7 Pulmonary Infections: Imaging with MDCT

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7.1 Introduction

Pneumonia is one of the major infectious diseases responsible for significant morbidity and mortality throughout the world. It is the most prevalent community-acquired infection and the second most common nosocomial infectious disorder. Despite the availability of antimicrobial agents, pneumonias constitute the sixth most common cause of death and are the number one cause of death from infections (Fraser et al. 1994; Moine et al. 1994; Lynch 2001; Levy et al. 1988). Pneumonias may develop into a life-threatening condition especially in immunocompromised patients, in children, and in the elderly population.

Imaging plays a crucial role in the detection and management of patients with pneumonia. Chest radiography is the imaging technique of choice in evaluating patients with suspected pneumonia because of its low radiation dose, low cost, and wide accessibility. In daily practice, radiographs are used to confirm the clinical diagnosis of pneumonia, characterize the extent and severity of disease, search for complications, monitor the response to therapy, and examine for possible alternative or additional diagnoses (Katz and Leung 1999); however, an increasing number of patients undergo thin-section CT of the chest, when there is a high clinical suspicion for pneumonia in the presence of abnormal or questionable radiographic findings (Schaefer-Prokop et al. 2000). The introduction of multi-detector row CT (MDCT) scanners in 1998 incrementally improved the capability of CT to acquire volumetric data of the lungs with unprecedented spatial resolution. Recently introduced 16-row MDCT scanners are able to acquire an isotropic volumetric data set of the entire chest during a single breathhold, thereby allowing high-quality reconstructed images in any desired plane. In the following chapters the impact of MDCT imaging for the diagnosis of infectious lung diseases will be evaluated.

Franquet and colleagues (2001) have shown that a combination of radiologic pattern recognition with knowledge of the clinical setting is the best approach to the pulmonary infectious processes; thus, the differentiation between community-acquired pneumonia, nosocomial pneumonia, and pneumonia in the immunocompromised patient is of practical interest. Although the spectrum of offending organisms (Table 7.1) differ between these disorders, considerable overlap exists between their radiologic features.

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7.2 Spread of Infection and Patterns of Imaging

By far the most common route of infection occurs via the tracheobronchial tree by aspiration or inhalation of microorganisms. Traditionally, pneumonia

Table 7.1. Overview of organisms potentially causing infectious lung diseases

Bacteria
Aerobic bacteria: gram positive
Streptococcus pneumoniae
Staphylococcus aureus
Bacillus anthracis
Aerobic bacteria: gram negative
Klebsiella, Enterobacter, Serratia species
Escherichia coli
Haemophilus influenzae
Pseudomonas aeruginosa
Legionellaceae
Anaerobic bacteria
Mycobacteria
Actinomycosis
Mycoplasma pneumoniae
Chlamydia pneumonia, C. psittaci
Rickettsiae
Fungi
Histoplasmosis
Coccidiomycosis
Blastomycosis
Cryptococcosis
Aspergillosis
Mucormycosis
Nocardiosis
Viruses
Respiratory syncytial virus
Adenovirus
Varicella zoster virus
Protozoa
Pneumocystis carinii
Helminths
Strongyloides stercoralis

acquired that way has been divided into air-space (lobar) pneumonia, bronchopneumonia, and interstitial pneumonia (Fraser et al. 1994). Infection by the way of the pulmonary vasculature often occurs in conjunction with extrapulmonary infection; particularly in tuberculous or fungal disease, the primary focus of infection is the lung itself. Because of preferential gravity-related blood flow to the dependent portions of the lung, hematogenously spread infection tends to show considerable basal predominance. A nodular appearance of the individual foci of infection is typical.

Direct spread across the chest wall or diaphragm or from the mediastinum may occur in association with penetrating thoracic wounds or by extension of infection from an extrapulmonary source, such as a subphrenic abscess. In these cases, pulmonary disease usually is localized to an area contiguous with the extrapulmonary source of infection and often takes the form of an abscess (Fraser et al. 1994).

7.2.1 Localized Air-Space Disease

Lobar pneumonia is characterized by homogeneous consolidation of lung parenchyma with well-defined borders, and does not typically respect segmental borders. Air bronchograms are present, and usually the lung volume is normal with the exception of gram-negative pneumonias where volume loss is frequently seen. The typical features may be altered in the presence of underlying disease. For example, the inflammatory exudate may not fill emphysematous spaces, resulting in a sponge-like appearance of the consolidated lung. Frequently, lobar pneumonias are related to bacterial organisms such as *Streptococcus pneumoniae* (Fig. 7.1), most gram-negative bacilli, and *Legionella pneumophila*. Cavitation is rare in pneumococcal infections but typical in gram-negative pneumonias (Gharib and Stern 2001).

Bronchopneumonia (Lobular pneumonia) is characterized by the absence of air bronchograms, a patchy, segmental distribution, since the infection usually occurs at multiple foci at the same time, and volume loss. Typically, lobular boundaries are respected resulting in involvement of secondary pulmonary lobules while sparing adjacent lobules. Bronchopneumonia is exemplified by infection by *Staphylococcus aureus*, many gram-negative bacteria (e.g., *Haemophilus influenzae)*, *Mycoplasma pneumoniae*, and fungi (Reittner et al. 2003). In *Pseu-*

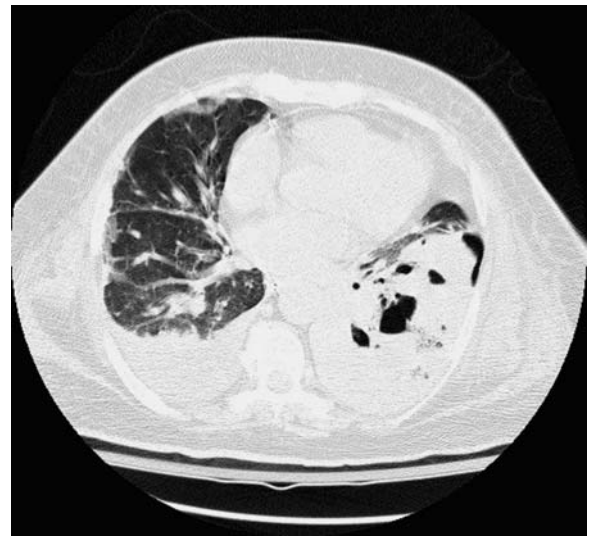


Fig. 7.1. Streptococcal pneumonia in a 61-year-old woman. Chest CT scan (collimation 4×1.25 mm) shows consolidation of left lower lobe with associated areas of cavitation

domonas aeruginosa pneumonia, bilateral disease, lower lobe predominance, and abscess formation are also common. Resolution of the infiltrates may take several weeks, particularly in *Staphylococcus aureus* infections and *Mycoplasma pneumoniae*.

In addition, rounded pneumonia represents an infection process that does not have a lobar pattern but rather presents as a rounded density that does not follow anatomic landmarks. Rounded or nodular forms of pneumonia are usually due to pneumococcal, *Legionella*, or fungal infections. This pattern is more common in children (Slone et al. 1999).

