Imaging of Community-acquired Pneumonia

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Abstract: Community-acquired pneumonia refers to an acute infection of the lung in patients who did not meet any of the criteria for health care–acquired pneumonia, and is associated with at least some symptoms of acute infection, accompanied by the presence of an acute infiltrate on a chest radiograph. Chest radiography remains an important component of the evaluation of a patient with a suspicion of pneumonia, and is usually the first examination to be obtained. The diagnosis of community-acquired pneumonia is based on the presence of select clinical features and is supported by imaging of the lung, usually by chest radiography. Infection of the lower respiratory tract typically presents radiologically as one of 3 patterns: (a) focal nonsegmental or lobar pneumonia, (b) multifocal bronchopneumonia or lobular pneumonia, and (c) focal or diffuse "interstitial" pneumonia. High-resolution computed tomography allows a better depiction of the pattern and distribution of pneumonia than the radiograph but is seldom required in the evaluation of patients with suspected or proven bacterial pneumonia. However, high-resolution computed tomography is a useful adjunct to conventional radiography in selected cases.

Key Words: lung infections, HRCT, Chest radiograph

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Respiratory infections are the commonest illnesses occurring in humans, and pneumonia is the leading cause of hospitalization and death among adults in the United States, irrespective of age.

Pneumonia is currently classified according to where it is acquired in 3 categories: (a) community-acquired pneumonia (CAP), (b) health care–acquired pneumonia (HCAP), and (c) hospital-acquired/ventilator-acquired pneumonia.[1–3] This review will focus on the imaging diagnosis of adults with acute CAP.

CAP

CAP refers to an acute infection of the lung in patients who did not meet any of the criteria for HCAP, and it is associated with at least some symptoms of acute infection, accompanied by the presence of an acute infiltrate on a chest radiograph.[4] In adults, CAP incidence increases with age: almost 1 million episodes occur in persons aged above 65 years, and about 1/20 persons aged above 85 years experience an episode of CAP.[5]

Bacterial and viral microorganisms are the most common etiologic agents responsible for CAP. Identification of causative microorganisms in CAP remains challenging and in 30% to 65% of cases.[6–8] Patients with chronic obstructive pulmonary disease (COPD) are at increased risk for CAP caused by *Haemophilus influenzae* and *Moraxella catarrhalis*.[9]

Viruses such as influenza, adenovirus, and respiratory syncytial virus (RSV) may also be included as a cause of atypical pneumonia. New emerging pathogens have been recognized, such as community-acquired methicillin-resistant *Staphylococcus aureus* (MRSA), avian influenza A viruses (H5N1), coronavirus associated with severe acute respiratory syndrome (SARS), Middle-East respiratory syndrome (MERS), and swine flu (H1N1).[10–19]

CLINICAL UTILITY AND LIMITATIONS OF CHEST RADIOGRAPHY AND COMPUTED TOMOGRAPHY (CT)

Chest radiography remains an important component of the evaluation of a patient with a suspicion of pneumonia and is usually the first examination to be obtained. The American Thoracic Society (ATS) guidelines recommend a posteroanterior (and lateral when possible) chest radiograph, to establish the diagnosis of pneumonia in all patients with suspected CAP, and to assess for the extent of disease (multilobar disease) and for pleural effusion.[9]

Pulmonary opacities are usually evident on the radiograph within 12 hours of the onset of symptoms.[20] Chest radiography is also useful to determine the extent of pneumonia and to detect complications (ie, cavitation, abscess formation, pneumothorax, and pleural effusion), for detection of additional or alternative diagnoses and, in some cases, to guide invasive diagnostic procedures.[4] Differentiating pneumonia from conditions such as left heart failure, pulmonary embolism, and aspiration pneumonia may sometimes be difficult.[2,16] Normal resolution of pneumonia is variable and depends on the causative agent and the host response to the invading pathogen.

Radiographic Imaging of CAP

The radiographic patterns of CAP are often related to the causative agent. Infection of the lower respiratory tract (LRT), acquired by way of the airways and confined to the lung parenchyma and airways, typically presents radiologically as one of 3 patterns: (a) focal nonsegmental or lobar pneumonia, (b) multifocal bronchopneumonia or lobular pneumonia, and (c) focal or diffuse "interstitial" pneumonia.[21]

Lobar Pneumonia

Lobar consolidation, involving single or multiple lobes, is the most common radiographic pattern of community-acquired pneumococcal pneumonia.[22] Common causes of lobar consolidation are *Legionella* species, *Streptococcus pneumoniae*, and *Mycoplasma pneumoniae*. Radiographically, it shows a nonsegmental, homogenous consolidation involving predominantly or exclusively one lobe with visible air bronchogram (Fig. 1).[23] Some pneumonias present as spherical or nodular areas of consolidation (Fig. 2). They occur

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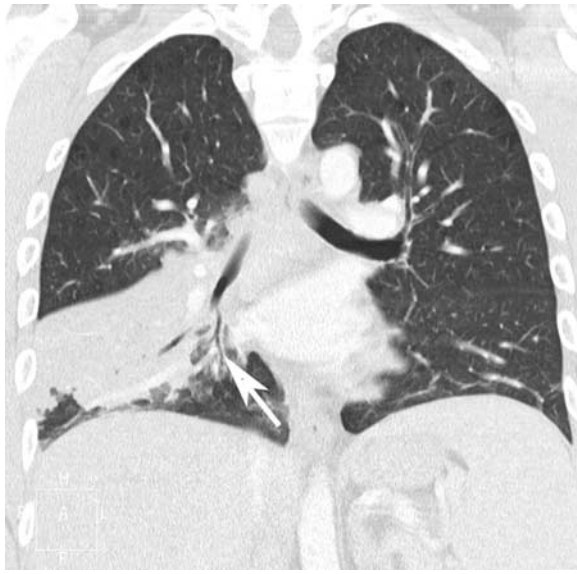

FIGURE 1. Lobar pneumonia due to *Streptococcus pneumoniae*. Coronal CT reformation of a 29-year-old woman with pneumococcal pneumonia shows complete consolidation of the right lower lobe. Note the presence of air bronchogram (arrow).

more commonly in children than in adults and are most often caused by *S. pneumoniae*.[24]

Bronchopneumonia

Bronchopneumonia, which is most commonly caused by *S. aureus*, *H. influenzae*, and fungi, occurs when infectious organisms deposited on the epithelium of the bronchi produce acute bronchial inflammation with epithelial ulcerations and fibrinopurulent exudate formation. As a consequence, the inflammatory reaction rapidly spreads through the airways' walls and into the contiguous pulmonary lobules. When affected areas coalesce, the shadowing may become more uniform and resemble lobar pneumonia. Radiographically, these inflammatory aggregates cause a typical patchy pattern

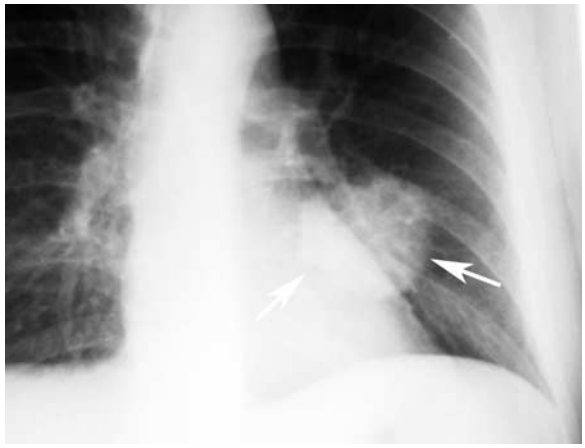

FIGURE 2. Round pneumonia. Anteroposterior chest radiographs of a 58-year-old man with pneumonia due to *Streptococcus pneumoniae* shows a sharply defined rounded opacity in the left lower lung zone (arrows).

