Chapter 4
Imaging of Pneumonias

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Introduction

Pneumonia is the 6th most common cause of death, and the leading cause of death from infection in the United States 1,2. The diagnosis of pneumonia requires combination of careful clinical evaluation, appropriate laboratory investigations including microbiological tests, and radiological confirmation of pneumonia. The chest radiograph is the cornerstone of radiological diagnosis, and the imaging modality of choice in establishing the presence of pneumonia, including its severity and extent. The efficacy of the clinical examination in detecting pneumonia is acknowledged to be less sensitive, with auscultatory evidence of pneumonia reported to be absent in a quarter of patients 3. In addition, Osmer and Cole found that stethoscopic findings were often not in concordance with radiographic findings 3.

As this book deals with imaging of SARS, a predominantly pneumonic illness, this chapter serves to provide a background to the radiological appearances of pneumonias of different aetiology. The main radiographic feature of any pneumonia is consolidation, defined as an opacity that obscures vascular markings, which can range from small ill-defined areas to larger areas involving one or more lobes. The pulmonary acinus is the smallest airspace unit visible on the radiograph (4-9mm in diameter) and is that part of the lung distal to the terminal bronchiole including respiratory bronchioles, alveolar ducts and alveolar sacs. Filling of the acini by fluid, whether by inflammatory exudates, transudates or blood will result in patchy areas of consolidation that could either be restricted to the secondary pulmonary lobule appearing as patchy areas of bronchopneumonia, or involve the whole lobe as lobar pneumonia. As connective tissue (interstitium) separates the secondary pulmonary lobule from each other, infective processes that affect the interstitium will produce reticular opacities on the chest radiograph. Similar opacities are however seen with pulmonary oedema and inflammatory processes including the various interstitial pneumonitides that result in lung fibrosis.

The radiographic appearances of pneumonia can be broadly classified into bronchopneumonia, lobar pneumonia or interstitial pneumonia based on the type of morphologic change at the level of the secondary pulmonary lobule 6. The radiographic manifestations of an infective process are also affected by a number of factors including age, immunological status of the host, and pre or coexisting lung conditions 7,8. Hence, the clinical settings under which pneumonias occur are an important consideration in the diagnostic algorithm, and can be categorised as community acquired infection, nosocomial
(hospital acquired) infection and infection occurring in immuno-compromised hosts. In the appropriate clinical setting the radiographic pattern can be helpful at narrowing the diagnosis to a few differential possibilities, although the radiographic features are usually not specific to any aetiological agent as an overlap often occurs.

### Key Points
- **Diagnosis of pneumonia requires combination of careful clinical evaluation, appropriate laboratory investigations including microbiological tests, and radiological confirmation of pneumonia.**
- **The chest radiograph is the cornerstone of radiological diagnosis, and the imaging modality of choice in establishing the presence of pneumonia, including its severity and extent.**
- **The radiographic appearances of pneumonia can be broadly classified into bronchopneumonia, lobar pneumonia or interstitial pneumonia.**

### Radiographic Pattern

#### I. Lobar Pneumonia

Lobar pneumonia is characterised by rapid production of oedema in the distal airspaces (alveoli) with relatively minimal cellular reaction occurring initially in the subpleural regions of the lungs. The fluid spreads from acinus to acinus through the pores of Kohn and canals of Lambert, ultimately to involve the whole lobe. This mechanism of spread respects pleural boundaries, and as the airways are largely spared, with minimal volume loss. Radiographically lobar pneumonia manifests as non-segmental homogeneous consolidation (Figure 1) involving predominantly or exclusively one lobe. As the larger airways remain patent, air-bronchograms are common associations. If untreated and particularly in *Klebsiella pneumoniae* infections, voluminous inflammatory exudates result in expansion of the involved lobe (Figure 2), often accompanied by the bulging fissure sign.

