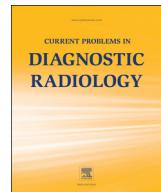


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Asbestos-Related Lung Disease: A Pictorial Review

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Asbestos exposure can lead to a variety of adverse effects in the thorax. Although currently in the western world, levels of exposure are kept in check by strict regulations, history of previous asbestos exposure continues to have an effect on many, owing to the latent nature of the pathophysiological response of the body to the inhaled fibers. The adverse effects of asbestos generally fall under 3 categories: pleural disease, lung parenchymal disease, and neoplastic disease. Effects on the pleura include pleural effusions, plaques, and diffuse pleural thickening. In the parenchyma, rounded atelectasis, fibrotic bands, and asbestosis are observed. Differentiating asbestosis from other forms of interstitial lung diseases, such as idiopathic pulmonary fibrosis, usual interstitial pneumonia, smoking-related lung disease, and mixed interstitial lung diseases, is important because the prognosis, course of disease, and management of the patient should be tailored based on the specific etiology of the disease. In this review, imaging findings specific to asbestosis are discussed. Finally, exposure to asbestos can lead to neoplastic disease such as pleural mesothelioma, peritoneal mesothelioma, and bronchogenic carcinoma. The purpose of this article is to review the effects of asbestos exposure in the thorax, pathophysiology of these responses, and disease course. Particular emphasis is placed on the radiographic appearance of the disease, discussion of various imaging modalities and their utility, and the role of imaging in the management of patients with previous asbestos exposure and asbestos-related pulmonary disease.

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Introduction

Asbestos is a generic term for fibrous silicate minerals that are heat resistant. The material was commonly used in manufacturing, mining, and construction during the industrial era. Overall, approximately 2–6 million people have been exposed in the United States. The 9/11 Twin Tower attack and Hurricane Katrina are recent events that have critically exposed many people to asbestos. There are 2 morphologic types of silicates: amphibole and serpentine fibers. The amphiboles are straight, rigid, needlelike fibers. The major types of amphiboles are crocidolite (blue asbestos), amosite (brown asbestos), tremolite, and anthophyllite (the rarest). Altogether, these account for only 10% of the asbestos in use. Serpentine accounts for the other 90%. Chrysotile (white asbestos), the only serpentine of commercial importance commonly used today, has curly, pliable fibers that readily decompose into finer particles.¹ There are 2 major sources of exposure to asbestos dust: (a) the primary occupations of asbestos mining and processing and (b) secondary occupations such as insulation manufacturing, textile manufacturing, construction, shipbuilding, and the manufacture and repair of gaskets and brake linings.²

Disease of the Pleura

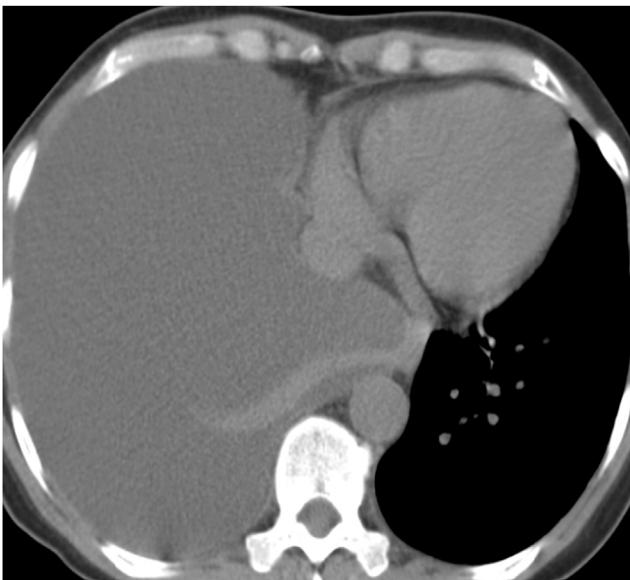
Pleural Effusions

Pleural effusions are the earliest and most common abnormality seen with asbestos exposure; they are usually seen within the first 10–20 years. They may occur even after minimal exposure to asbestos.³ Effusions are of mixed cellularity and do not contain asbestos fibers. They tend to be exudative and often hemorrhagic and can have an increased eosinophil count.³ Although the effusions are usually small, they can recur or occur bilaterally. Effusions typically must be large to cause symptoms; however, small ones may cause symptoms. Effusions may be benign or malignant, and occasionally, a large pleural effusion may be the first manifestation of a pleural mesothelioma (Figs 1 and 2). The differential diagnosis for an exudative effusion includes para-pneumonic effusion, tuberculosis, malignancy, pulmonary embolus, pancreatitis, connective tissue disease, trauma, and azotemia. These entities should be duly considered.

Pleural plaques are another manifestation of asbestos exposure but are typically seen more than 20 years later. Pleural plaques are discrete elevated areas of hyaline fibrosis almost invariably arising from the parietal pleura. Plaques can be elliptical, irregularly shaped, or round, and they are usually limited to the parietal pleura but may also be located in the fissures. Microscopically, they consist of relatively acellular bundles of collagen in an undulating “basketweave” pattern and may contain abundant numbers of asbestos fibers, almost exclusively chrysotile fibers, but asbestos

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Figs 1 and 2. CT images from a patient with history of asbestos exposure demonstrating large right pleural effusions. Although not typical, the effusions in asbestos sometimes become large enough to cause symptoms. In this particular case, the pleural thickening at the right lung base (arrow) can be noticed. Biopsy demonstrated epithelioid mesothelioma. (Color version of figure is available online.)

bodies are absent.^{1,4} The inner side is covered by normal mesothelial cells, and the costal side may demonstrate signs of low-grade inflammation.¹ Pleural plaques tend to lie adjacent to relatively rigid structures such as the ribs, vertebral column, and tendinous portion of the diaphragm. Plaques in and of themselves do not usually cause any functional limitation.

Pathophysiology of Plaque Formation and Disease Course

Despite much speculation, the pathogenesis of pleural plaques remains uncertain. The pleura appears to be more sensitive than the lung parenchyma to the effects of asbestos fibers: pleural plaques occur with lower inhaled fiber burdens, whereas asbestos is associated with a higher fiber burden.⁵ Thus, pleural plaques can result from small temporally remote dust exposures. No correlation between fiber counts in the lung parenchyma and the parietal pleura associated with plaques has been established.⁶ In the past, it was believed that the fibers caused direct mechanical irritation of the parietal pleura (the so-called scratching theory).⁷ It is now thought that short asbestos fibers reach the parietal pleura by passage through lymphatic channels, where they excite an inflammatory reaction, whereas the largest fibers, amphiboles, are retained in the lung parenchyma.^{6,7} Alternative explanations for the presence of fibers in the parietal pleura are via the blood supply or by direct migration of fibers through the visceral pleura.⁶ Pleural plaques slowly progress in size and amount of calcification with time, independent of any further exposure.⁸ There is no evidence that pleural plaques undergo malignant degeneration into mesothelioma.^{9,10}

Imaging of Pleural Plaques—Plain Radiography vs Conventional Computed Tomography vs High-Resolution Computed Tomography

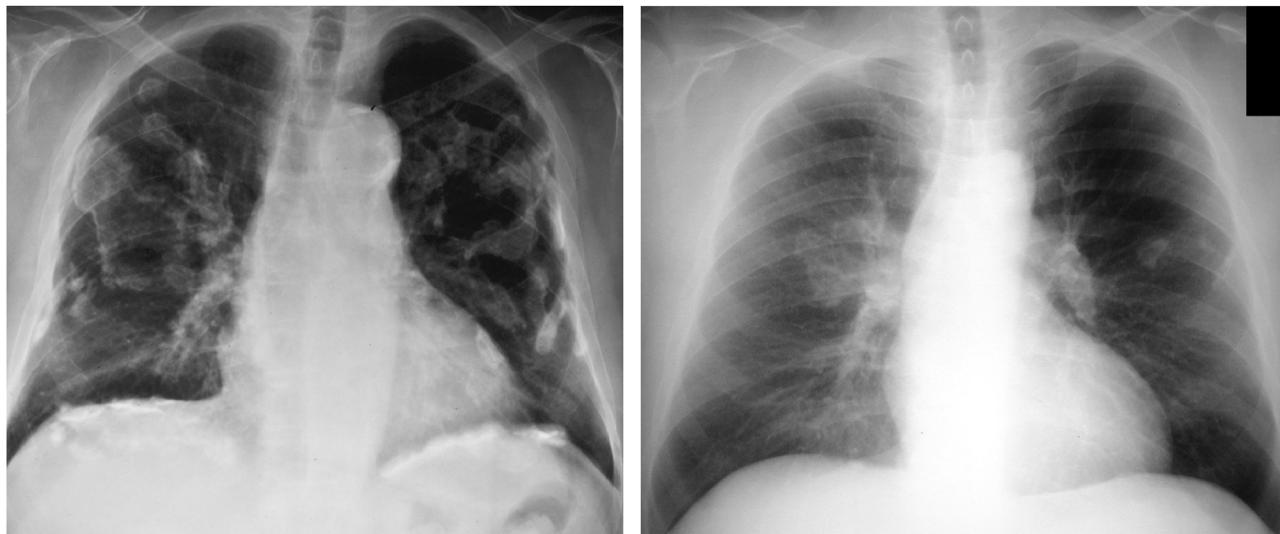
On plain radiographs, the characteristic locations of plaques are on the posterolateral chest wall between the seventh and tenth ribs, on the lateral wall between the sixth and ninth ribs, on the dome of the diaphragm, and on the mediastinal pleura particularly over the pericardium (Figs 3 and 4).⁴ This distribution is largely borne out by computed tomography (CT) studies.¹ The plaques may or may not be calcified, and the percentage of those found that are calcified varies depending on the study,¹ but

