Computed Tomography in the Management of Chest Infections: Current Status

Jane H. Wheeler and Elliot K. Fishman

The application of computed tomography has advanced our ability to diagnose and treat chest infections. Although conventional computed tomography has been shown to be useful in diagnosing pulmonary disease, new technological developments including high-resolution computed tomography (HRCT) and spiral (continuous imaging) computed tomography have resulted in earlier detection and more precise characterization of parenchymal lung infections and their complications. For the immunocompetent host, computed tomographic findings are helpful in the staging of disease, in differentiating infections from tumors, and in detecting complications. For the immunocompromised host, HRCT is useful in identifying subtle infiltrates earlier than other imaging methods can. Computed tomography is also useful in guiding transthoracic biopsy, aspiration, or drainage of chest infections or abscesses. In addition, computed tomographic findings can provide guidance for surgical biopsy, bronchoscopic biopsy, and bronchoalveolar lavage.

The advent of computed tomography has advanced our ability to diagnose, treat, and better understand diseases of the chest. The plain chest film, in addition to sputum smears and cultures, remains an important initial means for evaluating known or suspected pulmonary infection. Many pneumonias, especially those that are acquired by otherwise healthy hosts in the community, require little else for appropriate diagnosis and treatment. However, complicated or confusing chest infections require the excellent two-dimensional discriminatory capabilities of computed tomography. Chest infections are common in immunocompromised patients, and early recognition and diagnosis are crucial in decreasing the associated morbidity and mortality among patients in this population. For the immunocompetent host, distinction between infection and malignant processes as well as staging of disease and identification of complications is clinically important.

In addition to conventional computed tomographic techniques, new technological refinements such as spiral and high-resolution imaging have further enhanced detection and diagnosis of infection in the chest. Although standard computed tomography usually provides an adequately detailed image of the lung parenchyma, high-resolution computed tomography (HRCT) provides finer interstitial detail and may detect subtle pneumonias sooner than do other techniques. HRCT has proved to be particularly useful for immunocompromised patients, in whom infection can quickly overwhelm the depressed immune system. Spiral computed tomography enables increased soft-tissue discrimination and allows multiplanar reconstructions; a mass can usually be distinguished from an infiltrate and vascular structures.

In this article, we will address the use of computed tomography in the diagnosis and treatment of infectious diseases in the chest, including pneumonia and its complications in the immunocompetent host as well as opportunistic infections in the immunocompromised patient.

Computed Tomography Techniques

Standard dynamic computed tomography is performed with the patient in the supine position. A scoutview or topogram is obtained to localize the desired starting position. An initial axial image is obtained at the level of the thoracic inlet. An iodinated contrast agent (120 mL) is injected into a peripheral vein at a rate of 1–3 mL per second. Dynamic transaxial images of the chest, from the thoracic inlet to the adrenal glands, are obtained at 8-mm intervals; the thickness of each image is 8 mm. Each image is taken at end inspiration.

HRCT can be performed on all late-generation computed tomographic scanners. HRCT is similar to dynamic computed tomography, except that collimation of the X-ray beam results in a thinner (1–2 mm rather than 8 mm) image section, and a high spatial-frequency reconstruction algorithm is used. Both of these adjustments result in higher spatial resolution. Retrospective targeting to a smaller field of view also increases spatial resolution [1]. Intravenous contrast medium is not administered when HRCT is performed because contrast makes the interstitium appear more prominent, which could lead to false-positive diagnoses of interstitial disease. Because of its increased spatial resolution, HRCT has been shown to be supe-
Figure 1. Three-dimensional reconstruction of right upper-lobe mass.

Spiral (or helical) computed tomography is based on the new slip-ring technology, which allows multiple 360-degree rotations of the gantry while the table moves continuously. With this technology, contiguous scans through the entire chest during a single breathhold can be obtained. This results in a “volume” of data rather than the typical “slices of information” obtained by dynamic computed tomography. Spiral computed tomography is widely used in the United States today. Data from a spiral computed tomogram (CT) is acquired during a single breathhold (usually 24–32 seconds, depending on the scanner). The entire chest CT can thus be obtained in 24 seconds, with no motion artifacts.