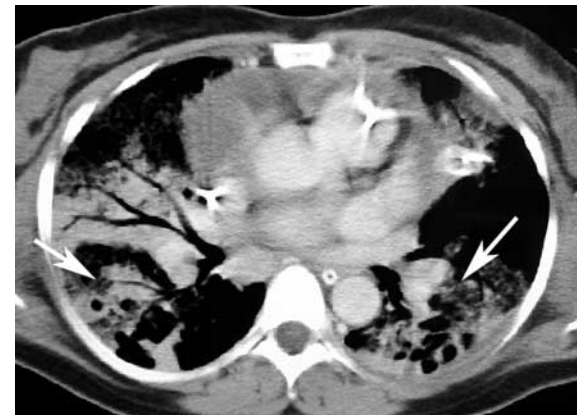

FIGURE 3. Pneumonia due to *Pseudomonas aeruginosa*. Contrast-enhanced CT of a 68-year-old man shows bilateral multifocal focal areas of consolidation and cavitation consistent with abscess formation (arrows). Note a middle lobe consolidation with visible air bronchogram.

of bronchopneumonia or, occasionally, a homogeneous segmental consolidation that may also cavitate (Fig. 3).

Interstitial Pneumonia

In interstitial pneumonia, the initial damage is directed toward the mucosa of the bronchioles, and, later, the peribronchial tissue and interlobular septa become edematous and infiltrated with inflammatory cells. On the chest radiograph, interstitial pneumonia is characterized by extensive peribronchial thickening and ill-defined reticulonodular opacities; associated patchy subsegmental or plate-like atelectasis is common. Diffuse bilateral interstitial and/or interstitial-alveolar (mixed) opacities are most commonly caused by viruses and *M. pneumoniae* (Fig. 4).[25–27] Up to 30% of all pneumonias in the general population may be caused by *M. pneumoniae*.[28]

CT

CT, particularly high-resolution CT (HRCT), has been shown to be more sensitive than the radiograph in the

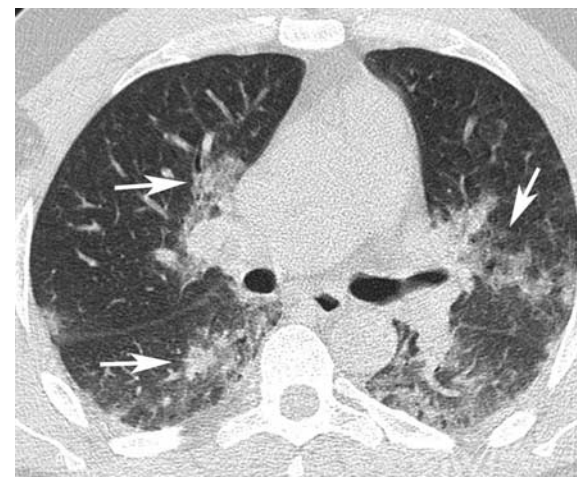

FIGURE 4. Mycoplasma pneumonia. HRCT of a 36-year-old man with *Mycoplasma pneumoniae* pneumonia shows bilateral lobular ill-defined ground-glass opacities (arrows). HRCT indicates high-resolution CT.

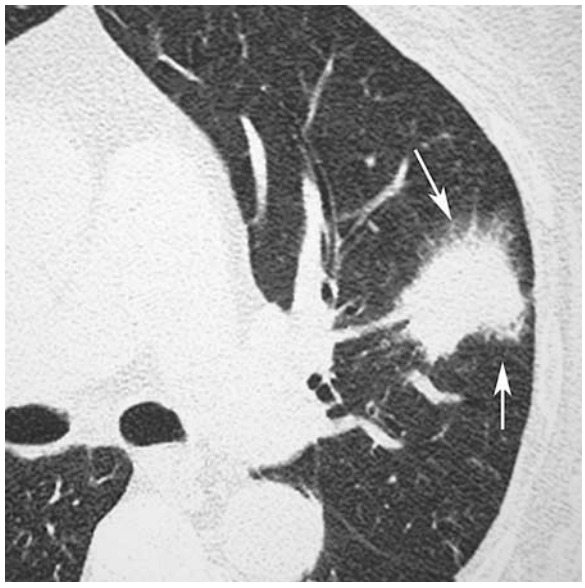

FIGURE 5. Angioinvasive aspergillosis. Close-up view of the left upper lobe from a HRCT scan of a 33-year-old man with severe neutropenia shows a nodule surrounded by a halo of ground-glass attenuation (halo sign) (arrows). HRCT indicates high-resolution CT.

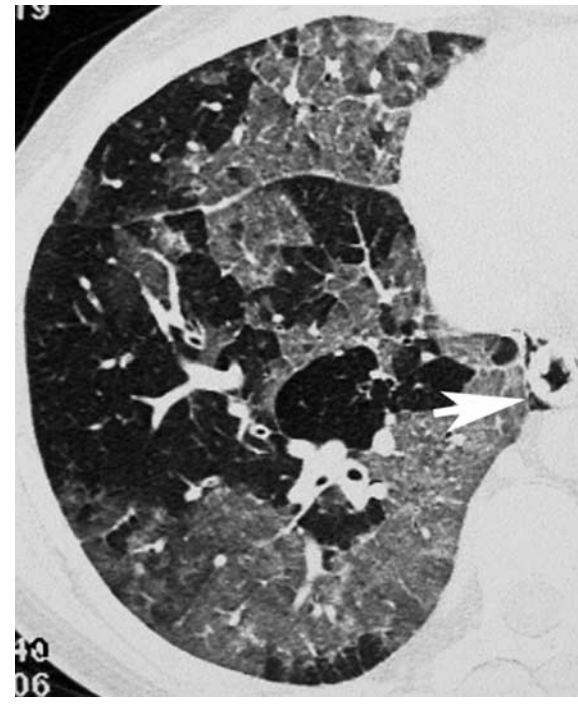

FIGURE 6. *Pneumocystis jirovecii* pneumonia in AIDS. HRCT of a 34-year-old man with acquired immunodeficiency syndrome shows bilateral ground-glass opacities interspersed by normal lung parenchyma. Also note a pneumomediastinum (arrow). HRCT indicates high-resolution CT.

detection of subtle abnormalities and may show findings suggestive of pneumonia up to 5 days earlier than chest radiographs.[29,30]

HRCT is a useful adjunct to conventional radiography in selected cases such as clinical suspicion of infection and normal or nonspecific radiographic findings, assessment of suspected complications of pneumonia, suspicion of an underlying lesion such as pulmonary carcinoma, and in patients with pneumonia and persistent or recurrent pulmonary opacities.[28,31–35]

CT Imaging of CAP

The findings of air-space disease, including air-space nodules, ground-glass opacities, consolidation, air bronchograms, and centrilobular or perilobular distribution are better seen on CT than on chest radiography. Air-space nodules measure 6 to 10 mm in diameter, and they usually reflect the presence of peribronchiolar consolidation, and are therefore centrilobular in distribution. In some circumstances, nodules may be associated with a "halo" of ground-glass attenuation, which usually reflects the presence of hemorrhage surrounding the nodule. In severely neutropenic patients, the "halo" sign is highly suggestive of angioinvasive aspergillosis (Fig. 5).[36] However, a similar appearance has been described in other conditions including infection by nontuberculous mycobacteria, Mucorales, Candida, Herpes simplex, and cytomegalovirus (CMV), granulomatosis with polyangiitis, Kaposi sarcoma, and hemorrhagic metastases.[37]

Ground-glass opacities are defined as a localized increase in lung attenuation that allows visualization of vascular structures coursing through the affected region. They may be attributable to infection caused by *Pneumocystis jirovecii* (Fig. 6), CMV, and mycoplasma.[38]

A "tree-in-bud" pattern reflects the presence of bronchioles filled with mucus or inflammatory material resulting in centrilobular tubular, branching, or nodular structures.[39] A variety of bacterial, mycobacterial, fungal, and viral pathogens may cause bronchogenic dissemination and bronchiolar impaction by mucus or pus, resulting in a tree-in-bud pattern (Fig. 7).