The term "atypical pneumonia" was originally applied to pneumonias with atypical clinical, laboratory, and/or radiographic features. It was primarily used to describe atypical bacterial infections. Besides numerous viruses, the main bacterial pathogens causing atypical pneumonias are *Mycoplasma pneumoniae*, two chlamydial species, *Chlamydia pneumoniae* and *Chlamydia psittaci* (Fig. 7.2), one rickettsia, *Coxiella burnetti*, and several *Legionella* species (Saikku 1997). In the group of "atypical" bacterial pneumonias, *Legionella pneumophila*, but also *Mycoplasma pneumoniae* and *Chlamydia* infections, demonstrate a radiographic pattern of air-space disease indistinguishable from that of other typical bacterial infections. It is important to know that unilateral or bilateral air-space disease may be caused by a so-called atypical organism.

Localized air-space disease may be seen as a manifestation of *Mycobacterium tuberculosis.* The typical radiographic features of postprimary disease in the adult consist of patchy areas of ill-defined opacities in the upper lobes, with or without cavitation (Fig. 7.3). In primary tuberculosis, parenchymal consolidation, with or without hilar and/or mediastinal lymphadenopathy, may be present and can overlap to some degree. In some cases, differentiation of primary and post-primary disease may be difficult. The tree-in-bud pattern has become a popular descriptive term for various diseases of the peripheral airways in which mucous plugging, bronchial dilatation, and wall thickening are present. It has primarily been used as a descriptive term for abnormalities found on CT scans of the lung in patients with endobronchial

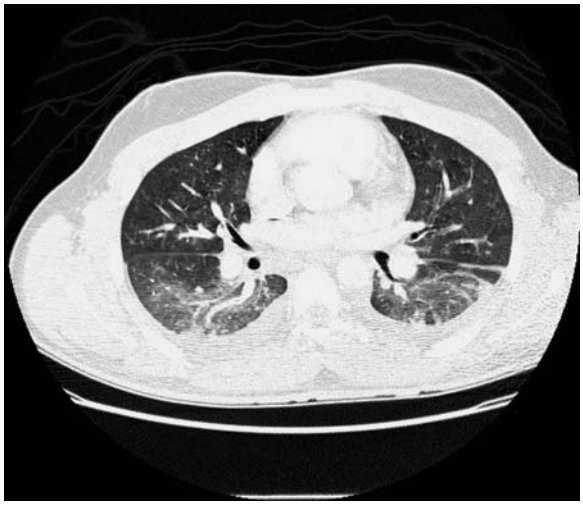
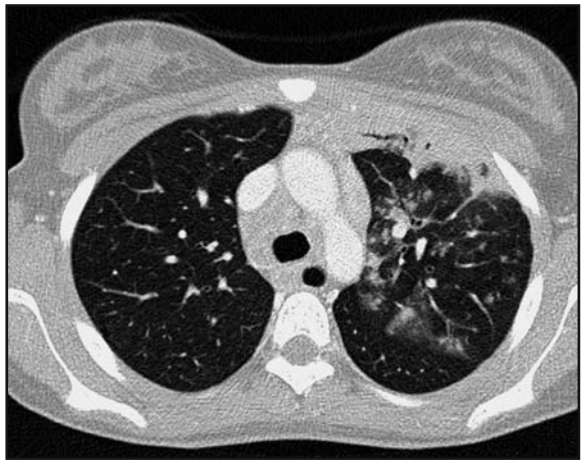


Fig. 7.2. Psittacosis in a 19-year-old man. Chest CT scan (collimation 8×1.25 mm) shows diffuse, bilateral ground-glass opacities predominating in lower lobes and associated with small pleural effusions



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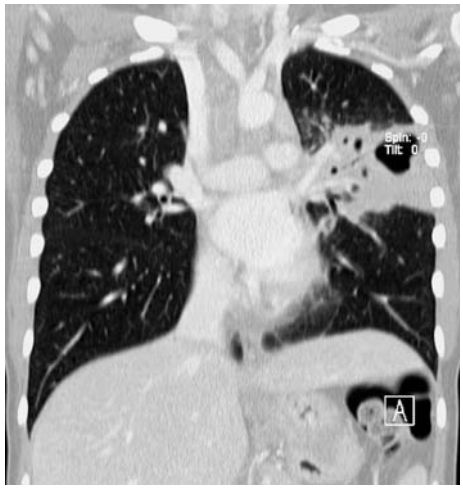


b

Fig. 7.3a, b. Tuberculosis in a 14-year-old girl. **a** Chest CT scan (collimation 12×0.75 mm) shows areas of consolidation in left upper lobe associated with centrilobular nodules in the lung periphery (*arrows*). Mediastinal lymphadenopathy in the right paratracheal and aortopulmonary window stations is also present. **b** Coronal reformatted image shows consolidation and associated cavitation

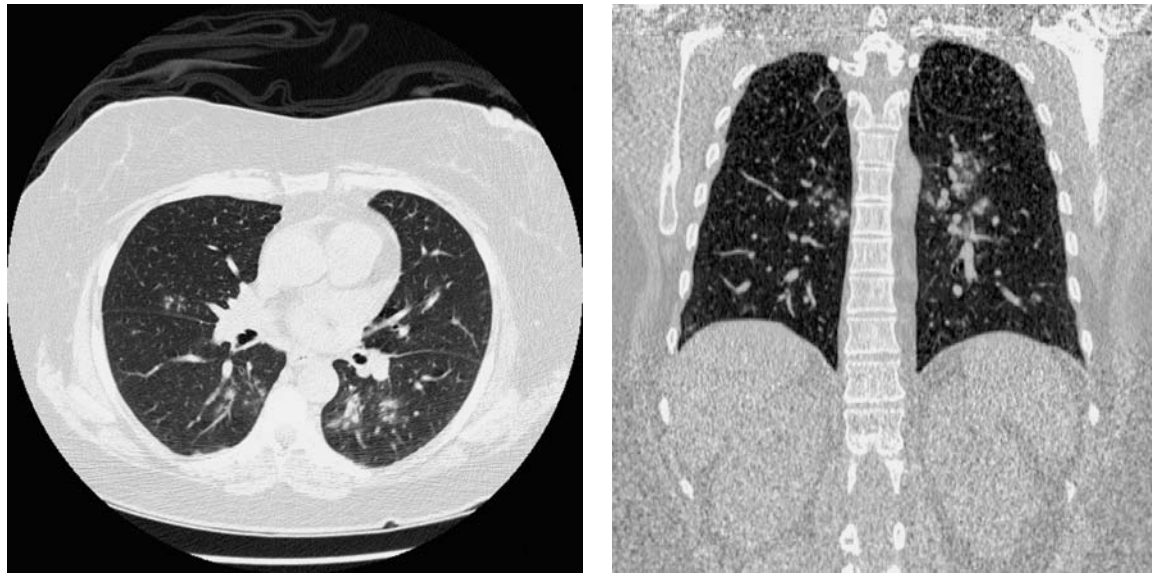
spread of *Mycobacterium tuberculosis*; however, any infectious organism, including bacterial, mycobacterial, viral, parasitic, and fungal agents, can involve the small airways and cause a tree-in-bud pattern (Eisenhuber 2002).

