

SILICOSIS, THE MOST IMPORTANT OF THE PNEUMONIOSES

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A historical survey of this subject cannot be accomplished within the space of this article. In spite of the voluminous literature concerning this disease there is not yet available any treatise concerned with a critical review of the subject from the historian's point of view. Indeed, such a contribution is sorely needed now for it would bring together the development of the various forces which have influenced the growth of our knowledge and the formulation of opinions. For a brief temporal review of the medical aspects the reader may consult Sayers and Lanza.¹ The history of this subject is rooted in antiquity but knowledge of the condition blossomed in the latter part of the 19th and continues thus far into the 20th century. This parallels the achievement of scientific technique not alone in medicine but in engineering, chemistry, physics and geology and also in the growth of social consciousness and responsibility. In the history of this subject the student of the humanities will find engrossing material for reflection upon the inter-relationship of Medicine, Law, Industry and Labor. I have long felt that history will yet be written from the point of view of medicine and health—for the influence of the growth of our knowledge of disease on social and economic laws is profound and far reaching. An important contribution to this type of literature is Hans Zinsser's "Rats, Lice and History" showing the influence of typhus on civilization.

The by far most important scientific contributions have come from Italy, Germany, South Africa, England, and the United States in order of historical development. However, in the last 30 years all countries affected by mining and industrial developments have been active in research. No student of the subject can afford to ignore any source of information, but I recommend particularly the work develop-

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1. Sayers, R. R. and Lanza, A. J.: *Silicosis and Asbestosis*, Oxford, Univ. Press, 1938. For an important beginning in this direction see *History of Miners' Diseases* by George Rosen, published by Schuman's, 1943.

ed in South Africa. In the publications of the South African² Institute for Medical Research will be found many basic observations all too often overlooked by subsequent writers on the subject. In the development of our present day understanding the experimental approach has been essential. In this country the contributions of Gardner³ and his associates at the Saranac laboratories have been outstanding. These studies have added much precise information concerning particularly the causes of the disease, its distribution in industry, the mechanism by which the changes in the human lung are brought about and the relationship to infection, particularly tuberculosis. Lagging behind but now gaining impetus is the inquiry into the effect of the disease on body function as contrasted with structure. Some important⁴ beginnings have been made. It is important now to bring to bear on this subject available knowledge and techniques belonging to other medical scientific disciplines and concerned with other diseases. Thus, there is available for use a great deal of information derived from studies in pathology⁵ and physiology which critically applied will aid in the explanation and interpretation of poorly understood, controversial or

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2. For many publications on this subject consult bibliography of the South African Institute for Medical Research, Johannesburg, South Africa.
 3. Gardner, L. U.: *Silicosis and Asbestosis*, Oxford Univ. Press, 1938. Also the *Journal of American Medical Ass'n.*, Vol. 114, p. 535, February 17, 1940.
 4. On this subject there has been a rather rich bibliography not yet correlated. Some of the important contributions are: (a) A series of publications by McCann, W. S., Hurtado, A., and Kaltreider, M.; *Journal of Industrial Hygiene and Toxicology*, Vol. 19, p. 163, April 1937. *Journal of Clinical Investigation*, Vol. 14, p. 18, January 1935. *Journal of Clinical Investigation*, Vol. 13, p. 1027, 1934. *Journal of American Medical Ass'n.* Vol. 103, p. 810, September 15, 1934. (b) Nylin, G.: *The Practical Applicability of the Cardio-Pulmonary Function Tests*, *Acta Medica Scandinavica*, Supplement 93, 1938. (c) Seever, M. H., Enzer, N., and Becker, T. J.: *The Respiratory and Circulatory Adaption to Acute Anoxia in Silicosis and Cardiovascular Diseases*, *Journal of Industrial Hygiene and Toxicology*, Vol. 20, p. 593, December, 1938. (d) Roelsen, E., Vay, N.: *Investigations of the Lung Functions in Silicotics*, *Acta Medica Scandinavica*, Vol. 103, p. 55, 1940. (e) Enzer, N., Simonson, E., Evans, S. M.: *Clinical Physiological Observations on Welders with Pulmonary Siderosis and Foundry Men with Nodular Uncomplicated Silicosis*, *Journal of Industrial Hygiene and Toxicology*, Vol. 27, p. 147, June 1945.
 5. Pathology: That branch of medicine which treats of the essential nature of disease, especially of the structural and functional changes caused by disease.

unsolved aspects of pneumoconiosis.⁶ This is merely another way of indicating that investigators and students of this subject must be aware of the influence of knowledge derived from one source, on another apparently unrelated subject. The physician particularly must apply his whole knowledge of the behavior⁷ of disease to enable him to understand this very complex subject.

Pneumoconiosis is the term applied to all forms of dust diseases of the lungs. Zenker, a noted German pathologist, introduced the term in 1866 deriving it from the Greek term meaning "hardening of the lung". In spite of the great variation in the manifestations of this disorder the term is retained to this day as a generic one qualifying it in each instance according to the agent producing the condition. Thus we may have silicosis, anthracosis, siderosis, asbestosis—in each instance derived from silica, coal, iron, asbestos, and so forth. This paper will concern itself only with a consideration of silicosis for several reasons. Silica (SiO_2), inhaled in a finely divided state, has been shown to be the only dust capable of producing the peculiarly characteristic lung condition known as nodular fibrosis,⁸ and when other dusts seemingly cause the same type of disorder, silica has thus far been found to be constantly present in the inhaled dust. Thus, the condition of silicosis is by far the most common and the most dangerous and disabling. When silicosis is well understood the effects and manifestations of other dusts on the lungs will be the more readily recognized and appreciated.