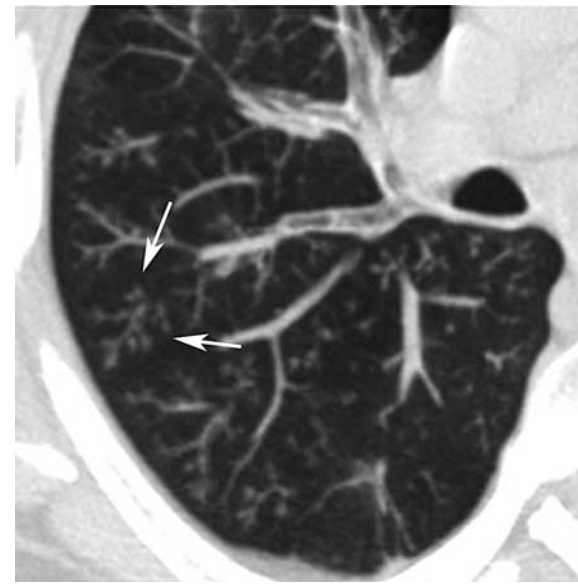

FIGURE 7. "Tree-in-bud" pattern in infectious bronchiolitis. HRCT of a 20-year-old woman with recurrent respiratory infections shows centrilobular branching nodular and linear opacities resulting in a "tree-in-bud" appearance (arrows). HRCT indicates high-resolution CT.

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Focal consolidation, defined as a localized increase in lung attenuation that does not allow visualization of vascular structures coursing through the affected region, may be seen in association with bacterial, fungal, and viral infections. Bacterial pneumonia is a common cause of pulmonary consolidation in AIDS patients.[40] Focal consolidation caused by fungi is most commonly seen in neutropenic patients with hematological malignancies. Parenchymal disease in mycobacterial infection may also appear as patchy nodular areas of consolidation, with or without cavitation.

Other less common radiographic findings include hilar and mediastinal lymphadenopathy, pleural effusion, cavitation, and chest wall invasion.[41]

COMMON CAUSES OF CAP

Gram-positive Bacteria

S. pneumoniae

S. pneumoniae, a gram-positive coccus, is the most common bacterial cause of CAP among patients who require hospitalization.[42] Pneumococcal infections occur predominantly in the winter and early spring and are often associated with prior viral infection. Risk factors include the extremes of age, chronic heart or lung disease, immunosuppression, alcoholism, and prior splenectomy.[43] The characteristic clinical presentation is abrupt in onset, with fever, chills, cough, and pleuritic chest pain. Clinically, the spectrum of pneumococcal pneumonia can vary from a very mild course to a severe complicated pneumonia associated with pulmonary necrosis (cavitation) and pleural effusion often requiring chest tube placement.

The typical radiographic appearance of acute pneumococcal pneumonia consists of a homogenous consolidation that crosses segmental boundaries involving only one lobe (lobar pneumonia). Occasionally, infection is manifested as a spherical focus of consolidation that simulates a mass (round pneumonia). Complications, such as cavitation and pneumatocele formation, are rare. Pleural effusion is common and is seen in up to half of patients.[44] CT seldom adds any clinically relevant information in patients with typical radiographic and clinical findings of pneumococcal pneumonia.

S. aureus

S. aureus is an uncommon cause of CAP, being responsible for about 3% of all cases.[45] *S. aureus* pneumonia has a well-recognized propensity for occurring in infants and elderly individuals, complicating influenza infection. The clinical presentation of staphylococcal pneumonia is changing, and, of particular importance, is the dramatic increase of the incidence of MRSA infections in recent years.

The characteristic pattern of presentation is as a bronchopneumonia (lobular pneumonia) that is bilateral in ~40% of patients. The radiographic manifestations usually consist of bilateral patchy areas of consolidation. Other features are cavitation and pneumatoceles (especially in children) (Fig. 8). Pneumatoceles tend to resolve spontaneously in weeks or a few months following infection. Pleural effusions occur in 30% to 50% of patients; of these, approximately half represent empyemas. Abscesses develop in 15% to 30% of patients.

Gram-negative Bacteria

H. influenzae

H. influenzae is a pleomorphic, nonmotile coccobacillus that accounts for 5% to 20% of CAP in patients in whom an organism can be identified successfully.[46] Factors that predispose to Haemophilus pneumonia include COPD, malignancy, HIV infection, and alcoholism.

The clinical presentation of *H. influenzae* pneumonia is indistinguishable from that of other bacterial pneumonias. It is often associated with a previous history of upper respiratory tract infection followed by onset of high fever, cough, dyspnea, purulent sputum, and pleuritic chest pain.

The typical radiographic appearance of *H. influenzae* pneumonia consists of multilobar involvement with lobar or segmental consolidation and pleural effusion (Fig. 9).[47] In 30% to 50% of patients, the pattern is that of lobar consolidation similar to that of *S. pneumoniae*.[48]

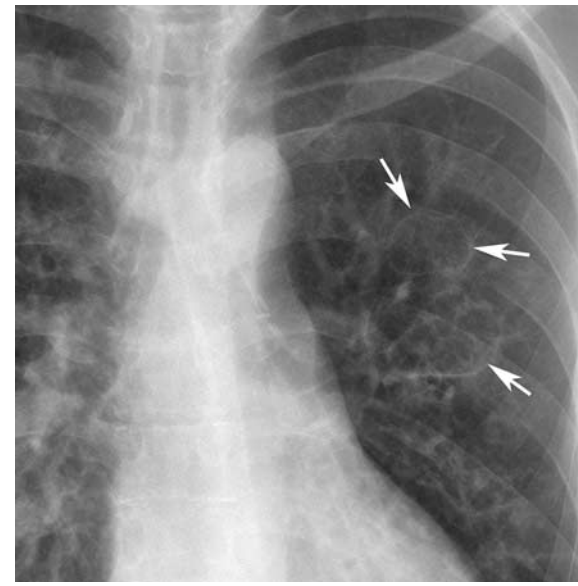

FIGURE 8. Pneumatoceles. Anteroposterior chest radiograph of a 58-year-old man with a previous *Staphylococcus aureus* pneumonia shows multiple sharply defined cysts (pneumatoceles) in the left upper lobe (arrows).

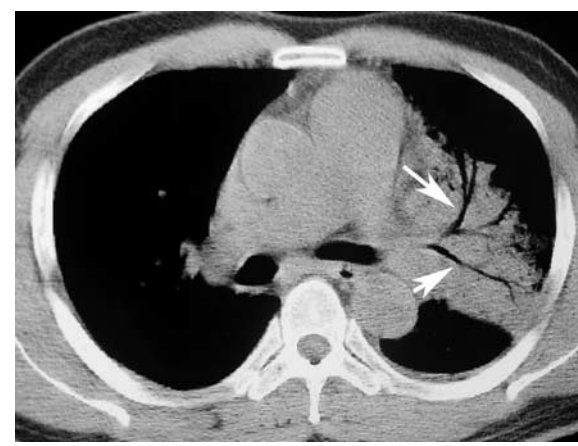

FIGURE 9. Pneumonia. CT of a 53-year-old man shows a focal area of homogenous consolidation in the left upper lobe. Note the presence of air bronchograms within the consolidation (arrows). Sputum culture produced growth of *Haemophilus influenzae*.