Invasive pulmonary aspergillosis (IPA) and mucormycosis are fungal pneumonias seen almost exclusively in immunocompromised patients. Arising from a nodular or patchy infiltrate. They progress to homogeneous peripheral wedge-shaped (sub)segmental or lobar consolidation, which represents infarction due to infiltration of pulmonary arteries by the fungus. Finally, air-space disease may be seen in viral and protozoal infections. In patients with CAP, one should be aware that the influenza virus may cause segmental air-space disease which may simulate bacterial infections. In patients with mild immunosuppression, segmental alveolar infiltrates may be caused by *Pneumocystis carinii* pneumonia.

7.2.2 Interstitial Pneumonia

Interstitial pneumonia reveals two imaging patterns. Firstly, the inflammatory process can be localized in airway walls and alveolar septa without any air-space disease. Secondly, in a more acute setting the inflammatory reaction may progress to air-space disease due to alveolar damage and proteinaceous exudate within air-spaces leading to diffuse areas of air-space opacification; thus, although primarily an interstitial process, disease of this variety typically evolves to affect adjacent air-spaces (Fraser et al. 1994). Typically, interstitial pneumonias are caused by viruses but may also be seen with organisms such as *Pneumocystis carinii* and *Mycoplasma pneumoniae*.

Diffuse bilateral lung disease is rarely seen in bacterial pneumonias. Diffuse lung disease is also rare in patients with CAP; however, if identified in otherwise healthy people, it is most commonly caused by viral pneumonias such as the respiratory syncytial virus (RSV; Fig. 7.4). In *Herpes varicellae* (*Varicella zoster*) pneumonia, diffusely distributed and well-defined patchy or nodular densities are the characteristic features. In immunocompromised patients, particularly in organ-transplant recipients, a symmetric, diffuse bilateral linear, or nodular pattern, potentially combined with patchy alveolar densities, is most commonly caused by cytomegalovirus (CMV) infection. *Pneumocystis carinii* pneumonia may resemble CMV pneumonia and begin with a discrete increase in pulmonary parenchymal density, which progresses to a reticular or mixed reticular-alveolar pattern, and finally to diffuse air-space consolidation. A diffuse interstitial nodular pattern, with nodules ranging from 3 to 5 mm in size, is typically seen in pneumonia caused by *Candida.* Diffusely distributed micronodules (miliary disease) indicate the hematogenous spread of a mycobacterial or fungal organism.



a **b**

Fig. 7.4a, b. Respiratory syncytial virus (RSV) infection in a 56-year-old woman after bone marrow transplantation. **a** Chest CT scan (collimation 16×1.25 mm) shows multiple centrilobular nodules located predominantly in both lower lobes. **b** Coronal reformatted image depicts craniocaudal distribution of centrilobular nodules

7.2.3 Nodular Lesions

Nodular lesions attributed to pulmonary infections are most often seen in nosocomial pneumonias and in immunocompromised patients. They may be caused by bacteria such as *Nocardia asteroides* (Fig. 7.5) and *Mycobacterium tuberculosis,* septic emboli, and fungi. *Nocardia asteroides* causes single or nodular infiltrates with or without cavitation. Invasive pulmonary aspergillosis, *Mucor*, and *Cryptococcus neoformans* may present with single or multiple nodular infiltrates, which often progress to wedge-shaped areas of consolidation. Cavitation (the "air-crescent sign") is common later in the course of the disease. In the appropriate clinical setting MDCT may aid in the diagnosis of IPA by demonstrating the so-called halo sign.

7.3 Clinical Setting of Patients

The immune status of the individual determines the type, severity, and susceptibility to infection; thus, it is useful to consider cases of pulmonary infections in three clinical and environmental groups: community acquired, nosocomial, and in the immunocompromised patient, since they differ not only in the types of offending organisms but also in their potentially different etiology, clinical features, diagnostic approaches, and therapeutic strategies.

7.3.1 Community-Acquired Pneumonia

Community-acquired pneumonia (CAP) is a major health care and economic problem. Hospital admission rates of CAP episodes vary from 22 to 51% (Niedermans et al. 1998). The spectrum of causative organisms includes gram-positive bacteria such as *Streptococcus pneumoniae (Pneumococcus)*, *Haemophilus influenzae*, and *Staphylococcus aureus,* atypical organisms such as *Mycoplasma pneumoniae, Chlamydia pneumoniae,* or *Legionella pneumophila,* and viral agents such as the influenza A virus and the RSV. It appears from the literature that the spectrum of organisms varies according to a patient's health and socioeconomic status as well as to the affected individual's temporal, geographic, and diagnostic factors (Fraser et al. 1994). Healthy individuals are most likely to contract *Mycoplasma pneumonia* or a mild form of *Pneumococcus pneumonia*. Debilitated patients, alcoholics, and chronically ill persons, however, more often present with severe pneumococcal pneumonia, or infections caused by *Staphylococcus aureus, Haemophilus influenzae,* or other gram-negative bacilli. *Legionella pneumophila* and *Chlamydia* infections are more common in patients with some forms of mild immunologic compromise. In

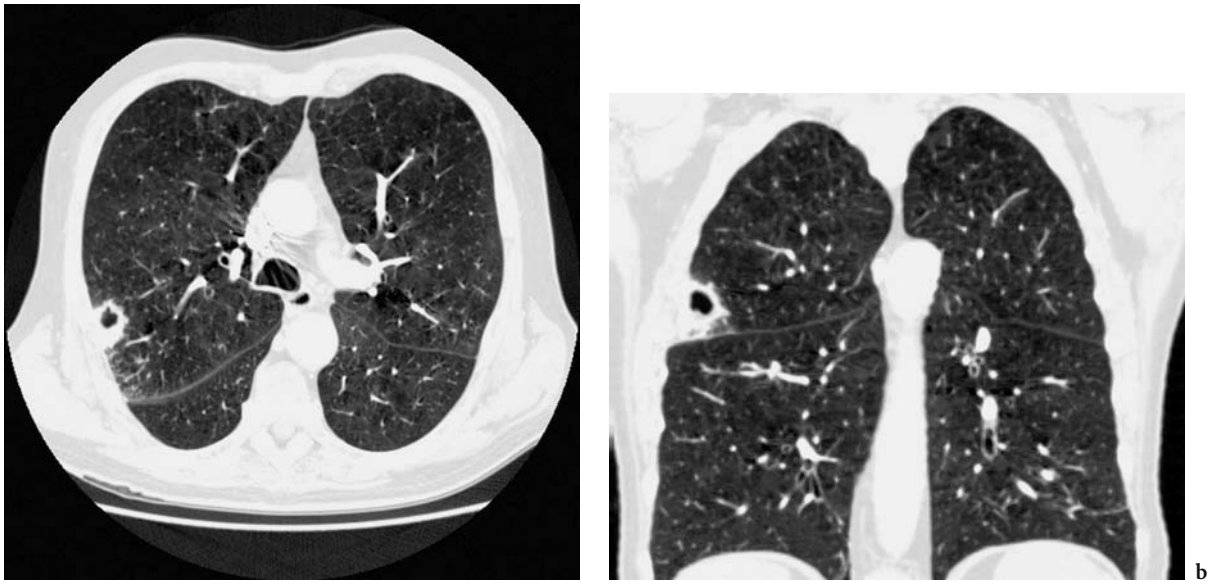


Fig. 7.5a, b. *Nocardia* infection in a 67-year-old man. **a** Chest CT scan (collimation 4×1.25 mm) shows a cavitary nodule in right upper lobe which extends to the costal pleural surface. **b** Coronal reformatted image shows relationship of nodule to adjacent major fissure

