Review

Inhalational Lung Disease

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Abstract

Inhalational lung diseases are among the most important occupational diseases. Pneumoconiosis refers to a group of lung diseases result from inhalation of usually inorganic dusts such as silicon dioxide, asbestos, coal, etc., and their deposition in the lungs. The resultant pulmonary disorders depend on the susceptibility of lungs; size, concentration, solubility and fibrogenic properties of the inhaled particles; and duration of exposure. Radiographic manifestations of pneumoconiosis become apparent several years after exposure to the particles. However, for certain types of dusts, e.g., silicone dioxide crystal and beryllium, heavy exposure within a short period can cause an acute disease. Pulmonary involvement in asbestosis is usually in the lower lobes. On the contrary, in silicosis and coal worker pneumoconiosis, the upper lobes are involved predominantly. For imaging evaluation of pneumoconiosis, high-resolution computed tomography (CT) is superior to conventional chest x-ray. Magnetic resonance imaging (MRI) and positron emission tomography (PET) scan are helpful in those with suspected tumoral lesions. In this essay, we reviewed the imaging aspects of inhalational lung disease.

Keywords

Occupational diseases; Anthracosis; Pneumoconiosis; Asbestosis; Berylliosis; Byssinosis; Silicosis; Imaging

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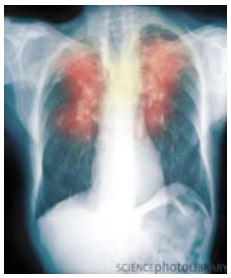

Introduction

By definition, inhalation is an active or voluntary drawing of air (and its contents) into the respiratory system via the nose or mouth. Inhalational lung disease comprises all disease conditions caused by inhalation of particles in the inspiratory air.

Pneumoconiosis refers to "any of a group of lung diseases resulting from inhalation of particles of industrial substances, particularly inorganic dusts such as the dust of iron ore or coal, and permanent deposition of substantial amounts of such particles in the lungs.[1] Some of these diseases are occupational. The term "environmental lung disease" has been proposed by some authors to be substituted for "pneumoconiosis." A full list of numerous causes of pneumoconiosis is presented in textbooks. Herein, we just described the radiologic presentation of some of these diseases.

Pathophysiology

Normally, the inhaled particles in air are exhaled from the lung by mucociliary protective actions.[2] Overdose of particles or impaired mucociliary function may result in deposition of particles in lung tissues. Usually, particles larger than 5 μm in diameter are trapped in the bronchial tree.[3] Smaller particles, however, may pass down to the alveoli. Exceptionally, larger parti-

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cles (*e.g.*, asbestos) may penetrate the wall of the bronchioles and enter the alveoli or the interstitium (Fig. 1).[4]

The air flow in the bronchial tree is rapid and turbulent. This may help in expulsion of particles. On the other hand, in the alveoli, the air flow is slow and laminar for which the particles are prone to deposit. These deposited particles in the alveoli or bronchial tree then become the primary nidi of pneumoconiosis.[5]

Susceptibility of lungs to these particles differs in various individuals. The size of particles, their concentration in air, the duration of exposure, their solubility and fibrogenic properties are other predictors for aggregation of these particles in lungs.[6] When a particle interacts with lung tissues including the lymphatic and blood vessels, abnormal soft tissue densities in the form of nodular, linear or mixed pattern become visible in chest x-ray which in general, are called "opacities." The opacities may be regional or diffuse, and have different sizes ranging from one millimeter to several centimeters, depending on the nature of the particle.