Silicosis is a condition of nodular fibrosis of the lungs having a characteristic pattern, produced by the inhalation of finely divided silica dust, or in certain instances by combinations of silica and other dusts as exemplified by anthracosilicosis. Elsewhere⁹ a more detailed discussion of the characteristics of a hazardous dusty atmosphere will be given. Suffice it to say here that it is important for the physician

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6. Pneumoconiosis: Lung disease due to the inhalation of minute particles.
 7. All diseases must be understood not only specifically but with respect to their biological pattern. In this regard see series of papers by Moschowitz, E., published in the *Journal of the Mt. Sinai Hospital*. New York, 1945 and 1946.
 8. Fibrosis: The formation of fibrous tissue.
 9. There is considerable literature on this subject. A good summary is available in Reference No. 1.

to have a basic knowledge of the hazardous industrial atmospheres although he need not be trained in the technique of industrial air hygiene. Brief mention must be made here of the condition known as asbestosis—a pulmonary fibrosis of certain pattern due to the inhalation of asbestos—a silicate¹⁰—the only one of its kind known to be responsible for a human disease. References¹¹ are available in the literature citing the industrial occupations in which silicosis is most prevalent. These include hard rock mining, quarrying of granite, etc., pottery making, foundries, talc and abrasive industries, stone finishing and so forth.

As knowledge accumulated, many attempts were made to classify silicosis cases according to their causes, industrial sources, clinical behavior, x-ray characteristics and pathology. At the present time two main groups are recognized—*simple or uncomplicated silicosis* and *infected silicosis or silico-tuberculosis*. The latter group is so designated because tuberculosis is by far the most important infection affecting the course, behavior and outcome of the individual with silicosis, and because it has been shown that silicosis and tuberculosis have a peculiar affinity, although in recent years some investigators¹² in this country have raised some doubts on that score. Simple silicosis has been classified according to the extent of the fibrosis and for convenience these have been called *1st or 2nd or 3rd stage of nodular fibrosis*. In some literature, silicosis has been classified as *1st, 2nd, and 3rd stage*—the 1st being very mild, the 3rd severe and usually complicated but not necessarily by infection. While such classifications are useful they are also arbitrary and take on different shades of meaning with the experience of the reporter. Lacking in such classifications are many important features such as duration and rate of development and non-infectious complications. These classifications may be

10. Gardner, L. U.: Pathology and Roentgenological Manifestations of Pneumoconiosis, *Journal of American Medical Ass'n.*, Vol. 114, p. 535, Feb. 1940.
11. Lanza, A. J. and Vane, R. J.: The Prevalence of Silicosis in the General Population, etc. *American Review of Tuberculosis*, Vol. 29, p. 8, 1934. Also see U. S. Public Health Bulletin No. 187, 1929 and No. 221, 1936. Also see publications of the U. S. Department of Labor.
12. Taylor, H. K. and Alexander, H.: Silicosis and Silico-Tuberculosis, *Journal of American Medical Ass'n.*, Vol. 111, p. 400, July, 1938. Ornstein, G., and Olmar, D.: Tuberculosis and Silicosis, *Quarterly Bulletin Seaview Hospital*, Vol. 2, p. 28, 1936.

misleading too—thus it has been denied that simple nodular silicosis may cause disability or death on the grounds that such cases are “early or mild silicosis”. Classifications should be used broadly and not in a binding fashion. This is very important in a medico-legal sense for it is easy to defend a case on the basis of a so-called recognized or accepted classification. Not all cases behave the same way even though they may resemble each other in many important features. Silicosis has been classified by the clinician,¹³ by the radiologist,¹⁴ and by the pathologist.¹⁵ There is need for further classification according to industry, for it seems that much important information may be obtained by such a breakdown in data. The background for the various classifications will be commented upon when we discuss the more specific clinical, radiological, and pathological features. At this time I wish to emphasize the danger and misleading effect of the terms “early” and “late”. These have a temporal significance and are not justified. For example, so-called 3rd stage silicosis is called “late”, but simple silicosis may be present much longer and produce severe effects. It is important to emphasize, too, that classifying a case of silicosis during the lifetime of the victim does not establish that the process in that case is fixed. In other words a case may be classified as simple nodular non-infected silicosis non-disabling in 1930, and in 1940 the same individual may be shown to be totally disabled without the objective characteristics of the fibrosis undergoing any change. We shall amplify this idea later.

The structural effects of the inhalation of silica dust are covered by the term “pathology of the disease”. It is important that everyone concerned with this problem understand certain established fundamentals. The lungs¹⁶ may be

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13. Clinician: An expert clinical physician or surgeon who is usually a teacher also.
 14. Radiologist: A physician with special experience in radiology. Radiology is that branch of medical science which deals with the use of radiant energy in the diagnosis and treatment of disease. The terms x-ray specialist and roentgenologist are used in a similar sense, but the term radiologist is preferred.
 15. Pathologist: A physician who specializes in pathology and is competent to perform the ante-mortem and post-mortem laboratory investigation necessary to determine the nature and extent of a disease process and/or the cause of death.
 16. See Miller, Wm. Snow: *The Lungs*, published by Chas. Thomas and Co. (This is indispensable for classical investigations on the

