Medical Surveillance of Pneumoconioses

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In living workers, the pneumoconioses are usually identified and diagnosed by chest radiography. The best available data for exploring the questions addressed at this seminar that are relevant to pneumoconiosis come from studies of coal workers' pneumoconiosis (CWP). My remarks therefore focus on x-ray surveillance of workers exposed to coal-mine dust. These observations are generally relevant to the screening and surveillance of workers exposed to mineral dusts.

THE TEST

A systematic method of recognizing and classifying the chest x-rays of people who have been exposed to mineral dust, which is distributed and periodically revised by the International Labour Organisation (ILO), is the ILO Classification of Radiographs for the Pneumoconioses.[1] This method of x-ray interpretation is used most commonly in organized programs of medical surveillance. Exposure to mineral dust causes either small-rounded, irregular, or large opacities. In order to apply the ILO system, a reader compares the chest x-ray of a worker with so-called standard films giving examples of abnormalities. Readers report the sizes, shapes, and profusion of the opacities. Profusion is rated on a 12-point scale (0/-,0/0,0/1,1/0,1/1,1/2,2/1,2/2,2/3,3/2,3/3,3/+). If no abnormal opacities are evident, the film is classified as 0/0. The dividing line between films that probably do not have abnormalities due to exposure to dust from those that probably do is between 0/1 and 1/0: 1/0 indicates that the reader thought the film might be normal but concluded that it was abnormal. This approach to determining the presence or absence of an abnormality is different from use of a blood test to determine a level of lead or the presence of antibodies. A test using a chest x-ray and a classification system to determine the presence or absence of a lung condition (pneumoconiosis) is influenced by a combination of factors related to the film, the reader, and the method of recording and reporting abnormalities. Recognition of pneumoconiosis does not rely on a single, discrete measurement but reflects a combination of skills, attitudes, and knowledge of the reader, the technical adequacy of the radiograph, and a method for consistently and accurately reporting and recording the film.

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THE DISEASE

The pneumoconioses are diseases of the lungs resulting from reactions of the lungs to inhaled, retained dust. There are three major pneumoconioses: asbestosis, caused by exposure to asbestos; silicosis, caused by exposure to crystalline silica (quartz); and coal workers' pneumoconiosis (CWP), caused by exposure to coal-mine dust, a mixed dust that includes coal, silica, and a variety of other elements. Exposure to coal-mine dust can result in either chronic or simple CWP, progressive massive fibrosis, or both. A person with this condition usually has diminished life expectancy and a substantially impaired ability to pursue normal life. People with CWP without progressive massive fibrosis sometimes have substantial impairment and sometimes do not. People exposed to coal-mine dust are also at increased risk for emphysema and bronchitis, with varying levels of airways obstruction. In addition, depending on the silica content of the coal-mine dust, they may have acute, accelerated, or chronic silicosis. People exposed to coal-mine dust may have emphysema with or without CWP. Although progressive massive fibrosis can occur in the absence of simple CWP, people who have CWP often have concurrent bronchitis and emphysema.

The relationship between coal-mine dust or silica exposure and disease [a category 1/0 or higher (1/0+) chest x-ray] is not always straightforward. The likelihood of having a category 1/0+ film or worse depends on the extent of exposure, so the more exposure, the greater the likelihood the x-ray will be categorized as 1/0+. In addition, the older individuals are, the more likely it is that their x-rays will be positive for the same level of exposure. The intensity and duration of exposure, the latency, and the post-exposure period of observation influence the likelihood of an abnormal chest x-ray in ways that have not been completely quantified. People with the same cumulative exposure over a short period may have different levels of chest x-ray abnormalities from those exposed over an extended period. Very intense exposure, especially to dust with a high silica content, can create substantial abnormality; exposure for a longer duration at a lower level may have a less dramatic result.