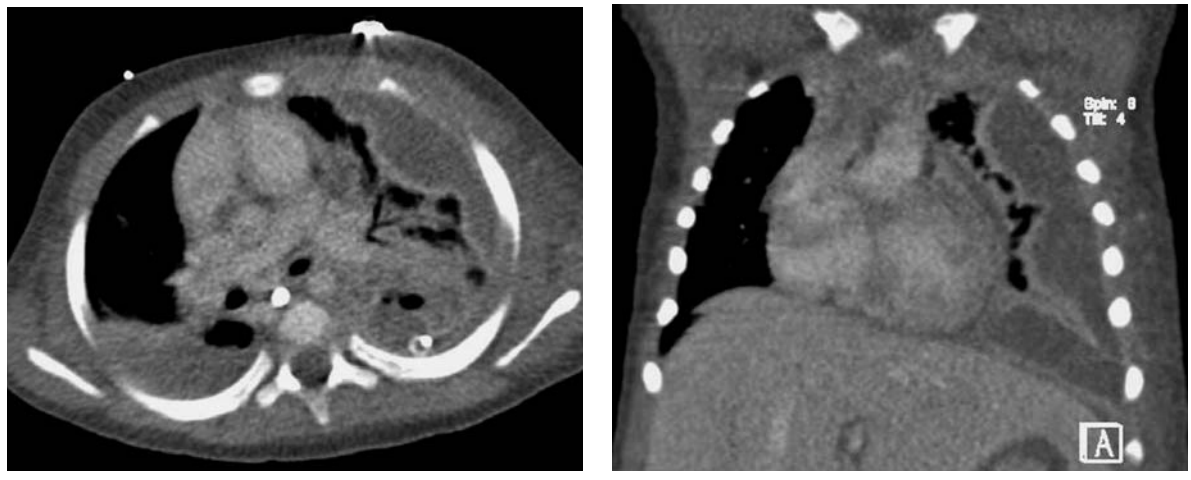
these patients, *Mycobacterium tuberculosis* infections are more prevalent in comparison with healthy persons without risk factors. Patients with poor oral hygiene and occasional loss of consciousness (epilepsy, alcoholism) may suffer from anaerobic pulmonary infections resulting from aspiration.

The spectrum of causative organisms of lobar pneumonia includes gram-positive bacteria such as *Streptococcus pneumoniae*, the most common cause of complete lobar consolidation, as well as *Klebsiella pneumoniae* and other gram-negative bacilli as *Legionella pneumophila, Haemophilus influenzae*, and occasionally *Mycoplasma pneumoniae*. Bronchopneumonia, characterized by peribronchial alveolar opacities leading to segmental consolidation, which may also cavitate, is typically caused by *Staphylococcus aureus* and *Haemophilus influenzae*. Bacterial infections in CAP may also produce multiple rounded pulmonary nodules or masses, with or without cavitation, occurring from infection with *Nocardia*, *Aspergillus*, *Legionella*, Q fever, and *Mycobacterium tuberculosis* (American Thoracic Society 1996; Tanaka et al. 1996). *Mycoplasma pneumoniae* is typically a disease of children and young adults. The MDCT findings consist mainly of centrilobar nodules often in a lobar distribution and thickening of the peribronchovascular and interlobar septal interstitium. These findings are often difficult to identify on chest radiographs but can usually be recognized on CT scans (Reittner et al. 2000).

When an out-patient presents with symptoms such as fever, cough, and purulent tracheobronchial secretions, he or she may or may not suffer from pneumonia; thus, the diagnosis of pneumonia is based on the detection of a pulmonary infiltrate on the chest X-ray. This practice relies on the pathophysiologic events that lead to the development of a visible pulmonary infiltrate. Although some variation exists regarding the time frame between the onset of clinical symptoms and the development of a radiographically visible pulmonary infiltrate, it has been stated that the vast majority of infiltrates appears within the time period of 12 h from development of symptoms (Spencer 1985). This time frame allows detection or exclusion in most cases of CAP as patients are generally seen by the radiologist within a few days following initial clinical presentation.

Although MDCT has no role in the primary diagnosis of CAP, recurrent pneumonias can indicate the presence of an underlying problem such as congenital or acquired immunologic disorder; airway abnormalities such as chronic bronchitis, bronchiectasis, and bronchogenic carcinoma; cardiac problems (congestive heart failure); or systemic diseases such as diabetes, chronic alcoholism, and intravenous drug abuse. In these patients, MDCT should be used to exclude the presence of a predisposing morphologic abnormality. Moreover, MDCT is indicated for the assessment of complications, or investigation of persistent infiltrates. In complicated childhood pneumonia, CT is far superior to conventional chest radiographs in revealing pleural and parenchymal complications, which may require early surgical intervention (Fig. 7.6; Tan Kendrick et al. 2002).

Moreover, some diseases may mimic infectious lung diseases and require cross-sectional imaging.



a b

Fig. 7.6a, b. Empyema (*Enterobacter* infection) following streptococcal pneumonia in a 2-year-old child. **a** Contrast-enhanced chest CT scan (collimation 12×0.75 mm) shows loculated fluid collection with enhancing pleural margins in left hemithorax. Note consolidation in adjacent left lower lobe and small right pleural effusion. **b** Coronal reformatted image shows craniocaudal extent of empyema

Extrinsic allergic alveolitis (EAA) is an immunologically mediated lung disease caused by inhalation of antigens contained in a variety of organic dusts. Heavy exposure to the inciting antigen may lead to the acute form of EAA characterized by dyspnea and fever developing within 4–6 h after exposure. Thin-section CT has been shown to be particularly helpful in the assessment of patients with subacute EAA. Characteristic features include bilateral areas of ground-glass attenuation and poorly defined centrilobular nodules. The centrilobular nodules measure less than 5 mm in diameter and are most numerous in the middle and lower lung zones (Remy-Jardin et al. 1993).