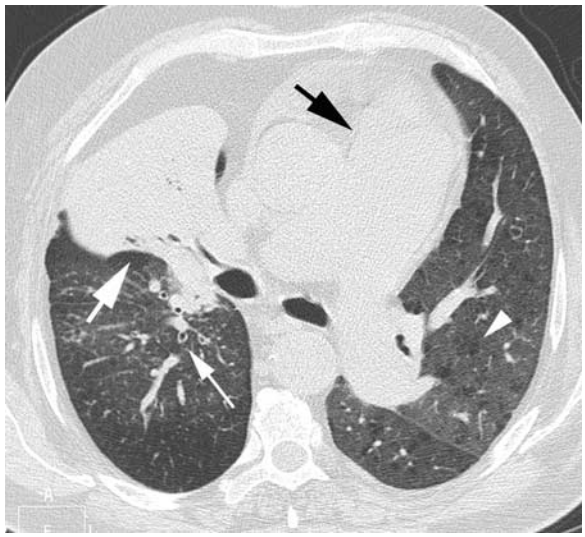

FIGURE 10. Lobar consolidation. HRCT of a 52-year-old man with emphysema shows a homogenous lobar consolidation in the middle lobe (arrow). Note the presence of air bronchograms within the consolidation, thickening of the bronchial walls (thin arrow), and severe pulmonary hypertension (black arrow). Sputum culture produced a heavy growth of *Moraxella catarrhalis*. HRCT indicates high-resolution CT.

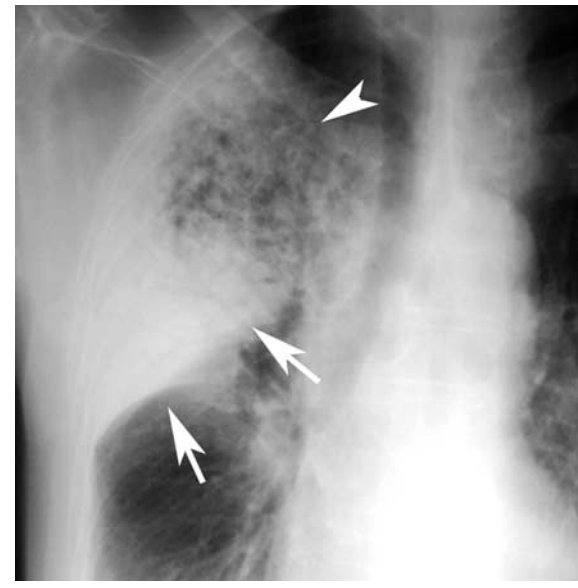

FIGURE 11. Severe pneumonia due to *Klebsiella pneumoniae*. Close-up view of the right upper lobe of a 66-year-old man with *K. pneumoniae* pneumonia shows dense right upper lobe consolidation with areas of necrosis (arrowhead). Note the downward bulging of the minor fissure (arrows).

M. catarrhalis

M. catarrhalis is an intracellular gram-negative coccus now recognized as one of the common respiratory pathogens. *M. catarrhalis* causes pneumonia and acute exacerbation of COPD.[49] *Moraxella* pneumonia is increasingly affecting children, neonates, and elderly individuals. It is currently considered the third most common cause of community-acquired bacterial pneumonia (after *S. pneumoniae* and *H. influenzae*). *M. catarrhalis* in respiratory infections is significantly increased during the late fall through early spring period.

The majority of patients with pneumonia (80% to 90%) have underlying chronic pulmonary disease, and their clinical illness may be difficult to distinguish from exacerbations of lung disease by other causes.[50]

Chest radiographs show bronchopneumonia or lobar pneumonia that usually involves a single lobe (Fig. 10). Interstitial or mixed interstitial and airspace opacities superimposed on preexisting chronic lung disease may also be seen. Pleural effusion and cavitation may occur.[51]

Enterobacteriaceae

Gram-negative bacilli cause 5% to 10% of CAPs. CAP due to gram-negative bacilli is often severe and frequently requires ICU care.[52] Although *Escherichia coli* and *Klebsiella pneumoniae* are the species of aerobic gram-negative bacteria most commonly recognized as a cause of CAP, *Pseudomonas aeruginosa* may occasionally result in CAP.[53] Among Enterobacteriaceae, *E. coli* is the single most frequent cause of CAP.

Community-acquired *Klebsiella* pneumonia, similar to pneumococcal pneumonia, typically presents as a lobar pneumonia with visible air bronchogram.[54] The consolidation usually begins in the periphery of the lung adjacent to the visceral pleura and spreads centripetally via interalveolar pores (pores of Kohn) and small airways and may lead to lobar expansion (bulging fissure sign) (Fig. 11). Abscess formation, pleural effusion, and empyema are commonly seen.

ATYPICAL CAP

The term "atypical pneumonia" was introduced to describe a CAP syndrome distinct from the typical features of acute illness with fever and mucopurulent sputum. The diagnosis was based on Gram stains and culture on agar plates. Initially, the "atypical pneumonia" pathogens comprised *M. pneumoniae*, *Legionella pneumophila*, *Coxiella burnetii*, and *Chlamydophila* spp. Actually, molecular tests help us identify a specific pathogen or help distinguish between bacterial and viral infection.[55–59] Today, when new diagnostic techniques such as direct antigen detection, polymerase chain reaction, and serology (ELISA) have moved beyond the initial diagnostic methods, a debate with regard to the appropriate use of the term "atypical pneumonia" is open.[56]

M. pneumoniae

M. pneumoniae accounts for up to 37% of CAP in persons treated as outpatients and 10% of pneumonia in persons requiring hospitalization.

The radiographic findings in *M. pneumoniae* are variable and, in some cases, closely resemble those seen in viral infections of the LRT. Chest radiograph shows fine linear opacities followed by segmental air-space consolidation.[47] A focal reticulonodular opacification confined to a single lobe is a radiographic pattern that seems to be more closely associated with mycoplasma infection. Lymphadenopathy is uncommon in *M. pneumoniae*, but unilateral hilar lymph node enlargement has been described. CT findings consist of patchy segmental and lobular areas of ground-glass opacity or air-space consolidation, centrilobular nodules, and thickening of the bronchovascular bundles.[34,60]

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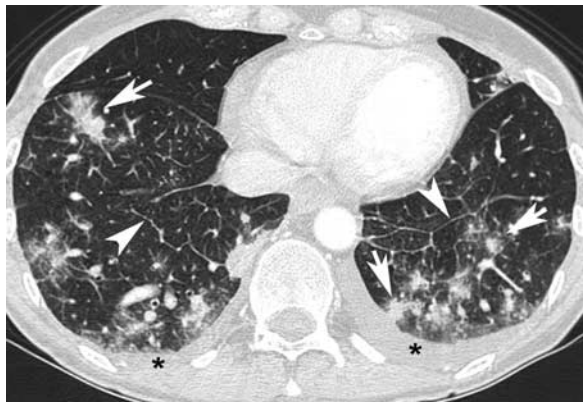

FIGURE 12. *Chlamydia pneumoniae* pneumonia. HRCT of a 45-year-old man shows multiple rounded ground-glass opacities (arrows), mild thickening of the interlobular septa (arrowheads), and bilateral pleural effusion (*). HRCT indicates high-resolution CT.

Chlamydia pneumoniae

C. pneumoniae is among the 3 most common etiologic agents of CAP accounting for 6% to 25% of cases.[61]

Chest radiographs tend to show less extensive abnormalities than are seen with other causes of pneumonia. On CT, *C. pneumoniae* pneumonia demonstrates a wide spectrum of findings consisting of areas of consolidation, bronchovascular bundle thickening, nodules, small pleural effusion, lymphadenopathy, reticular or linear opacities, and airway dilatation (Fig. 12).[62]

L. pneumophila

L. pneumophila is one of the most common causes of severe CAP in immunocompetent hosts. Human infection may occur when Legionella contaminates water systems, such as air conditioners and condensers.[63] Patients with *Legionella* pneumonia usually present with fever, cough, initially dry and later productive, malaise, myalgia, confusion, headaches, and diarrhea.

Radiographic findings include peripheral airspace consolidation similar to that seen in acute *S. pneumoniae* pneumonia. In many cases, the area of consolidation rapidly progresses to occupy all or a large portion of a lobe (lobar pneumonia) or to involve contiguous lobes or to become bilateral.[64] CT findings consist of bilateral, multiple affected segments and peripheral lung consolidation with ground-glass opacity.[65] Pleural effusion may occur in 35% to 63% of cases (Fig. 13).

