Imaging of Pulmonary Infections

Philip Goodman[1], Helmut Prosch[2], Christian J. Herold[2]

[1] Duke University Medical Center, Durham, NC, USA
[2] Department of Radiology, Vienna General Hospital, Medical University of Vienna, Vienna, Austria

Introduction

Pulmonary infection is one of the most frequent causes of morbidity and mortality throughout the world. Many infections occur in individuals with concomitant intrapulmonary or extrathoracic diseases; however, they commonly develop in otherwise healthy people. In the non-immunocompromised population, pneumonia is the most prevalent community-acquired infection and the second most common nosocomial infectious disorder. In immunocompromised patients, in children, and in the elderly, pneumonia, as well as other pulmonary infections, may develop into a life-threatening condition.

In this chapter, the most important principles regarding the epidemiology, pathogenesis, classification, and clinical and radiographic diagnoses of pneumonias are reviewed. Our aim is to formulate an integrated approach to the diagnosis of pneumonia that combines clinical and radiologic information. As such, we focus on: (1) community-acquired pneumonia (CAP); (2) nosocomial pneumonia (NP); and (3) pneumonia in immunocompromised patients including those infected with the human immunodeficiency virus (HIV). The differentiation between CAP, NP, and other forms of pneumonia is of paramount importance because of the potentially different etiologies, clinical features, diagnostic approaches, radiologic patterns, and therapeutic strategies. Although the spectrum of causative organisms differs between these disorders, there is considerable overlap with regard to their radiologic features.

Community-Acquired Pneumonia

Pathogenesis

Pneumonias acquired in the community are the form of pneumonia most often seen in the offices of general practitioners, private radiologists, and, in a hospital setting, in the outpatient department or the emergency room. Most CAP patients are children (15–35 of 1,000 children per year) and the elderly (30–40 per 1,000 persons per year). The mode of transmission in CAP is usually person-to-person, via water or mucus droplets laden with viruses or bacteria. The most frequent pathogens are gram-positive bacteria, such as *Streptococcus pneumoniae* (*Pneumococcus*) and *Staphylococcus aureus,* and gram-negative bacteria, such as *Haemophilus influenzae* and atypical bacteria, including *Mycoplasma pneumoniae, Chlamydia pneumoniae,* and *Legionella pneumophila*. Viral forms commonly include those caused by respiratory viruses, such as influenza viruses, human metapneumovirus, respiratory syncytial virus (RSV), rhinovirus, parainfluenza viruses, adenoviruses, and corona viruses. According to the literature, the spectrum of organisms varies according to patient-related, temporal, geographic, and diagnostic factors.

In CAP, the patient's health and socioeconomic status may provide clues as to the spectrum of causative organisms. Healthy people are most likely to contract mycoplasma pneumonia or a mild form of pneumococcal pneumonia. Debilitated patients, alcoholics, and the chronically ill more often present with severe pneumococcal pneumonia or infections caused by *H. influenzae, S. aureus,* or gram-negative bacilli. *L. pneumophila* and *Chlamydia* infections are more common in patients with some form of mild immunologic compromise. Patients with poor oral hygiene and occasional loss of consciousness (epilepsy, alcoholism) may suffer from anaerobic pulmonary infections. In these patients, *Mycobacterium tuberculosis* infections are more prevalent than in healthy individuals without risk factors. Recurrent pneumonia in outpatients usually indicates an underlying problem, such as congenital or acquired immunologic disorder; airway abnormalities, such as chronic bronchitis, bronchiectasis, and bronchogenic carcinoma; cardiac conditions (congestive heart failure); or systemic diseases, such as diabetes, chronic alcoholism, and intravenous drug abuse. Up to 10% of CAPs are aspiration pneumonias caused by the aspiration of colonized oropharyngeal or gastric contents. The

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most frequently isolated pathogens in aspiration pneumonia are gram-negative bacteria. Aspiration pneumonia must be differentiated from aspiration pneumonitis, which is a chemical pneumonitis that results from the aspiration of noncolonized gastric contents (Mendelson's syndrome).

The definition of CAP has been challenged over the last few years, as it also includes pneumonia in patients from nursing homes, rehabilitation hospitals, and outpatient-based surgical centers who routinely receive invasive medical treatment. The bacteriology and outcome of these patients are more similar to those of NPs. Therefore, it has been proposed that pneumonia in outpatients hospitalized for more than 2 days over the previous 3 months or who reside in nursing homes or extended-care facilities should be categorized as health-care-associated pneumonia (HCAP).