In acute interstitial pneumonia (AIP), previously healthy persons develop rapidly increasing dyspnea with fever over a few days, often following a short influenza-like prodrome (Armstrong et al. 2000). On thin-section CT, ground-glass opacity is a universal finding. It is commonly diffuse and patchy, sometimes with a geographic pattern. If related airways are of normal caliber, the histologic correlate of ground-glass opacity is exudative diffuse alveolar damage, but if airways are dilated, the histo-pathology shows proliferative or fibrotic diffuse alveolar damage. The second commonest CT finding, in two-thirds of patients, is consolidation which may have a subpleural predominance (Ichikado et al. 1997).

7.3.2 Nosocomial (Hospital-Acquired) Pneumonia

Nosocomial pulmonary infections that develop in hospital environment and were neither present nor incubating at the time of admission frequently occur in up to 5% of inpatients and are particularly common in mechanically ventilated patients in intensive care units (Eickhoff 1982). Mortality rates reported for NP have ranged from 20% in multihospital studies to 50% or higher in single referral centers and university hospitals. Mortality is related to the causative agent such that the prognosis associated with aerobic gram-negative pneumonias is considerably worse than that with gram-positive or viral agents. Typically, gram-negative bacteria have the tendency to colonize the oropharynx and gastrointestinal tract and are infrequent commensals in healthy persons, the carrier rate being estimated to range from 2–10%; however, in hospitalized patients who are not critically ill, the carrier rate has been found to approximate 30–40%, and in chronically or severely incapacitated in-hospital patients is as high as 60–75% (Fraser et al. 1994). Colonization is the result largely of contact spread from contaminated hospital personnel or equipment (e.g., inserted tubes, lines, and catheters). The persons at greatest risk are the elderly with underlying disease and patients who are malnourished or who have been inappropriately treated with broad-spectrum antibiotics. The spectrum of infectious agents has changed over the past decades. Enterobacteriaceae, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* became important problems; however, multiple infecting organisms (Fig. 7.7) may be identified in 20–40% of cases (A'Court and Garrard 1992).

The NP can be difficult to diagnose, since the classical findings for pneumonia, such as new fever, new pulmonary infiltrate, cough, sputum production, and elevated leukocyte count may not be present in the hospitalized patient with NP. If present, these symptoms may not necessarily be caused by pneumonia. Microbiologic evaluation of the patient with suspected NP (sputum, bronchoalveolar lavage) may or may not be helpful because of the difficulties in differentiating contamination from true infection. In addition, pulmonary disease in a hospital environment may be produced by more than one agent; therefore, the identification of a pulmonary infection, the use of various methods to obtain a specimen, and the value of isolation of potential pathogens are matters of constant discussion in the clinical diagnosis of NP.

Radiologically, the identification of the pulmonary infiltrate may be hampered by preexisting disorders or concomitant lung disease such as fibrosing alveolitis, lupus pneumonitis, hemorrhage or contusion, tumor, atelectasis, and embolic infarcts. The most

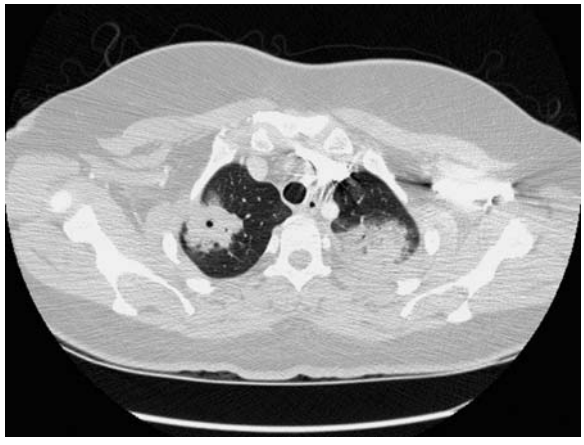


Fig. 7.7. Polymicrobial bacterial pneumonia in a 33-year-old woman. Chest CT scan (collimation 16×1.25 mm) shows bilateral nodules in upper lobes. Note small area of necrosis in right upper lobe lesion

common sources of septic emboli (Fig. 7.8) are infected venous catheters and tricuspid valve endocarditis (a major source in intravenous drug abusers; Julander 1983). The MDCT shows multiple lesions either round in shape or with the shape of a pulmonary infarct, namely a wedge-shaped density based on the pleura and pointing to the hilum. The lesions may be any size and frequently cavitate. A relatively common finding of both bland and infected infarcts, which may be helpful in differential diagnosis, is the "feeding vessel sign," a distinct vessel leading to the apex of a peripheral area of consolidation (Armstrong et al. 2000).

All of the above-mentioned disorders may obscure or alter the otherwise characteristic radiographic appearance of an infiltrate and also render the etiologic approach using pattern recognition difficult. Particularly in patients with adult respiratory distress syndrome (ARDS), the identification of ventilator-associated pneumonia is still a problem. Diagnostic accuracy for pneumonia was found to be fair (69%) owing to 70% true-negative ratings vs 59% true-positive ratings. No single CT sign was significantly different for pneumonia, but dependent atelectasis was more common in patients with early ARDS without pneumonia (Winer-Murham et al. 1998).

However, MDCT is used more often when an NP is suspected than in patients with CAP to detect early morphologic signs of infection (e.g., ground-glass opacities). The MDCT can also identify detect complications, and guide invasive diagnostic procedures such as bronchoscopy or percutaneous biopsy.

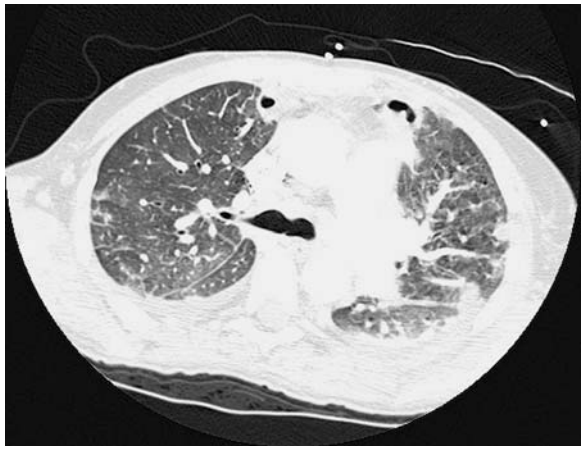


Fig. 7.8. Septic emboli in a 43-year-old woman with endocarditis. Chest CT scan (collimation 16×1.25 mm) shows multiple pleural-based nodules. Note vessel-feeding sign in left lower lobe and cavitary nodules adjacent to heart

7.3.3 Pneumonia in the Immunocompromised Patient

There has been a dramatic increase in the number of immunocompromised patients over the past two decades. The most common causes of immunosuppression are the acquired immunodeficiency syndrome (AIDS), hematologic malignancy such as leukemia or lymphoma, chemotherapy of tumors, and organ transplantation with consecutive medical immunosuppression (Naidich et al. 1998). Most notably, milder forms of immunosuppression may be seen in elderly individuals, pregnant women, alcoholics, and patients with severe malnutrition.

As the lung is particularly susceptible to infection in a compromised host, opportunistic pulmonary infections are an important cause of morbidity and mortality in the immunocompromised population. For example, pneumonia develops in up to 80% of patients with acute leukemia and is seen in up to 50% of organ transplant recipients. The mortality associated with pulmonary infection in the immunocompromised host may approach 50% (McLoud and Naidich 1992).