generally it is considered to be only 10%–15% of the time. There is evidence that the degree of calcification may continue to increase over time as the plaque ages. However, bilateral scattered calcified pleural plaques are very specific for and can be regarded as virtually pathognomonic of asbestos exposure.¹ Plain radiography of the chest is not particularly sensitive or specific for identifying plaques. Obtaining lateral oblique views may increase the sensitivity, but only marginally.¹ False positives are usually because of extrapleural fat or muscle. CT is more sensitive than plain film is for identifying plaques and can identify them in locations that may not be seen well in plain films, such as anterior and paravertebral plaques (Figs 5 and 6).⁴ High-resolution CT is particularly useful in distinguishing pleural disease from extrapleural fat.⁴ Neri et al have also shown that high-resolution CT (HRCT) can demonstrate pleural plaques and early lung involvement in asymptomatic amosite-exposed workers with apparently normal findings on chest radiographs.¹¹

There are several entities that can mimic the appearance of pleural plaques on radiographs, such as rib fractures, pleural vessels, intercostal muscle, pleurodesis, and degenerative spurs (Figs 7–9).

Diffuse Pleural Thickening

Diffuse pleural thickening is one complication that may result from multiple benign asbestos-related pleural effusions (Figs 10 and 11). This is essentially a plaque that extends over a long segment of the visceral pleura, but the specific definition varies. Some specific criteria, for example, list that it must be a continuous sheet of pleural thickening more than 5 cm wide, 8 cm craniocaudally, and at least 3 mm thick, but it need not meet these criteria to cause functional impairment. It is difficult to differentiate it from a plaque based on plain radiography, although generally plaques spare the costophrenic angles and apices, while diffuse pleural thickening causes blunting of the costophrenic angle. In addition, diffuse pleural thickening rarely calcifies, whereas plaques calcify more commonly, and diffuse thickening is ill defined and irregular, whereas plaques are well defined. Plaques rarely extend over more than 4 rib spaces unless multiple and confluent.¹ Another key distinction is that diffuse pleural thickening by definition involves the visceral pleura (eg, interlobar fissures), whereas plaques do not. Diffuse pleural



Figs 3 and 4. Chest radiographs from 2 patients with asbestos exposure demonstrate the typical radiographic appearance of calcified pleural plaques. The plaques are predominantly located in the posterolateral and lateral chest wall. The radiographic appearance has been described as similar to a "holly leaf."

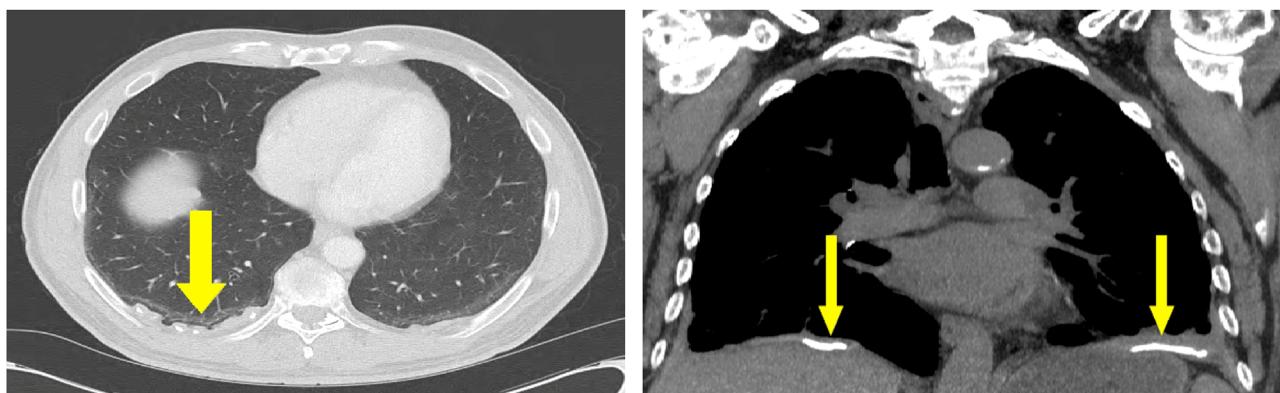
thickening involves fusion of the thickened and fibrotic visceral pleura to the parietal pleura and thus leads commonly to functional impairment, a restrictive pattern.¹ Based on the literature review, many authors believe development of diffuse pleural thickening to be related to the amount of asbestos exposure, unlike pleural plaques.¹ Histologically, there is similarity between pleural thickening and plaques, except that fusion of the pleural layers is suggestive of more intense inflammation in the former.¹ The underlying process is thought to be inflammation and fibrosis of lymphatic vessels and may be a direct extension of lung fibrosis.^{1,4}

Conventional and HRCT are more sensitive and specific for identifying diffuse pleural thickening when compared with plain radiography. Even with the additional oblique lateral views, which may increase the sensitivity for plain films, the positive predictive value was still only 13%–26%.¹ Abundant extrapleural fat accounts for most of the false-positive pleural fibrosis encountered on plain films. Diffuse pleural thickening is less specific for asbestos than are pleural plaques, as it may be seen in multiple other conditions including fibrothorax, empyema, mesothelioma, and metastatic disease.

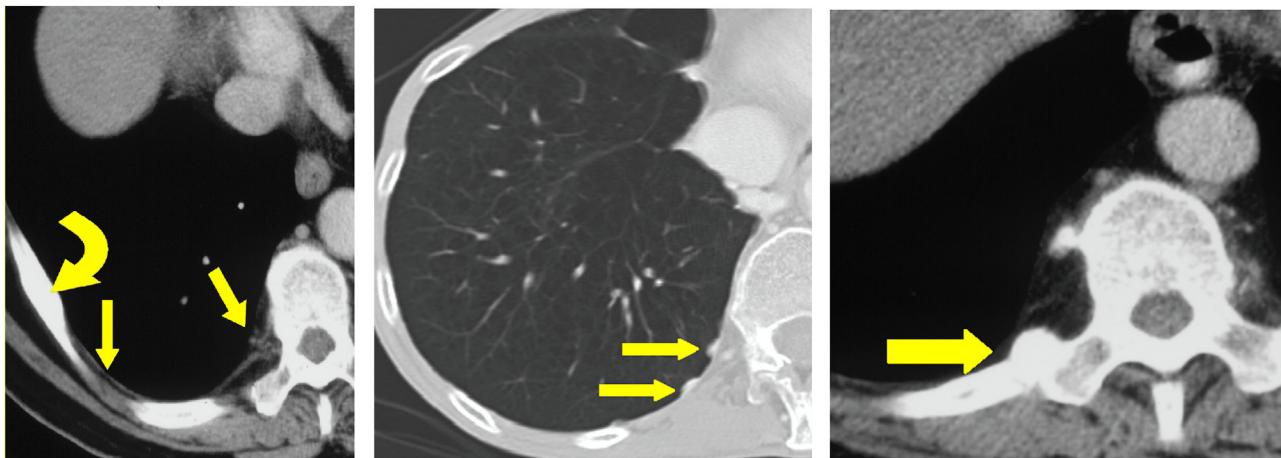
Diffuse Pleural Thickening—Differentiating Benign From Malignant Causes

Regarding diffuse pleural disease, according to a study published in 1990 in the American Journal of Roentgenology, several

features on CT scans were recognized to help distinguish between benign and malignant disease.¹² Leung et al¹² suggested that the presence of pleural rind, pleural nodularity, pleural thickening greater than 1 cm, and mediastinal pleural involvement were most discriminatory as these features are more frequent in malignant disease. Pleural rind refers to circumferential pleural thickening involving the entire perimeter of the hemithorax including the mediastinum. The presence of pleural rind was 100% specific for malignant disease, but 41% sensitive for indicating malignant pleural disease as opposed to benign pleural thickening. Nodular pleural thickening was 94% specific and 51% sensitive, parietal pleural thickening greater than 1 cm was 94% specific and 36% sensitive, and mediastinal pleural involvement was 88% specific and 56% sensitive. Reactive pleurisy usually does not affect the mediastinal pleura.¹⁴ Additionally, in the asbestos-exposed group, unilaterality or marked asymmetry of the pleural thickening must be considered suggestive of mesothelioma.¹² CT cannot distinguish between malignant mesothelioma and metastatic pleural disease (MPD). Pleural metastases may present with nodular or circumferential pleural thickening, loss of lung volume, and mediastinal or chest wall invasion or may only present as a pleural effusion. Loss of lung volume is relatively nonspecific and can be seen even in benign disease.¹² In a study, every case of malignant pleural effusion was indeed associated with pleural metastases rather than with malignant mesothelioma. Moreover, a significant proportion of malignant mesotheliomas are not asbestos related.