likened to a pair of honeycombed organs communicating with the outside world through the air passages known as bronchi and trachea and with the inside world by way of blood vessels (arteries and veins), lymphatic channels (nature's accessory drainage system), and nerves. The honeycombed structure is basically composed of clusters of open sacs developing in direct continuation with small bronchi. The general effect may be likened to a cluster of grapes—the main stem being the main bronchus, the secondary stems the bronchi, the tertiary stems the bronchioles and the grapes the air sacs arranged in clusters or lobules. In this analogy, of course, the entire structure should be visualized as hollow and enclosed in a membranous sac known as the pleura. The air sacs are lined by cells¹⁷ which constitute the important unit in silicosis. These cells are intimately in contact with blood vessels and lymphatics,¹⁸ the former important for respiration, the latter important for the removal of foreign or irritant material. In the presence of an irritation, the cells lining the air sacs go into action along with other cells derived from the capillaries (terminal blood vessels) and lymphatics. The most minute particles of silica inhaled reach the terminal air sacs and there a meeting of the invader and the defense mechanism of the lung takes place and the battle is joined. Some of the cells engulf particles and migrate by way of the lymphatic channels to certain depots scattered between the extreme periphery of the lungs and the lung roots. In these latter areas there are numerous

anatomy of the lung.)

See also Macklin, G., and Macklin, Madge T.: *Respiratory System in Problems of Aging*. Second edition, edited by Cowdry, E. U., published by Williams and Williams. This is an excellent and authoritative review of the aging processes in the lungs—indispensable for this subject.

17. The cellular reaction in silicosis is well reviewed in many papers, notably the publications from the South African Institute for Medical Research, publications by Gardner and his associates in the Saranac Laboratories. For an excellent review see also Belt, T. H.: *The Pathology of Pneumoconiosis*, *American Journal of Medical Sciences*, Vol. 188, p. 418, September 1934.
18. Lymphatics; Vessels which convey lymph, a transparent, slightly yellow liquid of alkaline reaction which is occasionally of a light rose color from the presence of red blood corpuscles, and is often opalescent from particles of fat. The lymphatic system is arranged to serve all parts of the body, and the collected lymph, made up largely of tissue fluids, empties at last into the right lymphatic duct and the thoracic duct passing thence into large veins in the neck region.

lymphnodes which have great storage capacity. The cells laden with their foreign material come to rest here. Other cells remain at the battlefield. There they are converted to scar tissue, apparently by the peculiar chemical effects of the silica particles. At this stage the silicotic nodule begins to take shape.

The location of the nodule in the lung is of some importance. In the main the production of scar tissue takes place in the walls of the air sacs chiefly at the point of junction of several contiguous sacs. In these zones the lymphatic drainage channels join to form larger tributaries ending finally in the large lymphnode¹⁹ depots at the root of the lung or hilum—the point of entrance into the lungs of the bronchi and large blood vessels from the heart. This localization of the silicotic nodules provides for the pattern so characteristic of the established disease—namely, a widely and rather uniformly disseminated nodular fibrosis. Sometimes, under the influence of such factors as infection, the distribution is extremely uneven—large areas of the lung being spared. This illustrates that while there is a basic pattern there are many variations too. In the proceedings of the International Conference on Silicosis,²⁰ held at Johannesburg, South Africa, in 1930, a rough standard of measurement was applied to give some expression to the degree of silicosis as seen in the lung at post mortem. The distribution was considered “sparse” when only one nodule could be detected by touch or naked eye in a 5 cm.²¹ square of lung surface; “moderately numerous” when one nodule is present in a 3 cm. square, “numerous” when the square is 2 cm. and “very numerous” when the square is less than 2

19. Lymphnodes: The lymphnodes are vital structures occurring at intervals in the pathway of the lymphatic channels. These constitute filtering agencies and centers of defense against irritating invaders and foreign substances. The pattern of the reaction in the lymphnode is determined by the irritability and toxicity of the invading agent. The layman recognizes these lymphnodes when they react to infection as commonly experienced for example in the armpit in response to an infection in the hand. Lymphnodes are strategically placed all over the body. There are none more important than those draining the lungs.

20. Silicosis International Conference, Johannesburg, South Africa, published by the International Labor Office, 1930, Geneva, Switzerland. This volume is practically indispensable as a source of information on this subject.

21. Centimeter: A measurement in the metric scale: one centimeter is approximately 2/5 of an inch.

cm. Up to this moment only simple nodular silicosis has been discussed. The effect of these nodules in the lung is of paramount importance. Since the size of the nodule may vary from 1 mm.²² to 10 mm., it is readily appreciated that in large numbers they constitute a considerable space-occupying lesion in the lung. This leads to the constant development of distortion and distention of the surviving air sacs (or as identified in anatomical language the "alveoli")—a condition known as *emphysema*. As the *emphysema* develops chiefly in the region of the nodules, one may readily appreciate that there is apt to be a quantitative relationship between the amount and distribution of the fibrosis and the *emphysema*.

If the nodules are very numerous, they may be so closely packed as to be almost continuous and a condition known as "confluent silicosis" results. In this type the essential nodular structure is maintained. But there is another form of confluence to be considered. In this latter form the fibrosis is massive and irregular and the nodule unit is lost. This form of confluence is generally the result of either infection pre-existing in the lung or complicating the fibrosis afterwards or in some instances, the confluent fibrosis appears to be the result of other dusts, such as iron or carbon.

Involved in the fibrosis are notably the lung alveoli and lymphatics but also the blood vessels, bronchioles, and bronchi. These structures may be involved in a mild or severe manner. Often the blood vessels are completely obliterated, but sometimes they are only encroached upon so that their passage-way is narrowed. In this manner, silicosis provides an impediment to the blood flow and interferes with oxygenation of the blood. Additional similar interference results from the *emphysema* process. The bronchioles and bronchi are mostly affected by an inflammation in their outer walls and by some similar reaction in the lining cells. In the pleura (covering membrane of the lung) deposition of dust occurs, too, so that it is usually slightly thickened and pigmented.

