with the fact that some subjects presenting r opacities have fewer fibrotic lesions than subjects presenting q opacities at a similar profusion category, highlights the importance of dust composition. It does seem that the higher the ash content of the dust the more likely that lesions will present as opacities on a radiograph. Similar comments regarding the effect of dust composition have been made by several other workers.^{3 4 7}

While it was not intended to be a central issue in this study we have added further useful information concerning the relation between lung dust content and opacity profusion. The overall correlation between retained dust and opacity profusion observed by ourselves⁵ and others^{4 6} appears, from our current results, to be due mainly to subjects showing p opacities and to a lesser extent those showing q opacities. When large fibrotic lesions are present, as in the case of subjects showing r opacities, and the dust contains a high proportion of ash, no relation is evident.

In conclusion, the results of this study and others^{2 4 6} make increasingly clear the complexity of the relation between what is seen on a chest radiograph and what is present in the lungs of coalworkers, and emphasise the fundamental importance of the character of the dust lesions and the composition of the dust itself. In view of this we hope at some stage to be able to repeat the present study selecting coalworkers from high and low rank collieries where the dust contains a low and a high percentage of ash respectively. Such a study should clarify the respective roles of dust composition and fibrosis in the generation of the different types of small rounded opacity.

We thank the pneumoconiosis medical panels for supplying most of the necropsy material and a large proportion of the chest radiographs used in this study. Our thanks also go to Drs J G Bennett, J Burns, J A Dick, and J S Washington of the National Coal Board for classifying the radiographs.

The study was jointly funded by the National Coal Board and the Commission of the European Communities.

Requests for reprints to: Dr June M Fernie, Institute of Occupational Medicine, 8 Roxburgh Place, Edinburgh EH8 9SU.

References

- 1 Gough J, James WRL, Wentworth JE. A comparison of the radiological and pathological changes in coalworkers' pneumoconiosis. *Journal of the Faculty of Radiologists* 1949;1: 28-39.
- 2 Caplan A. Correlation of radiological category with lung pathology in coalworkers' pneumoconiosis. *Br J Ind Med* 1962;19: 171-9.
- 3 Naeye RL, Dellinger WS. Coalworkers' pneumoconiosis. Correlation of roentgenographic and postmortem findings. *JAMA* 1972;220:223-7.
- 4 Rivers D, Wise ME, King EJ, Nagelschmidt G. Dust content, radiology and pathology in simple pneumoconiosis of coalworkers. *Br J Ind Med* 1960;17:87-108.
- 5 Ruckley VA, Fernie JM, Chapman JS, et al. Comparison of radiographic appearances with associated pathology and lung dust content in a group of coalworkers. *Br J Ind Med* 1984;41:459-67.
- 6 Casswell C, Bergman I, Rossiter CE. The relation of radiological appearances in simple pneumoconiosis of coalworkers to the content and composition of the lung. In: Walton WH, ed. *Inhaled particles III*. Old Woking, Surrey: Unwin Bros 1971:713-24.
- 7 Rossiter CE. Relation of lung dust content to radiological changes in coalworkers. *Ann NY Acad Sci* 1972;200:465-77.
- 8 International Labour Office. *International classification of radiographs of pneumoconioses*, 1971. Geneva: ILO, 1972. (Occupational safety and health series No 22.)
- 9 Guest L. The recovery of dust from formalin-fixed pneumoconiotic lungs: a comparison of the methods used at SMRE. *Ann Occup Hyg* 1976;19:37-47.
- 10 Dodgson J, Whittaker W. The determination of quartz in respirable dust samples by infrared spectrophotometry—I. The potassium bromide disc method. *Ann Occup Hyg* 1973;16:373-87.
- 11 Davis JMG, Chapman J, Collings P, et al. *Autopsy studies of coalminers' lungs*. Edinburgh: Institute of Occupational Medicine, 1979. (IOM report TM/79/9.)
- 12 Kundel HL, Revesz G. Lesion conspicuity, structured noise, and film reader error. *Ann J Roentgenol* 1976;126:1233-8.
- 13 Oosthuizen SF, Theron GP. Correlation between the radiographic and pathological findings in silicosis. *Medical Proceedings (Johannesburg)* 1964;10:337-42.
- 14 Theron GP, Walters LG, Webster J. The international classification of radiographs in the pneumoconioses. *Medical Proceedings (Johannesburg)* 1964;10:352-4.
- 15 Heitzman ER. *The lung. Radiologic-pathologic correlations*. St Louis: CV Mosby Co, 1973.