Clinical Diagnosis

Patients suffering from CAP usually present with fever, cough, dyspnea, sputum production, and pleuritic chest pain, as well as laboratory signs, such as leukocytosis. Because the clinical symptoms are nonspecific, most people who have fever and cough do not have pneumonia; in fact, about 30% of patients, and especially the elderly, are afebrile at presentation. Imaging is one of the most important tools in the diagnosis of CAP. The radiographic identification of a new pulmonary infiltrate is, in the appropriate clinical setting, indicative of pneumonia. Conversely, a patient who has fever and cough but does not have radiologic proof of pneumonia cannot be considered to have pneumonia. In CAP, the causative organism is frequently not identified because noninvasive tests such as sputum cultures correctly identify the offending organism in only 50% of cases, and invasive procedures are rarely used in patients with pneumonia.

Radiographic Diagnosis

In patients with CAP, the primary role of the radiologist is to detect or to exclude pneumonia. A second task is to aid the clinician in determining the etiologic diagnosis. Categorization of the causative organism is sometimes possible by integrating clinical and laboratory information with radiographic pattern recognition (see the section "Radiographic Patterns"). A specific etiologic diagnosis, however, is difficult to establish, given the increasing spectrum of causative organisms and their overlapping radiographic features. In a prospective study of 359 adults with CAP, Fang and coauthors compared the radiographic, clinical, and laboratory features of patients with bacterial pneumonia (caused by *H. influenzae, S. pneumoniae, S. aureus,* and aerobic gram-negative bacilli) and those with atypical pneumonia (caused by *M. pneumoniae* and *Chlamydia* spp.). The authors found no features that could reliably differentiate these two groups. Another group prospectively compared the clinical and radiologic features of CAP caused by *L. pneumophila* to those of patients with pneumococcal infections AUHA (Ahuja and Kanne, 2014). The authors concluded that *Legionella* infection may clinically as well as radiologically resemble a typical bacterial pneumonia.

The chest radiogram is the first-line tool in evaluating patients with suspected CAP. Computed tomography (CT) is reserved for assessing complications or for guiding further diagnostic procedures. It is definitely indicated in investigating patients with recurrent or persistent pulmonary opacifications.

Nosocomial Pneumonia

By definition, NPs develop in a hospital environment. The incidence of NP ranges from 0.5 to 5 cases per 100 admissions, but in the subgroup of ventilated patients in an intensive care setting it may reach 7–41%. Mortality rates reported for NPs range from 20% in multihospital studies to ⩾50% in single referral centers and university hospitals.

Mortality is related to the causative agent. The prognosis associated with aerobic gram-negative pneumonias is considerably worse than that associated with gram-positive or viral agents.

Pathogenesis

NP develops from bacterial colonization of the oropharynx followed by the aspiration of oropharyngeal secretions and gastrointestinal contents into the lungs. The majority of NPs are caused by gram-negative bacilli, including *Pseudomonas aeruginosa, Klebsiella* spp., *Enterobacteriaceae* spp., *Escherichia coli, Serratia marcescens,* and *Proteus*, and to a lesser extent by gram-positive cocci, atypical bacteria such as *L. pneumophila,* and viruses such as RSV. Microbial contamination of inserted tubes, lines, and catheters is an important source of infection. Less commonly, NP is the result of bacteremia originating from right-sided endocarditis or septic pelvic thrombophlebitis. Risk factors are either patient-related (underlying illness, previous surgery, prolonged hospital care) or iatrogenic (intravascular catheters, tracheal tubes, indwelling catheters, respirator equipment). Sources of infections are hospital personnel and patients with active infections. The inappropriate use of broad-spectrum and prophylactic antibiotics is an additional and important factor leading to an increased susceptibility to NPs.

Clinical Diagnosis

Compared with CAP, it may be difficult for the clinician to diagnose pneumonia in a hospitalized patient. The classical findings for pneumonia, such as new fever, new pulmonary opacification on chest radiographs, cough, sputum production, and elevated

leukocyte count may not be present in the hospitalized patient with NP. Moreover, even if these symptoms are present, they 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 caused by more than one agent. Therefore, identifying a pulmonary infection, the various methods used to obtain a specimen, and the value of isolating potential pathogens are matters of constant discussion in the clinical diagnosis of NP.

Radiographic Diagnosis

Because of the potential difficulties in the clinical diagnosis of pneumonia in the hospitalized patient, the radiologist has an important role in detecting and classifying suspected cases. However, the radiographic diagnosis of a pulmonary opacity in suspected NP is not as straightforward as it is in patients with CAP. The radiographic diagnosis of a pneumonia may be hampered by preexisting disorders or concomitant lung disease, such as fibrosing alveolitis, lupus pneumonitis, hemorrhage or contusion, acquired respiratory distress syndrome (ARDS), tumor, atelectasis, and embolic infarcts. These disorders may obscure or alter the otherwise characteristic radiographic appearance of a pulmonary opacification and thus render the etiologic approach using pattern recognition difficult.