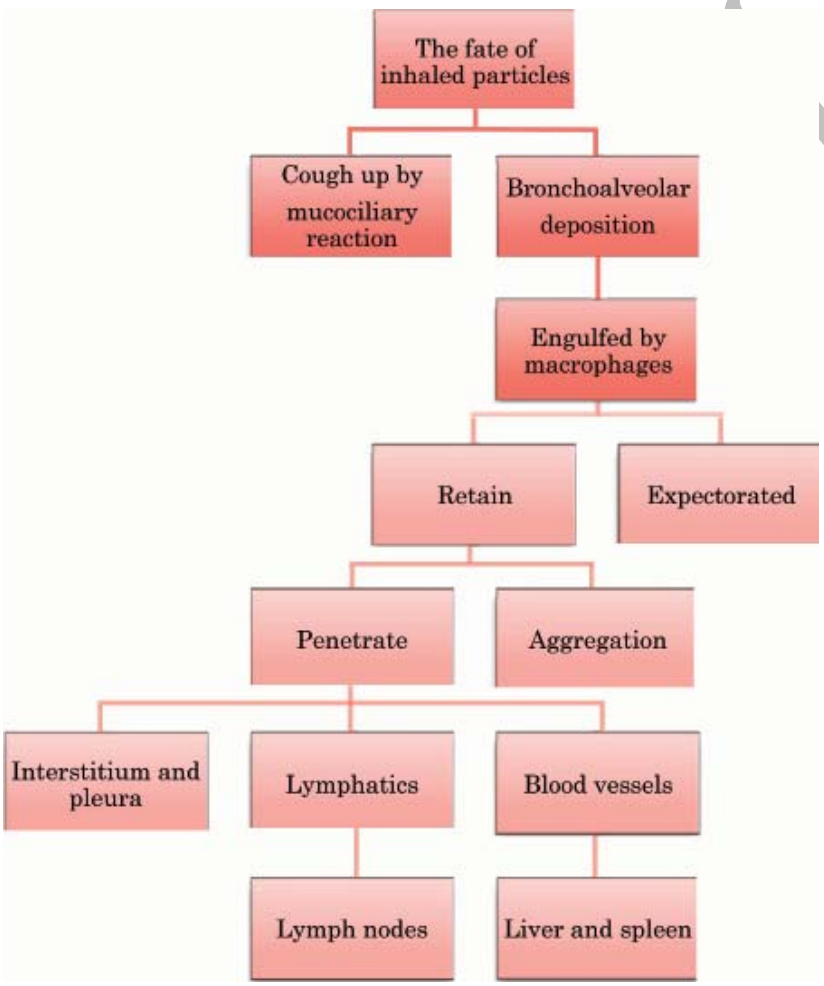

Figure 1: The fate of inhaled particles

The inhaled particles in the alveoli are engulfed by macrophages. The laden macrophages may be expectorated or settled down. In the latter condition, the coal particles are released after disintegration of dead macrophages. The coal particles spread in the interstitium in close vicinity of bronchovascular bundles and lymphatic tissue. Up to this stage, the projectable opacities on chest x-ray are smaller than 10 mm in diameter and are considered as "small opacities" (Fig. 2, 3) according to the International Labor Office (ILO) classification.[7,8] Focal emphysematous changes and fibrosis are seen at this stage. After progressive massive fibrosis, opacities larger than 1 cm appear on chest roentgenogram (Fig. 4,5). Fibrosis may be so extensive that it involves multiple segments or even a whole lobe of a lung.[9] The former small opacities are termed "simple pneumoconiosis" while the latter condition is called "complicated pneumoconiosis."[10,11]

Imaging

The lymphatic flow of the chest is partly affected by the pressure gradient between the right and left pulmonary trunks and respiratory motion of the thoracic cage.