Very important in the understanding of the effects of this disease is an appreciation of the deposit of silicotic

22. Millimeter: One-thousandth part of a meter; one-tenth of a centimeter. The meter is the basic measure of length in the metric system: it is equivalent to 39.371 inches.

fibrosis in the lymphnodes at the hilum of the lung²³ and in the spaces between the two lungs known as the mediastinum.²⁴ In the main, there is some parallelism between the extent of lymphnode fibrosis and the pulmonary fibrosis, but again with many exceptions and variations. I have seen cases with little effects and others with such massive involvement as to make difficult the removal of the lungs at post mortem. These massive lymphnodes literally anchor the trachea, bronchi, and large vessels entering the lungs into one large firm mass. I believe that this condition has an important bearing on the extent and severity of the complicating emphysema and on the impairment of the flow of blood from the heart through the lungs.

Emphysema²⁵ as a pathological and functional disorder of the lungs is intimately bound up with the silicotic process. Essentially, emphysema is characterized by a state of overdistention of the non-fibrosed lung tissue and consequently, it lacks the capacity to rhythmically distend and empty with the movements of respiration. In other words, the elasticity of the lung is reduced or lost in this condition. Emphysema occurs not alone in silicosis. It is a manifestation of aging as well, and may result from many other disorders than silicosis. But except for certain varieties which need not concern us now it results whenever the lung tissue is encroached upon, scarred or destroyed. It is nature's method of attempting to provide the human mechanism with suffi-

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23. Hilum of the lung: The depression on the medial (mediastinal) surface of the lung where the bronchus, blood vessels, nerves, etc., enter the lung.
 24. Mediastinum. The mediastinum is the space between the two lungs in the chest. It is occupied in front by the heart and in the back by the main air passages and large blood vessels. This is in reality a potential space rather than an actual space. The structures within the mediastinum have some elasticity and capacity for displacement but beyond a certain point there is a functional and structural reaction to growths or other space-occupying abnormalities. When lymphnodes become very large in this area, the blood vessels and lung roots chiefly are affected.
 25. Emphysema, as a factor in silicosis, is tremendously important. There is a significant literature on this subject. A few of the references are:
Kountz, W. B. and Alexander, H. L.: *Medicine*, Vol. 13, p. 251, 1934.
Miller, J. A.: *Pulmonary Fibrosis and Emphysema*, *Annals of Internal Medicine*, Vol 9, p. 219, September 1935.
Christie, R.V.: *Quarterly Journal of Medicine*, Vol. 5, p. 327, 1936.
Christie, R. V.: *Emphysema of the Lungs*, *British Medical Journal*, pp. 105 and 143, January 22 and 29, 1944.

cient aeration. This compensatory technique of nature itself leads to a disease state and disability. As we shall indicate later, emphysema is most important in aggravating the mechanism of disability in silicosis.

Tuberculosis adds greatly to the complexity of the pathology of this condition. From a causal relationship point of view or etiology, silicosis appears definitely to make the lung tissue more receptive to the tubercle organism. The pathological manifestations in the lung when the two conditions co-exist are wide and varied, but to the competent student easily recognized. We feel that two types of reaction occur—one in which the tuberculosis is dominant and the pathology is essentially that of the infection and so causes disability or death, and the other one in which the silicotic fibrosis is dominant and disability or death is due to the progressive embarrassment of respiration and circulation of blood through the lungs leading to right heart failure.²⁶ A combination of these types also occurs.

This brings us to an important phase of the silicosis problem, namely the relationship between the process in the lungs and the heart. Simply stated the heart consists of two functional units—a right and a left. The latter is responsible for the reception of blood from the lungs laden with fresh oxygen and the distribution of this blood to the body. The right unit is responsible for the reception of the used or venous blood from the body and the delivery of it to the lungs where it disposes of its waste gas, the carbon dioxide, and takes on a fresh supply of oxygen. There is good evidence in pathology, physiology, and clinical data to support the statement that the silicotic fibrosis by virtue of its extent, location, production of emphysema and lymph-node fibrosis creates a strain on the right heart by increasing the peripheral resistance to the flow of blood through the lung. This is a fairly simple pumping mechanism and if the resistance is sufficient and maintained over a long enough period of time the right side²⁷ of the heart will first

26. See, in this Symposium series, White, Paul Dudley and Smith, Hubert Winston: *Scientific Proof in Respect to Injury of the Heart (Medicolegal Aspects of the Heart)* (1946) 24 N.C.L. Rev. 106.

27. On this subject there are many important papers only a few of which can be mentioned here:
Griggs, D. E., Coggin, C.B., and Evans, N.: *Right Ventricular*

enlarge or hypertrophy because the muscles of the heart work harder, and later, the muscles failing, the right heart dilates, fails to pump well and heart failure ensues. There are many other complicating actions and principles involved but these merely account for the variables and not the basic pattern of the process.

With this brief sketch of the pathology of the disease we may consider now the most important phase of the clinical examination of the patient, namely the x-ray examination of the chest. It may be stated categorically that without the evidence of the disease on an x-ray film, the diagnosis of silicosis cannot be made during the lifetime of the patient. The x-ray film is a reflection of the pathology. On the film the dense fibrous nodules are indicated by corresponding shadows since these resist the passage of the x-ray—or are radio-opaque. The nodules appear in the film as white or gray tiny nodular shadows—corresponding in distribution to a wide dissemination throughout the lung fields and showing coalescence or massive fibrosis as the case may be. In most cases the simple film of the chest is adequate for diagnosis. But for the detection of emphysema, mediastinal lymphnodes, and effects on the heart, highly technical and refined methods are necessary calling for the most highly skilled and trained experts in radiology. These methods have not been used up to now as often as is desirable, and thus many of the effects of silicosis are not detected and an understanding and explanation of the symptoms hence are not achieved. When these special x-ray methods such as planography²⁸ and angiocardiology²⁹ are applied to more cases there will be a closer approximation of the clinical be-

Hypertrophy and Congestive Failure in Chronic Pulmonary Diseases, *American Heart Journal*, Vol. 17, p. 681, June, 1939.

