

Opportunistic bacterial, viral and fungal infections of the lung

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Abstract

Opportunistic infections are a major cause of morbidity and mortality in severely immunocompromised patients, such as those receiving chemotherapy or biological therapies, and those with haematological malignancy, aplastic anaemia or HIV infection, or recipients of solid-organ or stem cell transplants. The type and degree of immune defect dictates the profile of potential opportunistic pathogens; T-cell mediated defects increase the risk of viral (cytomegalovirus and respiratory viruses) and *Pneumocystis jirovecii* infections, whereas neutrophil defects are associated with bacterial pneumonia and invasive aspergillosis. However, patients often have combinations of immune defects and a wide range of other opportunistic infections can cause pneumonia. Importantly, conventional non-opportunistic pathogens are also frequently encountered in immunocompromised hosts and these should not be overlooked. The radiological pattern of disease (best assessed by CT scan) and speed of onset help identify the likely pathogen(s), which can then be supported by targeted investigation including early use of bronchoscopy in selected patients. Rapid and expert clinical assessment can identify the most likely pathogens, which can then be treated aggressively and so provide the best opportunity for a positive outcome.

Keywords

Aspergillus; fungi; immunocompromised host; opportunistic infections; pneumonia; viruses; Nocardia, Cryptococcus

Introduction

Opportunistic infections occur when loss of established innate or adaptive immune responses allow an organism that is normally weakly virulent to cause infection. The type and degree of immune defect dictate the profile of potential opportunistic pathogens (Table 1). Infections commonly encountered in healthy individuals should not be forgotten as they can also cause infection in immunocompromised hosts. Opportunistic lung infections are a major cause of morbidity and mortality for patients immunocompromised because of HIV infection, haematological malignancy, aplastic anaemia or chemotherapy treatment, or who are recipients of solid-organ or stem cell transplants, and also may complicate treatment with the new biological therapies for inflammatory conditions.¹ Expert clinical assessment with early diagnosis and aggressive treatment are required for a positive outcome. The CT scan is more sensitive than the chest radiograph at defining the predominant pattern(s) of lung involvement, and when combined with knowledge of the patient's immune status (loss of T-cell or antibody-mediated immunity, or defects in neutrophil-mediated immunity) can often identify the most likely pathogens. This review provides a concise overview of the most common opportunistic lung infections.

Bacteria

Conventional bacterial pathogens

Although the risk of opportunistic infection is high in immunocompromised patients, the majority of pneumonias are related to the more conventional bacterial pathogens that present similarly to pneumonia in immunocompetent individuals¹, with fever, respiratory symptoms, focal consolidation and rapid rises in inflammatory markers. These are particularly common post-viral illness. The major risk factors are neutropenia, antibody deficiencies and high-dose corticosteroids. The organisms involved are more diverse than those seen in conventional pneumonia and are more likely to be resistant to first-line antibiotics. These include both Gram-positive (*Streptococcus pneumoniae*, *Staphylococcus aureus*) and Gram-negative (e.g. *Pseudomonas aeruginosa*, *Proteus* species, *Escherichia coli* and other enteric pathogens) organisms. Re-activation of latent tuberculosis also occurs and *Mycobacterium tuberculosis* cultures and PCR need to be done on respiratory samples of immunocompromised individuals with pulmonary infiltrates, particularly in high prevalence areas

