RELIABILITY OF EARLY DIAGNOSIS OF PLEUROPULMONARY LESIONS IN WORKERS EXPOSED TO ASBESTOS: THE EFFECT OF POSITION, RADIOGRAPHIC QUALITY AND STORAGE PHOSPHOR IMAGING ON DIAGNOSTIC ACCURACY

JOHN H. FEIST, M.D. • Michael J. Hodgson, M.P.H., M.D. • Carl R. Fuhrman, M.D. • Gregory Owens, M.D. • David Gur, Sc.D.

From the Departments of Radiology and Internal Medicine
University of Pittsburgh School of Medicine and Presbyterian-University Hospital
Pittsburgh, PA USA

A fortuitous combination of circumstances prompted us to undertake this analysis of a pilot group of workers with documented asbestos exposure:

1. The availability of high quality conventional chest radiography with oblique projections.
2. The recognition that a significant proportion of workers referred to us because of positive readings of outside films actually had no recognizable interstitial disease or pleural lesions.
3. The fact that an experimental high resolution storage phosphor radiographic digital imaging system was in place in our department, to be tested with emphasis on general chest radiography, and
4. The workers were evaluated in our institution clinically and by pulmonary function studies.

Radiographically, the majority of these workers had either minimal abnormal findings compatible with asbestosis, or clearly normal chests. It is in this grey zone of minimal or equivocal evidence of disease that the greatest degree of uncertainty arises, that most disagreements occur between readers, and that the accuracy of interpretation is most critical. In these cases, the likelihood of false positive and false negative diagnoses is highest, resulting in substantial potential inequities to the workers and to society, ethically, medically, and economically.

In this study, "radiographic accuracy" means the recognition of existing lesions (true positives) and the demonstration of normal lungs and pleura when no evidence of asbestos-related pathology exists (true negatives), i.e.: the sum true positives plus true negatives, divided by the total number of cases. The former requires, of course, a technique with the highest practical ability to detect even minor lesions. The latter can only be defined tentatively, in the absence of autopsy confirmation, since all of the 100 workers are still alive. Therefore, the conclusion "No radiographic evidence of pneumoconiosis" is less than totally reliable but, with exacting imaging technique, does carry a very high confidence ratio.

In clinical practice, it is often difficult to decide whether a given individual worker does or does not have asbestosis, when the objective findings are borderline. Yet an all-or-none type of diagnosis must be made, and the impact of the conclusion carries serious consequences.

Perhaps distinct from epidemiologic survey situations, the individual patient requires the maximal practical accuracy. We have, therefore, chosen high quality chest radiography with oblique films as the diagnostic standard, and correlated it with the accuracy of other modalities, and the clinical and functional data.

MATERIALS AND METHODS

Patients

This study consists of 100 consecutive workers (99 males, 1 female) with an occupational exposure to asbestos, mostly for 15 years or more, who were referred here for medical evaluation because of a prior "B" reader's report of characteristic pleural lesions and/or a profuseness of small interstitial opacities of 1/0 or greater according to the 1980 ILO-U/C system.

Clinical and Functional Evaluation

These patients were examined in the Occupational and Environmental Medicine Clinic by one physician (M.J.H.). Standard respiratory questions were asked: "usual" cough and phlegm production, wheezing (never, occasionally apart from colds, most days and nights), and grades of dyspnea were recorded. The presence of clubbing (softened nail beds or increased angle) and fine crackles were coded as present or absent.

Pulmonary function studies were performed either using 1) simple spirometry or 2) whole body plethysmography with lung volumes (51 cases) and single breath carbon monoxide diffusing capacity (DLCO) in 77 cases.

Classification

Individuals were classified as having asbestosis if they had a substantial asbestos exposure and two of three in-house readers determined that interstitial fibrosis of 1/0 or greater was present on the basis of the complete set (PA, left lateral and both obliques) of in-house radiographs. A "B-reader diagnosis" of asbestosis was established by admitting one in-house B-reading and one outside B-reading classification of 1/0 or greater on PA films.

Conventional Radiography

In 98 patients, PA, left lateral and right and left 45 degree anterior oblique chest radiographs were obtained with 110 to 120 Kv and very short exposure times (0.005 to 0.010 seconds) depending on size and position, at 10 foot tube to film distance, with rare earth intensifying screens and Kodak OC or TMG radiographic film with a speed rating of 400, and automatic processing. The films were exposed, either on a dedicated chest unit with a 110 line, 10:1 grid and phototiming at 2.5 to 4 mas, or manual timing at 500 ma with a 6 inch air gap. The completed radiographs were checked immediately by the responsible radiologist for quality, position and completeness. Inadequate films were repeated as needed unless the patient had already left the department, or was of excessive body size to preclude optimal radiography. This technique affords wide contrast latitude, high detail, maximal image sharpness and facilitates detection of interstitial and pleural fibrosis, but soft tissue calcification is less obvious than with short contrast techniques. The oblique films were obtained with careful positioning to minimize obscuring the lung fields by the scapulae and shoulders, i.e.: both upper extremities elevated overhead in extension and internally rotated, instead of the more popular low shoulder position (Figure 1).

Figure 1. Patient's position for (anterior) oblique films.
A. Low shoulder position obscures lung and pleura.[2]

In 2 patients, only PA and left lateral projections were obtained, by clerical error, and 3 had technically unsatisfactory films (because of excessive body size) in the opinion of at least 2 of 3 in-house readers. Thus, 95 patients had complete sets of in-house radiographs of diagnostic quality.

Outside Films

In 60 patients, the films made elsewhere, on which the prior diagnosis of asbestosis was based, were available for review and identical copies made, except in 10 cases where the films were not copied and the originals seen only by in-house Reader No. 1.

Experimental Radiography

We had the opportunity to utilize an experimental general purpose chest radiography system, recently installed for trial in our department. This prototype storage phosphor digital radiography complex was described in a recent publication.[6] Whenever plates were available, the purpose and risks of one additional PA radiographic exposure, identical to the initial conventional PA film, were explained to the patients and a single PA storage phosphor plate was obtained when they signified their informed consent by signing an institutionally approved authorization form.

Figure 1. Patient's position for (anterior) oblique films.
B. Recommended position for optimal chest radiography.

This system is independent of over or underexposure within a wide range by virtue of its linear receptor response curve (Figure 2). It provides a wide contrast and resolution capability similar to computed tomography and, therefore, a nearly infinite spectrum of processing options by contrast expansion. In our case, the inherent contrast is 4096 shades of grey, and the approximate resolution is 5 lines/mm for the full size images, and 2.5 line/mm for the 2:1 minified images. The latter are produced by pixel interpolation, rather than optical reduction.

Available to us was a standard configuration of print-outs, illustrated in Figure 3, in the case of a very overweight asbestos worker, with previous right thoracotomy for lung abscess. His conventional chest radiographs were of marginal quality, with inconsistent readings for asbestosis. With one full sized print-out as reference, the selection of four minified images was designed empirically prior to our study by concensus among several general radiologists, primarily to facilitate recognition of nodules and visualization of mediastinal, retrocardiac, and retrophrenic spaces.

The resultant storage phosphor print-outs were classified technically as good, noisy, or unfit for diagnosis. The latter were discarded, leaving 50 film sets to be evaluated (35 technically good, and 15 usable but "noisy" print-outs). These films were then viewed and interpreted in the same manner as the conventional radiographs.

Interpretation of Radiographs

The radiographs of all 100 patients were evaluated in-house and scored according to the 1980 ILO U/C method by 2 experienced "B" readers (one chest radiologist and one pulmonary physician) and by 1 experienced chest radiologist, and re-read again by the latter after an interval of one to six months after his initial readings of the same cases. For each patient, each reader evaluated the images separately in this order:

1. In-house PA radiograph alone;
2. In-house combined set of 4 radiographs;
3. Previous outside PA film when available;

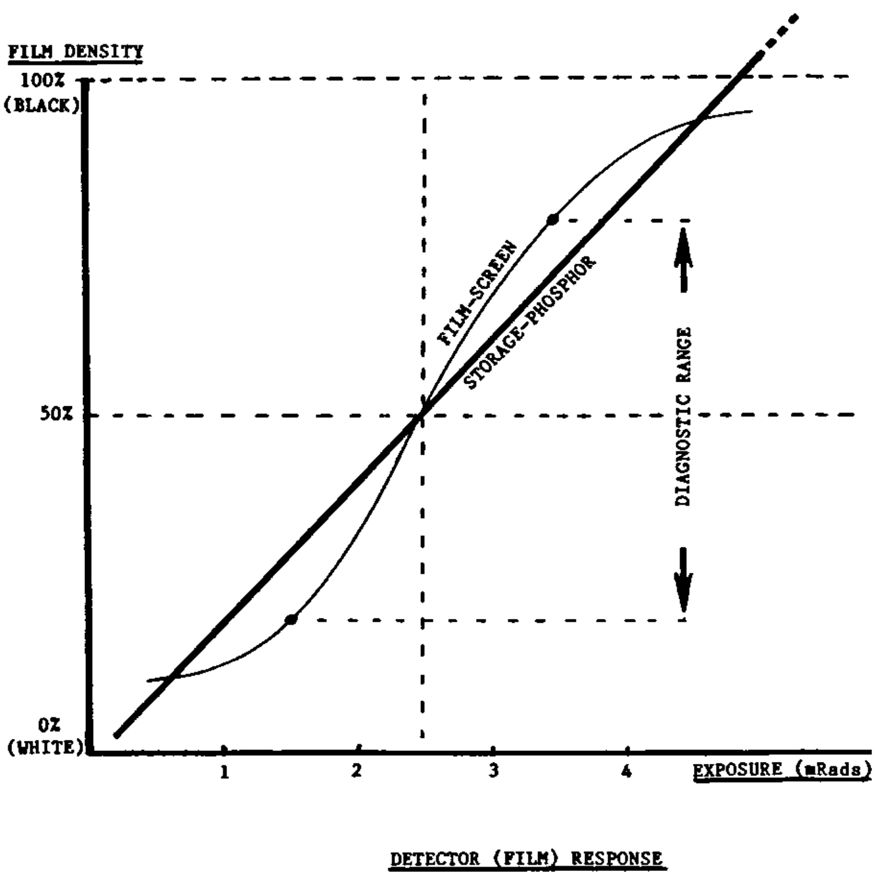

Figure 2. Comparison of detector response curve of film screen versus storage phosphor radiography.

Figure 3. Configuration of storage phosphor image print-outs of examination of a very large patient:
A. Full sized (12 × 14 inch) unprocessed.

4. Single PA full size unprocessed storage phosphor film when available; and
5. Combined set of 4 PA minified processed storage phosphor images when available.

This resulted in nearly 1,200 ILO U/C forms. From these, the following information was entered into the data base:

(a) Film quality: 1 Diagnostic; 2 Borderline readable; 3 Non-Diagnostic (faulty technique); and 4 Non-Diagnostic (faulty patient).
(b) Profuseness of small opacities compatible with pneumoconiosis.
(c) Pleural thickening consistent with pneumoconiosis.
(d) Pleural calcifications consistent with pneumoconiosis.

RESULTS

Because of the slower than anticipated presentation of workers for examination, the final readings were only completed one month ago. The statistical portion of this study is, therefore, incomplete and only preliminary.