Parkinson, J.: Enlargement of the Heart, "The Lumleian Lectures," *The Lancet*, June 1936.

Parkinson, J., and Hoyce, C.: The Heart in Emphysema, *Quarterly Journal of Medicine*, No. 21, p. 59, 1937.

Christie, R. V.: Dyspnea, *Quarterly Journal of Medicine*, No. 27, p. 421, 1938.

Giering, J. F. and Charr, R.: The Heart in Anthraco-Silicosis, *Journal of American Medical Ass'n.*, Vol. 113, p. 574, August, 1939.

See, also, White, P. D. and Smith, H. W., *supra*, f.n. 26.

28. Planography: This is an x-ray method whereby the film registers the findings at a given depth in the body.
29. Angiocardiology: This is a new development in x-ray diagnosis of the heart. Sussman, M. L.: *New England Journal of Medicine*, Vol. 228, p. 777, June, 1943.

havior, physiological disturbance and pathology. There is now a considerable difference of opinion concerning chiefly the interpretation of symptoms which I think is based upon the failure to apply new techniques and knowledge to the older established facts. It is wise to remember that the same set of facts may have different effects at different periods in our knowledge and thus receptive, open-minded students are apt to differ in some respects with the currently prevailing majority of opinion. The x-ray film may be said to be diagnostic when it depicts a nodular fibrosis or any variation thereof—but it is not diagnostic before that stage is reached. In other words, the long period of time which elapses before nodules develop (which may be from 2 to 20 years or more depending on the intensity and kind of dust exposure), does not produce diagnostic criteria visible on a chest film, although there are many pre-nodular changes which may possibly be noted in the film. This pre-nodular fibrosis is inconstantly shown. Since it may be produced by a wide variety of factors other than silicosis, it should arouse the suspicions of an alert physician to the possibility of silicosis, but it cannot be considered as adequate proof of silicosis.

The x-ray film will show reasonably well the extent of the fibrosis, but this is often obscured by the emphysema which overshadows the x-ray manifestations. The x-ray film is not under any circumstances a criterion of disability except by supporting the clinical findings or by demonstrating emphysema or enlargement of the right side of the heart or features consistent with infection.

In the foregoing we have made reference to the functional effects of silicosis. These are, of course, of the greatest importance for, in the last analysis, a structural defect in the body does not constitute "disease" unless it interferes with function or provides the soil for another disease-producing agent. Tuberculosis is an example of the latter. Individuals with silicosis, not complicated by tuberculosis, may develop symptoms of varying intensity depending on the extent of the interference with certain functions of the heart and lungs. This disturbance of function may be analyzed from two points of view—one, the effect on the lungs, and the other the effect on the heart. In the lung, the silicosis process eventually may reduce the efficiency for adequate

respiration. This is brought about by the space-occupying fibrosis, but mainly in the milder cases by the ensuing emphysema. In the severe cases the massive fibrosis drastically reduces the lung volume. In the milder cases the lung volume is increased by distention, but because emphysema involves a loss of elasticity, the flow of air in and out of the lungs is diminished and hence an inadequate oxygen supply to the body results. This type of impairment of lung function results in a reduction of respiratory capacity and can be measured by several tests such as the "minute-volume respiration," "vital capacity,"³⁰ "respiratory response to exercise" and others. These tests are useful only when it is shown that other disorders in the body are absent and that the lung condition is the *only or preponderant* source of the abnormal results obtained. Such tests have value when they are carefully performed by experienced physicians. All functional tests should be repeated several times over a period of weeks or months in order to give the broadest and yet the most accurate reflection of the patient's condition.

The heart, particularly the right side, is intimately concerned in this condition and in these tests. The heart may by virtue of its own intrinsic disability contribute greatly to the complaints and the abnormal results of special tests. Hence, all investigations on the function of the lungs and respiration must consider the status of the heart. All primary disorders of the heart must be distinguished, by appropriate tests and analyses, from the secondary disorders brought about by the lung condition. This sometimes requires the greatest judgment and clinical astuteness and is often not possible with presently available methods.

For a proper appreciation and understanding of this disease, as of any other disease, the first point to realize is that the behavior of the patient is not fixed or constant. While all cases of a given disease have certain things in common, there is a wide variation between individuals. This may be illustrated in a number of ways, but perhaps the disease hypertension, or high blood pressure, is a handy illustration. Every physician of any experience is aware of cases of extreme hypertension where the patient is without

30. Vital capacity: The number of cubic inches of air a person can forcibly expire after a full inspiration. There is a simple device available for measuring this volume: it is called a spirometer.

symptoms and apparently is unimpaired for work. They are aware of this disease making its appearance early in life or very late in life. It may or may not be associated with disorders of the heart or kidneys. Or, a relatively mild type of hypertension may be associated with severe symptoms and disability. Some cases die early of the condition and some live out their natural span and may even die of other conditions. Some cases are manifested by headache, others by shortness of breath. And so it is with silicosis. In spite of the fact that the cause of the disorder is precise, the manifestations of the disease vary considerably. Consequently, the physician must first thoroughly appreciate human vagaries and he must have a broad experience with a variety of cases in order to properly evaluate any particular case. The so-called textbook picture of any disease can only be used as a general guide. It serves to define the limits and to erect the framework within which a given case may be classified. Appreciation of the extremes of symptomatology and of behavior and disability is extremely important to the laity, to the legal profession, and to the judiciary. The important thing in presenting any problem of this kind for arbitration is that the medical investigation be thorough, observant, impartial, and intelligent and based upon an up to date knowledge of the auxiliary sciences necessary for a proper interpretation of this problem.