Figs 5 and 6. CT images from 2 patients with asbestos exposure demonstrate the typical elliptical and somewhat irregular appearance of calcified pleural plaques. The plaques are predominantly located in the parietal pleura and tend to be basilar. They are also usually found underneath the ribs. (Color version of figure is available online.)



Figs 7-9. Mimics of pleural plaques. Mimics of pleural plaques include rib fractures, pleural fat, intercostal vessels (Fig. 7), pleurodesis (Fig. 8), and degenerative disc disease (Fig. 9). (Color version of figure is available online.)

Disease of the Parenchyma

Rounded Atelectasis

Rounded atelectasis, also called “folded lung,” “Blesovsky syndrome,” “atelectatic pseudotumor,” and “pulmonary pseudotumor,” refers to peripheral atelectatic lung adjacent to an area of pleural thickening with characteristic drawing in of the bronchi and vessels into the atelectatic lung.^{13–15} It is strongly associated with asbestos exposure. However, any entity that leads to the formation of organized pleural exudate, such as tuberculosis, histoplasmosis, Dressler syndrome following cardiac surgery, and hemothorax, may produce the same radiographic appearance. It is most commonly seen in the lingula, followed by the right middle lobe and then the lower lobes, but any lobe may be affected.¹³

Conventional CT is most helpful in making the diagnosis, and 3 major features have been described: (1) rounded or oval mass (2.5–7 cm abutting a peripheral pleural surface); (2) the curving “comet tail” of bronchovascular structures passing into the mass, resulting in a blurred central margin; and (3) thickening of the adjacent pleura or hypertrophy of the subpleural fat with or without calcification, which is usually but not always thickest adjacent to the mass.¹³ Lynch et al¹⁶ included the additional feature of volume loss in the adjacent lung (Figs 12–15).

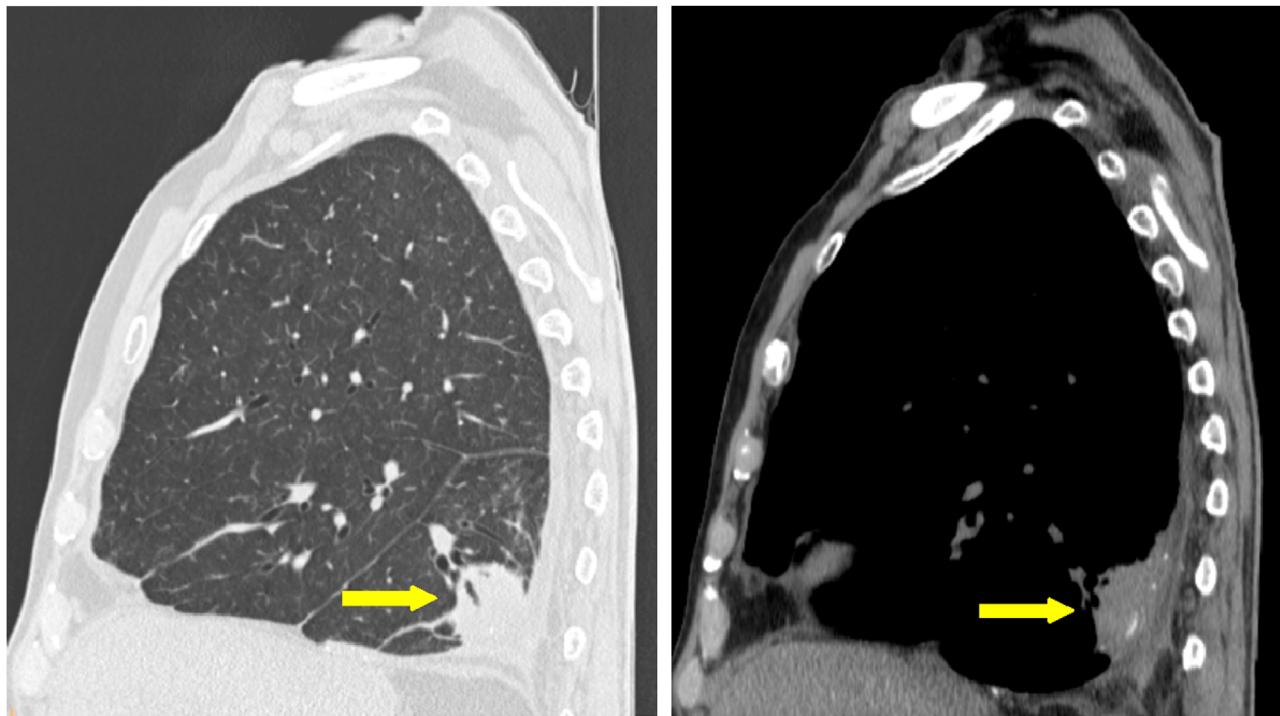
Importantly, rounded atelectasis can mimic bronchogenic carcinoma (Figs 16–18). Dynamic contrast-enhanced CT does not reliably differentiate rounded atelectasis from malignancy. According to some authors, ultrasonography may sometimes be helpful in reliably distinguishing between a bronchogenic carcinoma and rounded atelectasis.¹⁷ The ultrasonography features described in the latter are a pleural mass with thickening of the adjacent pleura and extrapleural fat. In a study, an echogenic line that extends into the mass from the pleura was seen in 86% of the patients studied, a finding thought to represent the scarred invaginated visceral pleura.¹⁷ In equivocal cases, a positron emission tomography (PET)/CT would be prudent.

Fibrotic Bands

Abundant inhalation of asbestos fibers can cause thickening of the visceral pleura with single or multiple fine or coarse pleural-parenchymal fibrous bands radiating from a single point on the pleura. This creates an image that can be likened to the appearance of crow’s feet or chicken’s feet (Figs 19 and 20). These are usually seen in connection with diffuse pleural thickening.^{18,19} It has been suggested that “crow’s feet,” pleural tags and parenchymal fibrotic bands are predominantly related to the fibrosis of the visceral pleura and should be differentiated from HRCT features more suggestive of diffuse interstitial fibrosis.⁸



Figs 10 and 11. CT images demonstrating bilateral pleural thickening and its usual continuous nature. The pleural thickening can be up to 3 cm in thickness. (Color version of figure is available online.)



Figs 12 and 13. Rounded atelectasis. CT images with lung and soft tissue windows demonstrating an area of rounded atelectasis in the lung base with “wrapping of the airway around the mass.” The soft tissue windows demonstrate association with partially calcified pleural plaque. The hypertrophy of the subpleural fat on the soft tissue windows can be noticed. (Color version of figure is available online.)

Asbestosis

General Characteristics, Definition, and Epidemiology

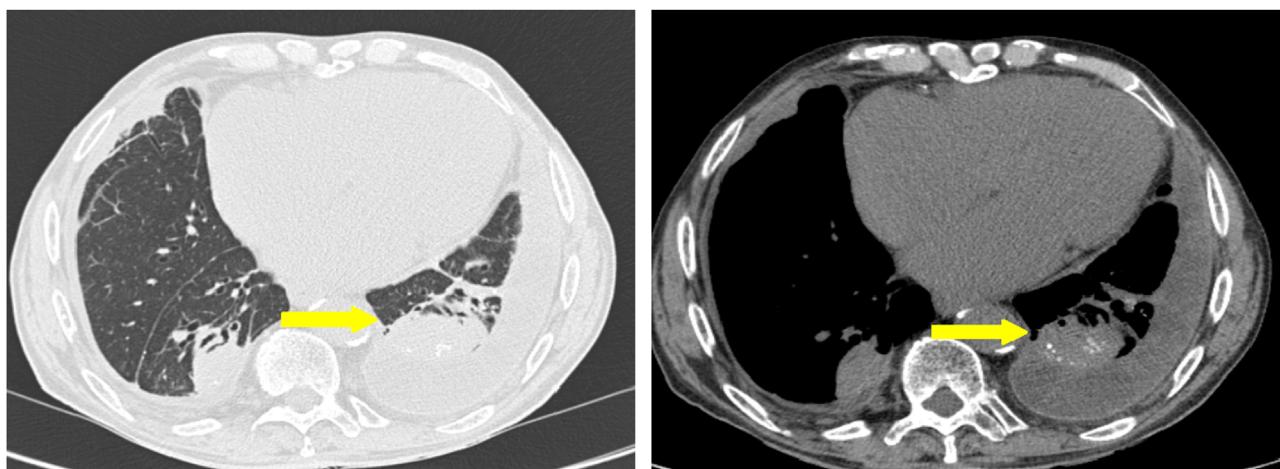
Asbestosis is defined as bilateral diffuse interstitial fibrosis of the lungs caused by the inhalation of asbestos fibers.²⁰ The term is reserved for interstitial fibrosis of the pulmonary parenchyma in which asbestos bodies or fibers can be demonstrated. Asbestosis is frequently associated with pleural disease—more with diffuse pleural thickening than with localized pleural plaques¹⁰—but parenchymal asbestosis should be considered separately from asbestos-related pleural abnormalities, as it differs markedly in epidemiology, clinical features, and prognosis.