The difficulties in diagnosing NP can be readily demonstrated by two examples. Winer-Muram et al. assessed the diagnostic accuracy of bedside chest radiography for pneumonia in ARDS patients. The overall diagnostic accuracy in these patients was only 42% because of false-negative and false-positive results originating from diffuse parenchymal areas of increased opacity that obscured the radiographic features of pneumonia. Wunderink et al. compared premortem chest radiographic findings with pulmonary autopsy studies in ventilated patients with NP. No radiographic sign had a diagnostic efficiency greater than 68%. The only radiographic sign that correlated with pneumonia, correctly predicting 60% of the cases, was the presence of an air bronchogram.

CT is used more often when an NP is suspected than in patients with CAP, as it can detect early morphologic signs of infection (for example, ground-glass densities). CT can also identify a pulmonary opacification in areas of preexistent disease, detect complications, and guide invasive diagnostic procedures, such as bronchoscopy or percutaneous biopsy.

Radiographic Patterns

In general terms, imaging patterns can be grouped into airspace consolidation (lobar pneumonia), bronchiolar disease (bronchopneumonia) and bilateral diffuse disease.

Most commonly, consolidation, confined to a segment or a lobe of one or both lungs, is caused by typical and atypical bacteria, whereas bronchopneumonia commonly relates to *Staphylococcus aureus*, *Haemophilus*, *Mycoplasma*, and tuberculous infection. Diffuse bilateral lung disease, frequently developing over time, can in most cases be attributed to viruses and fungi such as *Pneumocystis jirovecii*. Nodular disease may be attributed to septic emboli (small nodules), larger nodules can be caused by *Nocardia* and fungal disorders in immunocompromised hosts.

Again, these patterns are nonspecific, they overlap, may be mimicked by non-infectious lung disease and masked by pre- or coexisting lung conditions. Patterns can be identified both on chest radiography and CT but CT may help to identify complex or coexisting patterns and aid the novice in establishing a diagnosis.

Opportunistic Infections

Infectious agents that cause opportunistic pneumonia in humans include representatives from the classifications bacteria, virus, fungus, protozoa, and parasite. In the following, we review some of these pathogens and their appearance on chest film and CT. Usually, the chest radiograph will reveal the abnormality but, occasionally, the increased sensitivity of CT is necessary and even recommended to see the pneumonia. Whereas the findings on chest imaging may not be totally pathognomonic of the underlying etiology of infection, they may still be highly suggestive and will certainly lead to a reasonable differential diagnosis.

Human Immunodeficiency Syndrome

Since the first description of HIV/acquired immune deficiency syndrome (AIDS), pneumocystis pneumonia caused by *Pneumocystis jirovecii* (PJP) has been one of its most common complications. (Previously it was thought that *Pneumocystis carinii* was the cause of these infections, but this is not the case. The abbreviation PCP is still used in some circles to refer to pneumocystis pneumonia.) In recent years the incidence of PJP as a presenting abnormality in patients with AIDS has decreased. Nevertheless it still accounts for a considerable amount of diseases in patients not on highly active antiretroviral therapy (HAART) or prophylactic therapy and should be considered as a diagnosis when characteristic radiographic findings are noted. Patients with PJP typically present with increasing shortness of breath; the disease may run a gradual or fulminant course. Chest films classically reveal a bilateral fine to medium reticulonodular pattern, generally bilateral but occasionally focal or unilateral. If the patient remains untreated, the radiograph progressively becomes more

opaque and bilateral homogeneous opacities may ultimately be seen. While upper lobe involvement is more frequent, any lobe may be involved. On CT imaging PJP presents as ground-glass opacification in the areas of involvement, typically perihilar in distribution. The chest film occasionally may worsen within a few days of intravenous trimethoprim-sulfamethoxazole treatment secondary to overhydration and the production of pulmonary edema, but this can be treated quite effectively with diuretics.

Otherwise, with treatment, the radiographic course is one of steady improvement, with complete resolution usually occurring by day 11. Pneumatoceles , as seen on chest films, develops in ⩾10% of patients; the incidence is probably higher in patients evaluated by CT scanning. These air-filled cysts are frequently multiple, located in the upper lobes, measure 1–5 cm in diameter, and will resolve within 2 months. However, in 35% of patients, pneumatoceles may lead to pneumothorax, which can be extremely difficult to treat. Overall, pneumothorax develops in 5% of patients with PJP and AIDS. In about 10% of patients with PJP, the chest film may be normal. In some of these patients with normal radiographs, a CT scan will show the typical geographic, ground-glass opacities associated with pneumocystis pneumonia. Lymphadenopathy and pleural effusions are not part of the PJP picture.