SELECTION PRACTICES

One of the issues discussed at this seminar was the use of medical testing for selection of workers. In the United States, relevant legislation, the Americans with Disabilities Act, was enacted a few years ago. This legislation and related regulations specifically prohibit discrimination for employment on the basis of disability. The Americans with Disabilities Act requires that a workplace accommodate a worker with a disability if possible, but it permits exclusion of an individual worker on the basis of specific sensitivity. While "disability" refers to a medically determinable condition that affects a major life function, the definition of "susceptibility" in the United States is drawn very narrowly. For example, susceptibility may be specific sensitivity to a particular allergen that results in asthma. The concept of overall susceptibility and genetic determinants of increased risk are not taken into consideration. The fact that one worker may be at greater risk (e.g., due to atopic status rather than because of a specific allergy) than a co-worker does not mean that an employer can choose to discriminate.

Medical examinations associated with hiring are called "pre-placement examinations." Generally, a decision to hire is made independently of the medical examination. Medical examinations can be used to determine the appropriate place within an enterprise where a worker can work, or whether specific accommodations must be offered. I understand that what is called a susceptibility scheme in the introduction to these proceedings is what we would refer to as a risk-variability scheme. Rather than focusing on issues of susceptibility within the worker, we should indeed always be considering risk variability and its importance.

MEDICAL SCREENING AND SURVEILLANCE

The term "medical screening" refers to testing for presumptive identification of a disease sufficiently early that an available intervention can benefit the worker and reduce mortality or morbidity. There are a variety of considerations in medical screening, including the need to target appropriate, screenable diseases, provide reasonable tests, have adequate personnel and facilities, perform the tests at a frequency appropriate for some reasonable yield, and set the right normal and abnormal end-points. Beneficial actions should follow abnormal test results; these should include confirmation of the test, notifying the worker of the abnormality, and treatment.

Medical screening focuses on the health of the individual. While the term "medical screening" is used with some consistency, the term "medical surveillance" is used in various ways. At this seminar, some participants use the term "medical surveillance" for the periodic examination of an individual's health over time. Others call that a "periodic health examination." "Surveillance for public health purposes" includes the periodic collection, analysis, and reporting of information relevant to health for the purposes of prevention. Medical surveillance generally involves use of the same tests as medical screening and also the collection of results, group analyses, and reporting. Surveillance thus focuses on the health of populations and not only that of the individual. Medical surveillance has a variety of goals and purposes, including tracking trends in disease incidence and prevalence in populations; ranking the importance of problems, in order to set priorities for prevention; learning about new hazards or identifying populations at risk from old hazards; and looking at the effectiveness of prevention efforts.

Figure 1 gives an example from the x-ray surveillance program of coal workers in the United States. The rates of abnormal chest x-rays identified between 1971 and 1988 are arranged by mining tenure. Between 1971 and 1986, there was a progressive reduction in CWP, probably because of the controls on dust levels instituted in 1969. Reductions in disease are apparent after a latent period and as people exposed under older conditions began to retire. After the decrease in disease in 1986, there was a levelling off or increase, and then a return to reduced rates thereafter.

Concepts of screening and surveillance reflect a linear concept of health and disease (Figure 2). Exposure occurs at a time of "health." An individual then goes through a pre-symptomatic stage, when disease might be discovered by the proper test. Subsequently, there is overt disease, resulting in recovery, impairment, or death. Primary prevention is the preferred method, interrupting the path of exposure to the individual.