Classically, lobar pneumonia occurs from infections with *Streptococcus pneumoniae*. Other organisms that also give rise to lobar pneumonias include the aforementioned *Klebsiella pneumoniae* and *Legionella pneumoniae*. Less common organisms causing lobar pneumonia include *Mycobacterium tuberculosis*, *Actinomycosis* and *Nocardia species*, *Pseudomonas Aeruginosa* and *Escherichia coli*. 
**Streptococcus pneumoniae**

- Gram-positive bacteria, are found in 20% of the human population as commensal organisms. 
- The most common community-acquired bacterial pneumonia, found in 26% to 78% of all cases of pneumonia, and accounts for up to 40% of all isolated species in hospitalised patients with pneumonia. 
- Cause of death in 15% to 45% of community-acquired pneumonias that required admission to the intensive care unit. 
- Classical radiographic feature is lobar pneumonia (Figure 1 and 3). Other patterns include bronchopneumonia (20% to 70%), round pneumonia, and mixed airspace and interstitial opacities (13% to 22%). 
- Cavitation, pneumatocele formation and pulmonary gangrene are unusual complications that suggest polymicrobial infection. 
- Parapneumonic effusions are associated with bacteraemia.

*Figure 1*

Posterior-anterior (PA) chest radiograph in a 4-year-old child with *Streptococcus pneumoniae*. There is homogeneous opacification of the right upper lobe consistent with a lobar pneumonia.

*Figure 2*

1-year-old child with respiratory bronchiolitis secondary to *respiratory syncytial virus*. He developed superadded bacterial infection. *Klebsiella pneumoniae* was isolated from his sputum. The posterior-anterior (AP) chest radiograph shows right upper lobe consolidation with slight bulging of the horizontal fissure. Note hyperinflation and perihilar peribronchial infiltration consistent with respiratory bronchiolitis.
Figure 3
48-year-old female with multilobar consolidation due to *Streptococcus pneumoniae*. (a) Posterior anterior and (b) lateral chest radiographs show homogeneous consolidation in the right middle lobe and basal segments of the right lower lobe.

*Klebsiella pneumoniae* (Friedlander’s pneumonia)
- Gram-negative bacteria found in the oral flora.
- Immuno-suppressed individuals due to organ transplantation or cytotoxic chemotherapy, chronic debilitating disease and chronic alcoholism are at risk.
- Nosocomial rather than community acquired.
- Shares similar radiographic appearances as pneumococcal pneumonia (Figure 2)
- Bulging lobe and fissure now less common in present modern-day antibiotic era.
- Cavitation (30% to 50%)\(^\text{13,24,25}\) pleural effusions and empyema\(^\text{24,26}\) occur more frequently than pneumococcal pneumonia,

*Legionelle pneumophila*
- Aerobic gram-negative cocco-bacilli that infects humans from their natural habitat, which is water.
• Outbreaks result from infection via infected water sources such as cooling water towers, air-conditioning systems, shower heads and hot water storage tanks, rather than person-to-person.

• Immuno-compromised and elderly male patients are most susceptible.

• Accounts for 2% to 25% of community-acquired infections that required hospitalization, and 1% to 40% of nosocomial infections.

• Initial radiographic appearances are similar to those of pneumococcal pneumonia, with patchy consolidation starting at the lung periphery followed by progression to involve the whole lobe.

• Disease progression, despite antimicrobial therapy, is faster than that found in pneumococcal pneumonia, with multilobar and bilateral lung involvement.

• Cavitation is rare in immunocompetent patients and more common in immuno-compromised hosts.

• Pleural effusions are common as disease progresses in up to two third of cases.

**Key Points**

- **Lobar pneumonia** manifests as non-segmental homogeneous consolidation involving predominantly or exclusively one lobe, commonly associated with air bronchograms.

- **Streptococcus pneumoniae**, **Klebsiella pneumoniae** and **Legionella pneumoniae** are common pathogens causing lobar pneumonia.

- **Streptococcus pneumoniae** is the most common community-acquired bacterial pneumonia.

- **Klebsiella pneumoniae** causes nosocomial rather than community acquired pneumonia, and are more associated with cavitations, empyema and effusions than **Streptococcus pneumoniae**.

- **Legionella pneumoniae** outbreaks result from water-borne infection rather than person-to-person transmission.
II. Bronchopneumonia

In bronchopneumonia, there is relatively intense inflammatory exudate consisting primarily of polymorphonuclear leucocytes with oedema centred at the terminal and respiratory bronchioles. This infective process spreads along the intralobular airways until all the pulmonary lobules are involved. This gives rise to the radiographic (Figure 4) and high resolution computed tomography (HRCT) appearance of ill-defined fluffy centrilobular nodular opacities (Figure 5),

**Figure 4**
Anterior posterior (AP) radiograph of a child with bronchopneumonia secondary to Streptococcus pyogenes. There is ill-defined fluffy consolidation in the **right lung**.