Nocardiosis

Nocardiosis is an uncommon Gram-positive bacterial infection with a high mortality in disseminated disease. There are over 80 *Nocardia* species but those usually involved in human disease are the *Nocardia asteroides* complex. *Nocardia* are found in soil, decaying vegetable matter and stagnant water. Inhalation is the commonest route of entry so pneumonia is the commonest infection. The main risk factors are defects in T-cell mediated immunity (e.g. post-transplantation), prolonged glucocorticoid therapy, malignancy, graft versus host disease (GVHD), diabetes mellitus, chronic granulomatous disease and alveolar proteinosis. *Nocardia* pneumonia usually develops over weeks with cough, haemoptysis, weight loss, fever and night sweats but can be more acute. Common radiological features are patches of dense consolidation or macronodules, frequently pleurally based. Cavitation and pleural effusions are common. These appearances can be mistaken for metastasis. Local spread to the pericardium and mediastinum, and haematogenous spread to brain, joints and soft tissue occur in about half of patients. The diagnosis can be made rapidly through identification of characteristic beaded, branching Gram-positive and weakly acid-fast filaments on microscopy. Blood and sputum cultures can be positive but require prolonged aerobic culture. Susceptibility to antibiotics varies among the *Nocardia* sp. and treatment with two or three intravenous antibiotics may be necessary initially in immunocompromised individuals. Trimethoprim–sulfamethoxazole is first-line therapy, with carbapenems, amikacin, third-generation cephalosporins, tetracyclines or amoxicillin–clavulanate as alternatives. Duration of treatment is prolonged – up to 12 months in immunocompromised patients and central nervous system (CNS) disease.

Viral infections

Respiratory viruses

Lower respiratory tract infections with the respiratory viruses (respiratory syncytial virus, parainfluenza, influenza, adenovirus, metapneumovirus, coronavirus and rhinovirus) are relatively common in immunocompromised patients with defects in T-cell mediated immunity. Respiratory viruses usually cause a bronchiolitis that presents with coryzal symptoms, cough, fever and dyspnoea. In a minority of patients auscultation of the lungs reveals characteristic squeaks or wheeze. The chest radiograph is often normal or non-specific. CT scans classically demonstrate diffuse 'tree in bud' changes suggestive of small airways inflammation, but can also show ground glass infiltrates. The diagnosis can be confirmed rapidly using nasopharyngeal aspirate (NPA) samples for viral antigen immunofluorescence or PCR for viral nucleic acids, the latter being favoured in immunocompromised hosts. If NPA is negative, immunofluorescence or PCR on bronchoalveolar lavage fluid (BALF) has a higher sensitivity.⁵ In the absence of pneumonia, the mortality from respiratory virus infection is relatively low although infection can persist for several weeks. Treatment is supportive but in immunocompromised hosts specific antiviral treatment is recommended ([Table 2](#)) and in cases of severe infection combination with intravenous immunoglobulin is considered. Viral infection, particularly influenza (including H1N1) has effects on lung host defence and predisposes to secondary bacterial infection³, which in immunocompromised hosts

(particularly chronic glucocorticoid use, chemotherapy for cancer and haematopoietic stem cell transplant (HSCT) recipients) may lead to more severe illness. Clinically this is suspected when there is relapse of fever and respiratory symptoms with new radiographic evidence of infiltrates, but it is important to note that immunocompromised individuals fever may not be present. Antibiotic treatment for secondary bacterial infection should cover the most commonly encountered organisms post-influenza, which include *Strep. pneumoniae*, *Staph. aureus* and *Haemophilus influenzae*. More recently, novel viruses have emerged including the Middle East Respiratory Syndrome coronavirus and the avian influenza A strain H7N9, which although there is a low rate of transmission the mortality associated with infection is high.¹ Treatment of these infections is supportive.

Cytomegalovirus and other herpesviruses

The herpesvirus cytomegalovirus (CMV) is an important cause of lung infection in patients with impaired T-cell-mediated immunity such as transplant recipients. CMV infection is defined as active CMV replication regardless of symptoms or signs, whilst CMV disease is infection associated with evidence of organ-specific disease. CMV infection in immunocompromised patients is usually due to reactivation of latent CMV acquired in early life, but can also be primary infection in previously uninfected individuals, in whom it is often more severe. Pneumonitis is an important complication, and commonly presents with insidious onset of fever, malaise, cough and dyspnoea with hypoxia. Classic features on CT scan are symmetrical peribronchovascular and alveolar infiltrates predominantly affecting the lower lobes, but asymmetric changes, consolidation and effusions are not uncommon.

