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

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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;

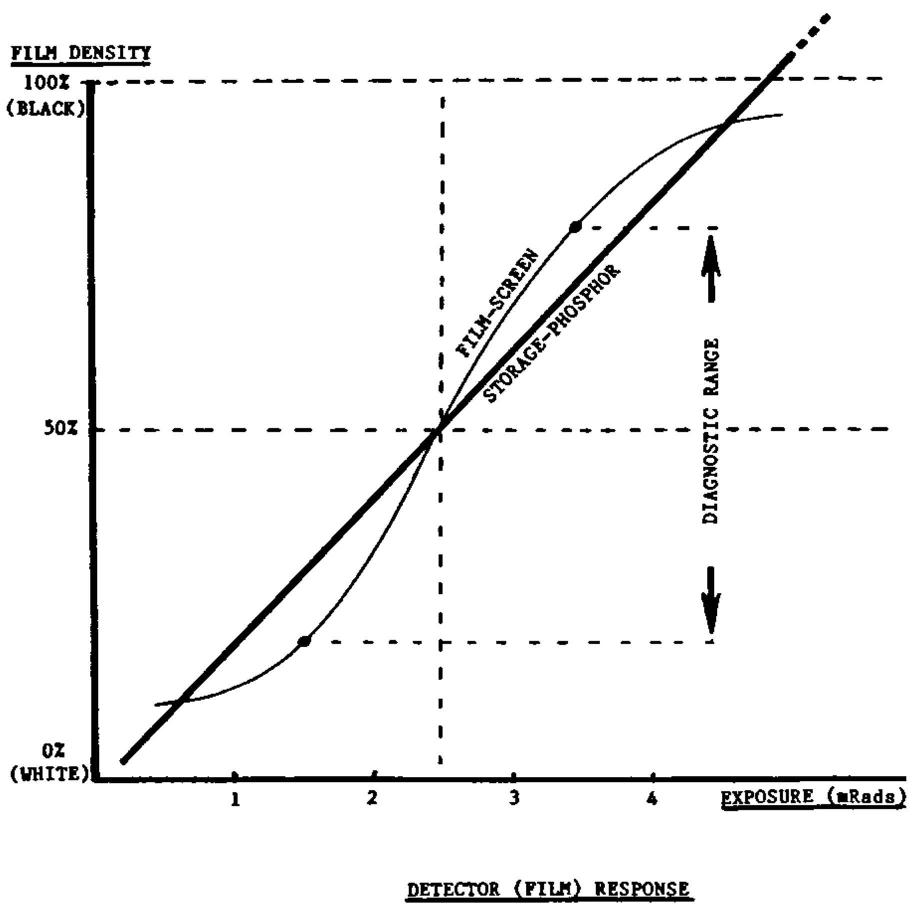

Figure 2. Comparison of detector response curve of film screen versus storage phosphor radiography.