**Figure 5**
HRCT scans of a 46-year-old man with Staphylococcal pneumonia. (a) Ill-defined lobular consolidation and ground glass opacities are noted in the superior segment of the right lower lobe, and also in the subpleural regions of the left upper lobe. (b) At a scan level caudad to (a) in the right lower lobe, a cavitating focal area of consolidation is noted.
which may coalesce to form a lobar pattern of consolidation, indistinguishable from lobar pneumonia \(^{42,43}\). However careful search in other areas of the lungs may reveal areas of volume loss, and segmental (lobular) distribution of abnormalities that indicates bronchopneumonia. Bronchiolar involvement can be appreciated on HRCT as branching opacities with tree-in-bud appearance.

The quintessential bronchopneumonia is exemplified by *Staphylococcus aureus* infection. As bronchopneumonia is associated with tissue destruction, complications such as pulmonary abscess, pulmonary gangrene and pneumatocele formation are quite common. Other organisms that can give rise to bronchopneumonia include most gram-negative bacteria such as *Pseudomonas Aeruginosa* and *Haemophilus influenza*, *Streptococcus pyogenes* and *Escherichia Coli*. Aspiration pneumonia from anaerobic bacteria such as *Bacteroides*, *Fusobacterium* and *Actinomyces* results in a similar bronchopneumonia pattern with predilection for gravity-dependent areas of the lungs. These areas include the superior segments of the lower lobes and posterior segments of the upper lobes in the recumbent position, and the basal segments of the lower lobes in the erect patient (Figure 6). There is right lung predominance due to the orientation of the right main bronchus. Cavitation or abscess formation develops in up to 60% of patients \(^{44}\).

![Figure 6](image.png)

*Figure 6*  
Posterior-anterior chest radiograph of a 67-year-old with cerebral infarction, who had difficulty swallowing. There are bilateral ill-defined patches of consolidation in the lower lobes, consistent with aspiration pneumonia. Note nasogastric tube instiut.
**Staphylococcus aureus**
- Gram-positive coagulase-producing bacteria, which rarely affect healthy adults\(^{16,45}\).
- Commonly affects debilitated hospitalised patients via aspiration of S Aureus from upper respiratory tract\(^ {46,47}\).
- Haematogeneous route is another method of spread in subacute bacterial endocarditis particularly in intravenous drug abusers (Figure 7), septic thrombophlebitis, and staphylococcal infection of indwelling catheters.
- Bronchopneumonia (Figure 5a) is the typical radiographic appearance although lobar pneumonia can sometimes be found.
- Lung abscesses are common, and if erosion into the bronchial tree occurs, air-fluid levels are seen (Figure 5b).
- Pneumatoceles are more common in children, and are thought to be due to ball-valve obstruction in small airways.
- Up to 50\% of staphylococcal pneumonia develop either pleural effusion of empyema, the latter is more commonly found in children\(^ {48}\).

![Figure 7](image)

**Figure 7**
Posterio-anterior chest radiographs of a male 35-year-old intravenous drug abuser who presented with rigors and fever. (a) Ill-defined patchy consolidation is noted in both lungs with bilateral small effusions. (b) Further evaluation of the patchy consolidation reveals cavitation (arrows) within the consolidation consistent with multiple septic emboli. **Staphylococcus pneumoniae** was cultured from his blood.
**Pseudomonas aeruginosa**

- Gram-negative rods, which are normal commensals in the human intestine and skin.
- It is the most lethal form of nosocomial infection, accounting for 20% of nosocomial pneumonia in adult ICU patients. High fatality rates are related to pre-existing disease such as chronic obstructive pulmonary disease (COPD), and multiorgan failure.
- Bronchopneumonia is the predominant radiographic pattern. Other patterns include multinodular and reticular patterns, and occasionally pulmonary infarction resembling invasive aspergillosis (Figure 8).

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**Figure 8**

A 29-year-old female with acquired immunodeficiency syndrome (AIDS). Posterio-anterior chest radiograph shows multiple peripheral wedge-shaped consolidation. *Pseudomonas aeruginosa* was cultured from her sputum.

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**Haemophilus Influenza**

- Gram-negative coccobacilli
- Accounts for between 5% and 20% of community-acquired pneumonias.
- Risk factors include advanced age, pre-existing lung disease such as COPD, chronic alcoholism, and immunocompromised patients with diabetes, immunoglobulin defects and AIDS.
- Variable radiographic pattern. Majority (50% to 60%) present with bronchopneumonia (Figure 9), while lobar consolidation is noted in 30% to 50% of cases either in isolation.
or in combination with bronchopneumonia. Nodular and interstitial patterns are rare, while pleural effusions are found in 50% of cases.