Therefore, the lymphatic clearance of particles in the left upper lung is better than in the right upper zone and that is why with some exceptions, radiographic manifestations of pneumoconiosis are expected to be first seen in the upper zone of the right lung.[5]

As far as the radiologic diagnosis of pneumoconiosis is concerned, the conventional chest x-ray is the first step. After wide application of computed tomography (CT), the conventional chest x-ray is currently used only as a guide.[12] It is recommended that both thick- and thin-section tomography are taken, since small opacities may skip in thick-section procedure and large opacities may not be well-demarcated in thin slices. Prone and supine CT is also suggested, because some lesions are position dependant.[13] Not too many details about application of magnetic resonance imaging (MRI) and positron emission tomography (PET) are available; however, in cases of suspected tumoral lesions and/or pneumoconiosis, MRI and PET scan with fluorodeoxy glucose are used as complementary procedures.[13]

The opacities on chest x-ray or CT vary in size and may be round or linear. According to the revised classification of ILO at the University of Cincinnati (ILO/UIC),[14] the opacities are categorized into "small" and "large" groups with subdivisions. The small opacities are those with a diameter <10 (with subdivisions of 0–1.5, 1.5–3, and 3–10) mm. Large opacities are those >10 mm in diameters and are subdivided into 10–50 and >50 mm.[15]

The classification is helpful in x-ray diagnosis when a good history and clinical data are available. The reaction of different lungs to a certain foreign body particle is not the same. On the other hand, different foreign body particles may have similar

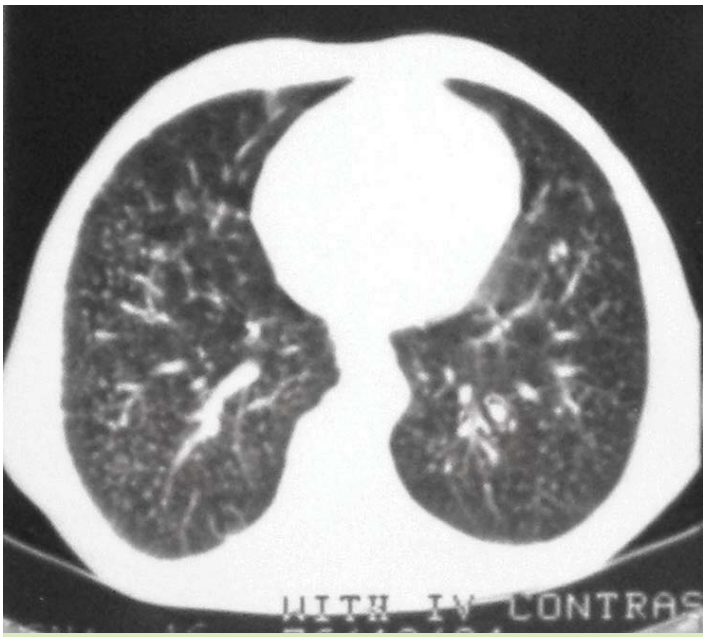

Figure 2: Small nodules, predominantly distributed posteriorly.

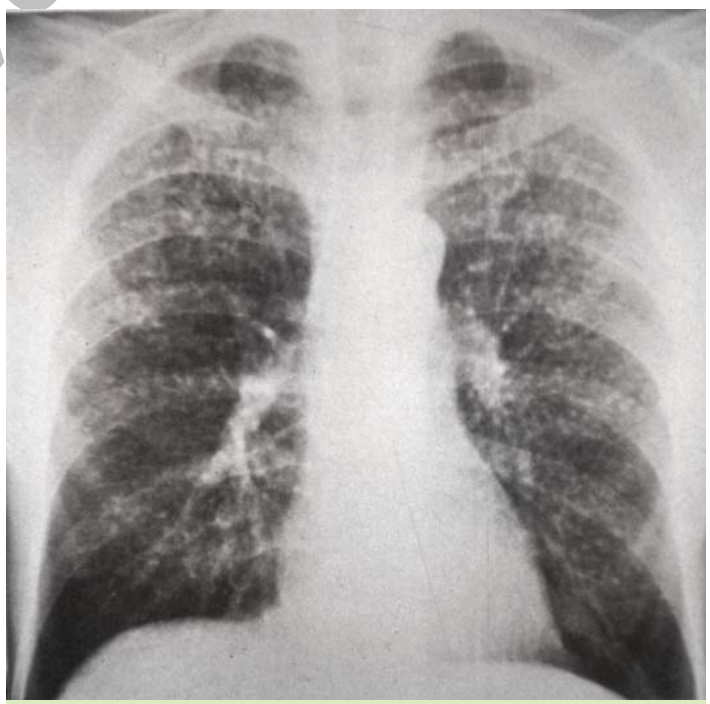

Figure 3: Many small nodules scattered throughout both lungs.