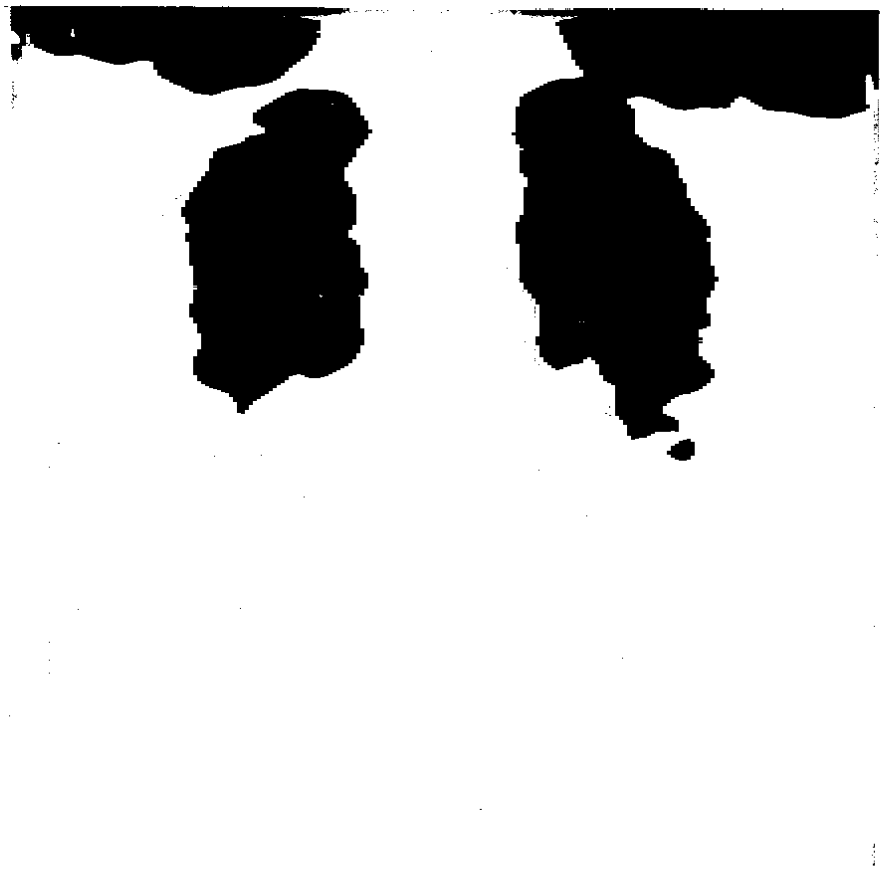

Figure 3. Configuration of storage phosphor image print-outs of examination of a very large patient:
A. Full sized (12 × 14 inch) unprocessed.