Cytomegalovirus (CMV) may mimic the appearance of PJP on chest film, with diffuse bilateral fine to medium reticulonodular opacities. On CT, centrilobular nodules and ground-glass opacities are reported. In some patients with CMV, the presence of discreet nodules, sometimes several centimeters in size, may help distinguish between these two entities. Lymphocytic interstitial pneumonia may also mimic PJP with fine reticular opacities on chest radiographs, ground-glass opacities on CT scans, and air-filled cysts seen on both forms of imaging.

Disseminated fungal infections, such as histoplasmosis and coccidiomycosis, generally produce bilateral, fairly symmetric, coarse, nodular opacities on chest radiographs.

The nodules and occasionally reticular opacities are larger than those seen with PJP, which may aid in distinguishing between the two processes. Discreet larger nodule(s) or disseminated disease may be seen with other fungal infections such as aspergillosis and cryptococcosis. With angio-invasive fungal infections cavitation may occur secondary to ischemia, regardless of the CD-4 lymphocyte count.

The imaging appearance of tuberculosis (TB) depends on the patient's immune status. In patients with relatively normal CD-4 lymphocyte cell counts, TB will look much like it does in the general population. That is, with primary infection, patients will present with a homogeneous lobar opacity and ipsilateral hilar and/or mediastinal adenopathy. With post-primary infection, chest films will show apical and posterior upper-lobe and/or superior segment lower-lobe heterogeneous opacities with or without cavitation; on CT scans, imaging may also demonstrate centrilobular nodules and/or tree-in-bud opacities. In patients with low CD-4 cell counts and primary infection, homogeneous lobar opacities with adenopathy similar to immune competent hosts may be seen on chest films, but increased adenopathy may also be present. With post-primary disease, the organism disseminates more widely, creating a diffuse, coarse, nodular pattern on chest film similar to the pattern seen with fungal infections. Cavitation does not develop, as the body's immune response is weak, such that well-formed granulomas and necrosis are unusual. In patients with improving cell-mediated immunity secondary to HAART, more typical findings of cavitation might be seen. If the organism is sensitive to the appropriate therapy, then some resolution of the abnormal findings should be observed on chest film within 1 week.

Ordinary bacterial infections now occur with increased frequency and among some patients with HIV are the most common type of infection. This increasing percentage of bacterial infections may reflect the larger number of pulmonary infections in populations in whom antiretroviral and prophylactic therapy is available. Common organisms are *S. pneumoniae, H. influenzae, S. aureus, and P. aeruginosa.* In the immunocompromised, pneumonias caused by these bacteria usually appear as they do in normal hosts, i.e., as homogeneous, peripheral, lobar opacities. Parapneumonic effusions may be present. *S. aureus,* and *P. aeruginosa* pneumonias may present with cavitations. These should begin to resolve within days of instituting antibacterial therapy, with complete resolution of abnormalities usually occurring in about 2 weeks. Other bacterial etiologies, such as *Rhodococcus equi* and *Nocardia asteroides*, are less common and may present as nodules or masses with or without cavitation.

With the use of antiretroviral therapy, noninfectious etiologies of disease have become more prevalent, such as pulmonary hypertension and chronic obstructive pulmonary disease (COPD), including emphysema and chronic bronchitis. Also, the immune reconstitution inflammatory syndrome (IRIS), occurring in up to 30% of patients after the initiation of antiretroviral treatment, may cause confusing clinical and radiological findings. With improving immune status, patients are able to mount a greater inflammatory response to existing organisms, resulting in worsening clinical disease and increasing lung parenchymal abnormalities and lymphadenopathy. This usually develops in individuals with low CD-4 counts and high viral loads, typically about one month after starting therapy (but as early as within days and as late as after several months). It is more commonly seen in patients with partially treated tuberculosis or non-tuberculous mycobacterial infection. Worsening of other infections and the development of sarcoidosis have also been attributed to HAART and IRIS.

Two infection-related neoplasms, non-Hodgkin's lymphoma (NHL) and Kaposi's sarcoma, may also be seen in patients with AIDS and could cause confusion in generating a differential diagnosis. NHL will produce well-defined, discete, nodules on chest films. The nodules range in size from about 1 cm to several centimeters. Solitary or multiple nodules may be noted. Lymphadenopathy and pleural effusions are also observed. The nodules have a tendency to grow extremely rapidly.

Whereas the nodules with NHL are very well defined, those associated with Kaposi's sarcoma are not. This disease produces poorly marginated nodules that tend to coalesce and occur in the perihilar lung and lower lobes. On CT, the distribution is along bronchovascular pathways.

(Other diseases seen in HIV/AIDS patients which occur along the bronchovascular bundles include lymphocitic interstitial pneumonia (LIP), Castleman disease, and sarcoidosis). In almost all cases of Kaposi's sarcoma involving the lungs, cutaneous lesions are also common, as is pleural fluid.