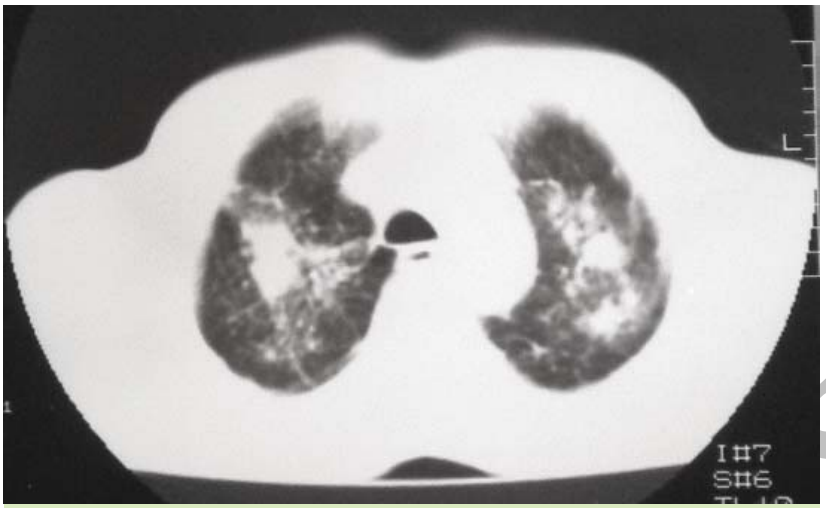

Figure 4: Large opacities—CT scan shows that large opacities are indeed created by coalescence of small nodules.

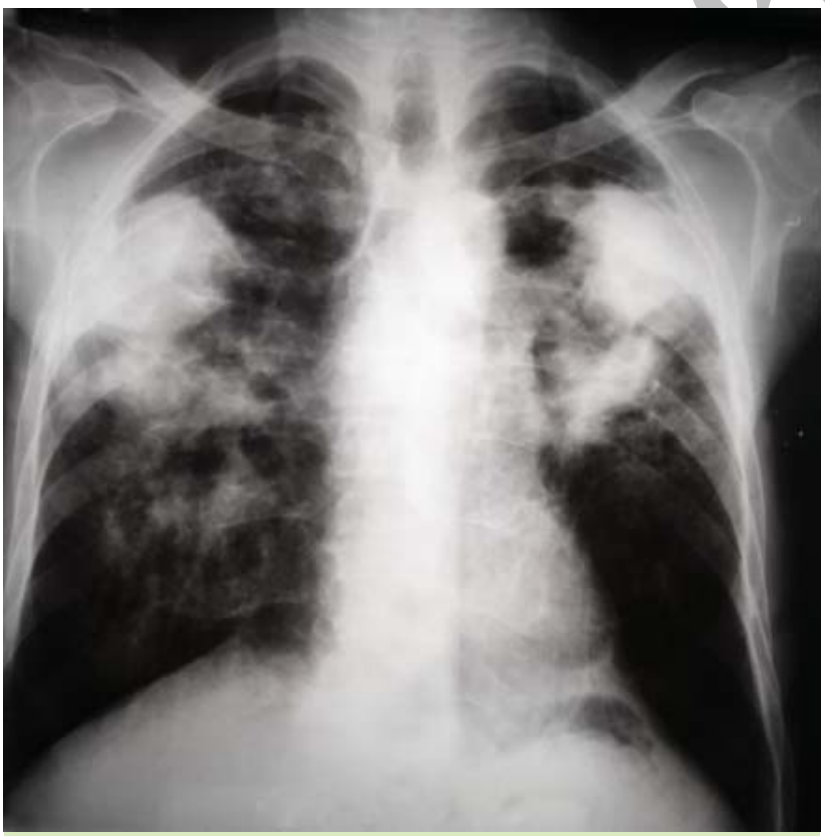

Figure 5: PMF—large opacities in the upper lung fields and bilateral basilar emphysema.