Pneumonia in the immunocompromised patient may represent a difficult diagnostic problem for the clinician. The spectrum of potentially causative organisms is exceedingly broad. Moreover, sputum and BAL cultures are frequently negative or contain more than one potential pathogen; thus, differentiation between contaminative, colonized, or pathogenic organisms is generally difficult. Further diagnostic invasive procedures in immunocompromised patients with thrombocytopenia or coagulopathy are problematic and are therefore frequently avoided by the clinicians. In order to make a meaningful contribution to the management of these patients, background information, such as the cause of immunodeficiency, current immunosuppressive therapy, white blood cell count (particularly the CD4 + count in AIDS patients), and overall medical status should be gathered, since these will serve as important diagnostic guides. When this information is available it is possible to extend the traditional role of a radiologist from one limited to detection and monitoring of pulmonary abnormalities.

Many of the bacteria causing CAP in the healthy community are also responsible for complicated infections in this high-risk group. In AIDS patients major causative agents for pneumonia include *Pneumocystis carinii* pneumonia (PCP; Fig. 7.9), *Mycobacterium tuberculosis*, and the *Mycobacterium avium* complex (Fig. 7.10; Chaisson and Pa 1995).

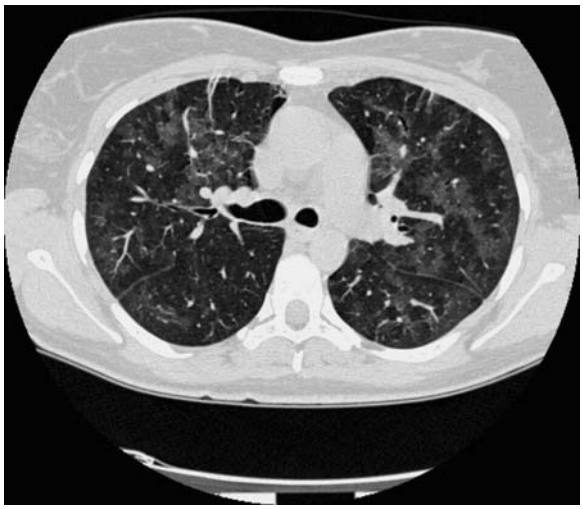


Fig. 7.9. *Pneumocystis carinii* pneumonia in a 36-year-old HIV-positive woman. Chest CT scan (collimation 12×0.75 mm) shows extensive, bilateral areas of ground-glass opacity which are found in a geographic distribution

Manifestation of opportunistic infections depends on the CD4+ cell count. Patients with CD4+cell counts of >200 cells/mm^3 are predisposed to bronchial infections and bacterial pneumonia, whereas patients with CD4+ counts of <200 cells/mm^3 are mainly predisposed to opportunistic infections such as PCP (Shah et al. 1997). The classic thin-section CT finding in PCP consists of extensive ground-glass opacities, corresponding to intraalveolar fluid exudation, often patchy or geographically distributed, with a predilection for the perihilar regions (Kuhlmann 1996). Recent literature describes the changing face of PCP as the classic radiographic presentation is being encountered less frequently (Boiselle et al. 1999): The most prevalent trend has been an increased frequency of diffuse cystic lung disease with description of cysts of different shapes, sizes, and varying degrees of wall thickness predisposing to spontaneous pneumothoraces. Upper lobe predominance of parenchymal opacities has been recognized in patients undergoing aerosolized pentamidine inhalation therapy and was initially explained by the insufficient agent distribution into the upper lobes when inhaling in an upright position. Other reports have also documented upper lobe predominance in patients without pentamidine prophylaxis. Atypical radiological features include parenchymal abnormalities as lung nodules and masses (varying in size from 2 mm to 1 cm in diameter), lobar consolidation, and interstitial fibrosis with septal thickening, bronchiectasis, and honeycombing. Nodules may also undergo calcification and rarely cavitation. Other described features are mediastinal and hilar lymph node enlargement and pleural effusion (Gruden et al. 1997).

Although *Candida* is the most common opportunistic mycosis, it rarely causes pneumonia in the absence of disseminated disease. End-stage AIDS patients and patients with severe neutropenia are more often affected by *Aspergillus fumigatus* (Fig. 7.11), causing bronchial invasive aspergillosis with clinical manifestation of acute tracheobronchitis, bronchiolitis, and bronchopneumonia. Typical thin-section CT features of angioinvasive aspergillosis are characterized by the presence of centrilobular nodules with patchy distribution and branching linear or nodular opacities giving an appearance resembling a "tree-in-bud" (Aquino et al. 1994). Conolly et al. (1999) summarized several forms of aspergillosis. Invasive pulmonary aspergillosis in patients with severe immunodeficiency is characterized on radiographs by multiple ill-defined 1- to 3-mm peripheral nodules, gradually coalescing into masses or areas of consolidation. An additional findings on CT scans are a rim of surrounding ground-glass attenuation surrounding the nodules (CT-halo sign) and the well-known air-crescent sign, indicating central cavitation. Chronic necrotizing or semiinvasive aspergillosis typically occurs in patients with mild immunodeficiency. It manifests with slowly progressive cavitary consolidation, which usually affects the upper lobes. Two forms of tracheo-

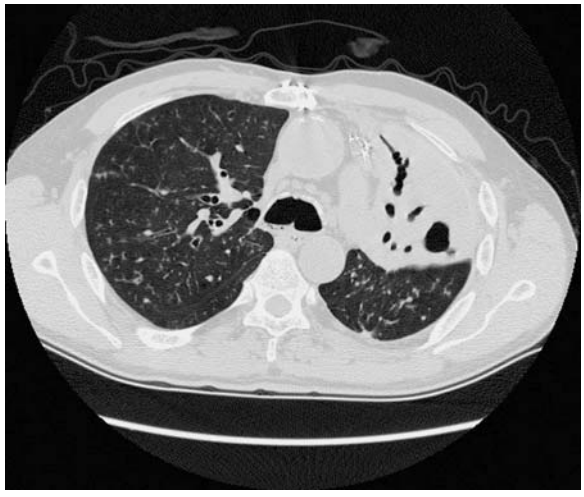


Fig. 7.10. *Mycobacterium avium* infection in a 59-year-old man. Chest CT scan (collimation 8×1.25 mm) shows left upper lobe consolidation with central necrosis and multiple centrilobular nodules in the superior segment of the left lower lobe as well as right upper lobe