VIRUSES

Influenza, RSV, and adenovirus usually cause mild, self-limited illness in adults. However, elderly and immunocompromised persons are at increased risk for development of severe pneumonia.

Influenza Type A

Influenza type A is the most important of the respiratory viruses with respect to the morbidity and mortality in the general population. CT findings include ground-glass opacities, consolidation, centrilobular nodules, and branching linear opacities (Fig. 14).[66]

RSV

RSV is a negative-sense, enveloped RNA virus. It is the leading cause of LRT infection in infants and young children. The predominant CT patterns include small centrilobular nodules (50%), airspace consolidation (35%), ground-glass opacities (30%), and bronchial wall thickening (30%) (Fig. 15). The abnormalities are located in the central and peripheral areas of the lungs.[67]

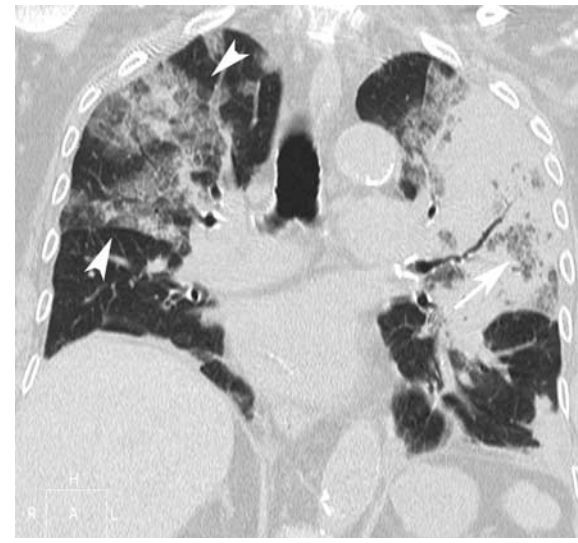

FIGURE 13. *Legionella pneumophila* pneumonia. Coronal CT scan of a 36-year-old man with *L. pneumophila* pneumonia shows ground-glass opacities in the right upper lobe (arrowheads).

Adenovirus

Adenovirus pneumonia in adults appears as bilateral patchy parenchymal opacities on chest radiographs and as bilateral ground-glass opacities with a random distribution with or without consolidation on HRCT.

EMERGING VIRAL DISEASES

Many new or previously unrecognized bacterial, fungal, viral, and parasitic diseases have emerged within the past 2 decades and pose important public health problems for both the developed and developing world. These include

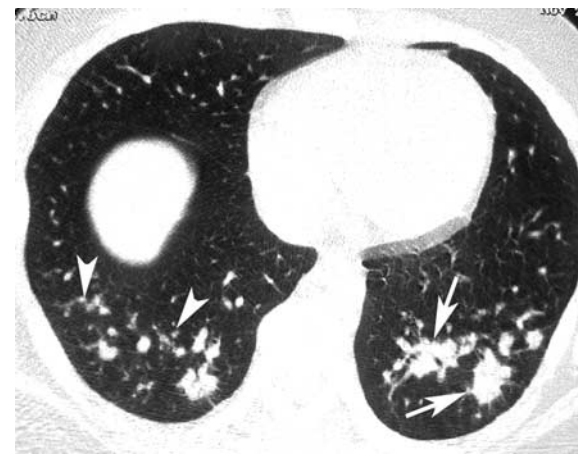

FIGURE 14. Influenza pneumonia. HRCT of a 20-year-old man with *Influenza pneumoniae* pneumonia shows centrilobular branching opacities (tree-in-bud pattern) (arrowheads), ground-glass opacities, and small lobular consolidations (arrows). HRCT indicates high-resolution CT.

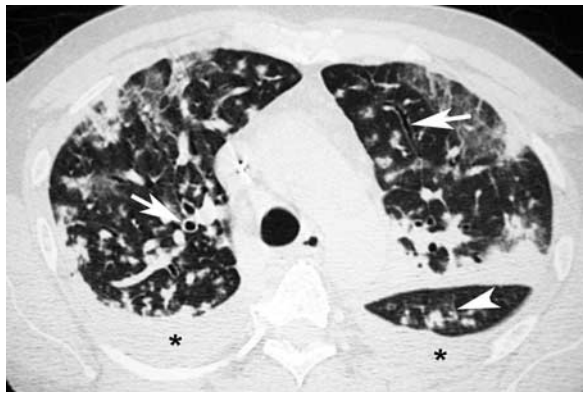

FIGURE 15. RSV pneumonia. HRCT shows bilateral patchy areas of ground-glass opacities and a dense focal area of consolidation in left upper lobe. Note dilatation and thickening of the bronchial walls (arrows). Branching centrilobular opacities (tree-in-bud pattern) in the superior segment of the left lower lobe (arrowhead) and bilateral pleural effusions (*) are also observed. HRCT indicates high-resolution CT; RSV, respiratory syncytial virus.

hantaviruses, Avian influenza viruses, SARS-associated coronavirus, and Swine-origin influenza A (H1N1).[68]

Hantaviruses

Hantaviruses are zoonotic viruses that have reemerged as human pathogens related to increases in interaction between humans and rodent reservoirs.

Hantavirus pulmonary syndrome, commonly referred to as hantavirus disease, is a febrile illness characterized by bilateral interstitial opacities and respiratory compromise, usually requiring supplemental oxygen and clinically resembling acute respiratory disease syndrome.

The chest radiographic features include interstitial edema and diffuse air space disease atypical of adult respiratory distress syndrome (Fig. 16).

SARS

SARS, is a recently recognized febrile severe lower respiratory illness that is caused by infection with a novel coronavirus, SARS-associated coronavirus.

The most common imaging findings of SARS patients at presentation are unilateral or bilateral ground-glass opacities or focal unilateral or bilateral areas of consolidation (Fig. 17). CT findings include ground-glass opacification, sometimes with consolidation, and interlobular septal and intralobular interstitial thickening.

MERS

MERS is a viral disease caused by a coronavirus (MERS-CoV), with most of the infections believed to have originated in Saudi Arabia and the Middle East. Most patients develop a severe acute respiratory illness, with symptoms of cough, fever, and dyspnea, with a high case-fatality rate of 30% to 40%.

Chest radiography may reveal pulmonary opacities and consolidation, with a peripheral predominance in the mid and lower lung zones in the initial stages of the illness. As the disease progresses, parenchymal abnormalities may spread to the central areas and become diffuse. Within the first week of the disease, CT may depict ground-glass opacities, consolidation, interlobular thickening, and pleural effusion. During the subsequent weeks, other findings may be present, such as centrilobular

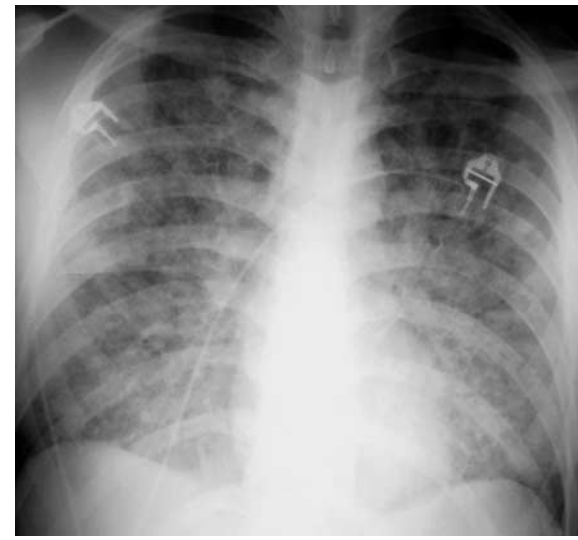

FIGURE 16. Hantavirus pulmonary syndrome. Chest radiograph of a 42-year-old woman shows extensive bilateral consolidation with relative sparing of the peripheral regions and lung bases. The patient presented with respiratory failure and developed acute respiratory distress syndrome. The infection was presumably related to contact with deer mice.