**Figure 9**
A 36-year-old female with community-acquired *Haemophilus influenzae* pneumonia. Patchy areas of bronchopneumonia are noted in both lower lobes.

**Esherichia Coli**
- Gram-negative bacilli that are commensals in the human small and large bowel.
- Affects debilitated people. Accounts for 5% to 20% of hospital-acquired and nursing home acquired pneumonias.
- Multilobar bronchopneumonia with lower lobe predominance and pleural effusions are common, while cavitation is uncommon.

**Key Points**
- *In bronchopneumonia, the infection is centred on the terminal and respiratory bronchioles with spread along the intralobular airways until all the pulmonary lobules are involved.*
- *Typical radiographic and HRCT appearances are ill-defined fluffy centrilobular nodular opacities (Figure 5), which may coalesce to from a lobar pattern of consolidation, indistinguishable from lobar pneumonia.*
Bronchiolar involvement can be appreciated as tree-in-bud opacities on HRCT.

Organisms that commonly cause bronchopneumonia include Staphylococcus Aureus, Pseudomonas Aeruginosa and Haemophilus influenza, Streptococcus pyogenes and Escherichia Coil.

Staphylococcus Aureus rarely infects healthy individuals, and acquired either haematogeneously or from aspiration of infected upper respiratory tract secretions. Cavitations, pneumatoceles, pleural effusions and empyemas are common associations.

III. Infectious Interstitial Pneumonia

This pattern of pneumonia results from inflammatory process with oedema centred on the interstitium, and bronchiolar and airway walls giving rise to reticular, reticulonodular and small nodular appearance. Insidious infections will result in lymphatic infiltration of the alveolar septae without parenchymal abnormality. However with more virulent infections, there is rapid progressive pneumonia that results in diffuse alveolar damage affecting both interstitium and airspaces. Organisms that are responsible for this pattern of pneumonia are mainly viruses, Mycosplama pneumoniae and Pneumocyctis Carinii.

Viruses

- Viral pneumonias that afflict immuno-competent hosts are Influenza A and B in adults, and respiratory syncytial virus, parainfluenza virus and influenza virus in children. Type A influenza causes epidemics and all pandemics, while type B influenza results in outbreaks and is more common in schoolchildren. Respiratory syncytial virus most commonly affects infants and small children and is normally restricted to an upper respiratory tract infection.

- Viral pneumonias that affect immuno-compromised hosts are cytomegalovirus, herpes simplex type 1 virus, varicella-zoster virus and adenovirus. Cytomegalovirus infection is common in solid-organ and bone marrow transplant recipients (Figure 10), while varicella-zoster pneumonia usually occurs as a complication of chicken pox,
although predisposing factors include neoplastic disease, immune deficiency and pregnancy.

![Figure 10](image)

**Figure 10**
Posterior anterior chest radiographs of a 43-year-old man with *cytomegalovirus* infection obtained (a) before and (b) after treatment. Multiple small nodules, almost miliary in distribution and appearance are noted bilaterally in (a), which resolved completely in (b). Note pneumomediastinum in (b) due to peritoneal dialysis. The patient had undergone renal transplantation 6 months previously, but suffered rejection almost immediately, and had to have the transplanted kidney surgically removed.

- Viral pneumonias predominantly infect the terminal and respiratory bronchioles with extension of the inflammatory processes to the adjacent interstitium resulting in an interstitial pneumonia. With more severe inflammation, filling of the alveoli with hyaline membranes and inflammatory exudates, which may be haemorrhagic, causes diffuse alveolar damage.
- The radiological features in viral pneumonias are variable and overlapping, and do not allow diagnosis of a specific virus. Viral pneumonias can manifest as poorly defined nodules (4-10mm in diameter), bronchial wall thickening, peribronchial opacities (Figure 11), perihilar linear opacities and patchy areas of ground glass opacities and consolidation. Due to associated bronchiolitis, air-trapping is common particularly in lower respiratory tract *respiratory syncytial virus* infection (Figure 2).
With severe fulminant viral pneumonias, there is homogeneous or patchy consolidation and ground glass opacities (Figure 12), associated with poorly defined centrilobular nodules.