It is generally agreed upon in the literature that higher cumulative doses of asbestos exposure are required to produce interstitial pulmonary fibrosis than those required to produce pleural effusions, plaques, and their sequelae.^{21,22} For example,

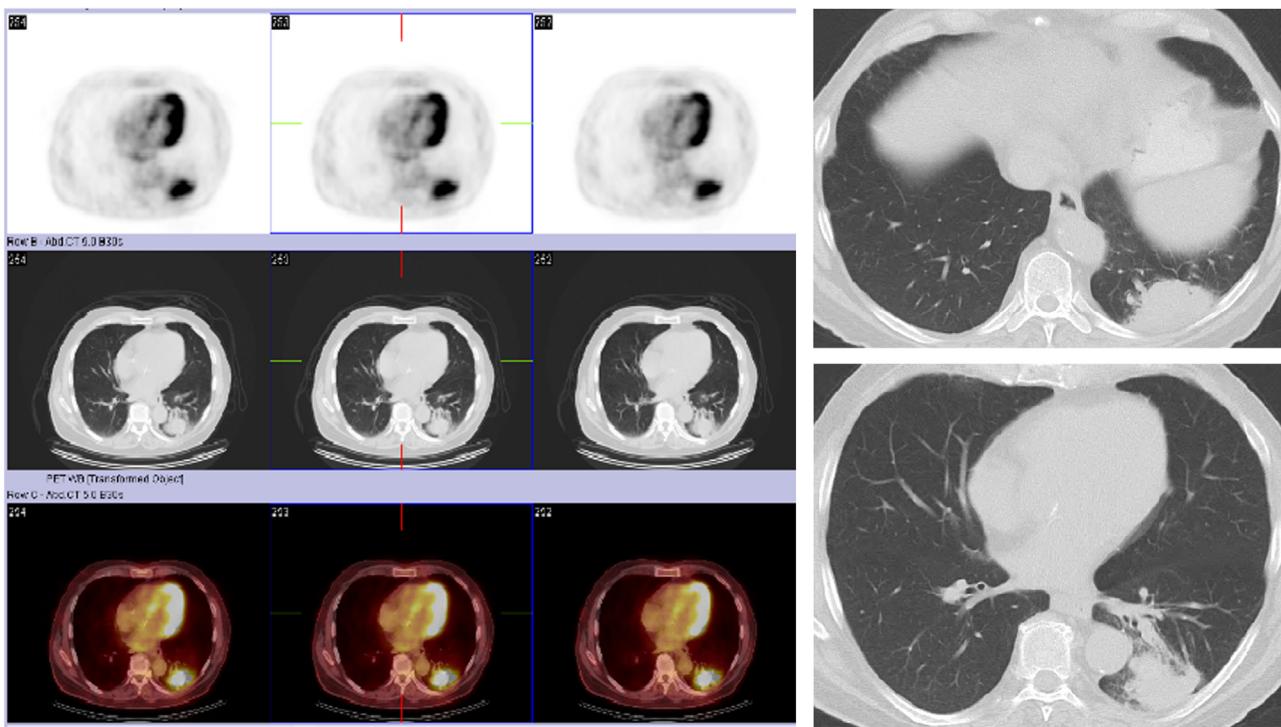
in 1985, Copes et al²³ showed that in chrysotile-exposed workers, interstitial fibrosis was associated with cumulative, continuous exposure, whereas pleural plaques tended to be associated with intermittent exposures. It has also been postulated that the intermittent exposure allows time for clearance of fibers from the lung with consequent accumulation in the pleura.⁹ Furthermore, the risk of developing asbestosis increases with smoking, whereas smoking does not correlate with the development of plaques or diffuse pleural thickening.²⁴

Radiographic Characteristics

The typical radiographic findings of asbestosis on plain film include a lower zone reticulonodular infiltrate or ground-glass opacification and ill-defined diaphragmatic contours.⁵ With conventional CT, subpleural lines, curvilinear opacities within 1 cm of the pleura and parallel to it that represent peribronchiolar fibrosis,



Figs 14 and 15. Rounded Atelectasis. CT images with lung and soft tissue windows demonstrating areas of rounded atelectasis in both the lung bases. The area of rounded atelectasis in the left lung base is associated with a pleural effusion. The subpleural bands in the right middle lobe can be noticed.



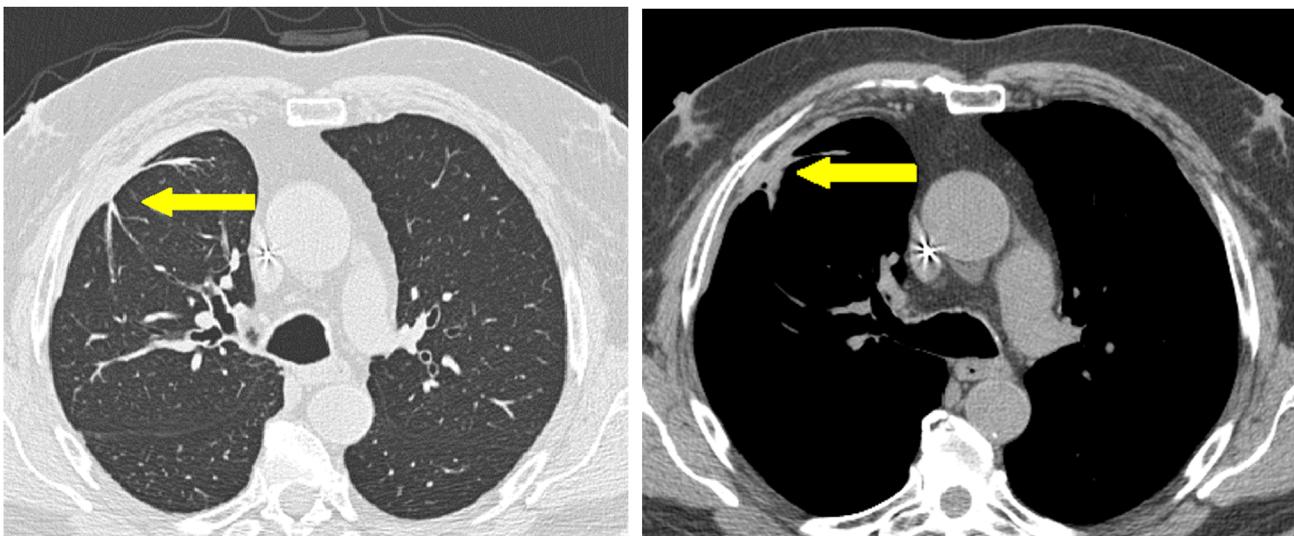
Figs 16-18. Bronchogenic CA mimicking rounded atelectasis. PET/CT and CT lung window images demonstrate an FDG-avid left lower lobe mass that was found to represent adenocarcinoma on biopsy. The imaging features on CT are strikingly similar to rounded atelectasis. FDG, fluorodeoxyglucose. (Color version of figure is available online.)

are an early feature.²² Parenchymal bands, linear opacities 2-5 cm in length running through the lung and usually contacting a pleural surface, may also be seen. Pulmonary arcades, most prominent in the posterior-dependent aspect of the lung, are branching linear structures that appear on conventional CT. It may be impossible to distinguish these arcades from prominent vessels. Traction bronchiectasis and cysts can also be seen.²⁵⁻²⁷ Other CT features that have been reported include ground-glass opacification secondary to mild alveolar wall fibrosis beyond the resolving power of CT, subpleural nodular or dotlike opacities, thickening of interlobular septa, and honeycombing, which occurs in advanced disease.²⁸ The changes of asbestosis are more pronounced in the lower lobes and subpleurally but often extend to involve the middle lobe and lingula. The upper lobes can be