nodules, a "crazy-paving" pattern, obliterative bronchiolitis, peribronchial air trapping, and organizing pneumonia.[69]

Swine Influenza A (H1N1)

In late March 2009, an outbreak of a respiratory illness, later proved to be caused by novel swine-origin

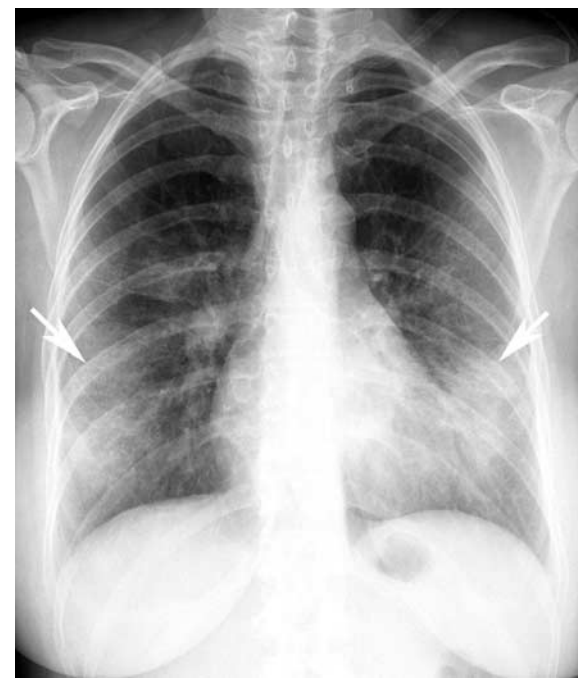

FIGURE 17. SARS. Chest radiograph of a 48-year-old man with SARS coronavirus pneumonia shows bilateral ground-glass opacities in both lower lungs (arrows). SARS indicates severe acute respiratory syndrome.

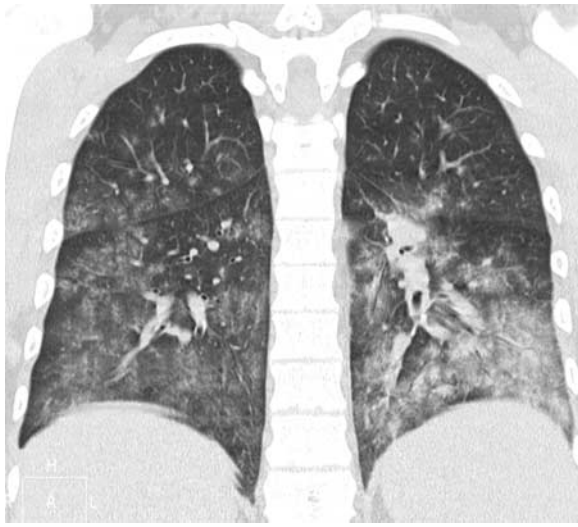

FIGURE 18. Severe acute H1N1 pneumonia. HRCT of a 48-year-old man with H1N1 pneumonia shows extensive bilateral ground-glass opacities. HRCT indicates high-resolution CT.

influenza A (H1N1) virus (S-OIV), was identified in Mexico, causing severe illness.[70] Actually, its virulence is not greater than that observed with seasonal influenza. CT findings consist of unilateral or bilateral ground-glass opacities with or without associated focal or multifocal areas of consolidation with a predominant peribronchovascular and subpleural distribution resembling organizing pneumonia (Fig. 18).[71,72]

FUNGUS

Fungi involved in pulmonary infections are either pathogenic fungi, which can infect any host, or saprophytic fungi, which infect only immunocompromised hosts.[73] Pathogenic fungi include coccidioidomycosis, blastomycosis, and histoplasmosis. Saprophytes include Pneumocystis, Candidiasis, Mucormycosis, and Aspergillosis. Pulmonary fungal infections may be difficult to diagnose, and a definitive diagnosis of pulmonary fungal infections is made by isolating the fungus from tissue specimen.

Cryptococcosis

Cryptococcosis is caused by inhaling spores of *Cryptococcus neoformans*, a fungus of worldwide distribution, which is found in soil and in bird droppings. Many patients have no symptoms, and the pulmonary lesions heal spontaneously. The most typical radiographic manifestation consists of pulmonary masses, homogenous segmental or lobar opacifications, and miliary, reticular, or reticulonodular interstitial patterns (Fig. 19).[74] *Cryptococcus gattii* is an endemic fungus causing pulmonary or central nervous system disease, typically in immunocompetent hosts.[75] Pulmonary manifestations include multifocal airspace disease, solitary nodules, pleural effusions, endobronchial lesions, and multiple cavitary nodules.[76]

Coccidioidomycosis

Coccidioidomycosis is caused by *Coccidioides immitis*, a fungus which is found in soil in arid regions of the southwestern United States, northern Mexico, and in the semiarid northeastern region of Brazil.[77] In primary coccidioidomycosis, unifocal or multifocal homogeneous opacities, resembling community-acquired bacterial pneumonia, may be seen. Cavitation and hilar/mediastinal adenopathy may be seen with ~20% of these lesions. Disseminated coccidioidomycosis may cause miliary nodules.[77]

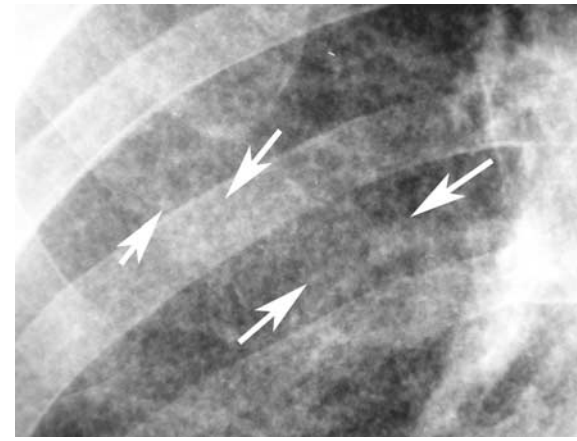

FIGURE 19. Cryptococcosis. Magnified view of a chest radiograph shows profuse ill-defined 1- to 2-mm nodules scattered throughout the lung (arrows). The patient was a 38-year-old man with AIDS, high-grade fever, and shortness of breath.

Histoplasmosis

Histoplasma capsulatum is a fungus found in moist soil and in bird or bat excreta in many parts of the world, but human infection is endemic in areas such as the Ohio-Missisipi and St. Lawrence River valleys (North America). Radiographic findings consist of diffuse nodular opacities of 3 mm or less in diameter, nodules > 3 mm in diameter, small linear opacities, and focal or patchy areas of consolidation.[73]

North American Blastomycosis

North American blastomycosis is due to *Blastomyces dermatiditis*. Pulmonary infection may be accompanied by infection of the skin, bones, and genitourinary tract. The chest radiograph reveals homogenous unifocal or multifocal segmental or lobar opacification indistinguishable from acute pneumonia. Cavitation occurs in ~15% of cases. Blastomycosis may cause miliary nodules particularly in immunocompromised patients.[77]

P. jiroveci

P. jiroveci (formerly *Pneumocystis carinii*) is a unique opportunistic fungal pathogen that causes pneumonia in immunocompromised individuals such as patients with AIDS (CD4 counts <100 cells/mm^3), patients with organ transplants, and patients with hematological or solid organ malignancies who are undergoing chemotherapy, and in patients receiving immune-suppressive treatments, particularly systemic corticosteroids.

Aspergillosis

Aspergillosis is a mycotic disease caused by *Aspergillus* species, usually *Aspergillus fumigatus*, a ubiquitous soil fungus. The histologic, clinical, and radiologic manifestations of pulmonary aspergillosis are determined by the number and virulence of the organisms and by the patient's immune response.