Other Conditions of the Immune-Compromised

Increasing numbers of transplant procedures, both solid organ and hematopoietic stem cell, have led to new populations of immunosuppressed individuals. The underlying diseases (e.g. leukemia) or the widespread use of induced immunosuppression for treatment purposes may result in neutropenia or other causes of immune dysfunction. Steroids are also being used with increased frequency for a number of medical conditions. Thus, infectious and non-infectious complications in the setting of transplantation or steroid use have become a major problem. Prophylactic drug treatment for pneumocystis, CMV, and occasional fungi may reduce the number of infections in some, but not all of these patients.

Bacterial pneumonias caused by a variety of organisms (e.g., *Pseudomonas*, *Nocardia*, *Legionella*) have a typical appearance of peripheral homogeneous opacification with or without air-bronchograms. More than one lobe might be involved. In the case of *Legionella* the opacification may simulate a mass.

The appearances on chest film and CT scans of CMV will be similar to that seen in patients with HIV infection, as described above. Other viral pathogens are also seen in this setting, including RSV, parainfluenza virus, adenovirus, and influenza virus in lung transplant patients, and varicella zoster, which may be seen in patients with lymphoma and those undergoing steroid therapy.

These same organisms are responsible for infections in patients who develop graft versus host disease. Many of these viral pneumonias have a similar appearance, including ground-glass and consolidative opacities, centrilobular and tree-in-bud opacities, and a frequently bilateral involvement. On chest film, varicella pneumonia usually produces bilateral symmetric acinar opacities (poorly marginated nodules 7–10 mm in diameter) that may coalesce as the disease worsens. CT shows similar-sized nodules and distribution as well as ground-glass opacities.

Among the fungal organisms seen with some regularity in this group of immunocompromised patients are PJP, *Cryptococcus*, and *Aspergillus*. Other emerging agents include *Pseudallescheria/Scedosporium species, Fusarium* spp., and *Mucorales* spp. The appearance of PJP is similar to that described for patients with HIV/AIDS. A recent report suggested that PJP in patients with HIV/AIDS as opposed to non-HIV/AIDS patients might have a higher incidence of pneumatoceles, but less extensive ground-glass opacities (Hardak et al., 2010).

Cryptococcus has numerous types of presentation on chest film. Perhaps most common is the appearance of well-defined nodules, usually solitary but sometimes multiple. If the nodules become masses, the margins may become indistinct. The nodules may cavitate. *Cryptococcus* may also manifest as a lobar pneumonia or diffuse heterogeneous reticulonodular opacities.

Aspergillus fumigatus is responsible for many lung infections. Up to 10% of pneumonias following allogeneic transplantation are due to *Aspergillus*. The pattern of abnormality seen on chest film depends on the patient's immune status. In the setting of immunosuppression (neutropenia), the typical appearance is that of invasive aspergillosis. In this form, the chest film initially demonstrates a poorly marginated area or areas of homogeneous opacity that may resemble ordinary bacterial pneumonia in appearance and distribution but is occasionally rounder and farther from the subpleural lung than common community infections. In some cases, the disease is peripheral and wedge-shaped secondary to infarction caused by the angio-invasive obstruction of pulmonary vessels. In time, the lesions become more discreet and rounder, thus resembling lung masses.

As patients are treated and immune status improves, there may be cavitation within the masses with the formation of an air crescent. Wall thickness of the cavity is generally moderate. The air crescent is created by the contained necrotic debris within the cavity. On CT, initially, the areas of homogeneous opacity may have air bronchograms, and commonly, additional regions of involvement are identified. A ground glass opacity that surrounds (frequently incompletely) a more opaque center of the lesion results in the "halo sign," in which the ground glass portion is an area of hemorrhage and the central area is necrotic lung. This sign was thought to be pathognomonic of invasive aspergillosis but it is also a feature of other infections, neoplasms, and inflammatory diseases. CT may also reveal bronchial wall thickening, peribronchial opacities, and small centrilobular nodules.

Take-Home Messages: Usefulness of Imaging Methods in Pulmonary Infections

Despite the increasing use of CT imaging for diagnosing chest disorders, plain film radiography remains the primary imaging modality for patients with suspected pneumonia. The presence of an appropriate lung opacity on a chest radiograph is considered the gold standard for diagnosing pneumonia. Extensive knowledge of the radiographic appearances of pulmonary infections, their complications, and their course is essential in aiding the referring clinician and, ultimately, the patient. CT imaging is useful in patients with CAP and NP when there is a non-resolving or complicated chest film and at times in immunocompromised patients with suspected pulmonary infections. CT can help differentiate infectious from noninfectious abnormalities. CT may detect empyema, cavitation, and lymphadenopathy when chest films cannot. CT should be performed in immunocompromised patients with a clinical suspicion of pneumonia when the chest film is normal. This is especially true when the early diagnosis of pneumonia is critical, as is the case with immunocompromised and severely ill patients.