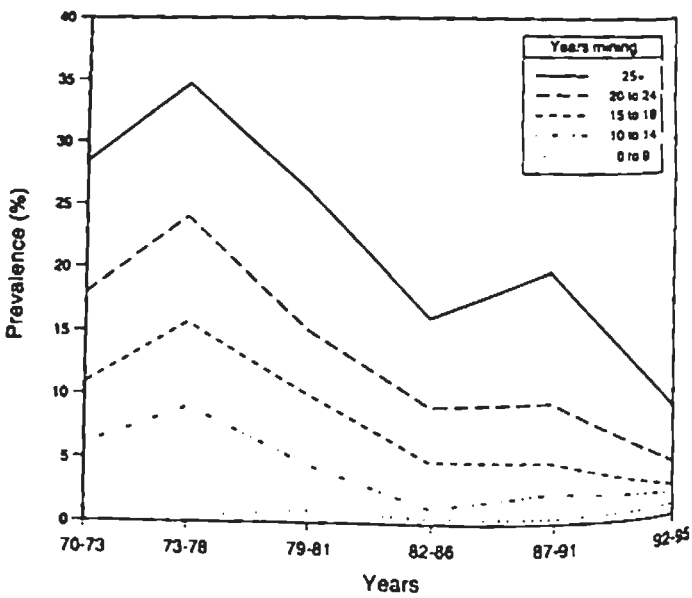

Figure 1—Prevalence of category 1 or higher coal workers' pneumoconiosis (CWP) identified in the Coal Workers' X-ray Surveillance Program since 1970 by tenure in coal mining. The numbers of miners examined during each round were 71,446 (1970–73), 115,386 (1973–78), 58,294 (1979–81), 25,154 (1982–86), 13,920 (1987–91), and 11,678 (1992–95). From Althouse (unpublished data).

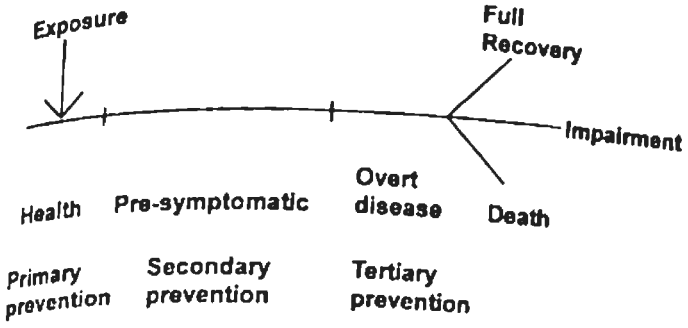

Figure 2—Natural history of disease

Screening is a secondary prevention strategy, an attempt at early identification of individuals who may have been changed by their exposure at a time when the consequence of exposure can be blunted so that the possibility of full recovery is increased or the likelihood of impairment or death diminished.

Screening and surveillance programs are conducted in a general context, which includes not only the individual and exposure in the work environment but also various legal, political, social, and economic concerns. In addition, there is active interaction between the choices and actions of a worker and the ultimate results of any screening or surveillance program for the purposes of prevention. Such programs can either be disabling or enable a range of actions that permits improved prevention.

PREVENTION STRATEGIES

Disease prevention is actually a cyclical system in which the most important element is often the anticipation that a problem may exist. Once problems occur, they must be rapidly recognized and evaluated and a control strategy must be developed and implemented. That control strategy should first focus on engineering controls, but can be supplemented by medical screening of workers to ensure the adequacy of control. An ongoing evaluation of the adequacy of control measures can involve both health and hazard surveillance. If those data show that the problem is not under control, efforts should be stimulated to improve the control measures. It goes without saying that screening and surveillance programs do not prevent disease. Monitoring and control of exposure are the critical issues in disease prevention.

ANALYSIS OF TEST RESULTS

As noted earlier, the commonest test used to recognize lung disease among coal miners is conventional chest radiography. The conventional chest x-ray defines the presence or absence of CWP.

The *accuracy* of a test, in this case the chest x-ray, depends on its sensitivity and specificity. In an ideal world, a test would completely separate those with the disease from those without. There would be individual variability and population variability, but people with normal test results could be distinguished. Unfortunately, the world is not ideal. The sensitivity of a test—its ability to correctly identify people with a disease or condition—and its specificity—its ability to prevent those without the condition from being labelled abnormal—are based on somewhat arbitrary determinations of what is normal and what is not. With regard to chest x-rays: if we choose to say that only a category 2 chest x-ray is abnormal, then we will be insensitive to recognition of the disease but highly specific, because few people who have a category 2 chest x-ray (in the absence of other disease) do not have significant abnormality due to exposure to dust.