In the absence of independent means for diagnosis, for the purposes of this study, as indicated previously, the diagnosis of asbestosis was made when at least two of three in-house readers reported a profuseness of interstitial fibrosis of 1/0 or greater on the set of 4 films, and was compared with a diagnosis of asbestosis based on concurrence of 1 outside B-reader with at least 1 in-house B-reader, on PA films only.

Of the 95 patients who had technically acceptable in-house films, 50 (52.6%) were interpreted by at least 2 in-house readers as having asbestosis. Table I lists the prevalence of symptoms, body mass index, and pulmonary function studies for individuals who did and who did not meet the criteria for asbestosis. Symptoms were generally not more frequent among individuals with asbestosis, with the possible exception of wheezing. Pulmonary function tests were compared between the two groups. Only mean percent of predicted DLCO was statistically significantly different between the two groups.

Table II illustrates that the diagnosis of asbestosis made by the two groups defined above differed significantly, indicating greater consistency of in-house readers, than concurrence without outside readers.

Diagnostic groupings were established, classifying cells by concordance and discordance of diagnosis. Table III presents

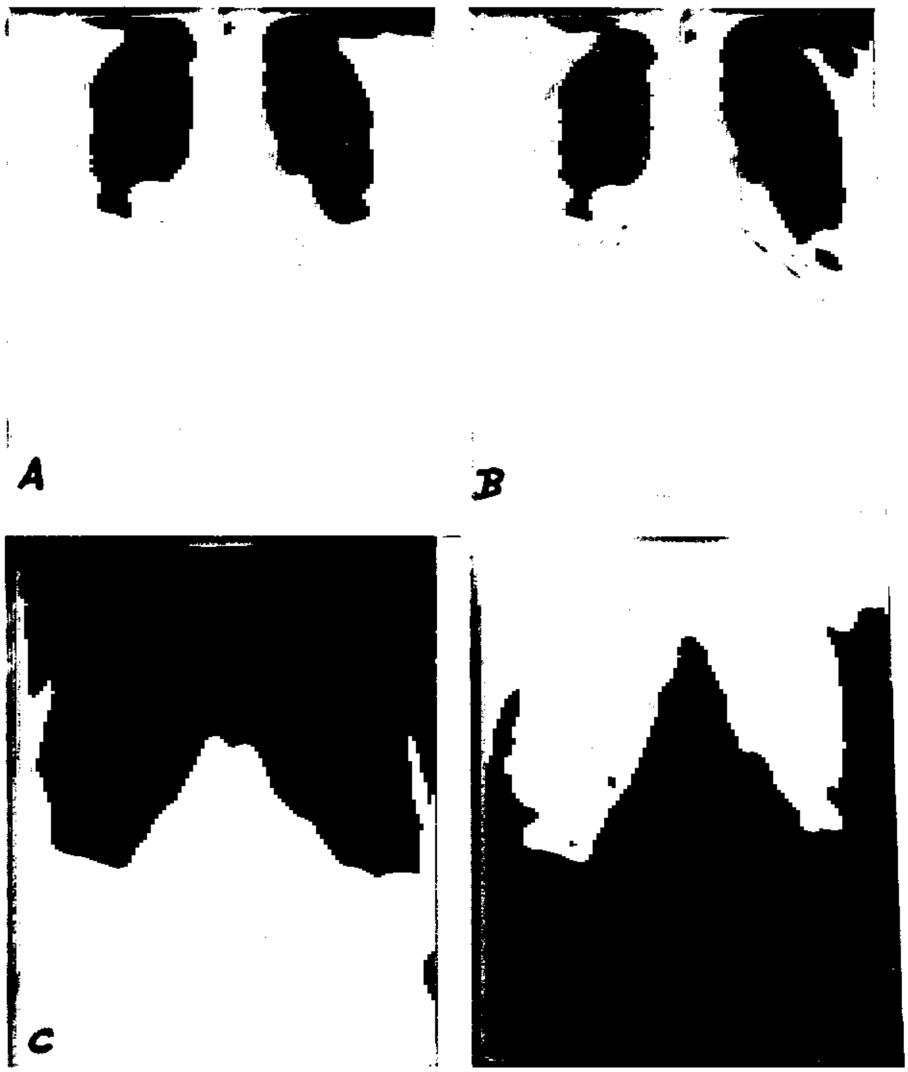

Figure 3. Configuration of storage phosphor image print-outs of examination of a very large patient:
B. 4 minified (6 × 7 inch) images:
(a) unprocessed, identical with A except for minification;
(b) mildly edge enhanced;
(c) mildly edge enhanced and contrast enhanced negative; and
(d) mildly edge enhanced and contrast enhanced positive ("black bone").

analyses of variance. DLCO was again the only variable which appeared unevenly distributed among groups, whereas age, symptoms, body mass index, and other pulmonary function studies were all random. While even DLCO only approached statistical significance, and the number of data is small, the trend supports the clinical impression that many outside films, which were of diagnostically acceptable quality, were erronously interpreted as positive.

Subsequently, each individual in-house reader's diagnostic interpretation of the PA film alone from the same set was compared with the readings of the complete set of in-house radiographs. Table IV presents the cross-classification of these results. Each individual reader disagreed in a substantial proportion of cases with his own diagnosis and with that of the combined in-house readings, in comparison with the diagnosis based on the complete set. This supports our thesis that PA films alone are an insufficient basis for the diagnosis of asbestosis in individual patients, although PA films are simpler to handle and may well suffice for epidemiologic purposes.[14]

Table I
Prevalence of Symptoms and Pulmonary Function Studies by the Diagnosis of Asbestosis

	Asbestosis	No Asbestosis	p-value
Age	57.2 (1.32)	58.9 (1.32)	0.324[1]
Body mass index	28.4 (0.798)	30.0 (0.778)	
Usual cough	35 (70.0)	25 (64.4)	0.7207[2]
Usual phlegm	32 (66.0)	32 (71.1)	0.8116[2]
Wheezing	46 (93.9)	34 (79.1)	0.0728[2]
DLCO (in per-cent of pre-dicted	77.2 (2.97)	89.0 (3.386)	0.011[1]

1 unpaired t-test
2 chi-square

Table II
Asbestosis by "B-Reader Diagnosis of Asbestosis"

Diagnosis of asbestosis by in-house experts

		Yes	No
B-readers	Yes	23	28
	No	9	40

chi-square = 7.023; p = 0.008

Table V summarizes the in-house readers' confidence in the tested modalities, for the conventional radiographs, and for our experience with interpreting asbestos related interstitial and pleural lesions with the storage phosphor films. This system has not yet been used in routine clinical practice, and the readers had no significant working familiarity with it. In our combined judgment, the experimental storage phosphor films used in this study were superior to the standard single PA radiograph only in the recognition of pleural calcifications, but not in diagnosing interstitial or pleural fibrosis. In contrast, the overall confidence rating in the reliability of the complete set of in-house radiographs was positive in all three regards.

Finally, Table VI lists the important unusual findings encountered in this group of patients, a by-product of substantial clinical significance.

DISCUSSION

The difficulty of recognition of minimal or early lesions is legendary, particularly concerning interstitial disease.[4,5,8,9,10] The threshold of recognition always depends on the stage of evolution of the lesions, the sensitivity of the detecting system, and the specificity of the process of interpretation. Clearly below this threshold are the histologically recognizable lesions which have not yet reached detectability

Table III
Analysis of Variance for Diagnostic Groups

Grouping	Single breath carbon-monoxide diffusing capacity (percent of predicted)
Asbestosis by in-house experts and by certified B-readers	77.7
Asbestosis by in-house experts but not by certified B-readers	76.7
Asbestosis not by in-house experts but by certified B-readers	86.0
No Asbestosis by in-house experts or by certified B-readers	89.9

F-value 2.311; p = 0.0835

Table IV
Cross-classification of Diagnostic Evaluation of Simple Posteroanterior Chest X-rays vs. the Diagnosis of Asbestosis on Complete Set of Films by at Least Two In-house Readers

Reader	Read	Diag. on full set: Positive	Diag. on full set: Negative	p-value by a chi-square test
Reader #1				
Asbestosis by PA only	Yes	31	16	0.0089
	No	20	33	
Reader #2				
Asbestosis by PA only	Yes	34	20	
	No	17	29	0.0168
Reader #3				
Asbestosis by PA only	Yes	34	5	
	No	17	44	0.0001

Table V

1988 ASBESTOSIS STUDY: Perceived Reliability of Tested Imaging Modalities Relative to Good Quality PA Radiographs Alone (Combined Valuation by 3 Readers)*

Modality	for interstitial disease	for pleural fibrosis	for pleural calcifications	Overall Confidence Rating
Complete Set (incl. obliques)	+1.3	+2.6	+1.3	+1.7
Exp'l Storage-Phosphor PA				
Single 14 X 17 unprocessed	-1.3	-1	-0.6	-1
Composite of 4 processed minified 4-in-1 films	-2	-1	+1.5	-1.5

*Valuation: Equal = 0, Better = +1 to +3, Worse = -1 to -3

Table VI

1988 Asbestosis Pilot Study: Significant Unusual Findings

1988 ASBESTOSIS STUDY

Significant unusual findings in 100 cases

Suspicious adenopathy or mass (R.O. CA)	12
Excessive pleural fibrosis (R.O. mesothelioma)	4
Bullous emphysema	6
Major cardiovascular abnormality	7
Mediastinal plaques	2
Pericardial plaques	5
Miscellaneous	6

by radiography.[10] A workable definition of a "threshold of detectability" needs to be established before much real progress is possible in this field. With time, lesions generally progress to a level where the recognition rate approaches 100%. Our concern involves the lower end of the spectrum, i.e.: borderline evidence of disease, where the errors in diagnosis abound. After a measure of the diagnostic error rate in general was ascertained over 30 years ago,[7,18] Morgan, et al.[13] first related it to pneumoconiosis and the use of the ILO U/C classification in particular. More recently, Rockoff and Schwartz[15] called attention to the underestimation of early asbestosis by the ILO classification, but because of lack of an independent "truth diagnosis,"[12] ROC analysis is not appropriate in this situation.

Diagnosis of Interstitial Lung Disease

The pulmonary interstitial markings are accentuated by certain technical factors, such as increasing contrast by low KV radiography, edge enhancement illustrated by the storage phosphor images, unsharpness (often due to prolonged exposure times as was the case in the majority of outside films with overinterpretation of interstitial patterns), or underexposure of the lungs (sometimes due to excessive body size) (Figure 3). By virtue of its linear response curve, deficiencies due to over or underexposure are characteristically reduced by the storage phosphor technique (Figure 2). Conversely, pulmonary interstitial markings can be minimized by overexposure of radiographs, deficiency of soft tissues, excessively deep inspiration, and by imaging techniques such as positive printing as illustrated by the positive image in the 4-in-1 storage phosphor print-outs (Figure 3B). The addition of oblique films affords substantially more correct evaluation of the interstitial patterns of the lungs, and increases the confidence of recognition of presence or absence of minor interstitial opacities (Figure 4).