The clinical analysis of silicosis may be divided into two main groups: (A) those working at full capacity without complaints but exhibiting x-ray manifestations of the disorder and (B) those who have complaints. This latter group may further be classified into sub-groups as follows: (1) those who offer some complaints but are able to work, (2) those who have complaints and have reduced working capacity, (3) those who have complaints and are totally incapacitated for work, and (4) those who have a complicating infection such as tuberculosis.

It is obvious that the first group, (A), would not be discovered without the facilities of x-ray examination. The physician who will correlate the x-ray findings, the induction of all workers engaged in the hazardous industries has provided the profession with a large store of material for the study of this disease. It is in this group of cases that there is room for more precise long-term study by physiologi-

cal methods. These cases should be studied by precise methods over a long period of time to evaluate the relationship between silicosis and the subsequent complaints should they appear, and other disorders, particularly those related to aging processes. We do not know yet why one case develops more emphysema than another. We do not know, either, why some individuals with massive fibrosis are able to work without disability and live out their normal span of life without complaints, while other individuals with far less fibrosis exhibit symptoms, are early disabled, and even die at an earlier age and with evidences of severe respiratory and circulatory embarrassment. It is important that the last word concerning silicosis be not left in the hands of the radiologist but rather in the hands of a competent examining physician who will correlate the x-ray findings, the industrial history, the medical history, the physical examination, and such other tests as may be indicated, such as examination of the blood, sputum, electrocardiography,³¹ etc. If we could have in addition to the ordinary methods of examination a record of precise measurements, particularly of the cardio-respiratory system,³² we might be able to detect impairment, if any should develop, before the patient develops subjective complaints or symptoms. The clinical behavior of these cases is difficult to evaluate for another reason. Workers engaged in these industries generally acquire deftness and adeptness so that they learn to accommodate themselves to the demands of their job with less expenditure of energy than the untrained person. Hence, they are able to continue to produce adequately in spite of a deterioration in their physical capacity. It is important to remember, also, that in very many cases there is a great economic and emotional demand on these people to continue to work as long as possible. Hence, assuming the workman to be possessed of fundamental character traits such as honesty and sincerity of effort, etc., complaints, when made by such a man, are extremely important from a medical point of view.

We come next to the second group of cases (B-1), those

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31. Modern developments in electrocardiography have refined the technique so that there is now a greater accuracy in determining strain on the right side of the heart. The application of this method requires consultation with an expert in this field.
 32. Cardio-respiratory system: This term is used to indicate the intimate and inseparable relationship between the heart and lungs.

in which we have evidence of silicosis and who offer some complaints but without evidence of work disability. The significance of these complaints is also extremely difficult to evaluate for they are common to many disorders, precise and undefined. For example, these individuals may complain of cough. Cough may be produced by a great many conditions ranging from habit to organic diseases of the heart and lungs. Shortness of breath and pain in the chest are symptoms common to many other disorders. Hence, the examining physician must be extremely astute and careful when he meets with these cases to be sure that all other possible causes of these complaints have been sought for before he attributes them solely to silicosis. It has been said that there are no complaints in uncomplicated silicosis, but about this there is a wide range of disagreement. My own experience is that there are complaints due to silicosis, but by no means consistently; nor do they occur consistently in all cases at the same stage of development of the disorder. But this is not unusual for it is characteristic of almost all diseases that individuals vary widely in their symptom responses. The next group of cases (B-2) are those who have some work disability, that is to say, they complain of fatigue, show a reduced capacity for work, more frequent absenteeism or they express a desire to change to lighter work. This group of cases is sorely in need of extremely careful medical and physiological study, in order to arrive at some adequate measurement of their degree of disability and then to relate it to the underlying cause. At this point it is well to emphasize that in the evaluation of a case of silicosis, examinations must not be directed to and limited solely to the chest but must be complete and the subject must be studied as a whole. It is important for the physician to know about other co-existing pathological conditions in the presence of silicosis. He is then faced with evaluating the relative role of these conditions in the production of the symptoms and the disabilities. The broadest kind of clinical experience is none too broad if these medical problems are to be properly solved. There are already published tests which should be more widely applied in the study of this group of cases but unfortunately these are complex and require laboratories and trained personnel not always available to perform them and evaluate the results. It appears that it may be necessary to