In suspected CMV infection/disease CMV replication can easily be identified and the viral load determined by polymerase chain reaction (PCR) or CMV pp65 antigen testing of blood or BALF. CMV infection can also be identified by culture of urine, throat and BALF specimens. Evidence of CMV reactivation does not always mean that concurrent lung disease is caused by CMV, and conversely CMV viraemia can occasionally be absent in patients with CMV pneumonitis. CMV pneumonitis is more likely with high-level viraemia, especially if the viral load increased rapidly. CMV pneumonitis can be confirmed by finding inclusion bodies in BALF cells or transbronchial or video-assisted thoracic surgery (VATS) biopsy samples.

First-line treatment of CMV pneumonitis is intravenous ganciclovir or oral valganciclovir. Second-line treatments include foscarnet, cidofovir and maribavir. CMV immunoglobulin can be used as an adjunct to therapy in immunocompromised individuals. Treatment efficacy is monitored by measuring blood CMV viral load, with treatment usually continued for at least 2 weeks after resolution of viraemia. Other herpesviruses such as herpes simplex virus (HSV), varicella zoster (VZV) and human herpesvirus (HHV) 6 are rare causes of diffuse pneumonitis similar to CMV in the immunocompromised host and may be associated with the characteristic rash. First line treatment of HSV and VZV is with acyclovir but valacyclovir, famciclovir, cidofovir and foscarnet can also be used. No drug has been specifically approved for the treatment of HHV-6 but ganciclovir and foscarnet are recommended by experts for the treatment of severe HHV-6 infection.²

Fungal infections

Treatment options for fungal pneumonias are listed in Table 3.

***Pneumocystis jirovecii* (formerly *P. carinii*)**

P. jirovecii pneumonia (PJP) is the most common AIDS-defining illness (CD4 counts <200 cells/mm³) but is also important in non-HIV immunocompromised patients with defects in T-cell mediated immunity or who are taking prolonged high-dose systemic glucocorticoids. Clinical presentation is classically insidious with slowly increasing dyspnoea, dry cough and hypoxaemia with few physical or radiologic findings, but can be fulminant. Exercise-induced oxygen desaturation is a sensitive marker. The chest radiograph features are diffuse, bilateral, interstitial infiltrates but can be normal, whereas high-resolution CT scan is much more sensitive and often shows extensive ground glass opacities with an apical distribution and peripheral sparing. Pneumatocoeles are not uncommon, and chronic infection can lead to bizarre-looking

cystic changes. PJP cannot be cultured and diagnosis requires identification of the organism in induced sputum or BALF by microscopy with Giemsa and Grocott stains. Immunofluorescence and PCR techniques increase the diagnostic yield but false-positive PCR can occur due to PJP lung colonization. *P. jirovecii* can be found in BALF for 48–72 hours after starting empirical treatment. First-line treatment is high-dose trimethoprim–sulfamethoxazole for 21 days, with adjunctive corticosteroids for severe hypoxaemia ($pO_2 < 8$ kPa) (Table 3). Second-line therapies include clindamycin plus primaquine, pentamidine, atovaquone, or trimethoprim plus dapsone. Prophylaxis with trimethoprim–sulphamethoxazole or nebulized pentamidine is recommended in patients with HIV infection (CD4 count < 200 cells/mm³), transplant recipients (solid organ and haematopoietic stem cell transplantation (HSCT)) and those receiving prolonged high-dose glucocorticoids (> 20 mg/day for 21 days or longer).³ Mortality is about 10%.