picture in chest x-ray.[16] So without a precise clinical history, the x-ray diagnosis is not quite valid. Mixed pneumoconiosis is not rare. A coal miner may inhale coal particles plus dust of silica, zinc and iron. So a combination of opacities may be projected in his chest x-ray.

With the exception of toxic and corrosive agents, the inhalational lung diseases are dose- and time-dependent with latent radiographic manifestations. A clear history and clinical signs are mandatory at the time of radiography and interpretations. New imaging modalities should be used for evaluating those findings which are ambiguous on conventional chest x-rays and also for earlier diagnosis.

Asbestosis

Because of wide range use of asbestos in industry, its production and processing has been increased from 50 to 6 000 000 tons during the last century. Commercial form of asbestos which is derived from silica hydroxide is a rigid material which is commonly used as heat and electric insulators.[5]

Both asbestos makers and asbestos users may inhale its fibers often shed off the crushed asbestos during work. Even children may be involved by the contaminated cloths of their parents, or unsafe constructions in school.

The asbestos filaments are serpentinences or amphiboles.[5] Asbestos fibers are up to 100 μm in length, can cause a fibrogenous effect on lung and pleura.[5] They are surrounded by a ferritin-like substance to make a particle called ferruginous body. A period of 8–20 years is estimated for the appearance of radiographic manifestations of asbestosis. Pleural plaque is the most common manifestation of asbestos exposure. Benign pleural plaques are generally

in parietal pleura, in posterolateral and in diaphragmatic pleura.[5] The ferruginous body spread throughout both the lower lung fields as small opacities which are projectable on chest x-ray.[17,18] This may be differentiated from early stages of silicosis and coal miners' lung in which the upper lobes of the lungs are initially involved. The particles which are projected "on end" in chest x-ray are dot-like opacities, while in profile view they appear as larger and thicker opacities. Progression of this process towards the cardiac boarder results in a "shaggy heart" appearance (Fig. 6).[19] The soft tissue masses which are formed by aggregation of these opacities and associated fibrotic changes lead to pseudotumor formation. Other changes such as round atelectasis, honey comb appearance, pleural effusion and calcification may also be seen in chest x-ray.[20,21] Sometimes confluent of normal shadows such as fat pads, intercostal muscles and reflection of pleura may mimic the appearance of plaque on chest x-ray.

The risk of lung cancer is higher in asbestosis, especially if the patient smokes. So any mass lesions in the lungs should be considered malignant unless proven otherwise. A patient with asbestosis may also develop other malignant lesions such as malignant thymoma, Hodgkin's lymphoma with pulmonary involvement.[22] The asbestos plaques must be differentiated from these lesions using CT.[21] Beside lung cancer, the pleura may also be involved by malignant or nonmalignant mesothelioma.[17] Also the pleural effusion may be of benign or malignant nature. So in some references, asbestosis is discussed together with asbestos-related diseases. MRI and fluorodeoxy-glucose (FDG) positron emission tomography (PET) imaging can differentiate malignant from benign pleural dis-