To reiterate: No pattern of abnormality seen on chest films can be considered pathognomonic of a specific infection. However, the distribution and appearance of lung opacities, especially in conjunction with clinical information, should enable one to produce a useful, ordered list of most likely possibilities helpful to our clinical colleagues and, most importantly, to our patients.

Suggested Reading

Ahuja J, Kanne JP (2014) Thoracic infections in immunocompromised patients. Radiol Clinics of North Am 52:121-136.

Albaum MN, Hill LC, Murphy M (1996) Interobserver reliability of the chest radiograph in community-acquired pneumonia. Chest 110:343.

Aquino SL, Dunagan DP, Chiles C, Haponik EF (1998) Herpes simplex virus 1 pneumonia: patterns on CT scans and conventional chest radiographs. J Comput Assist Tomogr 22: 795-800.

Aviram G, Boiselle PM (2004) Imaging features of bacterial respiratory infections in AIDS. Curr Opin Pulm Med 10: 183-188.

Bartlett JG, Dowell SF, Mandell LA et al (2000) Practice guidelines for the management of community-acquired pneumonia in adults. Infectious Diseases Society of America. Clin Infect Dis 31:347-382.

Bartziokas K, Daenas C, Preau S et al (2010) Vibration Response Imaging: evaluation of rater agreement in healthy subjects and subjects with pneumonia. BMC Medical Imaging 10:6.

Basi SK, Marrie TJ, Huang JQ, Majumdar SR (2004) Patients admitted to hospital with suspected pneumonia and normal chest radiographs: epidemiology, microbiology, and outcomes. Am J Med 117:305.

Bierry G, Boileau J, Barnig C et al (2009) Thoracic manifestations of primary humoral immunodeficiency: a comprehensive review. Radiographics 29:1909-1920.

British Thoracic Society Standards of Care Committee (2001) BTS guidelines for the management of community acquired pneumonia in adults. Thorax Suppl 4: IV1-IV64.

Carmona EM, Limper AH (2010) Update on the diagnosis and treatment of *Pneumocystis* pneumonia. Ther Adv Respir Dis 5:41-59.

Choi MH, Jung JI, Chung WD et al (2014) Acute complications in patients with hematologic malignancies. RadioGraphics 34:1755-1768.

Chou S-H S, Prabhu SJ, Crothers K et al (2014) Thoracic diseases associated with HIV infection in the era of anti-retroviral therapy: clinical and imaging findings. RadioGraphics 34:895-911.

Conees DJ (1999) Endemic fungal pneumonia in immunocompromised patients. J Thorac Imaging 14:1-8.

Connolly JE Jr, McAdams HP, Erasmus JJ et al (1999) Opportunistic fungal pneumonia. J Thorac Imaging 14:51-62.

Coy DL, Ormazabal A, Godwin JD et al (2005) Imaging evaluation of pulmonary and abdominal complications following hematopoietic stem cell transplantation. RadioGraphics 25:305-318.

Crothers K, Huang L, Goutlet JL et al (2010) HIV infection and risk for incident pulmonary diseases in the combination antiretroviral therapy era. Am J Respir Crit Care Med [Epub ahead of print].

Donnelly LF (1999) Maximizing the usefulness of imaging in children with community-acquired pneumonia. AJR Am J Roentgenol 172:505-512.

Ellis SM (2004) The spectrum of tuberculosis and non-tuberculous mycobacterial infection. Eur Radiol 14(Suppl 3):E34-E42.

Escuissato DL, Gasparetto EL, Marchiori E et al (2005) Pulmonary infections after bone marrow transplantation: high-resolution CT findings in 111 patients. AJR Am J Roentgenol 185:608-615.

Fang GD, Fine M, Orloff J et al (1990) New and emerging etiologies for community-acquired pneumonia with implications for therapy. A prospective multicenter study of 359 cases. Medicine (Baltimore) 69:307-316.

Franquet T, Gimenez A, Hidalgo A (2004) Imaging of opportunistic fungal infections in immunocompromised patients. Eur J Radiol 51:130-138.

French MA (2009) Immune reconstitution inflammatory syndrome: a reappraisal. Clin InfectDis 48:101-107.

Goodman P (2006) Radiographic assessment of HIV-related diseases. In: Peiperl L, Volberding P (eds) HIV InSite Knowledge Base. CD-ROM version.