The concept of accuracy incorporates issues of sensitivity and specificity. A study of asbestos workers for whom both chest x-rays and biopsy samples were available gives insight into the accuracy of the chest x-ray in recognizing pneumoconiosis. The study subjects had been exposed to asbestos and were undergoing open-chest operations. Tissue was examined for the presence or absence of fibrosis, and these results were compared with x-ray films evaluated by the ILO system for the presence or absence of fibrosis. Of 138 workers with pathologically determined fibrosis, 113 had fibrosis on their x-rays and 25 did not. Of the latter, 23 had moderate or severe fibrosis. In this study, x-ray was about 80% sensitive to moderate to severe pathologically confirmed fibrosis.[2]

In another study of coal workers, 20–30% of x-rays evaluated in the ILO system did not reflect moderate or severe macules (the hallmark of CWP) found on pathologic examination. Furthermore, in the absence of macules, 20% of the x-rays were read as showing some degree of abnormality. In that study, chest x-ray was about 80% specific and 80% sensitive.[3]

An x-ray may provide a false-negative result because of technique; e.g., an overly powerful x-ray beam will wash out details and make disease recognition difficult. An unskilled reader may not recognize abnormality if, for example, the subject is fat; passage of the x-ray beam through the fat of the chest can create an appearance similar to fibrosis; or the reader may incorrectly attribute all abnormalities to chest fat.

A study of a cohort of blue-collar workers who reported no occupational dust exposure but had chest x-rays is directly relevant to the question of specificity of this technique. Three readers who were unaware of the purpose of the study but were trained in recognizing the pneumoconioses read the films. Two readers made relatively consistent findings, showing that 0.5–1% of the x-rays of workers up to the age of about 50 were abnormal, giving a specificity of about 99%. For workers aged 50–59, there was about 97% specificity.[4] The issue of inter-reader variability is illustrated by the different results of the third reader—an "outlier."

Also relevant is a large study of readers who evaluated 1,000 or more comparable but not identical films from

a large pool of x-rays taken for relatively young naval workers in the United States who might have been exposed to asbestos. One reader reported close to 11% abnormalities, while the others were clustered down at 5% or less.

RELEVANCE

Table 1 shows the modeled lifetime risks for simple CWP, categories 1 and 2, and progressive massive fibrosis after exposures to dust at various levels. These conditions are exposure-related, and people who have progressive massive fibrosis have diminished life expectancy and substantial impairment for an extended time before death. So, we should consider the value of x-ray screening for identifying those people who may be at increased risk of progressive massive fibrosis. Table 2 shows the probability of having progressive massive fibrosis after detection of category 1 CWP, at various ages after a lifetime of work in the mines. For example, if a worker has a category 1 x-ray at age 23, he will have a 7.6% probability of having progressive massive fibrosis by age 58 and a 15.2% probability by age 78. Similarly, a category 1 x-ray at age 33 will confer a 13.1% probability of progressive massive fibrosis by the age of 68. The modeling is based on carefully observed levels of exposure and responses in British coal pits over 25–30 years. The same data can be used to model the risk for progressive massive fibrosis in the absence of a category 1 x-ray. Table 3 shows an absolute risk of 0.7% at 2 mg/m^2 of exposure

Table 1 Predicted prevalences (numbers) of simple coal workers' pneumoconiosis (CWP) and progressive massive fibrosis (PMF) among United States coal miners at age 65 after exposure to respirable coal-mine dust over a 45-year working lifetime

	No. of Cases/1,000		
Disease Category	Coal-mine Dust Concentration 0.5 mg/m^3	Coal-mine Dust Concentration 1.0 mg/m^3	Coal-mine Dust Concentration 2.0 mg/m^3
CWP ≥ 1	48	119	341
CWP ≥ 2	20	58	230
PMF	13	36	155

Source: Attfield and Seixas[6] (high-rank bituminous coal).