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

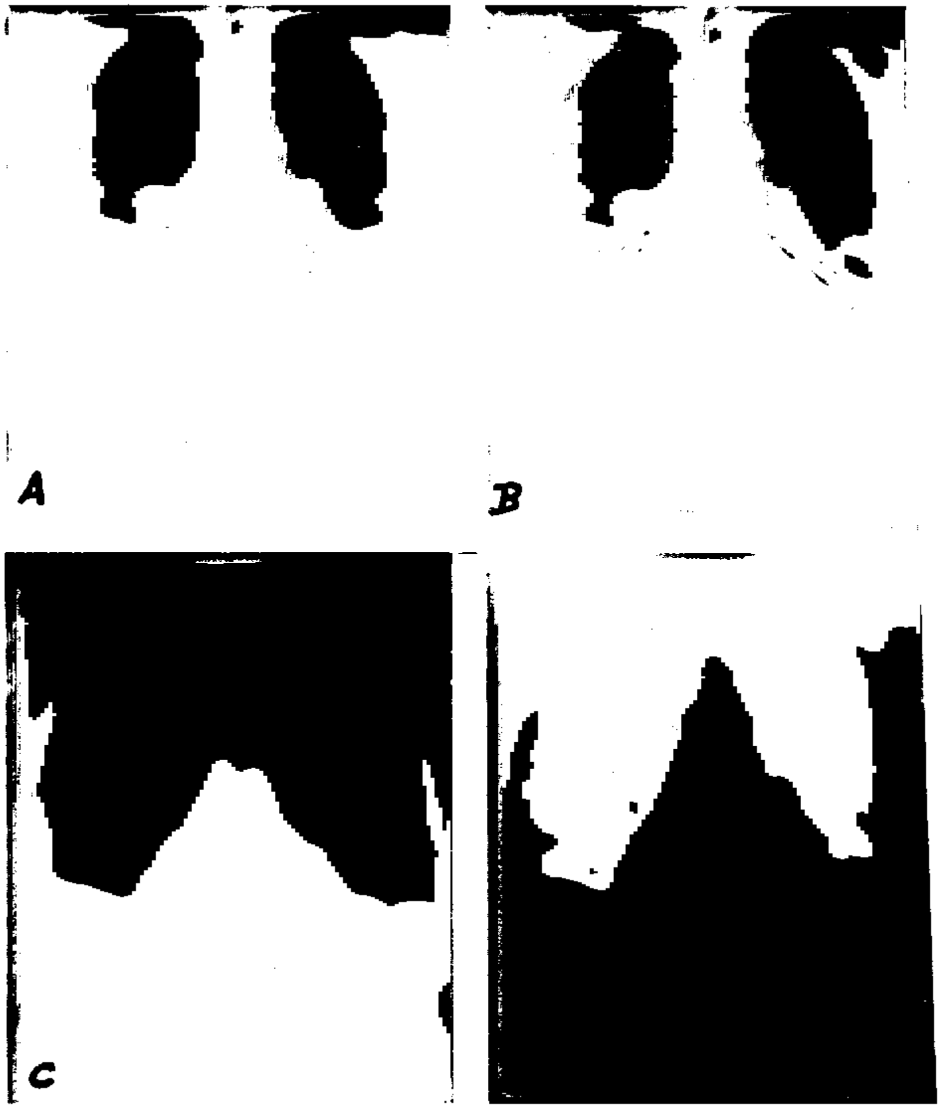

Figure 3. Configuration of storage phosphor image print-outs of examination of a very large patient:
B. 4 minified (6 × 7 inch) images:
(a) unprocessed, identical with A except for minification;
(b) mildly edge enhanced;
(c) mildly edge enhanced and contrast enhanced negative; and
(d) mildly edge enhanced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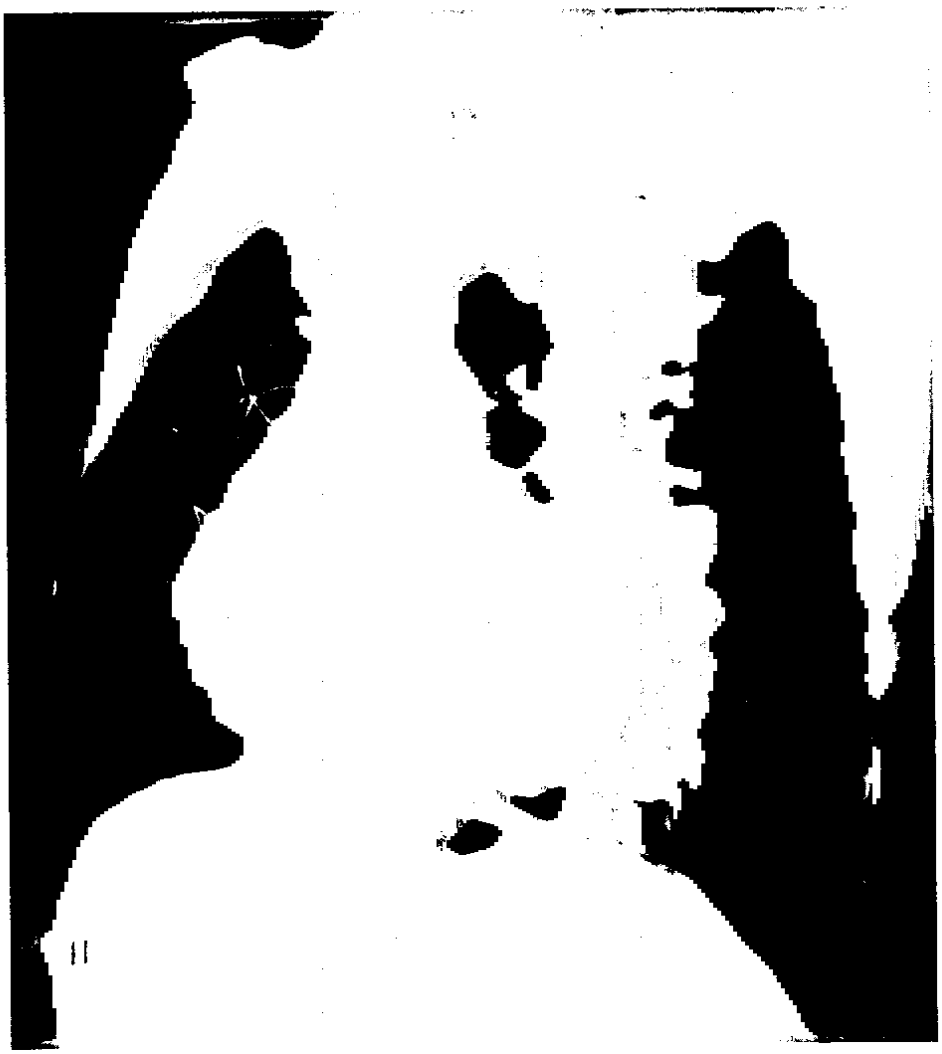