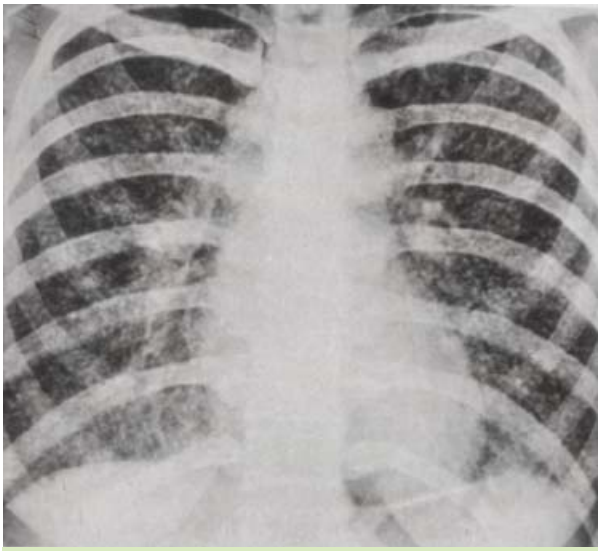

Figure 6: Asbestosis-induced reticulonodular shadows predominantly in mid and lower zones of both lungs.

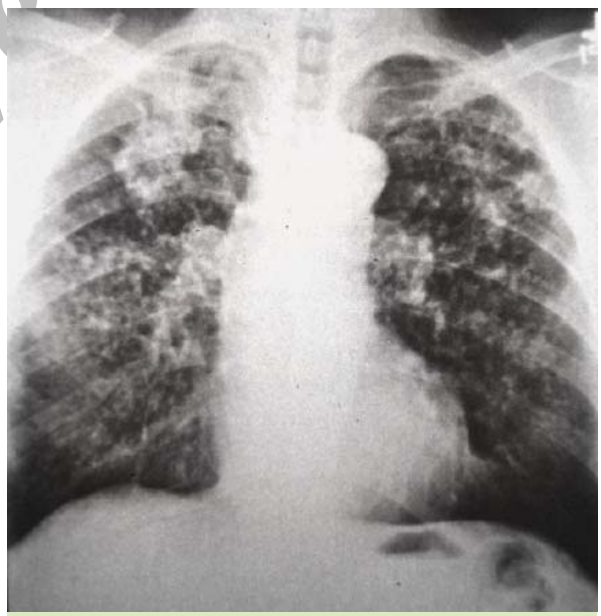

Figure 7: Silicosis—small and large opacities associated with emphysematous changes in lower zone of lungs. Cavitary changes in the center of the largest mass in the right upper lobe. Scattered calcifications are seen in lungs and hilar lymph nodes.

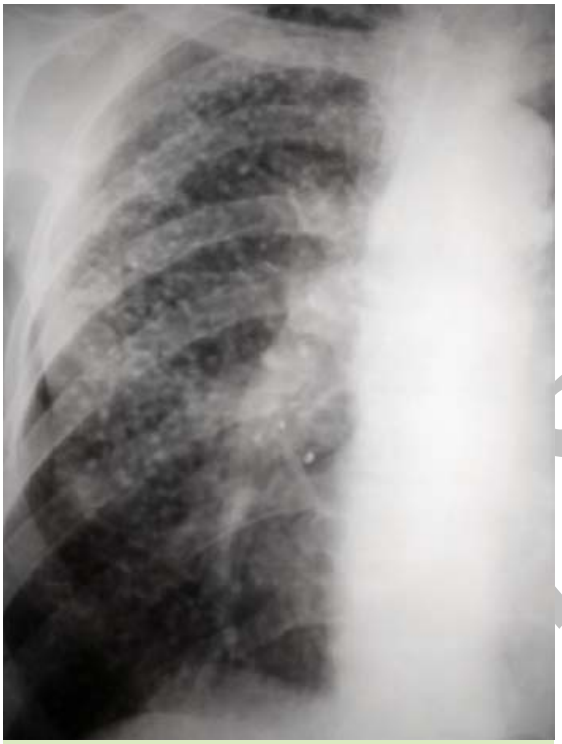

Figure 8: Silicosis—eggshell calcification in hilar lymph nodes.