Table 2 Probabilities of having progressive massive fibrosis (PMF) at ages 58, 68, and 78, given a category 1 x-ray at age 23–38*

Age at Which Category 1 Detected (Years)	Predicted % with PMF at Age		
	58 Years	68 Years	78 Years
23	7.6	11.0	15.2
28	8.3	12.4	17.3
33	8.4	13.1	18.7
38	7.8	13.2	19.5

*Average exposure to dust up to age 58 = 2 mg/m^3
Source: Hurley and MacLaren.[7]

Table 3 Risks of progressive massive fibrosis at age 58, given exposure to 2 mg/m^3 coal dust

Absolute risk on starting work at age 18	0.71%
Relative risk for those with category 1 at age:	
23	10.7%
28	11.7%
33	11.8%
38	11.0%

Source: Hurley and MacLaren.[7]

to coal-mine dust through a working lifetime; however, a miner with an abnormal chest x-ray has a relative risk that is more than 10 times the baseline risk. With a chest x-ray showing simple pneumoconiosis, the risk for progressive massive fibrosis increases massively.

In many jurisdictions, compensation issues result from having an abnormal chest x-ray. In the United States, there is a presumption of total disability if a miner has progressive massive fibrosis, and the miner is entitled to a disability award. Therefore, screening has some legal relevance.

The concept of *need or necessity* concerns whether the right test is used to identify the right conditions. As noted earlier, although the chest x-ray defines the presence of CWP, coal miners have a variety of other lung diseases resulting from their exposure. Both smoking and non-smoking dust-exposed coal miners have a substantial risk of airways obstruction. They have increased rates of emphysema, bronchitis, and airways obstruction that cannot be determined by chest x-ray. These are exposure-related phenomena resulting in substantial impairments.

"NEED/NECESSITY"

The question of need or necessity is thus whether other tests are available that can give the same information. Basically, the answer is no: there are no other tests, since the disease is defined by the test.

CONSEQUENCES

Table 4 is relevant to one of the key questions asked at this seminar: Is there a preventive intervention that can be made after the finding of an abnormal chest x-ray that will diminish the probability of progressive massive fibrosis over a lifetime. If, with periodic x-ray screening, CWP category 1 is detected at age 28, and at that point exposure to dust is diminished by half, the risk that a miner will have progressive massive fibrosis by the age of 58 decreases from 9.3% to 8.6%. Using this strategy, 143 people would have to be tested in order to prevent one case of progressive massive fibrosis.

If exposure is stopped completely after such a chest x-ray result, it is the risk of progressive massive fibrosis that is being modeled on the basis of the accumulated ex-

posure to dust up to the age at which the first abnormality is detected. As shown in Table 5, there is a substantial risk for progressive massive fibrosis over a continued lifetime without additional exposure. In fact, if exposure is reduced from 2 mg to 0 at the time a category 1 x-ray is found (for example if the abnormality is seen at age 23, and exposure is stopped at that point), there is still more than a 5% risk for progressive massive fibrosis by age 58. In order to save one miner from having progressive massive fibrosis, 45 miners will have been tested and transferred (exposure stopped).

As the prevalence of disease in a population decreases, the efficiency of such approaches plummets. With a very high population prevalence of abnormality, such screening is effective; but with successful control of exposure, resulting in lower levels of disease, the benefit of screening diminishes.