Diagnosis of Pleural Fibrosis

Asbestos related pleural fibrosis occurs most frequently posterolaterally, and in our series, nearly 50% of typical pleural lesions were only detected on oblique films. This has

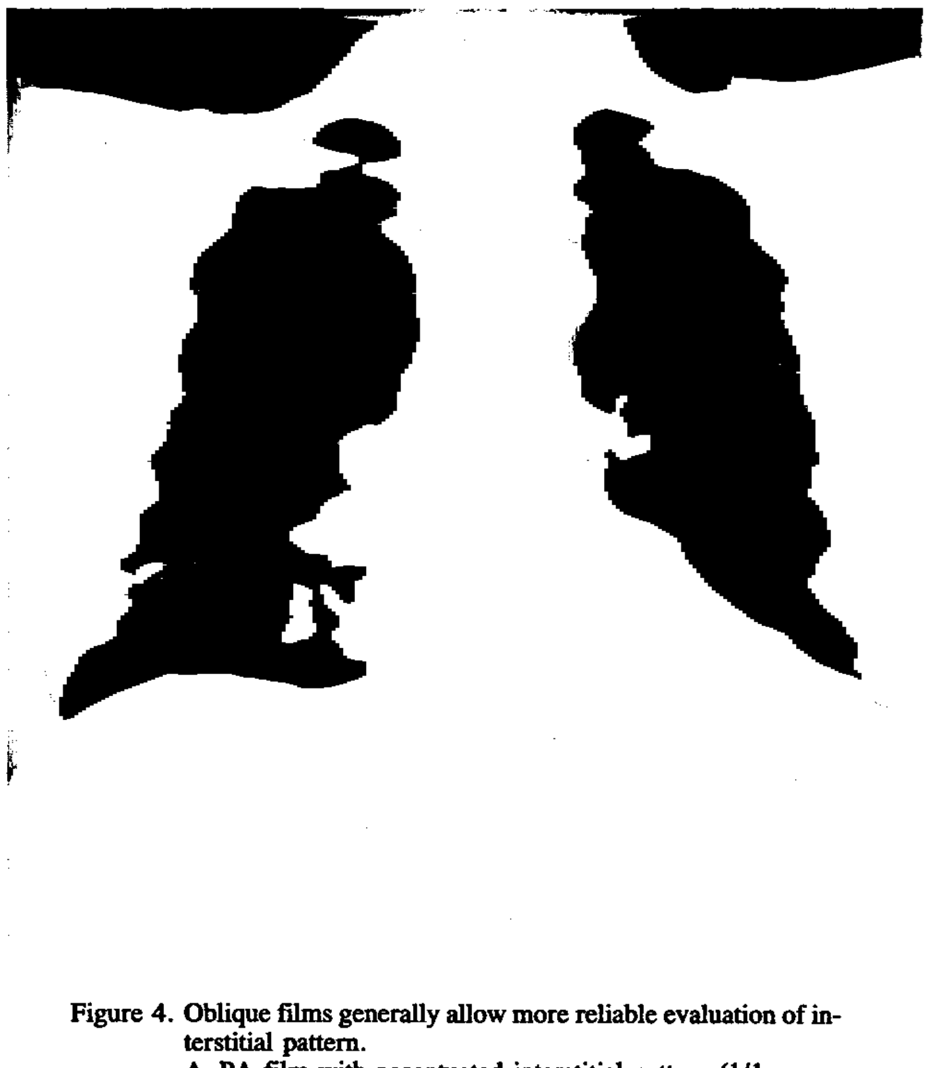

Figure 4. Oblique films generally allow more reliable evaluation of interstitial pattern.
A. PA film with accentuated interstitial pattern (1/1 profuseness of "t" irregular opacities on original film).

also been reported by others.[1,11,16] Oblique films also help in properly evaluating previously seen pleural lesions, but require some degree of experience. Furthermore, proper position is critical for a precise view of the pleura (Figures 1 and 5).

Although routine computed tomography of the chest was not included in our study, our experience and that of others,[9,17] indicates that pleural lesions, especially on the diaphragm, are most reliably recognized thereby. Probably, parietal pleural lesions will remain more easily recognizable by radiography with oblique projections, because of their predominantly craniocaudad orientation, while the diaphragmatic pleura as well as the areas of pleura normally obscured by the heart or diaphragm are more properly examined by computed tomography (Figure 6), where the right lower pleural mass probably represents a "rounded atelectasis."[3] Surprisingly, not a single patient in our series had pleural effusion.

Diagnosis of Pleural Calcifications

Calcifications, especially early, are not recognized radiographically unless a sufficient dimension of the calcified lesion lies parallel to the direction of the ray. Therefore, in a given population with various pleural calcifications, the detection rate will vary directly with the number of different projections. For instance, Figure 7 demonstrates diaphragmatic and substernal calcification, seen only in the lateral projection in this particular case. Calcifications are more readily demonstrable with relatively low kv and high contrast techniques, and with contrast enhancement (Table V).

RECOMMENDATIONS AND CONCLUSIONS

This pilot study confirms that increased reliability of the radiographic diagnosis of asbestos related pulmonary and pleural lesions varies directly with diagnostic quality, sharpness, contrast and positioning, and that, particularly in early cases, PA films alone do not suffice. In order to enhance

Figure 4. Oblique films generally allow more reliable evaluation of interstitial pattern.
B. Right anterior oblique film shows normal peripheral lung fields (no interstitial opacities on original film).

Figure 5. Effect of shoulder position on quality of oblique film:
A. Improper position (cf Figure 1A, low shoulder).

recognition of actual disease and minimize false positive diagnoses, the standard examination for individuals suspected of asbestos related disease should consist of PA, left lateral and both 45 degree anterior oblique projections with very short radiographic exposure, high kv technique, and proper positioning. Uncertainty concerning pleural and diaphragmatic lesions may be resolved by computed tomography. With the proper precautions, increase in individual radiation exposure to the chest, incurred by these diagnostic measures, is trivial, particularly in view of the medical and economic consequences of false diagnoses to the patient and to society. The potential for improving the diagnosis in asbestosis by alternative imaging procedures is illustrated by our experience with a new experimental storage phosphor technique, and warrants continued evaluation by using new imaging configurations, more suitable for interstitial and pleural disease.

Finally an objective detectability threshold for asbestos related pleural and pulmonary lesions is urgently needed.

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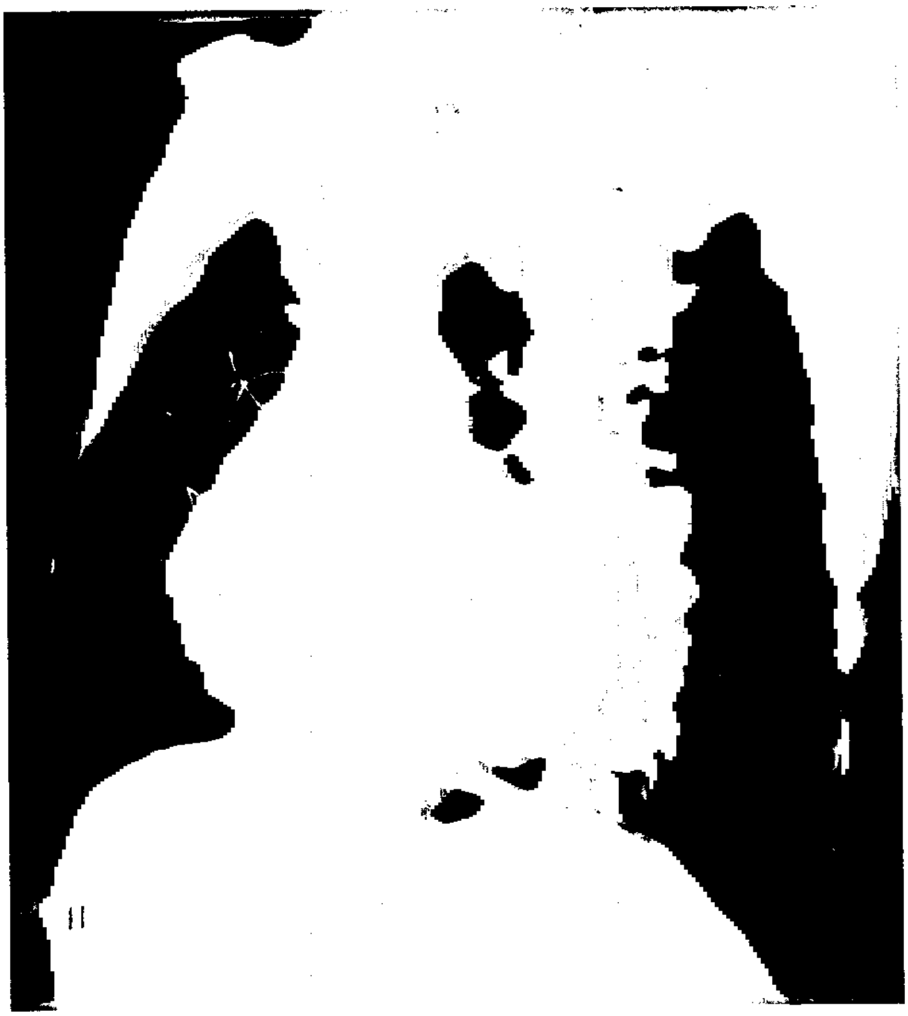

Figure 5. Effect of shoulder position on quality of oblique film:
B. Correct position (cf Figure 1B, upper extremities elevated, extended and internally rotated.

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Figure 6. Role of computed tomography for detection of pleural lesions in certain anatomic areas:
A. PA radiography shows interstitial opacities, pleural plaques and right diaphragmatic calcification.

Figure 6. Role of computed tomography for detection of pleural lesions in certain anatomic areas:

B. Computed tomogram shows 4 cm right lower retrophrenic pleural mass, not seen on any of the conventional radiographs (probably a rounded atelectasis).

Figure 7. Diagphragmatic and substernal calcifications seen only on lateral radiograph.

PRESENT USE AND TRENDS IN THE DEVELOPMENT OF THE ILO INTERNATIONAL CLASSIFICATION OF RADIOGRAPHS OF PNEUMOCONIOSES

ALOIS DAVID, M.D.
Occupational Safety and Health Branch
International Labour Office, Geneva, Switzerland

The First International Classification of Pneumoconioses, based both on radiographical appearances and respiratory function impairment, was adopted as early as 1930 at the First International Pneumoconioses Conference, convened by the ILO in Johannesburg. Substantial work has been devoted to the further improvement of the Classification which has resulted in five successive revisions, the latest being the ILO International Classification of Radiographs of Pneumoconioses, (further ILO Classification) 1980.[7] Recently some proposals for further improvement of the ILO Classification and methodology of reading radiographs and subsequent handling of data have been published.[1,2,9] For this reason, we addressed the major users of the ILO Classification and asked their opinions about the potential need of its revision.

METHOD

A questionnaire was sent to institutions responsible for matters of pneumoconioses in a number of countries exploring the present use and trends for further development of the ILO Classification. Replies were received from the following 29 countries: Australia, Austria, Belgium, Brazil, Canada, Chile, China, Czechoslovakia, Denmark, Egypt, Finland, France, German Democratic Republic, Greece, Indonesia, Mexico, Netherlands, Nigeria, Norway, Peru, Poland, Rumania, Spain, Sweden, Uganda, USSR, United Kingdom, United States of America and Yugoslavia. The cooperation of institutes and individuals from these countries is highly appreciated.

RESULTS

Use of the ILO Classification

In almost all of the above countries, a standardized classification of pneumoconioses is used for general or for specific purposes. There are exceptions in a few countries in which pneumoconioses appear to be very rare diseases due to the limited extent of industries involving exposure of workers to fibrogenous mineral dust.