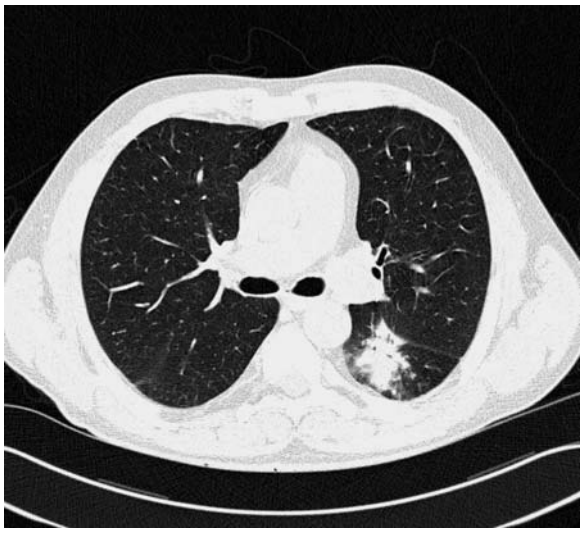


Fig. 7.11. Invasive aspergillosis in a 55-year-old man with acute myeloid leukemia. Chest CT scan (collimation 12×0.75 mm) shows nodule with surrounding ground-glass attenuation ("CT halo sign") in the superior segment of the left lower lobe

bronchial aspergillosis are described: invasive tracheobronchial and obstructing bronchopulmonary aspergillosis. Invasive tracheobronchial aspergillosis is commonly reported in patients after bone marrow or lung transplantation and is characterized by radiographic and CT findings of bronchial wall thickening, multiple poorly defined nodular opacities, atelectasis, and consolidation. Obstructing bronchopulmonary aspergillosis, typically seen in end-stage AIDS patients, is caused by an overgrowth of fungus within the tracheobronchial system without airway wall infiltration, and radiologically manifests as large mucoid impactions ("finger-in-glove sign") predominantly in the upper lobes (Conolly et al. 1999).

Occasionally, helminths, such as *Strongyloides stercoralis* (Fig. 7.12), cause pulmonary infections; however, in recent years severe disease (so-called hyperinfection) has been recognized in the immunocompromised AIDS population and in patients with asthma or chronic obstructive pulmonary disease receiving corticosteroid therapy (Fraser et al. 1994). Although reports are few, small nodules superimposed on diffuse interstitial infiltrates have been described (Makris et al. 1993). Other authors have described migratory pulmonary consolidations without recognizable segmental distribution most likely due to an allergic reaction in the lung parenchyma. Blood and sputum eosinophilia were often present, and the entity was therefore included as one of the causes of acute pulmonary infiltrates with eosinophilia (Löffler's syndrome; Armstrong et al. 2000).

Impaired host immunity is a predisposing factor for development of postprimary tuberculosis. Ikezoe and associates evaluated the CT features of pulmonary tuberculosis in immunocompromised patients compared with other patients without underlying disease and found that immunocompromised patients, who demonstrated a high prevalence of nonsegmental distribution of infiltrates and multiple small cavities within any given lesion, had a somewhat different presentation compared to patients without underlying disease who had a more segmental distribution of lesions in a single cavity within a given lesion (Ikezoe et al. 1992).

In bone marrow transplant (BMT) recipients, pulmonary infections occur in up to 50% of patients and the onset of new infiltrates on chest radiographs should prompt an early definitive diagnosis. The CMV is the most significant viral infection that occurs in BMT patients with a described prevalence of 50–70% of allogenic BMT recipients within a typical onset time of 1–4 months after transplantation. One-third of patients develop CMV pneumonia approximately 50–60 days after bone marrow transplantation (Cunningham 1992). Radiological findings of pulmonary CMV are nonspecific and may consist of lobar consolidation, diffuse and focal parenchymal haziness, and multiple small nodules with associated perifocal ground-glass attenuation ("halo"; McGuiness et al. 1994).

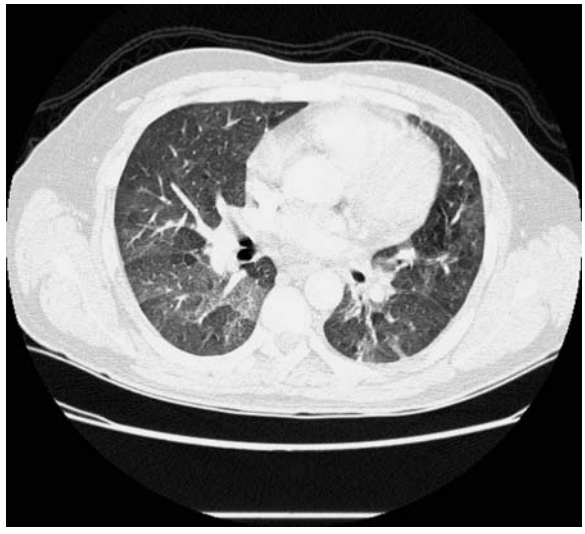


Fig. 7.12. *Strongyloides* in a 36-year-old man. Chest CT scan (collimation 16×1.25 mm) shows nonspecific bilateral areas of ground-glass opacity

Similar to patients after solid organ transplantation, the timeline of infections that occur in BMT recipients can be divided into three distinct periods differentiated on the basis of neutrophil count and degree of medical immunosuppression: 0–30 days post-, 30–120 days post-, and >120 days post-transplantation. In the early neutropenic phase, immediately after marrow ablative chemo- and radiation therapy, opportunistic fungi, such as *Aspergillus*, account for the majority of infections. While bacteremias are common, bacterial pneumonias are rare due to the widespread use of empiric broad-spectrum antibiotics for febrile episodes. In the second phase, after marrow engraftment and recovery of neutrophils, persistent deficits in cellular and humoral immunity predispose to infections with viruses, and more specifically CMV, which accounts for the majority of infections during this period. In the late post-transplantation period (>120 days), autologous recipients and allogeneic recipients without graft vs host disease (GVHD) experience relatively few late infections. Most infections occur in the setting of chronic GVHD which predisposes allogeneic recipients to infections with bacteria and opportunistic fungi (Leung et al. 1999).

Typical radiographic pattern for herpes simplex virus (HSV) pneumonia as a representative for viral pulmonary infection is diffuse and multifocal parenchymal disease with a patchy, predominantly ground-glass pattern with scattered, less dominant areas of consolidation (Aquino et al. 1998). Especially in immunocompromised patients, CT findings were described as helpful in narrowing the differential diagnoses of *Varicella zoster* pneumonia. In addition to multiple diffuse bilateral 5- to 10-mm ill-defined partially confluent intrapulmonary nodules seen on chest radiographs, CT scans also demonstrated nodules with surrounding ground-glass attenuation, patchy ground-glass opacities, and coalescence of lesions (Kim et al. 1999).

7.4 Combined Analysis of Radiologic Pattern and Clinical Setting

Many of the previously described imaging patterns are common knowledge from conventional chest X-rays. The knowledge of these signs and the distribution of abnormalities may be helpful for interpretation of MDCT images since coronal reformatted images closely resemble conventional chest films in the posterior anterior projection. In chest imaging, the value of multiplanar reformatted (MPR) images has been previously demonstrated for limited regions of interest (e.g., airway lesions, pulmonary vessels; Quint et al. 1995; Remy-Jardin et al. 1995; Storto et al. 1998); however, the value of coronal MPRs of the whole chest is still under evaluation for assessment of inflammatory lung diseases. To date, only casuistic descriptions are available regarding the value of MPR images (Johkoh et al. 2002). Multiplanar reconstructions may allow better depiction of the pattern and distribution of findings, thus improving recognition of abnormalities and narrowing the differential diagnosis.