Figure 11
Posterior anterior chest radiograph of a 2-year-old boy with metapneumovirus pneumonia showing perihilar peribronchial thickening and infiltrates.

Figure 12
a) Posterior anterior chest radiographs of a 6-year-old girl with adenovirus pneumonia showing right lower zone ground-glass opacities and bronchial wall thickening. There is a dense collapse-consolidation of the left lower lobe with an air-filled lucency. b) Computed tomography scan of the same patient shows ground-glass opacities and consolidation in the right lower lobe and bronchial wall thickening. There is chronic collapse-consolidation in the left lower lobe with a large cavity.
• Cavitation and pleural effusions are not prominent features. Hilar adenopathy is common with measles and varicella-zoster pneumonias but rare in other viral pneumonias.
• The above radiological features particularly centrilobular nodules, ground glass opacities, consolidation (Figure 12) and air trapping are best demonstrated on HRCT or CT scans. A predominant CT pattern of consolidation and ground glass opacities in a lobular pattern reflects diffuse alveolar damage. Interstitial inflammatory infiltration is represented by thickened interlobular septae or as ground glass opacities on HRCT. Areas of inflammatory or haemorrhagic nodules, and organising pneumonia on histopathology correspond to poorly defined centrilobular nodules on HRCT.
• Varicella-zoster and influenza pneumonias are associated with the highest frequency of centrilobular nodules on HRCT and chest radiographs, in addition to ill-defined consolidation and ground glass opacities. The nodules in varicella-zoster infection range from 5 to 10mm, and in less than 2% of patients these nodules may calcify as diffuse small foci throughout both lungs. Superadded bacterial infection may occur (Figure 2), particularly in Influenza pneumonia with S. pneumoniae, S. aureus and H. influenzae.

*Mycoplasma pneumoniae*
• *M pneumoniae* is a common cause of community-acquired pneumonia, accounting for up to 20% of pneumonias in the general population.
• Its clinical presentation and radiographic appearances resemble viral pneumonias. A mixed pattern of airspace and interstitial opacities, segmental (lobular) consolidation or diffuse reticulonodular opacities can be found (Figure 13).
• Pleural effusion and empyema are uncommon. The segmental distribution of consolidation, centrilobular opacities and interstitial opacities are better appreciated on HRCT than on chest radiographs.
**Pneumocystis carinii**

- *P. carinii* (PCP) is now considered more closely related to fungi than protozoa by most authorities\(^7^6\).
- It is almost exclusively a pathogen of immunocompromised hosts, accounting for approximately 60% of cases of pneumonia in AIDS patients\(^7^7\), particularly in those with CD\(_4\) count of < 200 cells/mm\(^3\)\(^7^8\). It is also prevalent in post transplant recipients\(^7^9\), and in patients with malignancies\(^8^0\) and connective tissue disorders\(^8^1\).
- The classic radiographic appearance is bilateral perihilar reticular, or reticulonodular opacities (Figure 14) that rapidly progress (3-5 days) to diffuse airspace consolidation involving almost the entire lungs (Figure 15)\(^7^7\), at which time acute respiratory distress syndrome may have supervened.

**Figure 14**
A 48-year-old with human immunodeficiency virus (HIV) infection, who developed *Pneumocystis carinii* (PCP) pneumonia. There are reticulonodular opacities around and radiating from the hilar and mediastinum.

**Figure 15**
*Pneumocystis carinii* (PCP) pneumonia in a 32-year-old man who had to be mechanically ventilated. There is diffuse consolidation affecting both lungs, with airbronchograms. This appearance is indistinguishable from acute respiratory distress syndrome.

- Unusual radiographic appearances include solitary or multiple nodules that cavitate\(^8^2\), lobar consolidation\(^7^7,^8^3\), pleural effusions\(^7^7,^8^4\) and enlarged mediastinal lymph nodes\(^8^5\). Pneumatoceles develop in 10% of cases, rupture of which may lead to spontaneous pneumothorax\(^8^6\).
• On CT and HRCT, the predominant abnormality is ground glass opacities, which may be diffuse (Figure 16) or patchy. In one series using HRCT for evaluation, consolidation was not found to be a main feature of PCP, although in another study using CT for evaluation, consolidation was present in 40% of cases. Resolution of ground glass opacities and consolidation may be incomplete, leaving residual interstitial opacities suggestive of fibrosis.