Invasive aspergillosis

Aspergillus species are ubiquitous and continuously inhaled by all humans but usually establish infection only when there are major defects in phagocyte function, such as severe and prolonged neutropenia (e.g. after HSCT or aplastic anaemia), in patients taking high-dose glucocorticoids, or in those with haematological malignancy or chronic granulomatous disease. Chronic graft versus host disease (GVHD) is also a significant risk factor and, rarely, patients with chronic lung disease or milder forms of immunosuppression can develop semi-invasive forms of aspergillosis. The most common infective species is *Aspergillus fumigatus*. The respiratory tract (including the sinuses) is most often affected, although blood-borne spread to internal organs (especially the CNS) and skin can occur. The classic presenting triad in invasive pulmonary aspergillosis (IPA) is fever, chest pain and haemoptysis, although fever alone or various respiratory symptoms can occur. *Aspergillus* has a predilection for growing into blood vessels, potentially causing fatal massive haemorrhage. Chest radiographs show patchy infiltrates or nodules that can cavitate. CT scan features include macronodules (single or multiple, with or without cavitation), or patchy consolidation. Nodules may show the ‘halo’ (surrounding ground glass infiltrates due to haemorrhage) or ‘air-crescent’ (cavitation around a fungal ball) signs. When the patient's immune function recovers, fungal balls may form in a walled-off cavity created by the invasive phase of the disease. Other manifestations of invasive aspergillus infections affecting the lung include:

- *Aspergillus* tracheobronchitis, in which infection is restricted to the tracheobronchial tree causing a relentless cough. CT scans may show focal bronchial wall thickening and ‘tree and bud’ changes.

Bronchoscopy is diagnostic, identifying highly inflamed mucosa with necrotic white slough that is positive on culture and histology for *Aspergillus*.

- Chronic necrotizing pulmonary aspergillosis (CNPA) or chronic cavitary pulmonary aspergillosis (CCPA), which are more indolent forms of invasive aspergillosis associated with mild immunosuppression or chronic lung disease. These present with a long history of cough and frequently with marked systemic symptoms, and a slowly progressive patch of consolidation with or without cavitation (CNPA), or an expanding dry upper lobe cavity with a thickened wall (CCPA).

Diagnosis of IPA is suggested by detection of galactomannan (a relatively specific cell wall component) or β -D-glucan (cell wall component of many fungi and *Pneumocystis*) antigen in blood or BALF. False-positives of the galactomannan antigen test occur with concomitant treatment with β -lactam antibiotics. Definitive diagnosis of IPA is made by positive culture for *Aspergillus* and histopathologic demonstration of tissue invasion on CT-guided or VATS biopsy specimens. Histology is highly sensitive, septated hyphae showing dichotomous (45°) branching on Gomori methenamine silver or periodic acid-Schiff staining. However histology specimens are often unavailable, and culture is relatively insensitive, so diagnosis is frequently made on clinical grounds (suggestive CT appearances, high-risk patient, positive galactomannan test). *Aspergillus* antibodies have no role in the diagnosis of IPA but are positive in CCPA and sometimes in CNPA.

It is important to note that world-wide there is an increase in azole resistance of *A. fumigatus*⁴ therefore combination of an azole with an echinocandin anti-fungal agent is recommended in immunocompromised hosts with severe IPA.

Non-Aspergillus filamentous fungi

Filamentous fungi, including *Fusarium*, *Zygomycetes*, *Scedosporium* and *Penicillium*, can cause invasive pulmonary infections in immunocompromised patients with a clinical presentation similar to IPA.

Diagnosis is made by culture from respiratory samples or lung biopsy, and is important as some species are resistant to conventional antifungal agents. Galactomannan and β -D-glucan cell wall antigen tests are negative in *Zygomycetes* infections. Mortality is high.

Candidiasis

Direct pulmonary invasion by *Candida* species is rare even in immunocompromised patients, despite frequent isolation from sputum. Pulmonary infection usually occurs in neutropenic patients as haematogenous spread from infected indwelling vascular catheters or infections related to transplant surgery. Lung nodules are often peripheral and sometimes very large. *Candida albicans* is the most common species identified but a range of non-albicans *Candida* also can cause disease (e.g. *Candida parapsilosis*, *Candida tropicalis*, *Candida glabrata*, and *Candida krusei*). A novel culture-independent test allows for the rapid detection of *Candida* in blood with a particularly high negative predictive value – positive results still require confirmation by culture.⁵ Indwelling lines should be removed.