Goodman PC (2007) Pulmonary infection in adults. In: Grainger RG, Allison DJ, Dixon AK (eds) Grainger & Allison's diagnostic radiology: a textbook of medical imaging, 5th Ed. Churchill Livingstone, London, New York, NY.

Hansell DM, Armstrong P, Lynch DA, McAdams HP (2005) The immunocompromised patient. In: Rozenshtein A (ed) Imaging of diseases of the chest, 4th Ed. Elsevier Mosby, Philadelphia, PA.

Hardak E, Brook O, Yigla M (2010) Radiological features of Pneumocystis jirovecii pneumonia in immunocompromised patients with and without AIDS. Lung 188:159-163.

Herold CJ, Sailer JG (2004) Community-acquired pneumonia and nosocomial pneumonia. Eur Radiol 14:E2-E20.

Heussel CP, Kauczor HU, Ullmann AJ (2004) Pneumonia in neutropenic patients. Eur Radiol 14:256-271.

Huang L, Cattamanchi A, Davis JL et al (2011) HIV-Associated pneumocystis pneumonia. Proc Am Thorac Soc 8:294-300.

Huang L, Crothers K (2009) HIV-associated opportunistic pneumonias. Respirology 14:474-485.

Ibrahim EH, Traey L, Hill C (2002) The occurrence of ventilator-associated pneumonia in a community hospital: risk factors and clinical outcomes. Radiology 223:884.

Jeong YJ, Lee KS (2008) Pulmonary tuberculosis: up-to-date imaging and management. AJR Am J Roentgenol 191:834-844.

Johnstone J, Majumdar SR, Fox JD, Marrie TJ (2008) Viral infection in adults hospitalized with community-acquired pneumonia: prevalence, pathogens, and presentation. Chest 134:1141-1148.

Jung JI, Kim H, Park SH et al (2001) CT differentiation of pneumonic-type bronchioloalveolar cell carcinoma and infectious pneumonia. Br J Radiol 74:490-494.

Kim EA, Lee KS, Primack SL et al (2002) Viral pneumonias in adults: radiologic and pathologic findings. RadioGraphics 22:S137.

Kollef MH, Shorr A, Tabak YP et al (2005) Epidemiology and outcomes of health-care-associated pneumonia: results from a large US database of culture-positive pneumonia. Chest 128:3854-3862.

Krishnam MS, Suh RD, Tamasian A et al (2007) Postoperative complications of lung transplantation: radiologic findings along a time continuum. RadioGraphics 27:957-974.

Lacombe C, Lewiin M, Monnier-Cholley L et al (2007) Imaging of thoracic pathology in patients with AIDS. J Radiol 88:1145-1154.

Leung AN, Brauner MW, Gamsu G et al (1996) Pulmonary tuberculosis: comparison of CT findings in HIV-seropositive and HIV-seronegative patients. Radiology 198:687.

Leung AN (1999) Pulmonary tuberculosis: the essentials. Radiology 210:307-322.

Lichtenberger III JP, Sharma A, Zachary KC et al (2012) What a differential a virus makes: a practical approach to thoracic imaging findings in the context of HIV infection – Part 1, Pulmonary findings. AJR Am J Roentgenol 198:1295-1304.

Lichtenberger III JP, Sharma A, Zachary KC et al (2012) What a differential a virus makes: A practical approach to thoracic imaging findings in the context of HIV infection – Part 2, Extrapulmonary findings, chronic lung disease, and immune reconstitution syndrome. AJR Am J Roentgenol 198:1305-1312.

Lieberman D, Shvartzman P, Korsonsky I, Lieberman D (2003) Diagnosis of ambulatory community-acquired pneumonia. Comparaison of clinical assessment *versus* chest X-ray. Scand J Prim Health Care 21:57-60.

Lim WS, Baudouin SV, George RC et al (2009) British Thoracic Society guidelines for the management of community acquired pneumonia in adults: update 2009. Thorax 64:1-55.

Little BP, Gilman MD, Humphrey KL et al (2014) Outcome of recommendations for radiographic follow-up of pneumonia on outpatient chest radiography. AJR Am J Roentgenol 202:54-59.

Mabie M, Wunderink RG (2003) Use and limitations of clinical and radiologic diagnosis of pneumonia. Semin Respir Infect 18:72-79.

Mandell LA, Bartlett JG, Dowell SF et al (2003) Update of practice guidelines for the management of community-acquired pneumonia in immunocompetent adults. Clin Infect Dis 37:1405.

Mandell LA, Wunderink RG, Anzueto A et al (2007) Infectious Diseases Society of America/American Thoracic Society consensus guidelines on the management of community-acquired pneumonia in adults. Clin Infect Dis 44 (Suppl 2):S27-S72.

Marchiori E, Zanetti G, Hochhegger B et al (2012) Reversed halo sign on computed tomography: State-of-the-art review. Lung 190: 389-394.