Generally, MDCT findings of pneumonia are nonspecific and diagnosis of a specific microbial organism is frequently not possible. Ground-glass opacities, air-space consolidations, cavitations, defined linear opacities, and especially poorly defined nodules, are early indicators for pulmonary infections (Siegelmann et al. 1986; Kauczor et al. 1996; Aberle 1993). As a general rule of thumb, localized segmental or lobar alveolar densities can be attributed to typical or atypical bacterial infections. In CAP, the main feature differentiating the two groups is the presence of centrilobular nodules which are much more frequently found in atypical bacterial pneumonia (*Mycoplasma pneumonia*: 89%), viral (77%), and fungal pneumonia (65%), as compared with typical bacterial pneumonia (17%; Reittner et al. 2003).

Diffuse bilateral interstitial and/or interstitial alveolar infiltrates most commonly are caused by viruses, atypical bacteria, and protozoa. A predominantly nodular pattern of pneumonia is seen with a variety of infections. Fungal pneumonia characteristically manifests as multiple, ill-defined nodules that may gradually coalesce to form a mass or an area of air-space consolidation (Conolly et al. 1999; Kuhlmann et al. 1988). In viral pneumonia, nodules are typically associated with a background of diffuse ground-glass attenuation and/or reticulation (Conolly et al. 1999; McGuiness et al. 1994). In *Mycoplasma pneumoniae* and bacterial pneumonias caused by *Nocardia*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*, nodules may extend to involve the entire secondary pulmonary lobule (Reittner et al. 2000; Worthy et al. 1995).

In HIV-infected patients having one or more pulmonary nodules on chest CT scan, opportunistic infections are the most common cause. Specific clinical and radiographic features can suggest particular opportunistic infections. Fever, cough, and size of nodules less than 1 cm on chest CT were identified

as independent predictors of having an opportunistic infection. Furthermore, a history of bacterial pneumonia, symptoms for 1–7 days, and size of nodules less than 1 cm on CT independently predicts a diagnosis of bacterial pneumonia. A history of homelessness, weight loss, and lymphadenopathy on CT independently predicted a diagnosis of tuberculosis (Jasmer et al. 2000).

The significance of ground-glass attenuation depends on the immune status of the patients. In immunocompromised patients, the presence of extensive, diffuse, bilateral ground-glass attenuation is highly suggestive for *Pneumocystis carinii* pneumonia (Gruden et al. 1997). This pattern was demonstrated to be present in up to 94% of AIDS patients with PCP (Hartmann et al. 1994). In immunocompromised patients who do not have AIDS and in immunocompetent patients with pneumonia, areas of ground-glass attenuation are a common but non-specific finding. Although viral pneumonia may produce extensive areas of ground-glass attenuation, viral infections are commonly associated with nodules and focal or diffuse areas of air-space consolidation (McGuiness et al. 1994; Kang et al. 1996). In *Mycoplasma pneumoniae* pneumonia, focal areas of ground-glass attenuation in association with centrilobular nodules are frequently present. These focal areas of ground-glass attenuation often have a lobar distribution (Reittner et al. 2000). In bacterial and fungal pneumonias areas of ground-glass attenuation tend to be minor findings adjacent to areas of air-space consolidation and nodules (Conolly et al 1999). Reticulation is a non-specific feature in all groups of pneumonias and may be associated with air-space consolidation, ground-glass attenuation, and nodules (Reittner et al. 2003). Micronodular disease is most often caused by miliary TB ("miliary pattern"), candidiasis, and histoplasmosis (small nodules), or viruses such as herpes or varicella zoster virus (diffuse nodules with hazy borders). Large, nodular lesions may represent bacterial abscesses, and in immunocompromised patients, may be caused by invasive aspergillosis and *Nocardia*.

Chest radiography is still the mainstay and primary imaging method in patients with suspected CAP. Diagnosis and disease management most frequently rely on chest radiography and do not require the use of further diagnostic tests. In these patients, MDCT scanning and invasive diagnostic procedures are reserved only for cases in which treatment failure or complications, such as abscess formation, influence the course of the disease. Conversely, in nosocomial or opportunistic infections, cross-sectional imaging techniques and invasive procedures, such as needle or bronchoscopically guided biopsies, are more often required, underlined by the fact that in most large series of pneumonia a causative organisms cannot be identified in 25–45% of patients even when extensive noninvasive diagnostic tests are performed. The NP are associated with a high mortality rate, ranging from 20 to 50%; thus, identification of the causative organism is more intensively pursued, with the use of fiberoptic bronchoscopic lavage, brushing, and/or biopsy. In many institutions, imaging methods, such as CT scans, are used for the guidance of invasive methods into areas of most severe involvement. The MDCT images (e.g., MPRs, virtual bronchoscopy) may also serve as a "road map" to direct fiberoptic bronchoscopy towards the lesion.

The use of transthoracic CT aspiration needle biopsy in the diagnosis of pulmonary infection is controversial. Nevertheless, when noninvasive techniques used to identify the underlying organism, such as sputum examination and cultures, are nondiagnostic, a choice must be made between empiric therapy and an invasive diagnostic test. While the majority of patients are treated empirically, the nature and course of pneumonias in nosocomial infections and in immunosuppressed individuals frequently dictates a more aggressive approach. In such cases, transthoracic needle biopsy may help to identify the causative organism (Sanchez-Nieto et al. 1998). Sanchez-Nieto et al. (1998) reviewed a series of 441 transthoracic needle aspiration biopsies to evaluate the use of the procedure in the diagnosis of pulmonary infections. In 67 patients in whom pulmonary infection was suspected, a specific diagnosis was made with needle biopsy in 45 cases. In 46 cases in which infection was ultimately found to be present, aspiration biopsy identified the organism in 35 cases. Overall, clinically useful information was obtained in 81% of aspiration biopsies performed for pulmonary infection. Since other authors have reported similar results, needle biopsy should be considered an important component of the radiologist's armamentarium in diagnosing and managing pulmonary infections.

It has been shown that even a small number of thin-section CT images provides adequate assessment of diffuse lung diseases (Kazerooni et al. 1997); thus, volumetric imaging throughout the chest is not likely to provide a significant advantage in the assessment of these patients. Furthermore, the potential benefits from volumetric imaging in these patients may be outweighed by the potential risks of the increased radiation exposure (Honda et al. 2002).

Overall, the role of MDCT in suspected or proven pneumonia can be summarized as follows: firstly, MDCT is a valuable tool in early diagnosis of pneumonia, especially in patient groups in which such an early diagnosis is important (immunocompromised patients and critically ill patients). Secondly, MDCT can aid in the characterization and localization of pulmonary infections and may suggest an etiologic diagnosis. Thirdly, MDCT is an excellent tool in assessing complications such as bronchopleural fistula. Fourthly, MDCT is required in the investigation of patients with persistent and recurrent pulmonary infiltrates.

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