A casual review of published epidemiological studies of pneumoconioses clearly proves that the ILO Classification has been universally applied in these surveys. Its general use to this purpose has been endorsed by the WHO.[8] The guidelines for its use explicitly state that the ILO Classification does not imply definitions of pneumoconiosis for compensation purposes but has as an object to codify the radiographic abnormalities of pneumoconioses.[3] Nevertheless, the criteria of the ILO Classification have been routinely incorporated into national classifications of pneumoconioses for the compensation of sick workers. Besides, the symbols for pulmonary X-rays changes are frequently used in surveillance of health of individuals and in clinical diagnosis, replacing lengthy verbal descriptions of the type and extent of the changes. For the same reason, they have been found useful even for registration of disseminated shadows in chest X-rays in lung diseases other than pneumoconioses.[5]

National classifications of pneomoconioses usually define minimum radiographical changes considered as compatible with a definite diagnosis of pneumoconioses as well as the grading of the less and more advanced stages (Table I).[6]

In view of their principal use, i.e. compensation of the disease, the national classifications sometimes slightly modify the ILO Classification or include additional criteria, in particular respiratory function impairment (Australia, Belgium, Chile, China, Denmark, Egypt, Finland, Greece, Indonesia, Mexico, Poland, Spain, USSR, Yugoslavia). The USSR Classification also takes into account aetiological factors by distinguishing, e.g., silicosis, silicatosis or mixed-dust pneumoconioses, in the latter the effect of silica being modified by other components of rocks. Whereas the ILO Classification contains three major categories of profusion of small opacities and three categories of large opacities, in some countries the number of stages of pneumoconiosis is limited to three: initial fibrosis, pneumoconiosis with small and with large opacities, to which cilicotuberculosis is added in accordance with the ILO Injury Benefits Convention, 1964 (No. 121) (Chile, China, Czechoslovakia, German Democratic Republic, USSR). For codification of radiographical changes, the symbols of the ILO Classification are used even in such cases.

Therefore, a clear distinction must be made between the national classifications of pneumoconioses as diseases, and the international classification of radiographical appearances of pneumoconioses. Whereas it would be extremely difficult to internationally harmonize criteria for compensation purposes, it is feasible in the case of radiographical changes only. For this reason, the ILO Classification has omitted criteria

Table I
Radiographical Criteria for Notification of Pneumoconioses as Occupational Disease in Selected Countries[6]

COUNTRY	SMALL OPACITIES PROFUSION	SIZE
Belgium	2	.
Bulgaria	2/2	p (s,t)
Czechoslovakia	3/2	.
France	1	.
FRG	3	.
GDR	1/1	p
Hungary	2/2	p
Poland	1/1	.
Sweden	2	.
UK	2/1	.

of respiratory function impairment since its first revision in 1950 and has limited itself to chest radiographs.

In most countries, the 1980 ILO Classification is used either exclusively (Australia, Austria, Finland, Indonesia, Mexico, Norway, Peru, USA) or together with one of the previous revisions, in particular the 1971 ILO Classification (Belgium, Brazil, Egypt, France, Poland, Spain, United Kingdom, Yugoslavia). However, there is a tendency to adopt the latest, i.e. the 1980 revision.

Nevertheless, for reasons of continuity in statistics and research, some cohort studies on miners which started even some decades ago continue to use the 1968 revision of the ILO Classification (France, United Kingdom).

A few of the countries which continue to use one of the older revisions of the ILO Classification indicated that the expense of providing all national centres responsible for evaluating pneumoconioses with new sets of standard radiographs of pneumoconioses prevented them from transition to the 1980 ILO Classification.

In some countries (China, Czechoslavakia, France, German Democratic Republic, Indonesia, Norway, Poland, Rumania, USSR), the use of a standardized national classification of pneumoconioses in compulsory for health services and social security institutions. In other countries, such as Australia (some states), Austria, Chile and Spain, social security enforces the use of a standardized classification for its own purposes. In the remaining countries, a standardized classification has been agreed upon by representative medical bodies or institutions specialized in occupational health, in particular in the field of pneumoconioses. In the USA, at least three Federal Agencies (Department of Labor, U.S. Navy and the National Institute for Occupational Safety and Health) have established the use of the ILO Classification, 1980.

Qualification of Readers and Organization of Reading of Radiographs

Only in some countries certificates are issued to physicians testifying their qualification for the evaluation of radiographs of pneumoconioses (Austria, Belgium, Egypt, German Democratic Republic, Indonesia, Rumania, Spain, USA, USSR). Qualification is achieved by participating in specialized post-graduate training courses or passing an examination. The most elaborated curricula for training of readers at two levels (A and B) have been established in the USA.

In the remaining countries, specialization in radiology, chest diseases or occupational medicine—exceptionally only a basic M.D. diploma—authorizes physicians to evaluate radiographs of pneumoconioses. Training is provided in short-term courses, in-house or as self-training.

Most of the specialized occupational health or social security institutions establish boards of specially trained readers, whose qualification has been tested and even re-tested.

In most countries there is a tendency to centralize the reading to a restricted number of special centres. This is facilitated by the fact that industries involving exposure to fibrogenous dust are frequently accumulated in certain areas close to mineral deposits (mines, quarries, ceramic industry) and that compensation claims concentrate in social security institutions.

Sometimes, large-scale screening is broadly decentralized, however, special boards or panels are used to confirm positive diagnosis of pneumoconioses or to settle widely divergent interpretations. There is no general rule about the size of the board or panel. The first screening is usually carried out by one reader, and the re-evaluation of the positive findings by two or more additional readers.

The on-going discussion concerning the potential use of specially trained lay-readers, instead of physicians, for the first screening or for epidemiological studies should be noted; there is no definite agreement on this point.[4]

Further Development of the ILO Classification

No classification can be considered to be a definite scheme and newly acquired knowledge may demand its modification. This need may be conflicting with the necessity for continuity of statistics or epidemiological cohort studies. The respondents to the ILO questionnaire expressed their general satisfaction with the ILO Classification, 1980, and mostly preferred continuation rather than a revision, but some of them considered that regular reviews may be useful. Several institutions made suggestions which are summarized as follows:

More attention should be given to incipient changes by adding in the standard set instructive radiographs of early stages (Australia), namely borderline films 0/1 and 1/0 of rounded and irregular opacities and a clear standard 1/1 (Brazil), a standard of 0/0 taken on an obese person (Finland), and additional radiographs of the peripheral parts and vascular patterns (Mexico);

On the other hand, treatment of silicotics influences the development of large opacities and for this reason a subdivision of large opacities is found useful for research and therapeutical considerations (France);

The present standard radiographs are mid-category ones; boundary films should be considered to exemplify the middle reading between each of the major categories (China, United Kingdom, USA);

Improvements could be made in the Guidelines for the Use of the ILO International Classification of Radiographs of Pneumoconioses;[3] they should not only be a supplement to the films, but a firm guidance (France); the reading sheet should be modified or simplified (Brazil, Norway, USA); they should also contain instruction on recommended methods for epidemiological research and group surveillance (Brazil); a symbol for lung vessel congestion should be added (Austria);

Criticism has been expressed concerning pleural pathology, its grading and the descriptive text (Belgium, Brazil, Finland, United Kingdom, USA).

It is my expectation that the discussion at this Conference will give advice for further action.

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AN ANALYSIS OF X-RAY READER AGREEMENT: DO FIVE READERS SIGNIFICANTLY INCREASE READER CLASSIFICATION RELIABILITY OVER THAT OF THREE READERS?

JOHN LEFANTE, Ph.D. • Janet Hughes, Ph.D. • Robert Jones, M.D. • Hans Weill, M.D.

Tulane University School of Medicine, Department of Medicine
Pulmonary Diseases Section, New Orleans, LA, USA

ABSTRACT

Five experienced readers, working independently and without exposure or other subject data, applied the ILO 1980 classification to the chest radiographs of 1,168 workers currently employed in the manufacture of man-made mineral fibers. To examine the effect of using five instead of three readers, we determined the difference in profusion of small opacities when using the median readings of all five readers, compared to the medians produced by each of the ten panels combining three of the readers. The distribution of small opacity profusion differed among individual readers, but most of the films were placed in low categories: fewer than one percent were above category 1/1. Readers also differed in their assessments of film quality, and showed differing sensitivities to radiographic effects of age and smoking. Despite these individual differences, the addition of two readers usually had little effect on median profusion judgments. For eight of the ten panels, five or fewer percent of films were classified differently; for all ten panels, fewer than two percent of films were reclassified beyond an adjacent category on the twelve-part scale. Eight panels were sensitive to radiographic effects of smoking, and three to effects of age; the five-member panel was also sensitive to smoking. We conclude that, when experienced readers are used, enlarging a panel from three to five members is unlikely to affect median small opacity profusion.

INTRODUCTION

The ILO 1980 Classification of Radiographic Appearances of Pneumoconioses is subject to inter- and intra-observer variability.[1] It has therefore been accepted practice to use several experienced readers—at least three—in order to minimize the chance of systematic bias.[3] The median reading for the readers has been used to summarize each film, since it is not affected by the values of the extreme readings, as would be the mean reading.[2] Although it is intuitively true that the accuracy of the summarized readings should increase with more readers, there is a question whether a significant proportion of readings would change if the number of readers was increased beyond three. In a study of a working population engaged in man-made mineral fiber manufacturing, ILO 1980 classifications of a set of chest X-rays by five readers were available for comparison with all possible subsets of three readers.

METHODS

The study materials consisted of the chest radiographs of 1,755 employees in seven plants. All five readers attempted to classify all films according to the ILO 1980 Classification. The readers concluded that a different percentage of these 1,755 films were of unreadable quality (0% to 8%). A total of 1,603 films were judged readable, and were classified by all five readers. At the time of this analysis complete smoking history was available for 1,168 subjects, and we will only consider this subset to assess the effect of age and smoking status on the classification of low-level opacities. The ages of the workers considered have a mean of 41 years, a standard deviation of 11 years, and a range from 19 to 76 years. Sixty-eight percent of the workers were either current or ex-smokers with pack years having a mean of 28, a standard deviation of 25, and a range from 0.2 to 168.

RESULTS

Most individual readings were concentrated in the lower profusion categories, as indicated in Table I. All readers classified between 82% and 98% of the films as 0/0, with only between 1% and 10% over 0/1. Two readers classified 0.5% of the films ½ or higher.

Table II considers the distribution of individual readings relative to the entire group. The entries in the table represent the percentage of times each individual reading deviates from the median reading for all five readers. For example, Reader A classified 3.5% of the 1,168 films one category higher than the classifications based on the median of all five readers. If we consider the number of times individuals rated

Table I
Distribution of Small Opacities Profusion in %, by Reader (N = 1,168)

Reader	0/0	0/1	Profusion 1/0	1/1	≧ 1/2
A	90.6	3.7	1.2	4.0	0.5
B	82.1	7.5	3.6	6.3	0.5
C	89.4	8.5	1.3	0.8	0.0
D	92.1	6.0	1.5	0.4	0.0
E	98.0	1.2	0.7	0.1	0.0
Median	94.8	3.6	1.1	0.5	0.0

Table II
Distributions of Individuals' Readings, by Distance from Median Reading (N = 1,168)

Reader	Number of Sub-Categories From the Median						
	−3	−2	−1	0	+1	+2	≧ +3
A	0.0	0.0	1.0	91.4	3.5	2.1	2.0
B	0.0	0.1	0.3	83.6	7.3	4.3	4.4
C	0.1	0.2	0.9	92.0	6.2	0.3	0.3
D	0.0	0.4	1.8	93.0	4.1	0.7	0.0
E	0.0	0.6	3.4	95.9	0.1	0.0	0.0

films more than one category above or below the median, we see that Readers A and B tended to read higher than the others. Readers C and D read on both sides of the median, with slightly greater readings above. Reader E read consistently lower than the others.