The consequences of x-ray screening are predictable: Someone falsely labelled abnormal has, e.g., diminished work opportunities. Programs can be designed, however, to minimize the adverse consequences and increase the probability of benefit. These require adequate resources, screening at the right frequency, setting appropriate cut-off points that result in a sufficiently sensitive test, considering the level of risk due to the test, ensuring that workers perceive the test as of some value, and determining that reasonable actions will be taken after an abnormal test result. Such actions can include modification of the workplace, educational efforts, medical treatment, and notification. Since screening programs generally involve very sensitive tests, a test to confirm the level of abnormality is often important. Examined workers must be notified directly of their test results, and there should be aggregate notification of employees and employers. In order for surveillance efforts to be successful, there must be high levels of participation, adequate data collection, accurate analysis, dissemination of appropriate information, and effective intervention. In no instance should medical screening be used as a substitute for exposure control.

Table 4 Effect on risk for progressive massive fibrosis (PMF) of transfer from a job with exposure to 2 mg/m³ coal dust to one with exposure to 1 mg/m³

Age at Which Category 1 Detected (Years)	Cases of PMF at Age 58		No. of Miners Tested to Prevent One Case of PMF
	No Transfer	Transfer	
23	7.6	6.7	111
28	9.3	8.6	143
33	9.5	9.1	250
38	9.2	9.0	500

Table 5 Effect on risk for progressive massive fibrosis (PMF) of transfer from a job with exposure to 2 mg/m³ to one with exposure to 0

Age at Which Category 1 Detected (Years)	Cases of PMF at Age 58		No. of Miners Tested to Prevent One Case of PMF
	No Transfer	Transfer	
23	7.6	5.4	45
28	9.3	7.8	67
33	9.5	8.6	111
38	9.2	8.7	200

CONCLUSIONS

A few lessons can be derived from the case of screening to detect CWP. First, it is critically important to match the target to the test. The chest x-ray may be appropriate for screening for CWP, but in many developed countries the test is not necessarily the best or only test for preventing lung disease among people exposed to coalmine dust. The overall disease burden may include more obstructive airways disease than pneumoconiosis, although this is not necessarily the case in some countries where there are extremely high levels of exposure. Therefore, it may be appropriate to perform pulmonary function testing as well as x-rays in the health surveillance of coal miners. Second, screening efficiency diminishes with successful prevention: the lower the population prevalence, the more workers must be screened to identify an abnormal worker. Nevertheless, some testing strategies that may not be justifiable on the basis of the individual may be justifiable on the basis of public health surveillance. For example, x-ray screening of individual miners exposed to low levels of dust benefits relatively few of them because most do not have abnormalities. They do benefit from having the assurance that the x-ray is normal. Also, in our aggregate efforts to control lung disease in miners, many benefit from the identification of trends and of places for interventions. A third lesson is therefore that the public health importance of surveillance may exceed the individual benefit of screening.

Variability is a key issue in screening. We tend to think too simplistically about a test result's being a "red light" or a "green light." The results are subject to laboratory variation, individual variability, and day-to-day variation, such as in blood counts. In pulmonary function tests, there is population variability and there are ranges of normal. We often ignore variability and confuse discrete and continuous variables. An "abnormal" or "normal" result is considered to be a discrete variable or at least a discrete categorization of a continuous variable. The choice determines the sensitivity and specificity of the test. The inter-relationships between groups and individuals, surveillance, individual health, and type of screening or surveillance program, and the extrapolation of information derived for groups to the individual are all critical issues that must be considered in order to understand screening and surveillance programs. They must be evaluated in the context of an overall system of prevention. There is no absolute answer on any of the key questions: It is neither right nor wrong to do a

screening test or to engage in health surveillance or a program of periodic health assessment. It is only by understanding the overall approach to prevention that an informed decision can be made about the usefulness of an individual screening practice.

My last point is that there are better and worse ways of engaging in any such program. A medical testing program with no notification, a testing program with an excellent test and notification but no effective intervention; or focusing solely on the individual and failing to focus on improved protection or exposure controls: any of these practices can limit the usefulness of what would otherwise be conceptually good and scientifically useful. Maintaining a clear prevention focus can improve the benefit and reduce the adverse consequences of any practice.

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