develop stations, where such work will be carried on, in larger centres such as hospitals or clinics where patients can be studied impartially and objectively, both those who are in no way involved in litigation and those who have compensation awards at stake. Group B-3 is comprised of individuals with more manifest disabilities and does not offer so difficult a problem to the examining physician except that there is still resistance to the idea that one need not have an advanced stage of fibrosis or complicating infection in order for the patient to be seriously disabled. The presentation of such cases before a commission or court should be made by experienced medical examiners thoroughly familiar with the complexities of this problem. When tuberculosis intervenes (B-4) there is generally very little argument about the relationship, although in certain stages of silicosis that relationship may legitimately be disputed and some investigators even refuse to admit dependence between the two diseases even in advanced cases. The relationship of silicosis to non-tuberculous infection is an extremely complex problem and by no means settled, and it is difficult to evaluate on the basis of group or statistical studies. Thus, for example, there is no precise evidence to prove that simple nodular silicosis prevents recovery from pneumonia, but should such an individual have emphysema and massive involvement of the lymphnodes at the root of the lungs, it would be extremely difficult for a physician to say that such a pre-existing condition did not unfavorably alter the ability of the patient to resist infection. *What the patient complains of is the most important index to his disability.* The examining physician must shrewdly appraise these complaints by painstaking history-taking. It is important to know when the symptoms began, and how they progressed. Since shortness of breath or dyspnea is the most disabling complaint, this requires special investigation. This is done first by a careful observation of the patient, for obviously since it is a subjective complaint, it may be exaggerated or misrepresented. However, there are ample methods for corroboration. Unless the dyspnea is very obvious, as in the cases with total disability, the condition should be investigated by the following methods³³; (1) vital capacity of the lungs, (2) range

33. For various methods see Moncrieff, A.: Tests for Respiratory Function, a publication of the Medical Research Council of Great Britain, October, 1934. Also consult literature referred to in References 4 and 15.

of chest expansion, (3) breathholding time, (4) minute-volume respiration, (5) response to short periods of dynamic and static exercise, and (6) response to sustained exercise. The results of these tests may then be compared with available standards for normal people of the same age and physical habitus. These tests cannot be applied precisely, but must be interpreted in the light of all available data concerning the case. In addition, medical information must be completed by an X-Ray examination of the heart and lungs, electrocardiographic studies, and blood and urine examinations. Sometimes it is not possible for the examiner to make up his mind about the genuineness or cause of the disability and the examinations must then be repeated at intervals for several months or even a year or two years. If the physician is unable to apply methods of precision he must rely on his evaluation of the patient and such observations as the patient's response to walking, stair climbing, work production and repeated investigation of the subjective complaints.

RECAPITULATION

The term pneumoconiosis embraces all forms of pulmonary reactions to the inhalation of inorganic dusts. Silicosis is the most important of these, but is rarely pure or uncomplicated for there is often an adulterating dust affecting the character of the lesions in various ways and degrees. The rate at which the disorder will develop depends upon the intensity of dosage and this involves consideration not only of the total amount of dust inhaled but the length of time over which it is inhaled and the chemical and physical structure of the dust. The more finely divided is the silica, the more dangerous is its effect. There is some evidence that neutralizing agents in the form of other dusts delay or reduce the severity of the reaction, but this is yet in the field of experimental study. It is important to remember that whatever notions we may have regarding the safe limits of a dusty atmosphere, the final factor determining a safe atmosphere is what happens to the individuals exposed to it. In other words, if an individual works in an atmosphere said by the industrial engineer to be safe, and as a result of this exposure develops X-Ray manifestations³⁴ of silicosis, the accuracy of the engineer's opinion is disproven.

34. This statement is somewhat misleading. It should be taken to mean that all other conditions which might cause an x-ray pattern similar to silicosis have been ruled out. Sometimes such cases must await post mortem investigations for solution.

The appearance of the lungs post mortem in any given case varies with the exposure, barring complicating tuberculosis. The literature generally emphasizes the more advanced stages of the disease. There are insufficient studies on the pulmonary findings discovered accidentally in individuals dying of other conditions. Such studies are of great value particularly if they can be compared with accurately made clinical observations. The essential anatomical features of the silicotic lung may be summarized as follows: (1) presence of a nodular fibrosis scattered throughout both lungs associated with a similar formation in the corresponding lymphnodes; (2) presence of coal or other dust pigment in the area of fibrosis in the lungs, lymphnodes and pleura; (3) pigmentation and some fibrosis thickening of the pleura; (4) the constant association of emphysema which may be of several varieties, as follows: (a) microscopic in the region of the nodule only, (b) widely disseminated and uniform, and (c) irregular or bullous;³⁵ *Emphysema is as much a part of the disease "silicosis" as is the fibrosis.* This concept is tremendously important in grasping the physiological effects of silicosis, in interpreting symptoms, and in evaluating disability. The effect of emphysema caused by silicosis, when sufficiently advanced, is to alter the shape of the chest and to increase its size; to produce a dyspnea or shortness of breath; and to obstruct the passage of blood through the lungs resulting in strain first on the right heart and later on the left heart, leading finally in some cases to death by heart failure; (5) with an increasing number of nodules there is a tendency to conglomeration. When this develops, gross scarring of the lung results and additional distorting emphysema occurs; (6) progressive enlargement and induration³⁶ of the hilum lymphnodes, often to the point of massive fixation of the mediastinum;³⁷ (7) evidences of bronchitis³⁸ and bronchiolitis,³⁹ (8) evidences of strain on the right

35. Bullous: A bulla is an inflated area or a large blister or vesicle filled with watery fluid.

36. Induration: The quality of being hard; the process of hardening.

37. Mediastinum: The space between the two pleural sacs which invest the lungs. The space extends from the sternum (breast bone) in front to the thoracic vertebrae behind and from the thoracic inlet above to the diaphragm (the large flat muscle which separates the thoracic cavity from the abdomen) below.

38. Bronchitis: Inflammation of the bronchial tubes.

39. Bronchiolitis: Capillary bronchitis, on inflammation of bronchial terminals.

heart as indicated by hypertrophy⁴⁰ of the right ventricle and dilation of the right chambers of the heart; (9) tuberculosis in any of its forms.

Having understood and studied the anatomical pattern of this disease we may better understand and more accurately interpret the X-Ray manifestations. Generally speaking the X-Ray film does not demonstrate as much of the fibrosis as the pathologist discovers at post mortem examination. This is due to the fact that the concomitant emphysema obscures the dense shadows.