In order to assess the effect of adding two readers to an original three, all ten possible panels of three readers were considered. For each of these panels of three, the median reading for each film was recorded. Table III demonstrates, for each combination, the percentage of films that changed their classification when the medians were based on all five readers. Since a change of more than one category is considered important, the combinations of readers in Table III are ranked in descending order according to the percentage of films that changed more than one subcategory when two readers were added. In the worst case, adding two readers made any change in only 7.4% of the films (when A, B, and C are the original three), and a change greater than one category in only 1.6%. In the majority of combinations (70%), fewer than 0.5% changed by more than one category. The combinations that are affected the most by adding two readers are the ones that include Readers A and B, the two highest readers based on Table II. The addition of two more moderate readers will affect a greater proportion of film classifications. Nevertheless, even in these cases only 1.5% of the classifications changed by two or more categories, indicating that the addition of two readers had little effect.

The possible effects of age and smoking status on the classification of low-level opacities was investigated for each reader. Exposure information on the workers was not available at the time of analysis and was not included. Obviously, this very important explanatory variable should be considered when possible, since any detectable effects due to age and smoking alone could be confounded with an exposure effect. The limited attempt here is to see how often detection of the radiographic effects of age or smoking are changed by changing the size or composition of panels. Table IV presents the result of logistic regressions on age, smoking (ever versus never), pack years, and finally pack years after adjusting for age, for each reader. Readers A and E, high and low readers respectively, detected no effects (with the exception of an age effect for Reader E). Readers B, C, and D detected almost every effect. Therefore, no discernible relationship to over- or under-reading exists. Table V presents the result of logistic regressions for each three-reader panel and for the five-reader panel. Eight panels were sensitive to the radiographic effects of smoking, as shown by a significant relationship between small opacity profusion and either smoking category or pack-years. Three panels were similarly sensitive to the effects of age. The five-member panel was also sensitive to smoking, indicating that the addition of two readers is unlikely to eliminate this possible source of confounding with dust effects.

CONCLUSIONS

When using three experienced readers (the widely accepted minimum for epidemiologic research), the effect of including two additional readers seems to be neglible. Despite using readers with significant inter-observer variability, only a small proportion of films were changed by more than one category, after adding two readers.

Table III
Rate of Change in Median Profusion Category After Adding Two Readers, for Each Possible Combination of Three Readers

Readers	Percent Films Showing Any Change	Percent Films Changing More Than One Sub-Category
A B C	7.4	1.6
A B D	5.7	1.5
A B E	5.0	1.4
B D E	3.2	0.4
B C D	4.6	0.3
C D E	3.3	0.3
A C D	2.4	0.3
A D E	2.7	0.3
B C E	3.4	0.3
A C E	2.2	0.2

Table IV
Sensitivities of Individual Readers to Age and Smoking Effects on Small Opacity Profusion (Logistic Regression, N = 1,168)

Reader	% > 0/0	Age	Smoking	Pack-Years	Pack-Years/Age
A	9.4	NS	NS	NS	NS
B	17.9	**	**	**	*
C	10.6	NS	*	**	**
D	7.9	**	**	**	**
E	2.0	*	NS	NS	NS

*significant $p \leqq 0.05$
**significant $p \leqq 0.01$
NS = not significant

Table V
Sensitivities of All Three-Reader Panels to Age and Smoking Effects on Small Opacity Profusion

Readers	Age	Smoking	Pack-Years	Pack-Years/Age
A B C	NS	NS	*	NS
A B D	*	NS	*	NS
A B E	*	NS	NS	NS
B D E	*	*	**	*
B C D	NS	*	**	**
C D E	NS	**	**	**
A C D	NS	*	**	*
A D E	NS	*	NS	NS
B C E	NS	*	*	*
A C E	NS	NS	NS	NS
ABCDE	NS	*	NS	NS

*$p \leqq 0.05$
**$p \leqq 0.01$
NS = not significant

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ILO CLASSIFICATION OF THE STANDARD CHEST FILMS OF THE 1986 CHINESE ROENTGENO-DIAGNOSTIC CRITERIA OF PNEUMOCONIOSES

T. K. HODOUS, M.D. • X. LU,* M.D. • R. A. DENTON, M.D.
Division of Respiratory Disease Studies, NIOSH, Morgantown, WV, USA
*Institute of Occupational Medicine, Chinese Academy of Preventive Medicine, Beijing, PRC.

ABSTRACT

As a preliminary step in joint Sino-American pneumoconiosis research efforts, the 32 standard chest films of the 1986 Chinese Roentgenodiagnostic Criteria of Pneumoconioses were interpreted according to the 1980 International Labour Office (ILO) Classification of the Pneumoconioses by three NIOSH-certified "B" reader radiologists. The Chinese interpretations on the films were obscured, and the films were read independently in random order. The median "B" reading was used in the analysis. The "B" readers' major category of profusion of small opacities agreed with the Chinese category in 27 of 34 cases. The Chinese category was included as either the major or alternative ILO profusion category in 32 of the 34 cases. The "B" readers' primary type of opacity agreed with the Chinese type in 24 of 32 cases, and agreed with regard to rounded or irregular lesions in all but one case. General agreement on zonal involvement and pleural plaques was also good. Four types of large opacities less than 1 × 2 cm (Chinese stage II+) were called either category "A" (3 cases) or coalescence of small pneumoconiotic opacities—"Ax" (1 case) by the "B" readers. Aspects of the Chinese classification without an ILO parallel include the concept of a bondary film, and the use of both profusion and zonal involvement to determine stage of disease. We conclude that, despite various differences, a clear correspondence can be made between the two pneumoconiosis classifications.

INTRODUCTION

A valid quantitative assessment of disease is a prerequisite to the development of appropriate dose-response relationships. The chest X-ray is the major tool in assessing the pneumoconioses, and in general has been found to be both valid and quantitatively accurate.[1-3] However, despite an international classification system for the pneumoconioses,[4] substantial differences in interpretation among X-ray readers in one country and among different countries are known to exist.[5-7] The differences between the Chinese and ILO classification systems pose another potential source of disagreement. Thus, before an effective exchange of epidemiologic pneumoconiosis data can take place, a clear correlation between the two classification systems is needed.

The 1986 Chinese Criteria is described in detail in another Proceedings paper (first authored by Lu Shixuan). In brief, the Criteria uses only a single (primary) type of small opacity (ILO letter system), the major category of small opacity profusion (ILO number system), a slightly modified large opacity classification, a simplified pleural disease evaluation, and similar "other symbols." In addition, the Chinese have stage symbols: 0, 0+, I, I+, II, II+, III, and III+, where 0 is normal and III represents large opacities (greater than 2 × 1 cm). The lower Chinese stages are determined by the number of lung zones involved as well as the profusion of small opacities. An abbreviated correspondence between the 1980 ILO and 1986 Chinese classifications is illustrated in Table I. For the first time, the Chinese Criteria in 1986 covers all pneumoconioses, and includes 32 standard films.

As a preliminary step in joint Sino-American pneumoconiosis research efforts, this study correlates the ILO and Chinese systems by evaluating 3 "B" readers' interpretations of the Chinese standard films.

METHODS

The 32 standard chest X-rays of the 1986 Chinese Roentgenodiagnostic Criteria of Pneumoconioses were interpreted according to the 1980 ILO Classification of the Pneumoconioses by three NIOSH -certified "B" reader radiologists. The Chinese interpretations on the films were obscured, and the X-rays were read independently in random order.

In the analysis the median "B" reading was used to compare to the Chinese interpretation. In a few cases, a simple median "B" reading of type of small opacity did not exist. In these cases the most frequent type (including primary and secondary) was selected. One Chinese film is divided into two sections and two into three sections; thus more than 32 comparisons are possible in some categories.

For profusion category, the kappa statistic[8] as well as the crude agreement value was calculated both between the Chinese and median "B" reading, and among the 3 "B"

Table I
Correspondence Between 1986 Chinese Criteria Stage and 1980 ILO Classifications of Pneumoconiosis

Chinese Stage	ILO Classification		
	Profusion of Small Opacities	Number of Zones	Comment
0	0/- ; 0/0	---	
0+	0/1	---	
I	1	2, 3, or 4	
I+	1	5 or 6	
	2	2, 3, or 4	
II	2	5 or 6	
	3	2, 3, or 4	
II+	3	5 or 6	
	--	---	Several types of large opacities < 2 X 1 cm
III	--	---	Large opacities > 2 X 1 cm but less than "C"
III+	--	---	"C" large opacity

readers. The statistic adjusts for the amount of chance agreement to be expected, and is expressed as:

$$\text{Kappa} = (\text{PC}-\text{PE})/(1-\text{PE})$$

where PC is the crude agreement (expressed as a proportion), and PE is the expected agreement. This is derived, as in a Chi-squared test of independence, from the expected numbers for the diagonal elements of the Table, which, in turn, are obtained using the products of the marginal totals. Kappa will equal zero if there is only chance agreement, and will be one with complete agreement.

RESULTS

The overall film quality was rated as quite good; all films having a median technical quality grade of 1 or 2.

Table II presents the reading data for the profusion of small opacities. The "B" readers' major category agreed with the Chinese category in 27 of 34 cases (79%). The kappa statistic, used to adjust the crude agreement, was 70%. By comparison, the average crude agreement among the three "B" readers was 61%, and the average kappa statistic 46%. The Chinese category was included as either the major or alternative ILO profusion category in 32 of the 34 cases. One of the remaining films, called 0/0 by median reading, was a "borderline" film in the Chinese classification. This film had profusion 1, but stage 0+ since the small opacities involved only one zone of the lung.

Table III presents the comparison of the type (size/shape) of small opacities. In all but one case, there was agreement with regard to rounded or irregular lesions. The "B" readers' primary type of opacity agreed precisely with the Chinese type in 24 of 32 cases. The only substantial disagreement was due to an apparent unwillingness of the "B" readers to report "t" opacities. In these 4 cases, however, the "t" opacity was recorded as the primary or secondary small opacity by either one (2 cases) or 2 (2 cases) radiologists. The comparison of zonal involvement is shown in Table IV. There was good general agreement, although it should be noted that over half of the cases had all 6 lung zones involved. All 4 examples of pleural disease were appropriately noted by the "B" readers.

The 1986 Chinese Standard Films contain examples of 4 types of large opacities (>1 cm) that are less than 2 × 1 cm. These abnormalities, all categorized as stage II+ are described as: 1. Aggregation of small opacities (analogous to the ILO "ax"); 2. Large opacities (which would be considered "A" lesions using the ILO scheme); 3. Definite shadows in appearance longitudinal, faint mottling in

Table II
Comparison of Small Opacity Profusion

Chinese Profusion Category	ILO Major Category 0	1	2	3	Totals
0	1				1
1	3	10	2		15
2		1	10		11
3		1		6	7
Totals	4	12	12	6	34

Table III
Comparison of Type of Small Opacities

Chinese Type	ILO Primary Type P	Q	R	S	T	U	Totals
P	4	2		1			7
Q	1	5					6
R			6				6
S				5			5
T				4	1		5
U						3	3
Totals	5	7	6	10	1	3	32

Table IV
Comparison of Zonal Involvement

Chinese Standards	"B" Readers 1	2	3	4	5	6	Totals
1		1					1
2				1			1
3		1		1			2
4				6			6
5				1		1	2
6					1	14	15
Totals	0	2	0	9	1	15	27

peripheral parts of both upper zones; and 4. Homogeneous, hazy, and patchy shadows over both upper zones. The individual and median "B" readings for these films are presented in Table V. Abnormalities 1, 2, and 4 were graded as showing "A" size large opacities by the median "B" reading. Abnormalities 1 and 3 were marked "ax". There was agreement on the three other examples of large opacities.