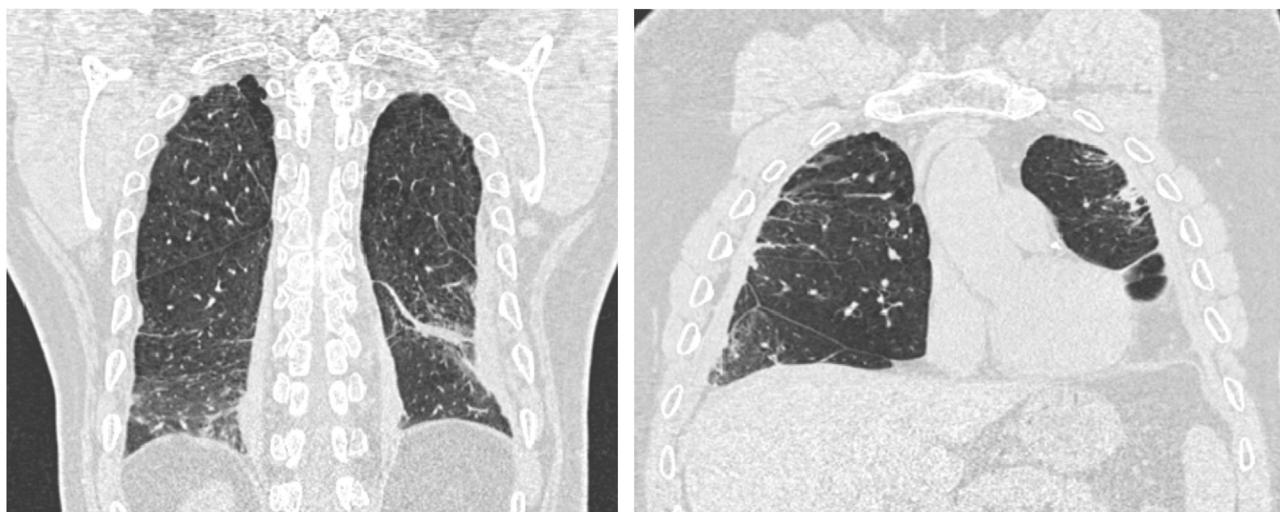
involved in advanced cases. Gamsu et al²⁹ found that interstitial lines (thickened interlobular septa and centrilobular core structures) were the most commonly found abnormality (84% of cases), followed by parenchymal bands (76%) and distortion of secondary pulmonary lobules (56%). Subpleural lines and honeycombing were less frequent (Fig 21-26).

Pathophysiology

The mechanism of lung injury in asbestosis is as follows: the asbestos fibers are inhaled, penetrate deeply into the lungs, and incite a foreign body reaction, consisting of the activation of the lung's local immune system and provocation of an inflammatory reaction. This inflammatory reaction can be thought of as a slow,



Figs 19 and 20. Crow's feet. CT images obtained at lung and soft tissue windows demonstrate a fibrotic band in the peripheral aspect of the right upper lobe. This band has been described as having the appearance of "crow's feet." (Color version of figure is available online.)



Figs 21 and 22. Asbestosis. Coronal CT images obtained at lung windows demonstrate basilar and peripheral predominant branching opacities, septal thickening, and reticulation. The patient also has concomitant emphysema.

ongoing activation of the immune system in an attempt to eliminate the foreign fibers. Macrophages phagocytose the fibers and stimulate fibroblasts to deposit connective tissue. As the asbestos fibers are remarkably resistant to digestion, the macrophage eventually dies, thus releasing cytokines and attracting further lung macrophages and fibroblastic cells to lay down fibrous tissue. This eventually forms a fibrous mass, resulting in interstitial fibrosis.^{30,31} It usually takes 20 years or more to see asbestosis develop after exposure.

The distortion of pulmonary architecture, namely, the laying down of collagen in an interstitial location, is similar to many of the features seen in usual interstitial pneumonia. Lung tissue becomes scarred around the terminal bronchioles and alveolar ducts. The fibrotic scar tissue causes alveolar walls to thicken, which reduces elasticity and gas diffusion, leading to reduced oxygen transfer to blood and removal of carbon dioxide. Moreover, asbestos, particularly amphibole in the form of crocidolite and amosite, includes iron and is considered responsible for the production of reactive oxygen and nitrogen species. These reactive oxygen and nitrogen species may further promote local chronic inflammation.^{30,31}

Because of these cellular and molecular events, cleaved asbestos fibers accumulate in regional lymph nodes, the distal end of

the alveolus, and the pleural cavity, particularly at the opening of lymphatic vessels. Local and circulating immune cells encounter these fibers repeatedly, and the process continues. This chronic inflammatory process is likely linked to the increased risk of developing malignancy, which is discussed further in the section on neoplastic disease.

Neoplastic Disease

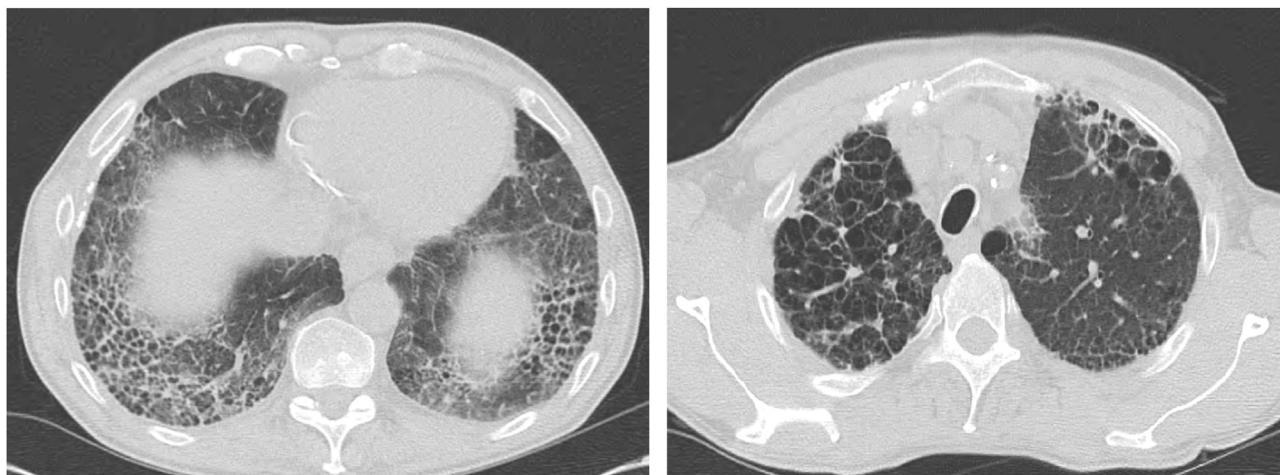
Malignant Mesothelioma

Malignant mesothelioma is known to be highly associated with asbestos exposure and occurs primarily in the pleura and the peritoneum, but it can also arise in the pericardium, tunica vaginalis testis, larynx, and kidney. Asbestos exposure has also been suggested as a contributor to nodular pulmonary amyloidosis.⁴

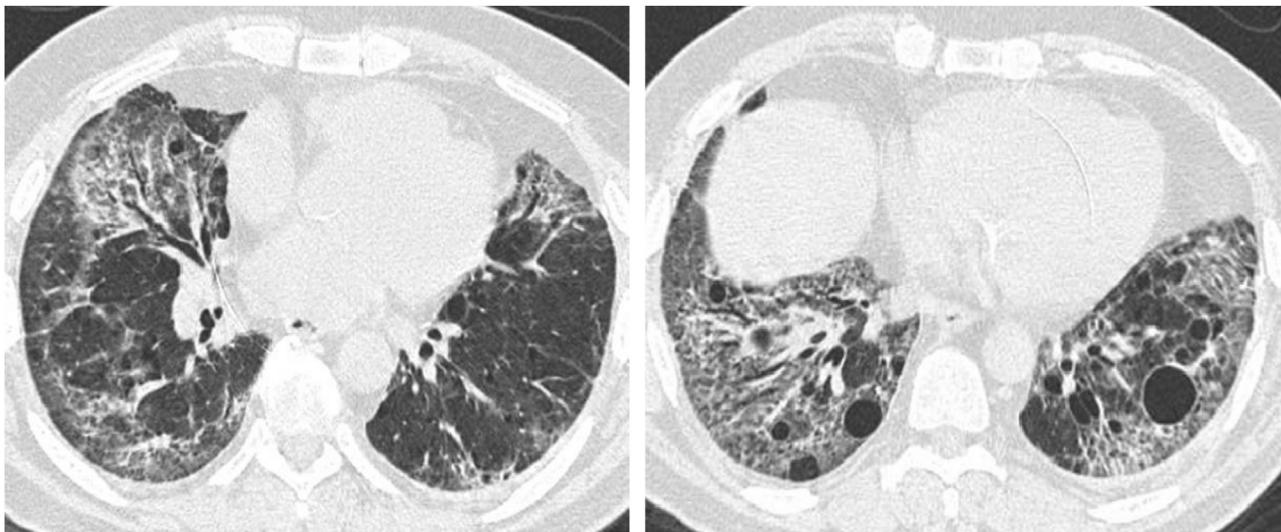
Malignant Pleural Mesothelioma

Epidemiology

Malignant pleural mesothelioma (MPM) is the most common primary neoplasm of the pleura^{32,33} but still a rare tumor. Pleural



Figs 23 and 24. Asbestosis and emphysema. CT images obtained at lung windows from a patient with asbestosis demonstrate honeycombing in both the lower lobes (Fig. 23) as well as septal thickening and diffuse emphysema in the upper lobes (Fig. 24).