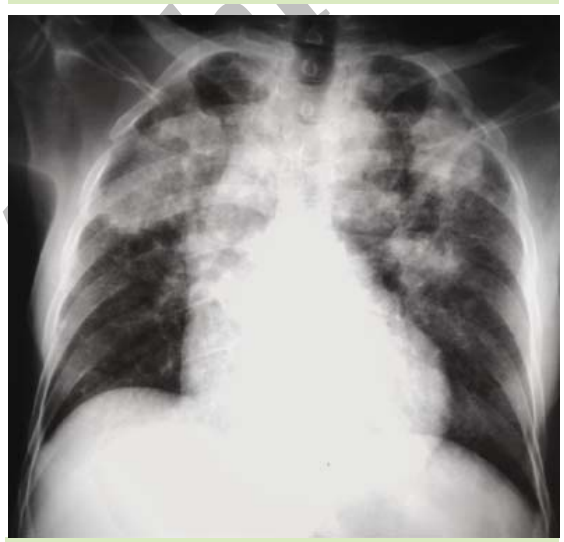

Figure 9: Progressive massive fibrosis stage of coal workers pneumoconiosis—large opacities in the upper zones of lungs and emphysematous changes in their periphery and in the lower lobes.

ease.[13] Non-detectable calcifications and pleural plaques in routine chest x-ray are projectable by CT.

The asbestos filaments with a length of almost 100 μm may penetrate into the interstitium and pleural layers.[4] Even capillary walls may be penetrated and rarely, particles may even migrate to the liver and spleen.

Silicosis

Silicosis is caused from inhalation of silicone dioxide crystal dust, although other forms of silicone may be associated.[20] The particles are not larger than 5 μm that deposit in and around respiratory bronchioles but after engulfment by macrophages followed by surrounding layers of hyalin and mucin, they tend to become fibrotic.[5] So the early radiographic manifestation in simple silicosis is the presence of round opacities usually 2–5 mm in diameter which is usually seen in the upper zone of the lungs, posteriorly and predominantly on the right (Fig 7).[5] Central calcification of nodules and "egg shell" calcification of hilar lymph nodes are seen in more progressed form of the disease (Fig 8).[23] The coalescent of the nodules tend to form opacities larger than 1 cm which is extensible by progressive massive fibrosis.[9,12] Central cavitation due to necrosis may be seen.[24] At this stage, the bulk of opacity with central necrosis must be differentiated from tuberculosis and cancer by MRI and/or PET scan. Even if the lesion is bilateral, associated cancer in one side cannot be excluded by conventional chest x-ray. Depending on the concentration of inhaled particles and duration of exposure the radiographic manifestations may be seen 4–20 years after the onset.[25]

A variety of the disease named "acute silicosis" is developed in massive expo-

sure to silica dust in closed spaces. In this case, the x-ray findings appear within a few months in the form of diffuse air space opacity which mimic the appearance of alveolar proteinosis. In some sources, this condition is termed "silicoproteinosis."[5,12,20]

Byssinosis

Inhalation of flax or hemp derivatives such as cotton fibers, in high concentration leads to bronchospasm and shortness of breath.[26] It is postulated that histamine or histamine-like substances are released after the inhalation. The symptoms subside by administration of bronchodilators and antihistaminics.

Since the symptoms develop at the beginning of the week when the workers start to work in cotton fiber polluted environment, the term "Monday fever" has also been used for this condition.[27] In Islamic and Jewish societies, it may be better to convert this condition to Saturday and Sunday fever, respectively. In mild and moderate forms of the disease, no characteristic x-ray findings are seen. In advanced cases, evidence of bronchitis and emphysema are predominant.[28]

In one of the Islamic ritual ceremonies—the Hajj pilgrimage—men should wear non-sewed cloths, mainly made from cotton or flax. Crowds of people participate each year in this ceremony. Therefore, some cotton fibers, normally shed off their cloths, float in space and are inhaled by people. Many of these people soon after returning home develop flue-like symptoms including malaise, chest tightness, low grade fever, and dry cough. The chest x-ray, although is negative for any certain diseases, may show accentuated vascular markings in the medial zones of lungs. The symptoms subside after a couple of weeks with or without treatment. Whether we can consider this condition as a transient form of byssinosis, is a matter of debate.