DISCUSSION

The 1986 Chinese Roentgenodiagnostic Criteria of the Pneumoconioses represents a marriage between the older (1963) Chinese classification[9] and features of the 1980 ILO classification. The Chinese stage system is maintained since there is much experience in this format which is also related to compensation for pneumoconiosis in the People's Republic of China. Aspects of the ILO classification included in the 1986 Chinese Criteria enable researchers to make a clear correspondence between the two systems. From this small study, it appears that there is a good correlation between the type (size/shape) and profusion of small opacities between the Chinese and ILO classifications. The two classifications contain different standard films, and the Chinese standards represent boundary films as opposed to the mid-category standards of the ILO. In addition, the algorithm to determine the overall profusion category is slightly different. Thus it is not surprising that some small differences might exist.

In the important area of large opacities, the Chinese system makes several distinctions which do not exist in the ILO classification, particularly for what might be regarded as borderline large opacities. Although more readings are needed, it appears that the "B" readers also considered these abnormalities to be borderline or early large opacities (Table V). The other areas of comparison also showed good general agreement.

It should be emphasized that because of (sometimes substantial) variability among pneumoconiosis reading,[5,7] different results might be obtained with additional "B" readers. However, the overall conclusion is that despite various differences between the 1986 Chinese and 1980 ILO classification, a clear correspondence can be made.

Table V
"B" Reader Interpretation of Large Opacities Less Than 2 × 1 cm

Chinese Abnormality (all Stage II+)	"B" Reader Interpretation Median	Reader #1	Reader #2	Reader #3
1. ax	ax, A	ax, A	ax, A	ax, A
2. A, < 2 X 1 cm	A	A	ax, A, R/O Ca	A, R/O Tb
3. Definite Shadows faint mottling	ax	ax	ax, A R/O Tb, Rp	O
4. Homogeneous, hazy & patchy	A	A	A, R/O Ca	B

R/O = Rule out; Ca = cancer; Tb = tuberculosis; Rp = Rheumatoid pneumoconiosis.

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AN ALGORITHM FOR THE DETECTION OF SMALL ROUNDED PNEUMOCONIOSIS OPACITIES IN CHEST X-RAYS AND ITS APPLICATION TO AUTOMATIC DIAGNOSIS

TOSHIHIRO WATANABE • Hidefumi Kobatake

Department of Electronic Engineering, Faculty of Technology
Tokyo University of Agriculture & Technology, Koganei, Tokyo 184, Japan

INTRODUCTION

Computer diagnosis of pneumoconiosis has been studied by several groups since 1970's. Fundamental approaches for classification of profusion of pneumoconiosis opacities can be divided into two categories. One is based on texture analysis of density pattern of lung area, which has been adopted by a large majority of research groups.[1-8] The other is an approach trying to detect directly small opacities of pneumoconiosis. It may be superior to texture analytic approach because it is robust against fluctuations of film quality and individual differences of normal structural patterns in lung area. And, perhaps the latter approach can meet the requirement better according to the ILO classification system whose categorization is based on the density of pneumoconiosis opacities. Typical methods of detecting small rounded opacities have been developed.[9,10] However, category classification based on them has not been performed. Recently, two opacity detection methods have been proposed.[11,12] One is based on a contour line processing and the other adopts a matched filtering technique. Experiments of four major category classifications have been performed by those two methods, whose results show the usefulness of the opacity detection method. This paper presents a new method to identify small rounded opacities of pneumoconiosis and to classify the grade of their density.

DETECTION OF SMALL ROUNDED OPACITIES

The new method for detecting small rounded pneumoconiosis opacities in chest X-rays is based on the processing of local density pattern. The gray value in an opacity area is of the distribution like a local convex surface. Detection of such convex surfaces is performed by two processing steps. The first step is to locate local peaks, and the second one is to identify the shape and the size of them, which is the segmentation of the local convex surfaces from their neighboring area.

The First Step

Candidates of pneumoconiosis opacities are detected by this processing. Figure 1 shows a filter to detect convex surface. Detectors are arranged on three concentric circles. Each detector covers, in general, rectangular region, and its output is the mean pixel value in that region. The output of the filter, X, is given as follows.

$$X = \begin{cases} 3, & A > MAX3, \\ 2, & A > MAX2 \text{ and } A < MAX3, \\ 1, & A > MAX1 \text{ and } A < MAX2 \text{ and } A < MAX3, \\ 0, & \text{others} \end{cases}$$

where, MAXi (i=1,2,3) is the maximum of B_i, C_i, D_i, ...,I_i which are output values of detectors on the same circumference. Diameters of three concentric circles are 1.5, 2.0, and 3.0 mm. They are determined considering the sizes of pneumoconiosis opacities p, q and r. Filter outputs 1, 2, and 3 mean that local convex surfaces can be candidates of pneumoconiosis opacities whose sizes are p, q and r, respectively. Many false pneumoconiosis opacities are detected by the proposed filter. They are called noise opacities in the following and the following screening algorithm to exclude those noises is adopted. First, expansion and contraction processing is applied to merge candidates which are closely adjacent to each other. The next step is the noise reduction in which characteristics of each candidate are evaluated and those which satisfy the following conditions are excluded.

1. Area is less than a threshold h_s.
2. Film density is less than a threshold h_p.
3. The shape is long and slender.

The third condition is investigated as follows. Let us denote the area of a candidate, its widths in the directions of abscissa and the ordinate by s, l_x and l_y, respectively. If the shape of the candidate is a circle, its diameter l is given as:

$$l = 2\sqrt{s/\pi},$$

which is equal to l_x and l_y. Considering this relationship, long and slender candidates can be detected as those which satisfy the following condition:

$$(l_x + l_y)/2 > 3l.$$

The Second Step

The second processing step includes precise measurement of opacity area and a supplementary noise reduction.

Identification of the boundary of pneumoconiosis opacity is performed as follows. It is assumed that the gradient vector at any pixel which belongs to a pneumoconiosis opacity is directed to the top of its convex surface. And the pneumo-

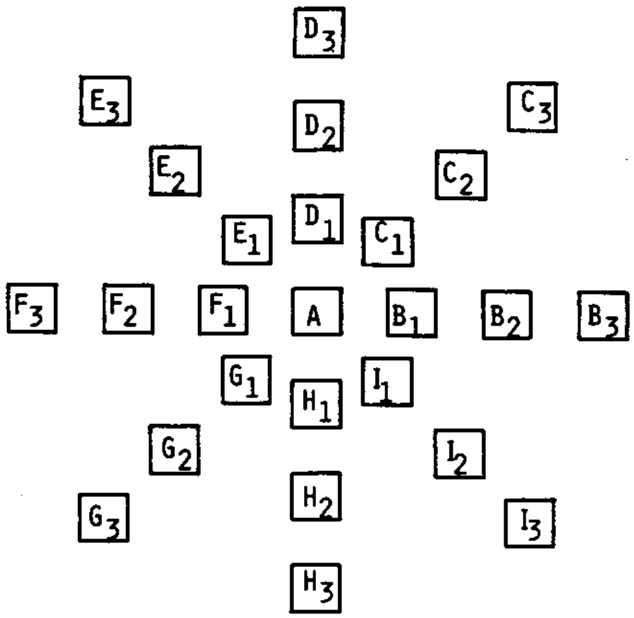

Figure 1. Pneumoconiosis opacity candidate detection filter.

coniosis opacity area defined in this paper is the union of the opacity candidate area and its neighborhood in which gradient vectors are directed to the opacity candidate area.

The second noise reduction algorithm is applied at this stage and the final result is obtained. Opacities which meet the following conditions are excluded.

1. The absolute value of a gradient vector in the opacity area is larger than a threshold h_d.
2. Those opacities which have large discrepancy between the output of the pneumoconiosis opacity candidate detection filter and the area measured in the second step.

EXPERIMENTS

Experimental Conditions

The films used in this study were 11 ILO 1980 standard films whose opacity shapes are rounded. Their classification is given in Table I. Each film was digitized by a drum scanner at a resolution of 5 pixels/mm with 12 bits accuracy and 3 partial zones with 350*200 pixels were extracted from each of the right and the left lung area. They correspond to the upper, the middle, and the lower lung zones. That is, 6 partial zones were extracted from one standard film. It is known that no pneumoconiosis opacities can be recognized in the lower lung area for two ILO standard films 1/1 q/q and 1/1 r/r, and four zonal images extracted from those areas were excluded from the experimental materials. Therefore, the number of zonal images used for automatic diagnosis was 62. Parameter values adopted in the following experiments were as follows.

h_s = 5 pixels,
h_p = 3200,
h_d = 500.

Verification of Opacity Detection Algorithm

Pneumoconiosis opacities identified by an expert reader and those detected by the proposed method were compared to each other. The test material was the upper half of the left lung area of the film 3/3 r/r. The number of pneumoconiosis opacities identified by an expert reader*) and that detected by the proposed method were 120 and 109, respectively. Among them, 66 opacities coincide with each other.

Classification Experiments

A. Features

In spite of the application of noise reduction in twice, noise opacities cannot be excluded completely. Therefore, it is necessary to extract information on the opacity density as much as possible, and the following 14 kinds of features were used for classification.

1. The numbers of opacities x_1, x_2, x_3 for which the convex surface detection filter outputs are 1, 2, and 3, respectively.
2. The numbers of opacities purged from x_1, x_2, and x_3 by the first noise reduction x_4, x_5 and x_6.
3. The sums of area for each opacity size x_7, x_8, x_9.
4. The number of opacities x_{10} and the total sum opacity area x_{11}.
5. The numbers of opacities for each size x_{12}, x_{13}, x_{14}.

The feature parameters $x_{10}, \ldots, x_{14}$ can be derived from the other parameters. However, the use of these dependent features were useful for classification.

Table I
Experimental Materials

major category	ILO 1980 standard film
0	0/0 × 2
1	1/1 p/p, 1/1 q/q, 1/1 r/r
2	2/2 p/p, 2/2 q/q, 2/2 r/r
3	3/3 p/p, 3/3 q/q, 3/3 r/r

B. Classification Method

Defining fourteen-dimensional feature vector $x^t = (x_1, x_2, \ldots, x_{14})$, distance of an input image from a category k is defined as follows:

$$d(k) = \| x - r_k \|$$

where, r_k is the reference pattern vector of category k. It is defined as the mean of feature vectors of the category k. The computer diagnostic testing procedure was one-at-a-time removal test procedure. That is, it consisted of removing one sample from 62 partial zones, training on the remaining 61 samples, and resubmitting the withdrawn sample for reclassification.

C. Classification Results

Results for four major category classifications are given in Table II. Zonal correct classification rate is 69.4 percent. If we adopt a majority rule for overall film classification, it is perfect. Classification rates reported hitherto range between 50 and 80 percent, which have been attained all by texture analysis approaches.