Figs 25 and 26. Asbestosis associated with cysts. CT images obtained at lung windows demonstrate diffuse reticulation and traction bronchiectasis in both the lower lobes, right greater than left, and multiple cysts of various shapes and sizes in a patient with asbestosis.

mesothelioma is strongly associated with asbestos—only 20% of cases occur in patients without a known history of asbestos exposure.³³ Although the association between asbestos and MPM was established in 1960 by Wanger et al,³⁴ leading to the implementation of strict regulations for limitations on exposure, the incidence continues to rise and is projected to keep rising until approximately 2020,³³ secondary to the latency period of 35–40 years from exposure to development. Men are usually affected in the sixth and seventh decades of life.³³ It is generally thought that the higher the length:diameter ratio of the fiber, the greater the threat it poses for malignancy.³³ Crocidolite is the form that confers the greatest risk.⁴ Risk ratios for chrysotile, amosite, and crocidolite of 1:100:500, respectively, have been postulated.⁴

There are 3 histologic types of MPM: epithelioid (50%–70% of cases), sarcomatoid (10%–20%), and biphasic (25%–35%).³³ Epithelioid neoplasms may appear similar to peripheral adenocarcinoma of the lung with pleural invasion or pleural metastasis, sarcomatoid neoplasms must be differentiated from a true sarcoma such as osteosarcoma or chondrosarcoma, and mixed neoplasms have features of both.³³ MPM is an aggressive neoplasm with a bleak prognosis; most patients die within 1 year of diagnosis, regardless of histologic subtype. Importantly, it can develop in patients with even transient or indirect exposure to asbestos.³⁵ Considerably lower doses of asbestos exposure are required to cause mesothelioma when compared with bronchogenic carcinoma or asbestosis⁴; however, in general, patients with higher levels of exposure develop MPM at a greater rate. The consensus in the literature is that there is no definitive correlation between MPM development and duration of asbestos exposure or smoking habit but rather that the total levels of exposure (cumulative burden) is what confers a greater likelihood of developing mesothelioma in the exposed population.²⁴ The patients with progressive pleural and parenchymal changes are at particularly high risk of developing MPM and must be under special surveillance.

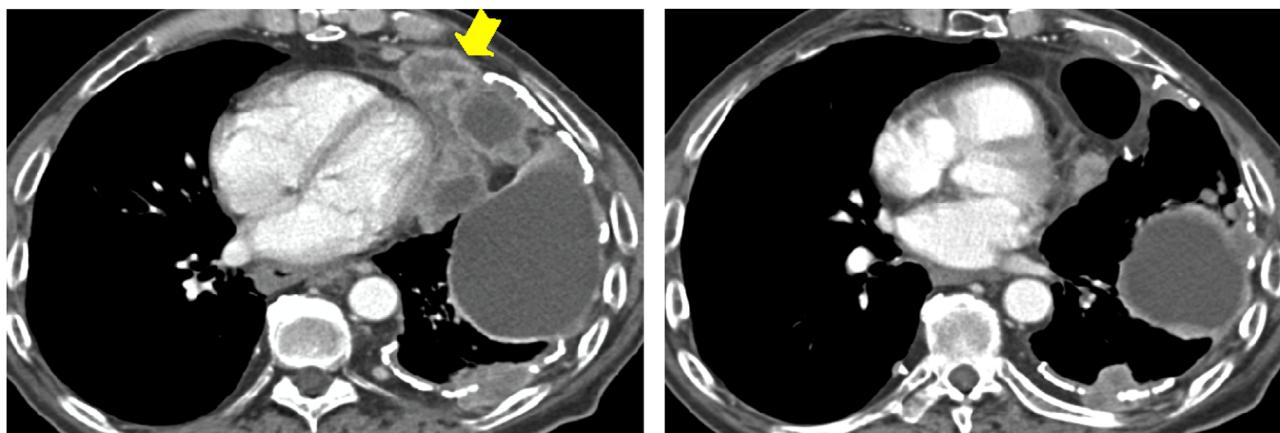
Radiologic Findings

On plain film, the most common features of MPM are irregular, nodular opacities around the periphery of the lung, which are associated with ipsilateral pleural effusion in 30%–95% of cases. The pleural effusion may obscure underlying pleural thickening or masses until thoracentesis is performed. Usually, this effusion does

not cause contralateral shift of the mediastinum because the pleural tumor constricts the ipsilateral side.³³

The nature of the lesion in pleural mesothelioma observed on CT scans can be a pleural mass with or without effusion, pleural thickening with or without effusion, or simply a pleural effusion. In the case of pleural thickening, it can be smooth, irregular, or nodular (Figs 27 and 28). Commonly, widespread nodular thickening of the pleura surrounding the lung, spreading into the fissures and extending into the mediastinum, is observed, often with an associated pleural effusion³³ (Figs 29 and 30). The lesion may invade the chest wall, extend below the diaphragm, or invade the mediastinal structures including the pericardium, great vessels, trachea, esophagus, and thoracic lymph nodes.^{12,33} Metastatic spread to the lymph nodes, contralateral lung, or liver may be observed. Both contraction³³ (in approximately 25% of cases) and enlargement (in approximately 10%) of the ipsilateral hemithorax can be seen. With volume loss due to contraction of the ipsilateral hemithorax, hemidiaphragmatic elevation, narrowing of the intercostal spaces, and ipsilateral shift of the mediastinum may be observed.³³ However, it should be reiterated that a pleural effusion may be the sole manifestation of malignant mesothelioma, that is, with the absence of pleural plaques or any other manifestation of asbestos-related disease.¹² In fact, in a study, concurrent bilateral pleural calcification and plaques indicative of previous asbestos exposure were identified in only 16% of patients.²⁷ Although CT plays an immensely important role in the diagnosis and assessment of treatment response, it has some limitations in specific areas in evaluating patients for surgical resection. CT failed to identify chest wall and mediastinal invasion in a number of patients who underwent surgical resections in a study.³² Magnetic resonance demonstrates value in determining local invasion when CT findings are equivocal. The superior contrast resolution is particularly helpful in determining extension into the chest wall or the diaphragm. It is also useful if patients who have a contraindication to iodinated contrast. The most common nodal site of involvement in metastatic disease is the mediastinum, but the celiac, cervical, and axillary nodes may be affected as well.³³

Differentiating malignant from benign pleural disease has been discussed in the first section on benign pleural asbestos-related disease. In general, if radiographic signs are equivocal, PET/CT may be of additional utility in delineating the benign or malignant etiology of an observed lesion. Separating malignant primary



Figs 27 and 28. Pleural mesothelioma. Images from a patient with pleural mesothelioma demonstrate soft tissue pleural nodularity with areas of central necrosis. **Figure 27** demonstrates medial pleural invasion, pericardial invasion, and chest wall invasion (arrow). Calcified pleural plaques are noted on the left and the right. (Color version of figure is available online.)

pleural mesothelioma from metastatic malignant pleural disease from another primary tumor is discussed.

MPM vs MPD

When another primary neoplasm metastasizes to the lung pleura, the most common finding is undoubtedly a pleural effusion. In review of thousands of cases of malignant pleural effusions, bronchogenic carcinoma, especially adenocarcinoma, was found in the greatest number of cases (36%), followed by breast cancer (25%), lymphoma (10%), ovarian cancer (5%), gastric cancer (5%, less), and unknown (7%).³³ Besides pleural effusion, metastatic disease to the pleura may also present as pleural nodules or extensive pleural thickening or as a solitary implant on the costal, diaphragmatic, or mediastinal pleura (Fig 31).³⁶ When there is a unilateral metastasis to the pleura, the radiographic findings may appear identical to those of mesothelioma.¹² In patients with primary mesothelioma of the pleura (MPM), the most common CT features were circumferential lung encasement by multiple nodules (28%), pleural thickening with irregular pleuropulmonary margins (26%), and pleural thickening with superimposed nodules (20%). In most (70%) cases, there was rindlike extension of tumor on the pleural surfaces. In multivariate analysis, the CT findings of “rindlike pleural involvement,” “mediastinal pleural involvement,” and “pleural thickness more than 1 cm” were independent findings in differentiating MPM from MPD, with the sensitivity and specificity values of 70 and 85, 85 and 67, and 59