The pulmonary manifestations of aspergillosis can be divided into 5 categories: (1) saprophytic aspergillosis (aspergilloma), (2) hypersensitivity reaction (allergic bronchopulmonary aspergillosis [ABPA]), (3) semi-invasive (chronic necrotizing) aspergillosis, (4) airway invasive aspergillosis, and (5) angioinvasive aspergillosis.[78]

Saprophytic Aspergillosis (Aspergilloma)

Saprophytic aspergillosis (aspergilloma) is characterized by *Aspergillus* infection without tissue invasion. It typically leads to conglomeration of intertwined fungal hyphae admixed with mucus and cellular debris within a preexistent pulmonary cavity or ectatic bronchus.

Radiographically, mycetomas are characterized by the presence of a solid round or oval mass of soft tissue density within a lung cavity. Typically, the mass is separated from the wall of the cavity by an air space of variable size and shape, resulting in the "air-crescent "sign.

Hypersensitivity Reaction (ABPA)

ABPA is seen most commonly in patients with long-standing bronchial asthma. This form of aspergillosis is characterized pathologically by the presence of plugs of inspissated mucus containing *Aspergillus* organisms and eosinophils. This results in bronchial dilatation typically involving the segmental and subsegmental bronchi.

Radiologic manifestations include homogeneous, tubular, "finger-in-glove" opacities in a bronchial distribution, usually involving predominantly or exclusively the upper lobes (Fig. 20). The CT findings of ABPA consist principally of mucoid impaction and bronchiectasis involving predominantly the segmental and subsegmental bronchi of the upper lobes.

Semi-invasive (Chronic Necrotizing) Aspergillosis

In mildly immunocompromised patients such as those with chronic illness, diabetes mellitus, malnutrition, alcoholism, advanced age, prolonged corticosteroid administration,

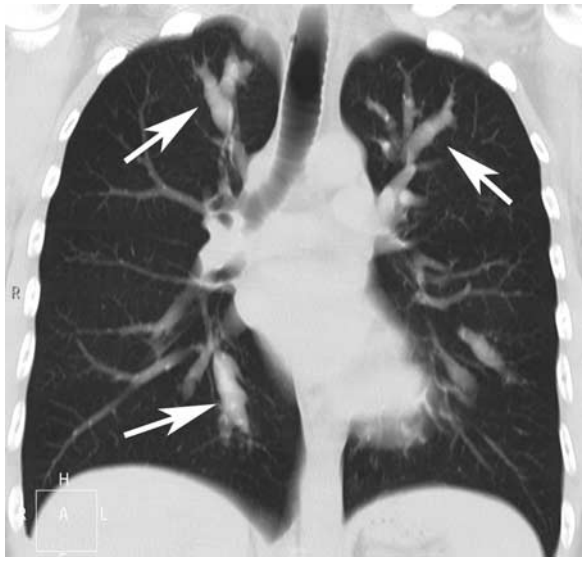

FIGURE 20. Allergic bronchopulmonary aspergillosis. Coronal HRCT of a 46-year-old asthmatic man with chronic cough, fever, and dyspnea shows bilateral central bronchiectasis with mucus plugging (arrows). HRCT indicates high-resolution CT.

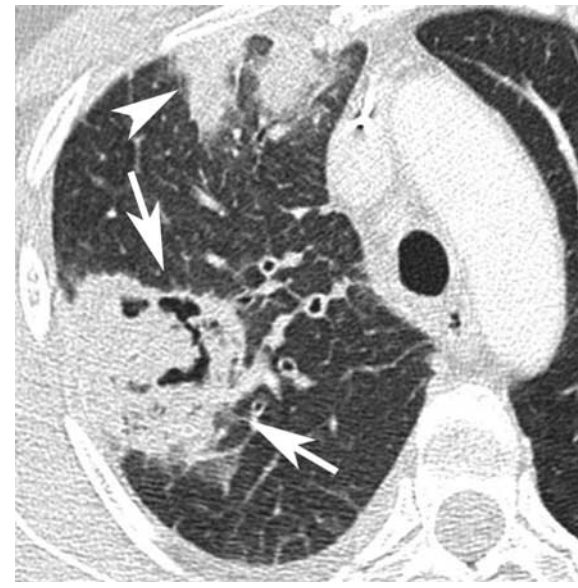

FIGURE 21. Semi-invasive aspergillosis. HRCT of a 68-year-old man with chronic bronchitis and recurrent episodes of mild hemoptysis shows a cavitary consolidation in the right upper lobe showing a characteristic "air crescent sign" (arrows). Focal areas of consolidation are also visible (arrowhead). HRCT indicates high-resolution CT.

and chronic obstructive disease, there has been described an aspergillosis form named semi-invasive or chronic necrotizing aspergillosis.

Radiologically, the appearances are variable, including unilateral or bilateral segmental areas of consolidation with or without cavitation and/or adjacent pleural thickening, and multiple rounded poorly marginated areas of homogenous opacification with or without air bronchograms. With time, the margins may become more discreet, and the lesions resemble masses. They may cavitate with the formation of an air crescent (Fig. 21).[79] The findings progress slowly over months or years.

Airway Invasive Aspergillosis

Airway invasive aspergillosis is characterized histologically by the presence of *Aspergillus* organisms deep into the airway basement membrane. It occurs most commonly in immunocompromised neutropenic patients and in patients with AIDS. Bronchiolitis is characterized on high-resolution CT by the presence of centrilobular nodules and branching linear or nodular opacities giving an appearance resembling a "tree-in-bud." The radiologic manifestations of *Aspergillus* bronchopneumonia are indistinguishable from those of bronchopneumonias caused by other microorganisms.

Angioinvasive Aspergillosis

Angioinvasive aspergillosis occurs almost exclusively in immunocompromised patients with a severe neutropenia. However, there has been a substantial increase in the number of patients at risk of developing invasive aspergillosis, for many reasons, including the development of new intensive chemotherapy regimens for solid tumors, difficult-to-treat lymphoma, myeloma, and resistant leukemia, as well as an increase in the number of solid organ transplantations and increased use of immunosuppressive regimens for other autoimmune diseases.

The characteristic CT findings consist of nodules surrounded by a halo of ground-glass attenuation (halo sign) (Fig. 5) or pleural-based wedge-shaped areas of consolidation. These findings correspond to hemorrhagic infarcts.

A similar appearance has been described in a number of other conditions including infection by Mucorales, Candida, herpes simplex, and CMV, Wegener granulomatosis, Kaposi sarcoma, and hemorrhagic metastases.[80]

COMPLICATIONS OF CAP

Although most CAPs are uncomplicated, the severity of these infections is related to the immune function of the host, the presence of underlying comorbidities, the inherent pathogenicity of the organism, and the evidence of mixed etiologies (2 bacteria, a bacterium plus a virus, and a bacterium plus an atypical pathogen). Bacterial coinfection in cases of influenza virus infection is a known cause for complications, including death. Postmortem lung examination of 77 fatal cases of 2009 H1N1 influenza identified bacterial pathogens in 22 of the cases and included *S. pneumoniae*, *Streptococcus pyogenes*, and *S. aureus*.

CARDIOVASCULAR COMPLICATIONS

Heart failure is one cardiovascular complication that seems to be highly prevalent in patients with CAP.[81] Acute infections can result in reduced myocardial function (eg, septic shock), increased oxygen consumption, tachycardia, and circulatory problems in elderly people and young patients.[81–83] Overall, 3.4%, 5.5%, and 31% of elderly patients admitted to hospital for pneumonia developed heart failure within 90 days, 1 year, and beyond 5 years, respectively.