Cryptococcosis

Cryptococcus neoformans pneumonia almost always affects only immunocompromised patients and can present with dyspnoea, cough and fever. HIV/AIDS (CD4 <200 cells/mm³) is the most common risk factor but cryptococcal pneumonia also occurs in other defects of T-cell-mediated immunity (especially post-solid organ transplantation). Radiological features include diffuse interstitial infiltrates, focal consolidation, discrete nodules, and hilar lymphadenopathy. Diagnosis is by microscopic identification (Indian ink stain) or culture from respiratory tract samples. The lung is the port of entry for disseminated infection (usually CNS), and neurological symptoms should prompt a lumbar puncture and cerebrospinal fluid culture.

Endemic fungi

Endemic fungi are found in specific geographical areas and cause primary infection by inhalation or inoculation of contaminated material (e.g. bat faeces). Reactivation of latent infection can occur in immunocompromised patients, especially with defects in T-cell-mediated immunity, so a history of travel or residence in a high-risk area can be relevant. Common endemic fungi causing pulmonary infections include *Histoplasma capsulatum*, *Coccidioides* (*Coccidioides immitis* and *Coccidioides posadasii*), *Blastomyces dermatitidis* and *Sporothrix schenckii*. Presentation varies with pathogen but tends to mimic tuberculosis with cavitating pneumonias, pulmonary nodules, enlarged mediastinal and hilar lymph nodes, or a miliary pattern. Systemic dissemination is not uncommon in immunocompromised patients. Diagnosis requires identification of the fungus in respiratory samples or biopsy material, including bone marrow aspirates. Culture may take 6 weeks. *H. capsulatum* can be rapidly detected with an antigen detection assay but this may cross-react with other endemic fungi. Serology will identify patients with previous exposure for most fungi, but is not reliable in immunocompromised patients. Mortality is high without timely appropriate treatment.

Key points

- Knowledge of the immune defect helps to narrow down the potential pathogens causing infection.

•CT scans of the chest are better than radiographs at defining the radiological pattern of disease in immunocompromised hosts

- In selected patients early bronchoscopy is helpful and increases the yield of microbiological identification of a potential pathogen.

Prolonged high-dose glucocorticoids (>20 mg/day for more than 21 days) predispose to *Pneumocystis jirovecii* pneumonia (PJP)

- Biological agents are associated with specific immune defects that increase the risk of opportunistic lung infections (e.g. tumour necrosis factor α inhibitors and risk of mycobacterial disease, endemic fungi and *Legionella pneumophila*; anti-CD20 drugs and mycobacterial disease, cytomegalovirus pneumonitis and PJP)

- Due to the increase in azole resistance of *A. fumigatus* combination of an azole with an echinocandin anti-fungal agent is recommended in immunocompromised hosts with severe IPA.

- Travel history is important to identify infections due to endemic fungi

Type of immune defect according to disease/treatment and range of pathogens commonly associated with infections in patients with this type of immune defect

| Immune disorder | Causes | Typical microorganisms |
|--|--|--|
| Neutrophil disorders | | |
| Neutropenia | Drugs (chemotherapy, azathioprine, methotrexate, carbimazole, sulphonamides) Leukaemia AIDS Felty's syndrome Aplastic anaemia Early haematopoietic stem cell transplantation (HSCT) | Gram-positive bacilli (<i>Staphylococcus aureus</i> , streptococci) Gram-negative bacilli Fungi (<i>Aspergillus</i> sp. <i>Candida</i> sp., non- <i>Aspergillus</i> filamentous fungi) |
| Neutrophil chemotaxis | Diabetes mellitus Cirrhosis Sarcoidosis Drugs (glucocorticoids, amphotericin B) | <i>Staph. aureus</i> Streptococci <i>Candida</i> sp. Zygomycosis |
| Neutrophil phagocytosis | Chronic granulomatous disease Myeloproliferative disorders Inherited phagocyte defects | <i>Staph. aureus</i> <i>Nocardia</i> sp. Gram-negative bacilli Fungi (<i>Aspergillus</i> sp. <i>Candida</i> sp., non- <i>Aspergillus</i> filamentous fungi) |
| T-cell mediated immunity | AIDS Lymphoma HSCT Solid organ transplantation Drugs (T-cell depleting antibodies, glucocorticoids, ciclosporin, tacrolimus) | Herpesviruses, Respiratory viruses <i>Pneumocystis jirovecii</i> Endemic mycoses e.g. <i>Histoplasma capsulatum</i> , <i>Cryptococcus</i> Parasites (<i>Strongyloides</i> , <i>Toxoplasma</i>) Mycobacteria <i>Nocardia</i> <i>Legionella pneumophila</i> |
| B-cell mediated/antibody deficiency | Multiple myeloma Plasmapheresis Drugs (anti-B cell therapies) HSCT Chronic lymphocytic leukaemia Lymphoma Multiple myeloma | Encapsulated bacteria (e.g. <i>Streptococcus pneumoniae</i> , <i>Haemophilus influenzae</i>) Herpesviruses |
| Other | | |
| Complement deficiency | Congenital Acquired (systemic lupus erythematosus, anorexia nervosa) | Encapsulated bacteria (e.g. <i>Strep. pneumoniae</i> , <i>H. influenzae</i>) <i>Staph. aureus</i> |
| Asplenia | Splenectomy Sickle cell disease | Encapsulated bacteria (e.g. <i>Strep. pneumoniae</i> , <i>H. influenzae</i>) <i>Staph. aureus</i> |