For many years individual silicotics will be symptom-free or they will disregard relatively mild symptoms such as dyspnea, cough and recurrent episodes of respiratory infections, until these become more persistent and constant. Shortness of breath is an outstanding symptom. It develops imperceptibility and at first the victim is unaware of it. But as it progresses it interferes with the individual's capacity for work and physical effort. It is never relieved. Pain in the chest occurs and is generally referred to both lungs, mostly anteriorly and in the lower parts. Some patients complain of precordial pain⁴¹ and it is often very difficult to distinguish cardiac angina⁴² from these complaints. In this regard it is important to remember that a chronic disorder of the lung which induces a state of reduced oxygen intake will cause cardiac symptoms, notably pain. Other features are changes in the chest outline, occasional loss of weight, sometimes a low fever. When these latter symptoms occur, infection should be sought for, but I have seen such cases without any evidence of infection even in the presence of an increased number of white blood cells⁴³ in the blood and an increase in the blood sedimentation rate.⁴⁴ The physical signs

40. Hypertrophy: The morbid enlargement or overgrowth of an organ or part.

41. Precordial pain: Pain over the precordium which is the region over the heart or stomach.—i.e. the epigastrium and lower part of the thorax.

42. Cardiac angina: Commonly known as angina pectoris: the latter is a symptom of insufficiency of circulation of the blood to the heart muscles through the coronary artery. It consists of a sensation of oppression under the breast bone, coming particularly on effort, lasting a few minutes, and relieved by rest or nitroglycerine. The pain may or may not radiate down the arm.

43. An increase in white blood cells or leukocytosis is generally but not always an indication of infection. Other forms of inflammatory reactions and other diseases may cause leukocytosis.

44. Blood sedimentation rate test: The blood sedimentation rate test is an extremely important and useful method of investigating a patient's reaction to disease. A rapid rate generally indicates severity and unfavorable reaction. It is very important in infection but a rapid rate occurs in other diseases.

are vague and often are absent for a long time. Fundamentally, when they are present, they are related either to the emphysema or to areas of massive fibrosis or to infection. With respect to the heart, the physical examination is extremely important but often is inadequate. Much more refined methods of investigating the heart are necessary. When death is not due to tuberculosis or infection, it is chiefly due to failure of the circulation based upon right heart failure.

Silicosis is progressive from two points of view. The actual fibrosis may progress even in the absence of continued exposure. This will depend upon the amount of dust inhaled and the intensity of the exposure. But examination of the silicosis nodule indicates that a slow peripheral (marginal) fibrous reaction takes place around the nodule for a long time. Such progressive changes are not easy to detect by any clinical methods now available. More important than this type of progress, however, is the progressive deterioration of the resistance of the circulation from the right side of the heart through the lungs and the deterioration in the elasticity of the lungs. In other words, if we visualize a given state of silicosis and its associated emphysema at a given point in a man's life, there may be at that time no evidence of the disorder. However, even then the heart is working against a greater resistance. With age the ability of the heart to overcome that resistance diminishes and symptoms appear. This is as much progression of the disorder as it is progression of the lesion. Perhaps stated another way it is more correct to say that *the effects of the silicotic fibrosis are progressive even though the lesions are stationary.*

COMMENTARY

Silicosis is a complex disease. To understand it thoroughly a physician must observe it from its inception until the last chapter has been disclosed on the autopsy table. But, even that would not be enough, for an appreciation of such observations must be based upon knowledge obtained from other disorders. The same set of facts known to one generation has an entirely different meaning to another generation because of the development of collateral knowledge in other disciplines. Thus, it is important for the physician who would understand silicosis to understand the physiology of respiration, the relationship between the heart and lungs, the cell reactions in the lungs and the various component systems in the lungs such as the lymphatic drainage and blood supply.

Equally important is the capacity and willingness of the physician to review both his own experiences and the literature of the subject constantly and critically. "The art is long, judgment difficult and experience fallacious." It is extremely easy for a physician to continue serenely in constant repetition without improving his knowledge or benefitting scientifically by his experience. One must be aware of falling into the error of maintaining a fixed opinion. "Prove all things and hold fast to the truth."

From the standpoint of those who pass judgment on the legal and financial aspects of this problem, it is equally important that they have open minds which makes it possible for them to free themselves of the stifling influence of precedents or of fixed notions.

When a disease acquires money value, a certain pattern of human reaction takes place. On the one hand there is a great cry against the so-called racketeering which implies that a great many people who do not deserve compensation try to get it. There is a rush to formulate certain protection against loss so that defendants will be not too severely penalized. There is at the same time an attempt to achieve some kind of indemnity for those who have suffered and will suffer from the disease.

Those who so quickly pin the label of "racketeer" on lawyers and doctors who have represented claimants in the near past should remember that there is no evidence that financial relief would have been afforded many sufferers from silicosis who did not present a claim. There is a further point to remember. Large insurance or industrial companies have unlimited resources to provide "experts." The individual claimant is generally without funds and by and large he is quite unable to make the most of his case in a legitimate fashion. Often unable to have more than a general practitioner or a family physician to represent him he finds himself met with a battery of experts of all kinds and specialties. He is unable to supply as evidence accurate details concerning the circumstances of his employment. He cannot afford elaborate and detailed medical examinations. Here then is a situation which should be corrected. Since the doctor should testify for the court, some steps should be taken to remove him from a partisan relationship. Doctors employed by the same company and industry or by lawyers over and over again, must guard jealously their independence and professional integrity and objectivity.