PLEUROPULMONARY COMPLICATIONS

Bronchopleural Fistula (BPF)

A BPF, either central or peripheral, is defined as a direct pathway between the bronchial tree or lung parenchyma and the pleural space. Peripheral BPFs are affiliated with necrotizing pneumonia, trauma, lung surgery, and malignancy.[84] Although chest radiography may be useful for detecting a pneumothorax and pleural changes, multidetector CT is the noninvasive method of choice for evaluating the presence, location, and size of a BPF (Fig. 22).

Lung Abscess, Necrotizing Pneumonia, and Pulmonary Gangrene

Lung abscess is defined as an inflammatory mass within lung parenchyma, the central part of which has undergone purulent liquefaction necrosis.[85] Extensive pulmonary necrosis causes lung abscesses and bronchopulmonary fistulas in 30% to 40% of patients with anaerobic pleuropulmonary infections. Common causes of lung abscess include anaerobic bacteria (most commonly *Fusobacterium nucleatum* and *Bacteroides* species), *S. aureus*, *P. aeruginosa*, and *K. pneumoniae*.[86] Air-fluid levels are seen in ~70% of cases and adjacent parenchymal consolidation in 50%.[87] Lung abscesses may be seen anywhere in the lungs but are most common in the posterior segment of an upper lobe or the superior segment of a lower lobe.

Necrotizing pneumonia and pulmonary gangrene can be sequelae of severe CAP or pulmonary tuberculosis. Lung abscesses caused by *S. aureus*, *K. pneumoniae*, and *P. aeruginosa* are associated with higher mortality. Recently, rapid and severe pleuropulmonary complications have been described in community-acquired MRSA positive for Panton-Valentine leukocidin.[88] Radiographically, pulmonary gangrene begins as a lobar consolidation, usually in the upper lobes, followed by development of lucencies, and coalescence of the lucencies to form a cavity (Fig. 23). A "mass within a mass" or "air crescent sign" may be present.[89]

Pneumatocele is a thin-walled, gas-filled space that usually develops in association with infection. It presumably results from drainage of a focus of necrotic lung parenchyma followed by check-valve obstruction of the airway

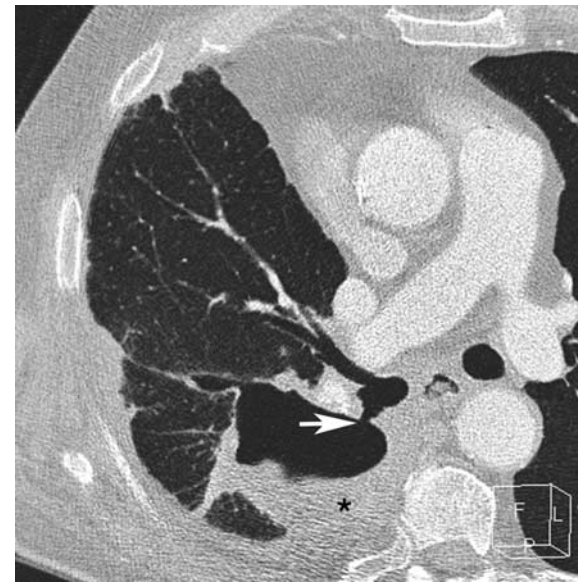

FIGURE 22. Bronchopleural fistula. Enhanced CT shows a bronchopleural fistula (arrow) outlined by the adjacent parenchymal consolidation and empyema (*).

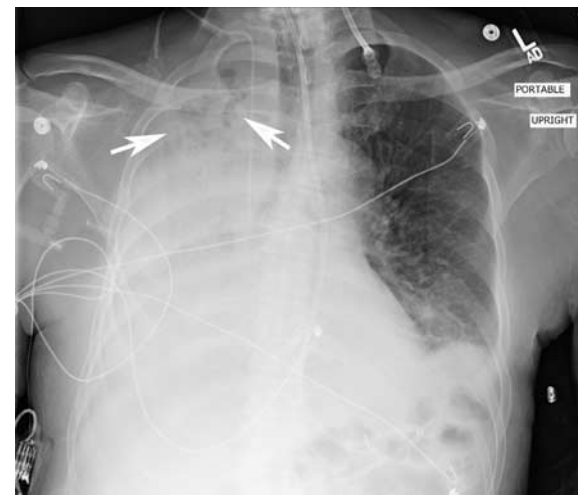

FIGURE 23. Bronchopneumonia due to community-acquired MRSA pneumonia. Chest radiograph of an 88-year-old man shows an extensive opaque right hemithorax. Irregular air-filled small cavities (arrows) are seen in the right upper lobe (arrows).

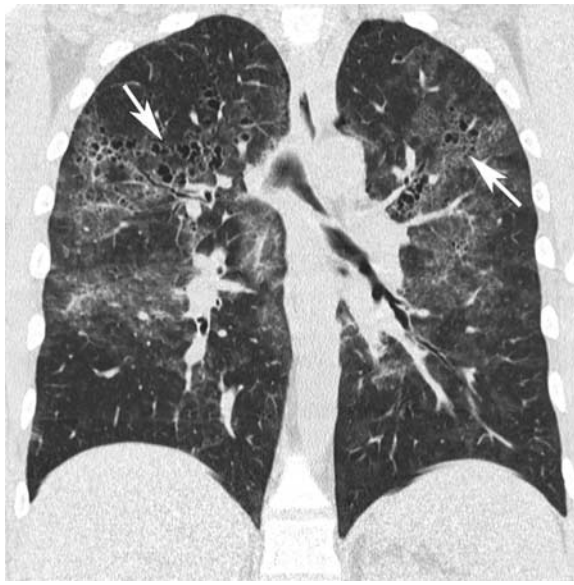

FIGURE 24. *Pneumocystis jirovecii* pneumonia. Coronal CT of a 36-year-old man with acquired immunodeficiency syndrome shows extensive bilateral ground-glass opacities. Numerous bilateral thin-walled cystic lesions (pneumatoceles) were seen at the level of the upper lobes (arrows).

subtending it, enabling air to enter the parenchymal space during inspiration but preventing its egress during expiration. The complication is caused most often by *S. aureus* in infants and children and *P. jiroveci* in patients who have AIDS (Fig. 24).[3]

Empyema

Pleural effusions develop in 20% to 60% of patients with acute bacterial pneumonia. Complicated parapneumonic effusions may progress to intrapleural loculation and empyema formation (Fig. 25). Contrast-enhanced CT appears to be sensitive to chest wall changes in patients with empyema.[90] Parietal pleural thickening at contrast-enhanced CT almost always indicates the presence of pleural exudates. Abnormally high attenuation in the extrapleural tissues can be expected to accompany exudative pleural effusion, particularly empyema, but not transudative effusion. Ultrasound is also useful for determining free-flowing fluid collections versus septated fluid collections.[91] The pathogens traditionally associated with empyema are *S. pneumoniae*, *S. pyogenes*, and *S. aureus*.

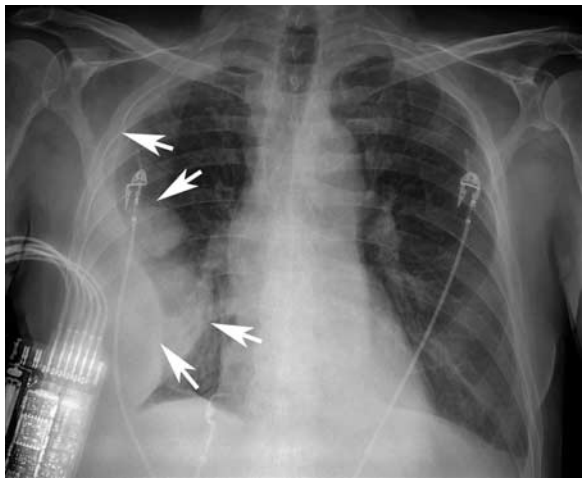

FIGURE 25. Empyema due to *Staphylococcus aureus*. Posteroanterior chest radiograph of a 67-year-old man shows large multiloculated right pleural effusion (arrows). There is no radiologic evidence of septic embolism.

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