**Figure 16**
HRCT scan showing diffuse ground glass opacification in patient with *pneumocystis carinii* (PCP) pneumonia.

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**Key Points**

- Interstitial pneumonia results from inflammatory process centred on the interstitium, and bronchiolar and airway walls giving rise to reticular, reticulonodular and small nodular appearance.
- Viruses, *Mycoplama pneumoniae* and *Pneumocystis Carinii* are common causes.
- Radiological features of viral pneumonias are variable and overlapping: poorly defined nodules (4-10mm in diameter), bronchial wall thickening, peribronchial opacities, perihilar linear opacities and patchy areas of ground glass opacities and consolidation.
- Cavitation, pleural effusions and hilar adenopathy are not common features of viral pneumonias.
On HRCT interstitial inflammatory infiltration is represented by thickened interlobular septae or as ground glass opacities. A predominant pattern of consolidation and ground glass opacities in a lobular pattern reflects diffuse alveolar damage.

Pneumocystis Carinii is almost exclusively a pathogen of immunocompromised hosts. It classically appears as bilateral perihilar reticular, or reticulonodular opacities which rapidly progress to diffuse airspace consolidation.

**Mycobacterium Tuberculosis**

*M Tuberculosis* bacilli are acid-fast aerobic bacteria. The incidence of pulmonary TB was in decline until the mid-eighties when there was resurgence in numbers due to the emergence of AIDS. The radiological manifestations of pulmonary TB are dependent on a number of factors primarily age of the patient, previous exposure to TB and host immune status. In immunocompetent patients there are 2 distinct patterns of pulmonary TB: primary TB in individuals without previous exposure, and post-primary TB in individuals with prior exposure who have acquired specific immunity.

**Primary pulmonary tuberculosis**

- Droplet infection is the mode of transmission, with droplets containing *M Tuberculosis*, infecting the gravity dependent regions of the lungs from which infection disseminates. Primary pulmonary TB can involve the tracheobronchial tree, lung parenchyma, mediastinal and hilar lymph nodes or pleura.
- Children with primary pulmonary TB may be clinically asymptomatic and without radiographic abnormalities while adults are usually symptomatic.
- The radiographic appearance of the primary focus (Ghon focus) is non-specific and can range from ill-defined airspace opacities to bronchopneumonia (Figure 17) and lobar consolidation. Right upper lobe is most commonly involved while the right middle lobe is least commonly involved. It is multifocal in 25% of cases and bilateral in 10% (Figure 18). Pleural effusion is more common in adults while enlarged mediastinal and hilar lymph nodes are more frequently present in children.
Figure 17
This is anterior-posterior chest radiograph of 12-year-old child showing ill-defined areas of consolidation. Her sputum was positive for *Mycobacterium tuberculosis*.

Figure 18
a) Posterior-anterior and (b) lateral chest radiographs of a 27-year-old female with primary pulmonary tuberculosis showing cavitating focal consolidation in the superior segment of the lower lobe, and more unusually another focal area of consolidation in the anterior segment of the right upper lobe.

- On CT, peripheral rim enhancement of the lymph nodes is present. The central low attenuation areas represent caseation necrosis.
- Cavitation is found in 8% to 29% of primary TB (Figure 19) \(^{91,94}\).
• Endobronchial spread occur after breakdown of a lobar infection or rupture of infected lymph node into a bronchus. Radiographically it is noted as ill-defined 5-10mm centrilobular nodules (Figure 19) \(^95\), while on HRCT, poorly defined centrilobular nodules (2-4mm in diameter), branching centrilobular opacities with tree-in-bud configuration (Figure 20), acinar shadows (4-10mm) and bronchopneumonia are seen \(^90,96,97\).

• Haematogenous spread results in diffuse miliary nodules (<3mm diameter)(Figure 21).

**Figure 19**
A 24-year-old female with endobronchial spread in primary pulmonary tuberculosis. (a) Posterior anterior chest radiograph showing an area of consolidation in the right lower zone, with (b) multiple small ill-defined nodules (2-4mm in diameter) seen predominantly in the right lung.