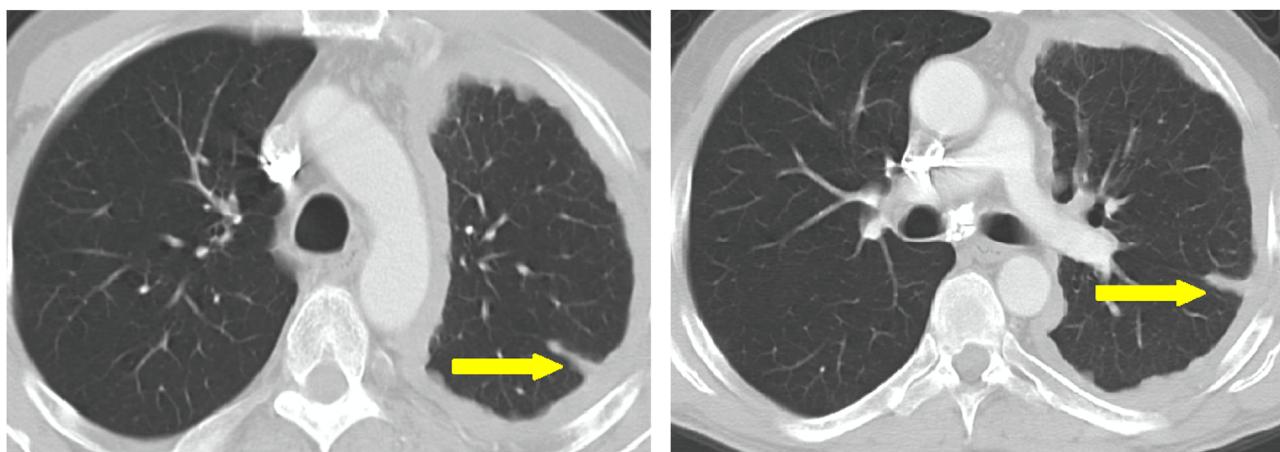
and 82, respectively.³⁷ There is a benign entity known to have the propensity to affect the mediastinal pleura in addition to the thoracic pleura, tuberculous empyema, or tuberculous fibrothorax.³³

Peritoneal Mesothelioma

Peritoneal mesothelioma is a rare primary peritoneal tumor (overall prevalence is 1-2 cases per million), but it accounts for up to 10%-20% of asbestos-related malignant mesotheliomas.³⁸ The prognosis is poor. Interestingly, the frequency of nonasbestos-related malignant peritoneal mesothelioma may be as much as 50%;³⁹ although the high majority of MPMs are associated with a history of past exposure to asbestos, only half of malignant peritoneal mesotheliomas may be.³⁹ Usually the patient presents with nonspecific symptoms such as abdominal pain, distention, or fullness.³⁹ Ascites and a peritoneal mass are present in most patients with confirmed diagnosis. Additionally, small peritoneal nodules and parietal peritoneal thickening, or thickened mesentery, may be found in slightly more than half of patients (Figs 32 and 33). Although CT findings are characteristic, tissue sampling for histologic examination with specific immunohistochemical staining is mandatory for diagnosis.³⁸

Pericardial Mesothelioma

Although primary pericardial neoplasms are rare, pericardial mesothelioma accounts for 50% of them,⁴⁰ and asbestos exposure



Figs 29 and 30. Pleural mesothelioma. CT images obtained at lung windows demonstrate mesothelioma involving both the mediastinal and parietal pleura. There is also fissural involvement and volume loss in the left lung (arrows). When there is mediastinal pleural involvement, a malignant cause is much more common than a benign cause for the pleural thickening. (Color version of figure is available online.)

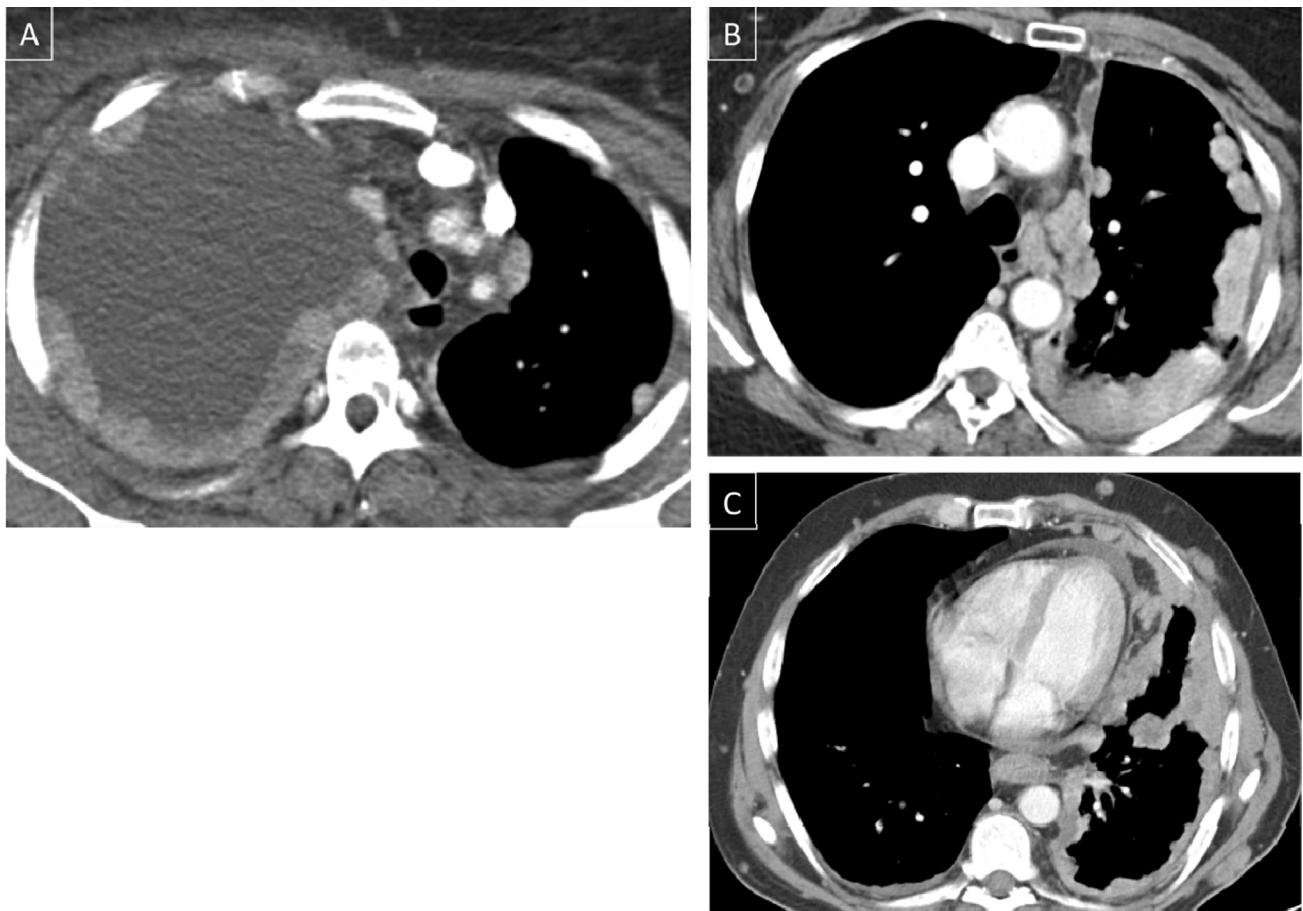


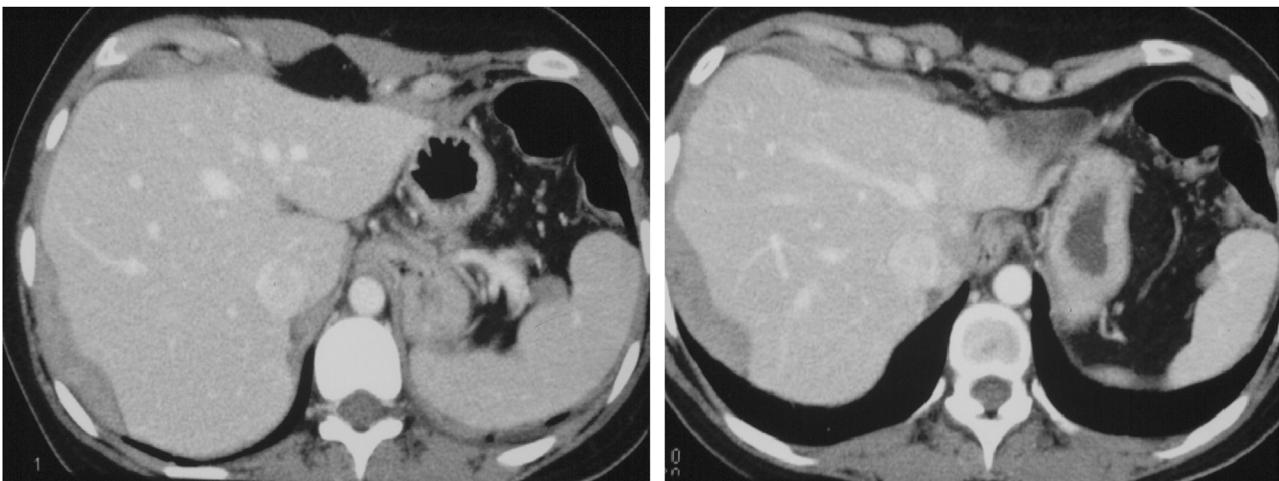
Fig 31. Metastatic disease mimicking mesothelioma. Pleural metastatic disease can mimic the nodular pleural thickening of the thoracic mesothelioma. Examples of metastatic (A) breast cancer, (B) lung cancer, and (C) melanoma are shown.

is a known risk factor. Chest radiographs in patients with pericardial mesothelioma typically demonstrate cardiac enlargement, evidence of pericardial effusion, an irregular cardiac contour, or diffuse mediastinal enlargement. Chest CT scans demonstrate irregular, diffuse pericardial thickening and pericardial effusion (Fig 34). Magnetic resonance imaging may also readily demonstrate cardiac encasement by a soft tissue pericardial mass, as well as an associated pericardial effusion (Fig 35).⁴⁰ To define