Table 1

Anti-viral treatments for respiratory viruses

| Virus | Treatment |
|-----------------------------|---|
| Influenza | Neuraminidase inhibitors (zanamivir or oseltamivir) ^a Amantadine |
| Parainfluenza | Ribavirin ^{b, c} Intravenous immunoglobulin (IVIG) ^b |
| Respiratory syncytial virus | Ribavirin ^c Palivizumab |
| Human metapneumovirus | Ribavirin ^{b, c} IVIG ^b |
| Adenovirus | Ribavirin ^{b, c} Cidofovir ^b Brincidofovir ^d |

^aEffective at reducing disease severity and duration.

^b*In vitro* activity present but no recommendations on treatment are currently available due to lack of data.

^c May be administered orally, intravenously or nebulized

^dIn phase III clinical trials

Table 2

Anti-fungal treatment choices

| Fungal pathogen | Treatment |
|---|--|
| <i>Aspergillus</i> species | <p>First-line: Voriconazole ± Caspofungin Lipid formulation of amphotericin</p> <p>Second-line: Posaconazole^a Itraconazole Isavuconazole Caspofungin Anidulafungin</p> |
| <i>Pneumocystis jirovecii</i> | <p>First line: Trimethoprim–sulphamethoxazole</p> <p>Second-line: Clindamycin plus primaquine Atovaquone Pentamidine Trimethoprim plus dapsone</p> |
| <i>Cryptococcus neoformans</i> | <p>Induction therapy: Liposomal amphotericin plus flucytosine</p> <p>Consolidation and maintenance therapy: Fluconazole</p> <p>Second line: Posaconazole Voriconazole</p> |
| <i>Candida</i> species | <p>First line: Fluconazole (<i>C. albicans</i>) Caspofungin (<i>C. glabrata</i> and <i>C. krusei</i>)</p> <p>Second line: Voriconazole Itraconazole Posaconazole^a Micafungin Amphotericin</p> |
| Non- <i>Aspergillus</i> filamentous fungi (eg. <i>Fusarium</i> , <i>Zygomycetes</i> , <i>Scedosporium</i> , <i>Penicillium</i>) | <p>Consider surgical debridement</p> <p>First line: Liposomal amphotericin</p> <p>Second line: Posaconazole</p> |
| Endemic fungi (<i>Histoplasma</i> , <i>Coccidioides</i> , <i>Blastomyces</i> , <i>Sporothrix</i>) | <p>First line: Mild disease immunocompetent: no treatment (<i>Histoplasma</i>), itraconazole (others) Moderate disease: itraconazole Severe disease: amphotericin</p> <p>Second line:</p> |

| Fungal pathogen | Treatment |
|-----------------|---|
| | Posaconazole Voriconazole Fluconazole |

^a Intravenous formulation not approved in the UK

Table 3

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