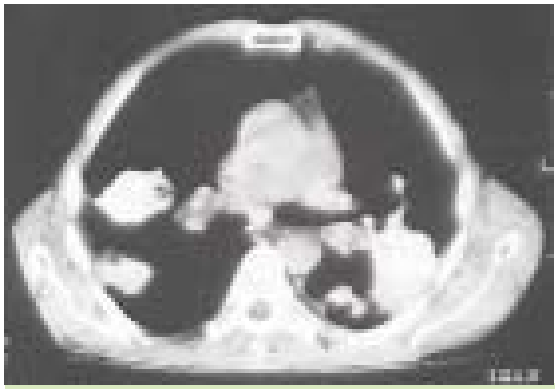

Figure 10: CT scan of coal workers pneumoconiosis indicating multiple nodules with well-defined borders in the upper lobes of both lungs.

Coal workers pneumoconiosis (CWP)

Although the disease is described more than 100 years ago, its well-established physiopathology dates back to 20–30 years ago. Mine workers are exposed to a variety of particles of coal, silica, iron, zinc, *etc*, so they develop a mixed dust pneumoconiosis.[29,30] Nonetheless, workers in refinery transport, storage and package units are exposed to exclusively coal particles with minuscule fractions of other dusts.

Normally, 10 years of exposure are required before small opacities become visualized on routine chest x-ray.[31] The particles, predominantly, tend to aggregate in the upper zone of the lungs (in contrast to asbestosis).[12] They are commonly round and rarely irregular. The large opacities, with >1 cm in diameter, due to progressive massive fibrosis, are also predominantly seen in the upper lungs.[20] With progression of the disease, the patient would finally develop large bulk of pulmonary fibro-

sis and compensatory emphysema (Fig. 9, 10). Central necrosis of the bulk of fibrosis due to ischemia may be seen.[20] The above-mentioned findings are projectable by routine chest x-ray but for differentiation of central cavities of tuberculosis, cancer and CWP, CT and MRI should be used.

Berylliosis

The tissue reaction to beryllium is not confined to the respiratory system. The liver, spleen, adrenal glands, myocardium, lymphatics, kidneys, salivary glands, skin, may all be involved in those with exposure to beryllium compounds for a long time.[30] For systemic involvement of the disease, therefore, the condition is better termed as "beryllium disease" rather than "berylliosis." In acute phase, a picture similar to alveolar proteinosis and pulmonary edema is seen in chest x-rays. In chronic cases, however, patchy infiltrates and granulomatous reactions are seen. In either case, the x-ray findings are not distinguishable from other disease conditions which cause pneumopathy in the form of ground glass or patchy pneumonia. A clear history to confirm exposure to beryllium and a systemic organ examination including skin test, lymph node biopsy and radiography should be correlated.[12]

Inert pneumoconiosis

The term "inert pneumoconiosis" is used to describe the deposition of particles, usually the metallic particles such as iron, zinc, tin, and few others, which are inhaled without a significant respiratory or systemic disorder.[32] On chest x-ray, inert pneumoconiosis appears as small opacities the density of which differs depending on the atomic number of the particles. No specific pulmonary or systemic symptom is mentioned unless the particles are associated with other harmful agents, *e.g.*, silica. Particles of certain metallic elements including tungsten and cobalt do not cause inert pneumoconiosis; they are harmful and cause heavy metal pneumopathies including emphysema, cor-pulmonale, bronchial disease, cancer and even death.[30]

Conflict of Interest: None declared

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