Image misregistration caused by respiratory variation can be significant when traditional dynamic computed tomography is performed. The short scanning time also enables the injected bolus of intravenous contrast medium (if used) to appear in the vascular phase, rendering vessels conspicuous and clearly distinguishing them from adenopathy or other masses. This is especially helpful in imaging the hila, mediastinum, and neck. In addition, vascular abnormalities are clearly demonstrated. Volume acquisition also facilitates multiplanar and three-dimensional reconstructions [3, 4] (figure 1).

General Signs of Infection

Infection in the lung may be reflected in a variety of patterns on CTs. Although the etiologic organism may not be determined by computed tomography, specific patterns in conjunction with clinical data may suggest the etiology of the infection and may also exclude other pathological processes such as tumors or other inflammatory processes. In addition, a CT may identify specific indications for treatment such as need for definitive drainage of an abscess or an empyema.

Lobar and lobular pneumonias due to bacteria appear as increased lung density as a result of air space filling. Lobar pneumonia often appears homogeneous with confluent areas, and air bronchograms are frequently seen on plain chest radiographs and CTs. This appearance is due to alveolar filling, with edema and inflammatory exudates. However, lobular pneumonia more frequently involves the larger airways (bronchioles). Patchy, multifocal areas of increased density are seen. Air bronchograms are not usually present, and a segmental distribution is common. Atelectasis may be seen.

The “ground-glass” infiltrate pattern may be seen in cases of viral or parasitic pneumonia and pathologically represents air space filling from alveolar edema. In such cases the CT demonstrates subtle homogeneous increased attenuation in the lungs, which may be diffuse or localized. Other noninfectious inflammatory processes may also present with this pattern.

Interstitial infiltrates can be present in patients with viral pneumonia. Alveolar wall edema or lymphatic infiltration causes thickening of the interstitium. Nodular changes can also be seen.

One or more focal lung masses may also represent infection in the lung. Cavitation may or may not be present. The borders of the masses commonly appear irregular or fluffy and are associated with peripheral infiltrates or vascular invasion; however, the borders may be smooth. In addition, a peripheral focal mass may have a peripheral wedge-shaped density, indicating infarction.

A focal lung mass with a thickened wall and an air-fluid level indicates a lung abscess. There may be associated peripheral infiltrates.

Mediastinal adenopathy and pleural effusions are often seen in patients with parenchymal lung infection. Although these findings are not specific for infection, their presence (or absence) in the chest may help in the inclusion or exclusion of a given etiology in the differential diagnosis.

The Immunocompetent Host

Community-acquired pneumonias are most commonly caused by *Mycoplasma pneumoniae*, *Streptococcus pneumoniae*, *Legionella pneumophila*, *Haemophilus influenzae*, *Chlamydia pneumoniae*, anaerobic bacteria, and viruses [5]. The chest radiograph, along with clinical and laboratory data, often provides adequate information for selecting an appropriate therapeutic regimen. The majority of bacterial pneumonias have nonspecific radiographic and computed tomographic presentations; these infections often present as air space filling with consolidation, sometimes in a lobar, segmental, or patchy pattern.

Computed tomography is particularly useful for evaluating the patient with recurrent or unresponsive pneumonia; this technique is also useful when an obstructing mass or tumor is
suspected on the basis of radiographic findings or when a complication of pneumonia is suspected. In addition, computed tomography is useful for staging the chest infection and thus for determining therapy and prognosis. Early diagnosis of complications often results in a change in case management: the antibiotic regimen may be altered, or open or percutaneous drainage, surgical excision, or radiation treatment of a tumor may be recommended.

Obstructive pneumonia. Lung tumors may present clinically as pneumonia. A lung mass may be interpreted as pneumonia, or pneumonia may complicate the clinical picture of a lung mass. For these reasons, computed tomography is useful in evaluating recurrent, unresponsive pneumonias or pneumonias that present on a plain film as masses or atelectasis.

Airway obstruction due to a tumor or other mass may lead to the development of segmental or lobar atelectasis; often an inflammatory obstructive component is present, which sometimes leads to the development of acute bronchopneumonia. The tumor may be identified as a bulge or mass deforming the apex of the atelectatic or consolidated segment or lobe. Enhanced dynamic (or spiral) CTs often demonstrate a mass with low attenuation and a collapsed lung parenchyma with higher attenuation, which is distal to the mass. When a completely obstructive lesion is present, no air bronchograms are observed because air cannot pass distally [6]. Adenopathy and concentric bronchial wall thickening due to the presence of a tumor can also lead to the development of obstructive pneumonia (figure 2).