Figure 5. Effect of shoulder position on quality of oblique film:
B. Correct position (cf Figure 1B, upper extremities elevated, extended and internally rotated.

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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).

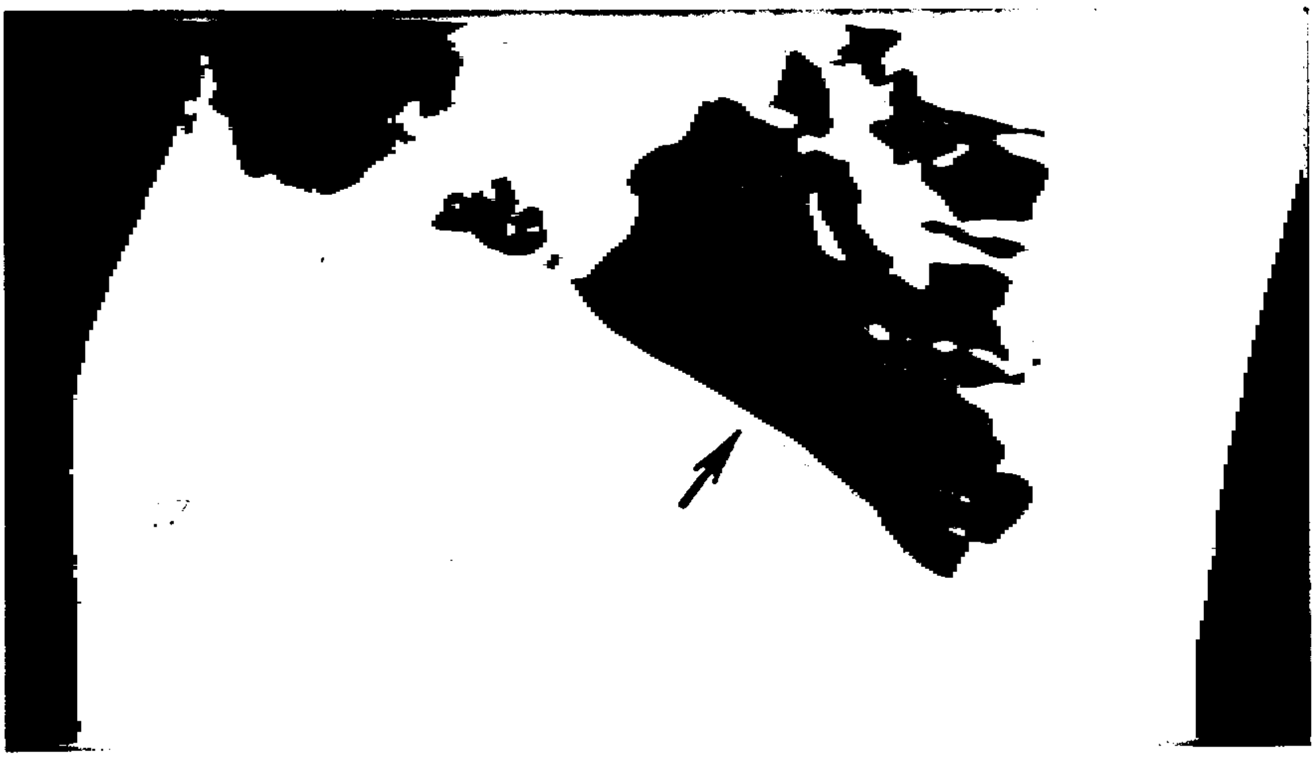

Figure 7. Diagphragmatic and substernal calcifications seen <u>only</u> on lateral radiograph.

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