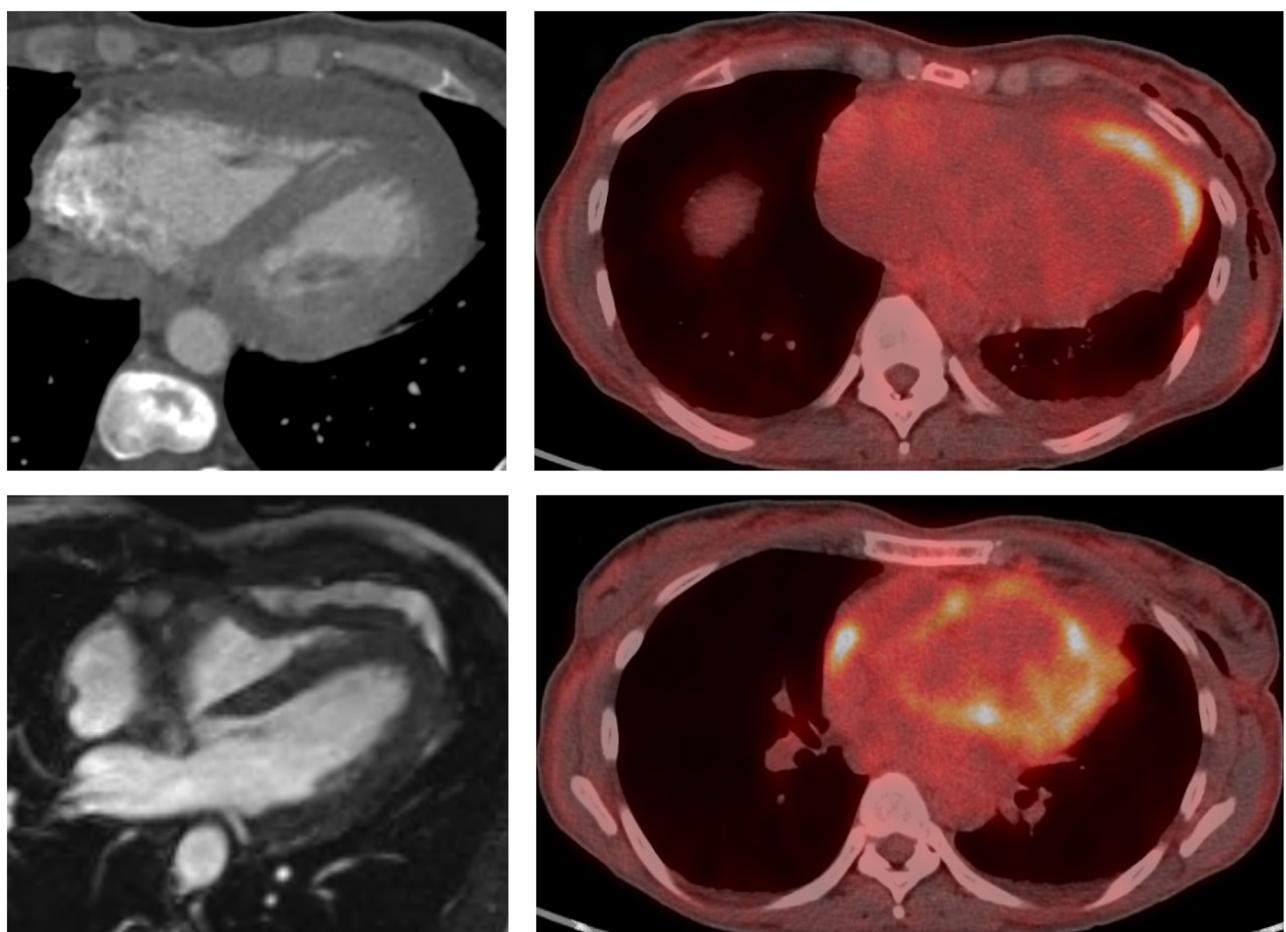
malignancy, PET/CT is of great utility (Fig 36 and 37), and for the ultimate diagnosis, tissue biopsy is required.

Bronchogenic Carcinoma

The link between asbestos exposure and lung cancer has been suspected since the 1930s but was proved in the 1950s.⁴ Smoking has a more than additive effect. The risk of bronchogenic



Figs 32 and 33. Peritoneal mesothelioma. CT images obtained at soft tissue windows demonstrate diffuse perihepatic soft tissue in a patient with asbestos exposure. Biopsy revealed mesothelioma.



Figs 34-37. CT (Fig. 34) and MR (Fig. 35) images demonstrate soft tissue nodularity along the pericardium, which demonstrates FDG avidity on the PET/CT images (Fig. 36 and 37). Biopsy revealed mesothelioma. FDG, fluorodeoxyglucose; MR, magnetic resonance. (Color version of figure is available online.)

carcinoma in asbestos workers who smoke may be as much as 80%-100% greater than that of the nonsmoking, nonexposed population. Additionally, it must be kept in mind that most asbestos workers smoked, putting this population altogether at a particularly high risk of developing bronchogenic carcinoma over time. Amphiboles are 10-50 times more potent than chrysotile is in

inducing lung cancer, but fortunately they are the lesser used form. The latent period is variable and can be anywhere from 10-30 years later.⁴ Asbestos-related tumors frequently occur in the periphery of the lungs with a lower lobe distribution, which correlates with the usual distribution of asbestosis (Fig 38).² Bronchogenic carcinoma is estimated to develop in 20%-25% of

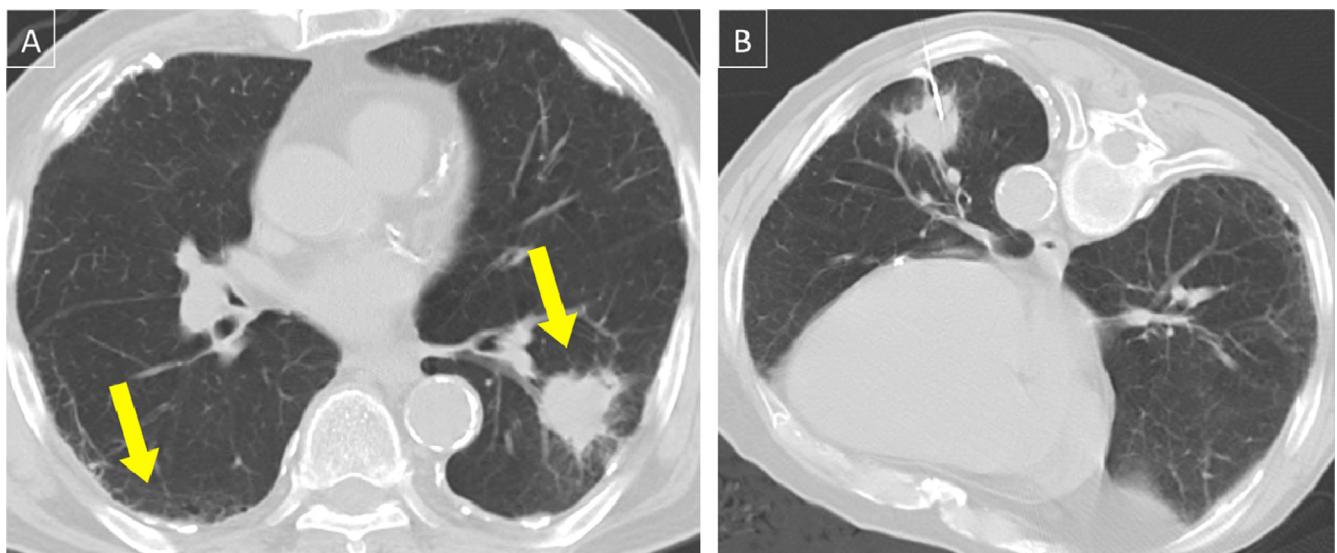


Fig 38. Bronchogenic carcinoma. CT image obtained at lung windows demonstrates a pulmonary mass in the left lower lobe. (A) Multiple bilateral pleural plaques and subpleural bands or fibrosis can be noted. (B) CT-guided biopsy of this mass demonstrated adenocarcinoma. (Color version of figure is available online.)

workers who are heavily exposed to asbestos.² The prognosis is similar to that for nonasbestos-related lung cancers, but the restrictive effect of coexistent asbestosis or diffuse pleural thickening could compromise patients' respiratory function and fitness for attempted resection.

Conclusion

Asbestos-related lung disease is a condition that has affected many patients and will affect many more in the years to come. Exposure to asbestos causes multiple effects on the lung parenchyma and pleura. Radiologists have an integral role in the diagnosis and management of these patients. Recognizing the imaging appearance of the pleural disease, lung parenchymal disease, and neoplastic disease caused by asbestos exposure is crucial to getting these patients the proper treatment.

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