Once a mass has been identified, computed tomography can be useful for planning bronchoscopic or percutaneous needle biopsy of the mass. In addition, areas of infiltrate may be aspirated percutaneously or bronchoscopically, or lavage may be performed to obtain fluid for bacteriologic culture and susceptibility studies.

Empyema. This infection of the pleural space may be caused by a variety of etiologic agents. Trauma, postsurgical complications, abdominal pathology, and primary pulmonary infection can lead to empyema. Bronchopleural fistulas are commonly associated with empyema [7].

Empyema may be indicated radiographically by the presence of pleural fluid. Contrast-enhanced computed tomography is helpful in delineating a consolidated lung and a pleural fluid collection. CT also demonstrates splitting of the visceral and parietal pleural surfaces by the empyema. Enhancement of the pleurae results from ingrowth of fibroblasts and capillaries. Loculations and underlying pathological processes in the lung can be evaluated well with use of computed tomography, and placement of chest tubes and performance of pleural taps may also be facilitated with use of this technique [7].

The often-difficult problem of differentiating a parenchymal lung abscess from empyema is easily solved with use of computed tomography. Stark et al. [8] studied 70 cases in which empyema was distinguished from abscess. Total (100%) diagnostic accuracy was achieved only with use of computed tomography. Pleural separation and adjacent lung compression were findings that were specific for empyema. In addition, the empyema wall is thin, uniform, and smooth on both the luminal margin and the exterior surface (figure 3). Computed tomographic findings were not specific for the etiologic agent [8].

Accurate differentiation between a lung abscess and empyema is important because therapy for empyema consists of chest tube drainage (with the tube placed percutaneously or surgically) or surgical decortication. In contrast, the initial treatment for a lung abscess is conservative [8, 9].

Lung abscess. The incidence of bacterial lung abscesses has declined since the 1940s as a result of effective antibiotic...
therapy. Despite the lower incidence of this infection, it remains an important medical problem. Periodontal disease, alcohol abuse, depression of the CNS, and impaired immunity place an individual at risk for developing a lung abscess. The most common predisposing event is aspiration of oropharyngeal or gastric contents. These patients frequently present with cough and fever. Groskin et al. [10] studied 63 patients with lung abscesses and found that 18% of the abscesses were radiographically occult on plain films and were diagnosed only at the time of surgery or autopsy.

The results of this study suggest the usefulness of computed tomography for diagnosing lung abscesses. These lesions typically are spherical, and their interior and exterior walls are thick and irregular relative to their size. Air is often present. Because the abscess is intraparenchymatous, it forms acute angles with the chest wall interface. Lung compression is absent. Bronchi and pulmonary vessels end abruptly at the wall of the abscess [9] (figure 4).

Initial treatment for lung abscess consists of antibiotics, postural drainage, and adequate pulmonary toilet [8, 10, 11]. Because many lung abscesses spontaneously drain into a patent bronchial tree, these conservative therapeutic measures are often curative [11].

vanSonnenberg et al. [11] reported the results of percutaneous drainage of lung abscesses in 18 patients who failed to respond to antibiotic therapy and postural drainage. Sepsis resolved in all patients, and open surgical intervention was averted for 16 (89%) of these patients. Computed tomography proved useful in the guidance of catheter placement in all of these cases.

The Immunocompromised Host

The increasing number of immunocompromised patients in the United States continues to challenge physicians. The AIDS epidemic remains an important factor in this increase; however, aggressive organ transplantation programs, immunosuppressive therapy, and chemotherapy for solid tumors and hematologic malignancies all contribute to the population of immunocompromised patients [2, 12, 13].

Although lung disease other than that due to infection (i.e., iatrogenic conditions, drug-induced disease, neoplasms, and pulmonary edema) plays a role in this population, infectious complications are an important cause of morbidity and mortality [2, 12, 13]. The mortality associated with lung infections has been reported to range from 40% to 50% [12, 13].

The immunocompromised host has a decreased ability to fight infection and is thus susceptible to a variety of organisms; the type of pathogen depends on the specific immunologic abnormality. The clinical picture for these patients is often complicated by the fact that those who are neutropenic typically do not produce sputum or may be infected with more than one potential pathogen. Examination of a lung biopsy specimen may not even yield the identity of the causative agent [12].