Table II

Confusion Matrix for 4 Major Category Classifications

		assigned category			
		0	1	2	3
input category	0	6	1	3	2
	1	1	12	1	0
	2	0	2	14	2
	3	5	1	1	11

The second experiment is the classification of ILO substandard films. Seven substandard films were used, which consist of two normal, two 2/2 and three 3/2 films. Zonal images with the same size were used for classification. Reference patterns were defined by using all zonal images of ILO standard films. Normal/abnormal classification results is shown in Table III. Correct classification rate was 83 percent, which shows the effectiveness of the proposed method.

CONCLUSION

Identification method of pneumoconiosis opacities and classification based on it have been given. The proposed method is not sensitive to the changes of film quality, which is superior to texture analytic approaches. And the correct classification rate by the proposed method has been shown to be comparable to them. However, many false opacities are detected as pneumoconiosis opacities, and the further improvement of the method is necessary.

Table III

Confusion Matrix for Normal/Abnormal Classification

		assigned category	
		N	A
input category	N	6	6
	A	1	29

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APPLICATION OF COMPUTED RADIOGRAPHY FOR THE DIAGNOSIS OF PNEUOCONIOSES

TOKURO NOBECHI • Yukio Tateno • Hisao Shida • Yutaka Hosoda • Junichiro Toriwaki • Hidefumi Kobatake • Takeshi Iinuma • Kenjiro Fukuhisa • Toru Matsumoto • Masao Takano • Hisatoyo Kato • Masatomo Tachi • Yasuyuki Chiba

Research Group for the Quantification of the Radiographs of the Pneumoconioses
Japan Industrial Safety and Health Association, Tokyo, Japan

In 1982, Research Group for the Utilization of Image Processing for the Diagnosis of Pneumoconioses was organized in the Japan Industrial Safety and Health Association and by the three years' survey, image processing is found very useful for the diagnosis of pneumoconioses with small sized output films of Fuji Computed Radiography (FCR).[1] FCR is a computed radiographic system utilizing imaging plate of laser stimulated luminescence[2] and has linear response to the X-ray dose, resulting extraordinary wide latitude for the exposure. However the output film of this system is ½ size in length of the ordinary radiographic film, such as the ILO standard film of pneumoconioses.

The authors carried out five steps of experiments as shown in Figure 1 since 1982, although in 1985 the name of the research group was changed to the "Research Group for the Quantification of the Radiographs of the Pneumoconioses."

For the experiments 2 and 3 shown in Figure 1, the ILO standard films and test films selected from training films of pneumoconioses in U.S.A. were digitized by using a drum scanner. Digitized images were processed with the several contrast and spacial frequency characteristics which were similar to those employed in FCR system, and finally written optically onto X-ray film in reduced size using a drum scanner. From these experiments gamma 0.85 is found quite satisfactory for this reduced size of the picture, so at the latter stage of the experiments, only 0.85 of gamma curve was used.

For the experiment 5 shown in Figure 1, FCR films of pneumoconioses patients were used with the fixed contrast of 0.85 gamma with several spacial frequency characteristics of E,F,G and H shown in Figure 2. Image processing factors of F.G. and H are almost equally good as shown in Figure 3, but the best is probably G., i.e., slight enhancement at 0.17 cycles/mm.[3]

Magnetic tapes of the digitized images of ILO standard film and test films aforementioned and FCR were used for the study of the automatic determination of the size and profusion of small rounded opacities. Two methods were utilized for this purpose, one is direct detection method using difference linear filtering and the other is texture analysis method, details of these studies are reported respectively by J. Toriwaki and H. Kobatake in this International Conference, so I will not discuss these matters.

It seems rather easy to determine the size, p, q and r, while the automatic categorization of the profusion is not so easy

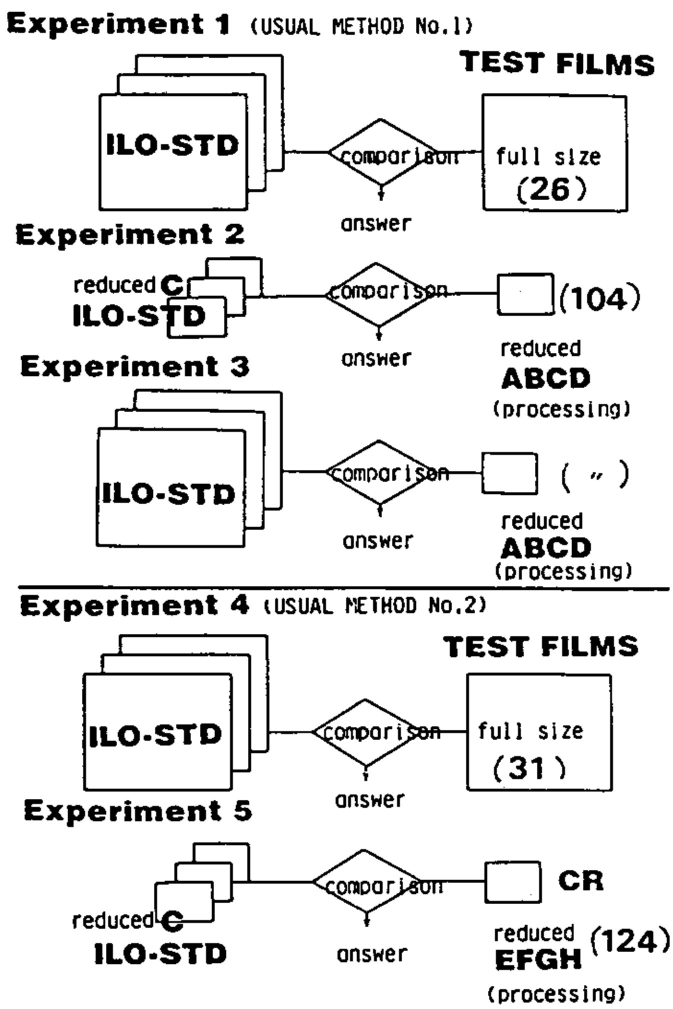

Figure 1. Reading experiments and their sequences.

FERQUENCY PROCESSING

PROCESSING	γ	RANK	BE	FRQ(cycle/mm)
A	0.85	-	-	-
B	0.85	4	0.50	(0.35)
C	0.85	2	0.25	(0.17)
D	0.85	4	0.30	(0.35)
E	0.85	-	-	-
F	0.85	0	0.30	(0.085)
G(≒C)	0.85	2	0.30	(0.17)
H(≒D)	0.85	4	0.30	(0.35)

↑ GRADATION PRECESSING

BE : THE DEGREE OF SPATIAL FREQUENCY ENHANCEMENT

FRQ: THE CENTER OF ENHANCEMENT

Figure 2. Image processing factors.

for the low profusion groups, although various methods disclosed the accuracy of 45 to 71%, if majority rule is applied 82% was obtained by texture analysis. The result of the investigation is very promising for the future application of computer technique for the automatic diagnosis of pneumoconioses.

At present the authors are collecting more cases with FCR, for the preparation of excellent standard films of our country, and for the creation of better program of automatic diagnosis by computer.

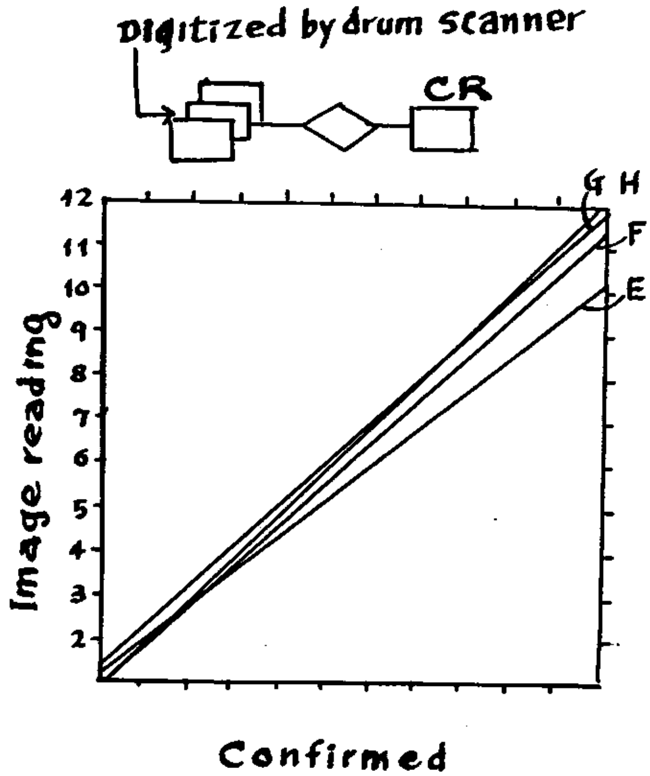

Figure 3. Accuracy of image reading.

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THE POSSIBILITIES OF THE NEW THORACIC IMAGERY FOR EARLY DETECTION OF INTERSTITIAL SYNDROMES AND OF SILICOSIS

J.-P. SENAC* • J. Giron* • C. Bousquet* • Ph. Godard† • F-B. Michel† • J. Loriot‡

*(Service de Radiologie)
†(Service de Pneumologie)
‡(Service de Médecine du Travail)
C.H.U. de Montpellier, France

In the study of Pneumoconioses, Tomodensitometry appears much more precise (high definition—separation power = 0.17 mm^2—interseptal interstitium = 100 μm) and objective (numerical image—unstacked millimetric cross sections of the thorax) than the standard plate. We have already observed the value of the tomodensitometry for the diffuse parenchymal pathology in general.

Our study covers 59 cases of Pneumoconiosis (20 cases of silicosis, 39 cases of asbetosis). The Pneumoconios diagnostic was made in the light of several elements (exposure time, clinical data, Table I, EFR—DLCO—scintigraphy—bronchiolo-alveolar flush—pulmonary imagery—pulmonary biopsy). Pulmonary imagery is not, indeed, the only method of diagnosis. It must be confronted with other non-morphological methods (for example, we carry out a prospective study on the respective contributions of tomodensitometry and of the other methods of diagnosis—DLCO—scintigraphy—LBA in early detection of the lung, of AIDS).

Table I

New Thoracic Imaging, Insterstitial Syndromes, Pneumoconiose Early Detection—Pittsburgh 1988

DIAGNOSTICS PROCEDURES

- DURATION OF EXPOSURE
- CLINICAL EXAMINATION
- PULMONARY FONCTION TEST
- C O TRANSFERT
- B A L
- SCINTIGRAPHY
- MEDICAL IMAGERY
- PULMONARY BIOPSY

In our series of 50 Pneumoconiosis the pulmonary biopsy was only carried out 7 times; most of the diagnoses were made on epidemiological and clinical data, and on the results of bronchiolo-alveolar flush (28 cases).

All of these Tomodensitometric explorations were made with an apparatus from the "Compagnie Générale de Radiologie" (CGR) CE 1200. The realization protocol was as following (Table II):

Table II

New Thoracic Imaging, Instertitial Syndromes, Pneumoconiose Early Detection—Pittsburgh 1988

METHODS

- C.G. R. : C.E. 10 000 C.T.
- SECTION THICKNESSES : / 10 mm
- CONTIGUOUS SCANS
- "BONE" ALGORYTHM
- SUPINE OR PRONEPOSITION. IF NECESARY
- HIGHT RESOLUTION C.T. (HRCT)FOCALISED ON AREAS OF INTEREST.

- edge to edge cross-sections of 1 cm.
- focalized millimetric cross-sections using the high definition-algorithm for reconstruction of bone type. Table III–IV.
- window systematically wide—250, 1800. This window gives the histologically most faithful image of the thorax (for example there are false thickenings of the bronchial walls when the so-called pulmonary window is used—700, 700). The other windows (mediastinal, parenchymal) were only used when needed (for example, in the search for calcifications).