Melbye H (2002) Community pneumonia – more help is needed to diagnose and assess severity. Br J Gen Pract 52:886-888.

Melbye H, Dale K (1992) Interobserver variability in the radiographic diagnosis of adult outpatient pneumonia. Acta Radiol 33:79-83.

Metlay JP, Fine MJ (2003) Testing strategies in the initial management of patients with community-acquired pneumonia. Ann Intern Med 138:109-118.

Metlay JP, Kapoor WN, Fine MJ (1997) Does this patient have community-acquired pneumonia? Diagnosing pneumonia by history and physical examination. JAMA 278:1440-1445.

Mortensen EM, Copeland LA, Pugh MJ et al (2010) Diagnosis of pulmonary malignancy after hospitalization for pneumonia. Am J Med 123:66-71.

Musher DM, Thorner AR (2014) Community-acquired pneumonia. N Engl J Med 371:1619-1628.

Nambu A, Ozawa K, Kobayashi N, Tago M (2014) Imaging of community-acquired pneumonia: Roles of imaging examinations, imaging diagnosis of specific pathogens and discrimination from noninfectious diseases. World J Radiol 6:779-793.

Niederman MS, Mandell LA, Anzueto A et al (2001) American Thoracic Society. Guidelines for the management of adults with community-acquired pneumonia. Diagnosis, assessment of severity, antimicrobial therapy, and prevention. Am J Respir Crit Care Med 163:1730-1754.

Pupaibool J, Limper AH (2013) Other HIV-associated pneumonias. Clin Chest Med 34:243-254.

Primack SL, Hartmann TE, Lee KS, Mueller NL (1994) Pulmonary nodules and the CT halo sign. Radiology 190: 513-515.

Reeders JWAJ, Goodman PC (2001) Differential radiological patterns in AIDS at a glance. In: Reeders JWAJ , Goodman PC (eds) Radiology of AIDS, Springer-Verlag, Heidelberg, pp 293-324.

Reittner P, Müller NL, Heyneman L et al (2000) Mycoplasma pneumoniae pneumonia: radiographic and high-resolution CT. Features in 28 patients. AJR Am J Roentgenol 174: 37-41.

Remund KF, Best M, Egan JJ (2009) Infections relevant to lung transplantation. Proc Am Thorac Soc 6:94-100.

Reynolds JH, McDonald G, Alton H, Gordon SB (2010) Pneumonia in the immunocompetent patient. Br J Radiol 83:998-1009.

Shah RM, Wechsler R, Salazar AM, Spirn PW (1997) Early detection of pneumonia in febrile neutropenic patients: use of thin-section CT. AJR Am J Roentgenol 169:1347-1353.

Sharma S, Maycher B, Eschun G (2007) Radiological imaging in pneumonia: recent innovations. Curr Opin Pulm Med 13: 159-69.

Sider L, Gabriel H, Curry DR, Pham MS (1993) Pattern recognition of the pulmonary manifestations of AIDS on CT scans. RadioGraphics 13:771-784.

Speets AM, Hoes AW, van der Graal Y et al (2006) Chest radiography and pneumonia in primary care: diagnostic yield and consequences for patient management. Eur Resp J 28:933-938.

Syrjala H, Broas M, Suramo I et al (1998) High-resolution computed tomography for the diagnosis of community-acquired pneumonia. Clin Infect Dis 27:358.

Valles J, Martin Loeches I, Torres A et al (2014) Epidemiology antibiotic therapy and clinical outcomes of healthcare-associated pneumonia in critically ill patients: a Spanish cohort study. Intensive Care Med 40:572-581.

Vento S, Cainelli F, Temesgen Z (2008) Lung infections after cancer themotherapy. Lancet Oncol 9:982-992.

Wagner AL, Szabunio M, Hazlett KS et al (1998) Radiologic manifestations of round pneumonia in adults. AJR Am J Roentgenol 170:723.

Winer-Muram HT, Rubin SA, Ellis JV et al (1993) Pneumonia and ARDS in patients receiving mechanical ventilation: diagnostic accuracy of chest radiograph. Radiology 188:479-485.

Wunderink RG, Waterer GW (2014) Clinical practice. Community-acquired pneumonia. N Engl J Med 370:543-551.

Wunderink RG, Woldenberg LS, Zeiss J et al (1992) The radiologic diagnosis of autopsy proven ventilator-associated pneumonia. Chest 101:458-463.

Yeh JJ, Chen SC, Chen CR et al (2014) A high-resolution computed tomography-based scoring system to differentiate the most infectious active pulmonary tuberculosis from community-acquired pneumonia in elderly and non-elderly patients. Eur Radiol 24:2372-2384.