**Figure 20**
HRCT scan showing centrilobular nodules with tree-in-bud (arrows) configuration in the superior segment of the right lower lobe in a patient with endobronchial tuberculosis.
Post-primary tuberculosis

- Reactivation of previously dormant primary infection accounts for 90% of cases, while exogenous re-infection is rare. Risk factors for re-infection include immunosuppression, malnutrition, old age, and debilitation.
- Typical radiographic appearances are focal ill-defined consolidation with adjacent satellite nodules, cavitation in single or multiple sites, upper lobe predominance (apical and posterior segments), and absence of lymphadenopathy.
- Miliary TB is denoted on HRCT as tiny (<4mm) well-defined nodules with random distribution throughout the lungs.
- Tuberculomas are common. These are solitary nodules, 1 to 4cm in diameter with smooth margins although spiculated and lobulated margins can be found. Satellite lesions are commonly associated, and calcification occurs with time.
- Prolonged infection results in severe upper lobe fibrosis with bronchiectasis and tracheomegaly in both primary and post-primary TB.
Figure 22
65-year-old male with post-primary tuberculosis in the upper lobes. (a) HRCT shows multiple cavitating lesions (arrows), and smaller nodules (arrows) in both lung apices. Reticulation in the right lung suggests mild fibrosis. (b) Caudad to (a), areas of bronchopneumonia (asterisk) are noted together with bronchial wall thickening and dilatation (arrowheads).

Figure 23
HRCT scans of a 46-year-old man with reactivation of tuberculosis. (a) Cavitating area of consolidation is noted in the posterior segment of the right upper lobe. (b) Centrilobular and tree-in-bud opacities (arrows) are noted in the anterior segment of the right upper lobe.
Non-tuberculous Mycobacteria (NTMB)

- Commonly caused by *Mycobacterium avium-intracellulare* and *M. Kansasii*.

- *M. xenopi, M. fortuitum* and *M. chelonae* are uncommon pathogens for pulmonary infections although they tend to cause a spectrum of pulmonary, cervical lymph node, cutaneous and soft tissue infections.

- Pre-existing lung disease is often present, particularly in elderly white Caucasian males but not in women.

- There is a considerable overlap in radiographic features between NTMB and *M tuberculosis* infections.

- Characteristic radiographic appearances in males include bronchiectasis, cavitation (80% to 95%), pleural thickening (37% to 56%) and upper lobe fibrosis. Endobronchial spread is found in 40% to 70% of cases with typical features of branching centrilobular nodules on HRCT.

- Characteristic radiographic appearances in women are bronchiectasis and centrilobular nodules (Figure 25) without upper lobe predilection, although the bronchiectasis is “typically” found in the right middle lobe and lingula. Pleural effusions and mediastinal lymphadenopathy are rare.
Key Points

- **Primary TB lesions can range from ill-defined airspace opacities to bronchopneumonia and lobar consolidation.** Necrotic lymph nodes and cavitation are common features.

- **Post-primary TB is characterized by focal ill-defined consolidation with adjacent satellite nodules, cavitation in single or multiple sites, upper lobe predominance (apical and posterior segments), and absence of lymphadenopathy.**

- **In both primary and post-primary TB, endobronchial spread and military TB can occur.** Endobronchial spread is characterised by presence of ill-defined centrilobular nodules (2-4mm in diameter), branching centrilobular opacities with tree-in-bud configuration (Figure 21), acinar shadows (4-10mm) and bronchopneumonia on HRCT.

- **Non-tuberculous mycobacteria infection is commonly caused by *Mycobacterium avium-interacellulare* and *M. Kansasii*.**

- **There is a considerable overlap in radiographic features between NTMB and *M tuberculosis* infections.**

Fungal Pulmonary Infections

- Fungi can be categorized into 2 groups: primary pathogens that infect healthy individuals, and opportunistic pathogens that affect immunocompromised individuals or pre-existing lung conditions.

- *Histoplasma capsulatum, Coccidioides immitis* and *Blastomyces dermatitidis* represent the first group of pathogens and are usually saprophytes

- *Aspergillus* and *Candida* species form the opportunistic group.

- In acute histoplasmosis (*H. capsulatum*) chest radiographs can be normal although ill-defined consolidations with hilar lymphadenopathy are common. Miliary nodules (3-4mm) resembling miliary TB are seen in the disseminated histoplasmosis. In chronic histoplasmosis, the radiographic appearances are indistinguishable from postprimary TB.
• In coccidioidomycosis (*C. immitis*), the chest radiograph may be normal, or show segmental consolidations with lower lobe predominance, which may resolve and reappear elsewhere in the lung. Prolonged infection is characterized by peripheral lung nodules (5mm to 5cm) in the upper and middle lung zones, with cavitation in 10% to 15% of cases. Chronic infection results in cavities and fibrosis.