The criteria of standard radiological interpretation were those recognized by the I.L.O. The standard plates were examined independently of the tomodensitometric documents.

Table III

New Thoracic Imaging, Interstitial Syndromes,
Pneumoconiose Early Detection—Pittsburgh 1988
High Resolution C. T. Scan

TECHNICAL CONSIDERATIONS

- THIN SECTION C.T.SLICES (1 to 2 MM)
- LARGE WINDOW : (WIDTH OF 2000 UH)
  (LEVEL OF -750UH)
- HIGHEST SPATIAL FREQUENCY ALGORITHM OF RECONSTRUCTION ("BONE ALGORITHM" FOR EXAMPLE).
- MATRICE AND CIRCLES OF RECONSTRUCTION.

The criteria of tomodensitometric interpretation have previously been defined in the chapter on pulmonary parenchymal pathology. Let us remember that the semiology of the interstitial syndrome is made up of several stages and expressions (Figure 1): Table V.

1. Homogenous thickening of the interstitial sector parieto-alveolar septal and peri-broncho vascular and sub-pleural; this thickening gives rise to a sign which we have described as "trussed joint". Table VI.
2. Nodular thickening micro and macro-nodular septal or parieto-alveolar; the limit of separation in high tension is 0.17 mm^2; thus a very small nodule can theoretically be detected, nevertheless, this type of lesion is indiscernible from a pulmonary vessel. Table VII.
3. Mixed lesions of interstitial thickening and of pulmonary nodule.
4. "Honey comb" lung indicating an advanced parenchymal destruction.
5. In the case of asbestosis, the sub-pleural curvilineal opacity described by YOSHIMURA, corresponding to a peripheral atelectasis zone, can be bronchiolar and premonitory, in the asbetosis but also in other chronic interstitial pneumopathies, of an evolution towards the "honey comb" lung.

The results of this series are as follows:

29 silicosis were studied, divided into three categories according to the I.L.O. classification and each examined in thoracic tomodensitometry where a score of interstitial disease was given to them (light, moderate, severe disease).

Tomodensitometry shows the parenchymal lesions better than the standard plate (Table I). Thus out of 7 patients in category 1 of the I.L.O. classification, only one shows light disease with tomodensitometry. The six others have moderate disease. Out of 10 cases in category 2 I.L.O. 7 show severe disease with tomodensitometry, only 3 moderate disease. Table VIII.

The high resolution tomodensitometric semeiological study shows nodular disease for all cases, which concords well with the fundamental histological lesion (silicotic nodule), a diffuse disease of the interstitium often occurs also in 25 cases out of 29. The "honey comb" lung is clearly shown in 5 cases as compared to only 2 visible in standard radiography. With tomodensitometry accompanying lesions show up much better than with standard radiography (Table IX).

- 15 cases of emphysemias in smokers as against only 5 detectable with standard radiography.
- 14 cases of associated bronchiectasis invisible with standard radiography.

Table IV

New Thoracic Imaging, Interstitial Syndromes, Pneumoconiose Early Detection—Pittsburgh 1988
High Resolution C. T.

MATRICE \ CIRCLE OF RECONSTRUCTION	525	393	262	131	87 H R
256/256	2 MM2	1,4 MM2	1 MM2	0,5 MM2	0,34 MM2
512/512	1 MM2	0,7 MM2	0,5 MM2	0,25MM2	0,17 MM2

Table V

New Thoracic Imaging, Interstitial Syndromes, Pneumoconiose Early Detection —Pittsburgh 1988, High Resolution C. T.

SEMEIOLOGY (INTERSTITIAL SYNDROME)
- HOMOGENEOUS THICKENING OF INTERSTITIUM
- NODULAR
- MIXED (THICKENING AND NODULAR)
- "HONEY COMBING" LUNG.

Table VI

New Thoracic Imaging, Interstitial Syndromes, Pneumoconiose Early Detection —Pittsburgh 1988, Semeiology Homogeneous Thickening

- INTERLOBULAR SEPTA
  - SHORT LINES - ASPECT OF "TRUSSED JOINT".
  - LONG LINES
  - MACRORETICULATION - DRAW NING OF SEPTA ARCHITECTURE.
- INTRALOBULAR LINES - MICRORETICULATION.
- BRONCHIAL VISIBLE MORE PERIPHERALLY WITH THICK IRREGULAR WALL
- HAZINESS OUTLINES OF THE VESSELS.
- VISCERAL PLEURAL THICK AND IRREGULAR

Table VII

New Thoracic Imaging Interstitial Syndromes, Pneumoconiose Early Detection—Pittsburgh 1988

SEMEIOLOGY

- NODULAR

- MACRO–NODULES :

  DIFFERENTIAL DIAGNOSIS : ALVEOLAR NODULES.

- MICRO–NODULES :

  DIFFERENTIAL DIAGNOSIS : NORMAL VESSELS.

Table VIII

New Thoracic Imaging, Interstitial Syndromes, Pneumoconiose
Early Detection—Pittsburgh 1988

SILICOSIS (N = 29)

COMPARAISON OF I L O / U C RADIOGRAPHIC WITH H R C T SCORE

I L O SCORE	NO OF SUBJECTS	H R C T SCORE		
		LIGHT	MODERATE	HIGHT
1	7	1	6	
2	10	0	7	3
3	12	0	0	12

Table IX

New Thoracic Imaging, Interstitial Syndromes, Pneumoconiose
Early Detection—Pittsburgh 1988

ABNORMALITIES ON H R C T IN SUJECTS WITH SILICOSIS (N = 29)

BRONCHO-PARENCYMAL FINDINGS	HRCT SCORE
- HOMOGENEOUS INTERSTITIAL THICKENING	25
- NODULAR INTERSTITIAL	29
- MIXED (THICKENING AND NODULAR)	16
- "HONEY COMBING"	5
- EMPHYSEMA	15
- BRONCHIECTASIS	14
- NEOPLASM	2 (WITH BIOPSY ON CT)

- 8 pseudo-tumoral masses, 4 of which were necrosed.
- 2 peripheral bronchio neoplasms, the histological diagnosis of which was carried out by puncture under tomodensitometric control.

30 cases of asbetoses were studied with the following final diagnosis (Table X):

- pleural disease alone: 11 cases.
- parenchymal disease alone: 1 case.
- associated pleural parenchymal disease: 18 cases.

Table X

New Thoracic Imaging, Interstitial Syndromes, Pneumoconiose Early Detection—Pittsburgh 1988

ABESTOSIS (N = 30)

FINAL DIAGNOSIS

– PLEURAL DISEASE ALONE	11
– PARENCHYMAL DISEASE ALONE	1
– PLEURO–PARENCHYMAL DISEASE	18

Where pleural disease is concerned (Table XI), the inadequacies of standard radiography as compared with tomodensitometry are obvious since 50% of the cases showing pleural disease (asbetiosic plaques and benign pleuresy) are retrospectively invisible in standard radiography and evident in tomodensitometry. The same applies for the pleural calcifications easily discerned with tomodensitometry.

In the case of associated parenchymal interstitium disease tomodensitometry has a higher score than standard radiography since it reveals, in 5 cases, a disease of the pulmonary parenchyma associated to a pleural disease whereas the standard plates showed a pleural disease alone (certain in 3 cases, uncertain in 2). In these 5 cases, showing up a pulmonary interstitial syndrome allowed for the diagnosis of associated parenchymal disease which was confirmed by the other methods of diagnosis (bronchiolo-alveolar flush in particular) and by pulmonary biopsy in one case. Table XII.

Interstitial disease of the pulmonary parenchyma in asbestosis shows up in our cases mainly through homogeneous thickening of the pulmonary interstitium of the diffuse alveolar fibrosis type whereas nodular disease is more scarce and more tardy. The curvilineal sub pleural line described by YOSHIMURA was observed in 4 cases, 2 of which "honey combed" towards the lung.

The account of these results caused much comment and questions from the audience. All of which may be resumed as follows:

1. Nobody doubts the superiority of Tomodensitometry over standard radiography in early detection of Pneumiconioses. This kind of exploration, however, must be carried out correctly (centimetrical edge to edge cross-sections then orientated usage of millimetric cross-sections and of high resolution). This superiority is clearly illustrated in Asbestosis (early detection of pleural plaques and of parenchymal disease). Other authors on important series (GISSEROT) underline, as we do, this interest of Tomodensitometry. By using Tomodensitometry the pre-radiological phase of the Pneumoconioses is reduced.

Table XI

New Thoracic Imaging, Interstitial Syndromes, Pneumoconiose Early Detection—Pittsburgh 1988, Asbestos (N = 30) Comparison of Pleuro-Parenchymal Involvement on Chest Radiographs and HRCT Scans

	C.R.	H R C T
PLEURAL INVOLVEMENT	15	30
PARENCHYMAL INVOLVEMENT	10	15

Table XII

New Thoracic Imaging, Interstitial Syndromes, Pneumoconiose
Early Detection—Pittsburgh 1988
Asbestosis (N = 30)

PLEURO–PARENCHYMAL ABNORMALITIES ON H R C T SCANS.

– PLEURAL

BEGNIN	PLAQUES	29
	EFFUSION	6
	MESOTHELIOME	2

– PARENCHYMAL

– THICKENING INTERSTITIUM	19
– NODULAR	7
– MIXED (THICKENING AND NODULAR)	5
– CURVULIGNE SUB PLEURAL LINES	4
– HONEY COMBING	3

2. As well as early detection, Tomodensitometry allows for a better morphological and topographical appreciation of the lesions (for example: pseudo mass—lesions of focalized fibroses or "honey combing" in general sub pleural postero-inferior latero-vertebrals), a better study of the associated lesions and of the complications (emphysemia, bronchial dilatation, bronchial or pleural neoplasm, secondary infection, tuberculosis). This morphological and topographical precision of the lesions will surely guide the pulmonary biopsy when necessary whether it be carried out by surgery or by puncture under tomodensitometry as was the case in 2 bronchial peripheral neoplasms in our series.

3. Tomodensitometry presents two disadvantages inherent to Medical Imagery in general:
   - The histological non specificity of the lesions. Numerous interstitial syndromes of various etiologies resemble each other even if that of silicosis is more nodular than that of asbestosis which is more linear. The finding of such lesions must therefore be confronted with the other methods of diagnosis (bronchiolo-alveolar flush and pulmonary biopsy if necessary). At the limit of high definition it is impossible to distinguish between a micro-nodule and an intra-lobular vessel. Other arguments must therefore be taken into account (the number of "vessels" per surface unit of the parenchyma for example). Nevertheless, allow us to point out that if the tomodensitometrical lesions are not very specific, those observed with standard radiography are even less so, harder to interpret in the face of artefacts linked to superpositions and to the technical realization of the plates.
   - The difficulty of quantifying the parenchymal disease. Interesting work is being done in this field (BERNADAC—GRENIER) using computerized mathematical analysis.

In conclusion, in the light of the various works, the possibilities which Tomodensitometry offers for the study of Pneumoconioses are far superior to that of the standard plate which, nevertheless, remains very useful for monitoring these lesions for example. The I.L.O. classification will certainly have to be revised or completed in the light of Tomodensitometry. In this type of pathology, the place of this examination is yet to be defined for, in spite of the present diffusion of the appliances, tomodensitometric exploration is still more expensive and harder to get than a simple standard plate.