• Aspergillosis is usually caused by *A. fumigatus* and *A. niger*. Aspergillosis can manifest in 3 ways: (a) as a saprophytic fungal ball in immunocompetent host with pre-existing lung conditions such as asthma, COPD, bronchiectasis or cavitatory lung disease without invasion of host tissue; (b) as allergic aspergillosis; and (c) as invasive aspergillosis. In allergic aspergillosis, mucoid impaction of ectatic bronchi are typically seen with finger-in-glove, or cluster of grapes appearance while invasive aspergillosis can manifest as bronchopneumonia (Figure 26), an angioinvasive process (Figure 27), acute tracheobronchitis or chronic necrotising infection. Angioinvasive aspergillosis is most common, characterised by focal cavitating opacities (Figure 27), and on CT or HRCT a halo sign may be found.

**Figure 26**
A 42-year-old man with acute myeloid leukaemia with *Aspergillus Fumigatus* pneumonia. (a) Posterior-anterior chest radiograph shows ill-defined opacities in both lungs. Note Hickman line in situ. (b) HRCT scan confirms presence of ill-defined areas of bronchopneumonia mainly in the subpleural regions of the lungs.
**Figure 27**
Posterior-anterior chest radiograph in a 60-year-old man with acute myeloid leukaemia and invasive aspergillosis. Cavitation is noted within the area of consolidation in the right lower lobe.

• Cryptococcus (*C neoformans*), infect both immunocompetent and immunocompromised individuals with AIDS or lymphoma $^{104}$. The most common radiographic manifestation is single or multiple nodules (5mm to 4cm) usually peripheral in site (Figure 28), followed by ill-defined consolidation. Cavitation, enlarged mediastinal and hilar lymph nodes, and disseminated disease including multiple or miliary nodules are found in immunocompromised hosts $^{105,106}$.

**Figure 28**
HRCT scan in a 47-year-old female with cryptococcus infection. (a) There is a large subpleural area of consolidation in the superior segment of the left lower lobe with surrounding ground glass opacity and satellite nodules. (b) Smaller nodules associated with ground glass opacities are also found in the both upper lobes and in the left lower lobe.
Key Points

- **Histoplasma capsulatum**, **Coccidiodes immitis** and **Blastomyces dermatitidis** are fungi that infect immunocompetent individuals as saprophytes.
- **Aspergillus** and **Candida** species are opportunistic fungi that infect immunocompromised hosts.
- Both acute and chronic histoplasmosis infection can mimic mycobacterial infections.
- **Aspergillosis** can manifests in 3 clinical syndromes: as saprophytic fungal ball, allergic aspergillosis and invasive aspergillosis.

Utility of Computed Tomography

CT or HCRT evaluation of pneumonias serves as a useful adjunct to chest radiographs in selected circumstances when the chest radiograph is non-revealing or non-diagnostic and to evaluate complications of pneumonia such as abscess formation (Figure 29), empyema, parapneumonic effusions and bronchopleural fistulas (Figure 30). 

CT and HRCT provide greater anatomic detail and superior morphologic evaluation of opacities including their pattern and extent. Ground glass opacities, consolidation, centrilobular nodules, peribronchial distribution, airbronchograms, septal thickening, and bronchial wall thickening are all better appreciated on CT and HRCT than chest radiographs. Identification of pleural, pericardial or lung complications in pneumonias directs appropriate and early management of these complications.

*Figure 29*

Contrast enhanced CT scan showing consolidation in the anterior segment of the right middle lobe with central area of cavitation and air-fluid level. Right pleural effusion is also present.
Several studies have also reported the utility of HRCT in the early detection of pneumonia in immunocompromised patients with neutropenic fever and normal chest radiograph.\textsuperscript{114,115}

**Figure 30**
Bronchopleural fistula demonstrated on (a) axial CT section and (b) two-dimensional reformation showing a large air-filled pleural cavity in direct communication with the apicoposterior segmental bronchus of the left upper lobe (arrows). The patient had history of tuberculous infection that had destroyed part of the left upper lobe.

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**Key Points**

- The role of CT or HRCT in the imaging of pneumonias is to (a) further characterize lung lesions or detect pneumonia when the chest radiograph is non-revealing or non-diagnostic, and (b) evaluate complications of pneumonia such as abscess formation, empyema, parapneumonic effusions and bronchopleural fistulas.
References