Findings on a chest radiograph may be normal for 10% of symptomatic patients [2, 13]. For this reason, computed tomography (and especially HRCT) often detects abnormalities when the plain film shows no abnormalities or shows a questionable finding. HRCT may allow more confident diagnoses to be made in such cases [2]. In addition, computed tomography can be helpful for localizing the most abnormal areas and guiding percutaneous biopsy, bronchoscopic biopsy, or open biopsy.

Protozoan infections. The most common life-threatening infection in patients with AIDS is the protozoan infection Pneumocystis carinii pneumonia (PCP) [14]. Other immunocompromised patients, especially organ transplant recipients and patients with lymphoproliferative disorders, are also at risk for developing this infection [2, 13]. The radiographic findings associated with PCP have been well studied [2, 12–15]. The computed
tomographic findings of PCP include a “patchwork pattern,” ground-glass infiltrates with preservation of vessels, and, less commonly, interstitial infiltrates. These findings reflect the pathological findings of fluid-filled alveoli and inflammatory cells. The infiltrates are bilaterally symmetrical and distinctly patchy, with spared areas [14–16]. Thickened interlobular septae are also seen [2, 14, 15] (figure 5).

Prophylaxis with inhaled pentamidine for PCP has been shown to decrease the incidence of the infection ≈20% over 1 year. This therapy results in a distribution of the pneumonia predominantly in the upper lobes [2, 13, 16].

Cystic spaces have also been observed on CTs of the lungs of patients with PCP. These cysts may occur acutely or as sequelae of PCP; they may resolve or persist after therapy is discontinued [2, 15, 17–19] (figure 6). A higher incidence of pneumothorax is seen in patients with PCP-related cysts than in those with PCP alone [2, 17, 18]. Nodular components, adenopathy, and pleural effusion are uncommon findings in patients with PCP [2, 13, 19].

Fungal infections. The incidence of opportunistic fungal pneumonias has increased since the 1960s secondary to new therapies, immunosuppression, organ transplantation, and the AIDS epidemic [20]. Fungal infections may occur in any immunocompromised patient but are most commonly seen in those receiving aggressive chemotherapy for leukemia or conditioning for bone marrow transplantation. Aspergillus fumigatus, Candida albicans, and Histoplasma capsulatum are the most common fungal pathogens in these patients [2].

Aspergillus species rarely cause disease in the immunocompetent host; however, these organisms cause a variety of infections in immunocompromised patients. An aspergilloma (fungus ball) may occupy a cavity caused by tuberculosis (TB), sarcoidosis, histoplasmosis, or asbestosis [20]. Computed tomography easily demonstrates a round mass in the preexisting cavity. A crescent of air surrounds the fungus ball [12, 20, 21] (figure 7).

Invasive pulmonary aspergillosis occurs in severely immunocompromised patients and may have a fulminant course. Granulocytopenic patients (those with granulocyte counts of <500/mm³) with hematologic malignancies, as well as bone marrow transplant recipients and solid-organ transplant recipients, are at particular risk for developing this infection [2, 13, 20]. Because the mortality associated with this form of infection is high, early recognition is crucial for prompt intervention with antifungal therapy. The computed tomographic findings for patients with aspergillosis are distinctive: parenchymal nodules are surrounded by a halo of ground-glass attenuation that represents the hemorrhagic necrosis observed on pathological examination (figure 8, figure 9). Segmental or subsegmental consolidation secondary to pulmonary infarction also occurs [2, 12, 13].

Figure 6. Residual cavity in the lung of HIV-infected intravenous drug user with *P. carinii* pneumonia.

Figure 7. Left upper-lobe tuberculous cavity that contains an aspergilloma in a 49-year-old female.

Figure 8. Invasive pulmonary aspergillosis in a 19-year-old male with acute myelogenous leukemia; note the right upper-lobe mass with a “ground-glass halo” representing hemorrhagic necrosis.
C. albicans may cause parenchymal lung disease in the immunocompromised patient. Patchy, bilateral air-space consolidation may be seen on the CT; however, nodules are a more common finding [2, 12, 13]. This “halo sign” may be seen surrounding nodules [2, 12] (figure 10).

Patients with impaired T cell–mediated immunity are at risk for developing progressive disseminated histoplasmosis. This disease can occur after recent exposure in an area where *Histoplasma capsulatum* is endemic or secondary to a previously acquired infection [22]. Half of these patients may initially have normal radiographic findings [2, 22]. HRCT most commonly demonstrates a diffuse miliary pattern, often with septal thickening and nodularity of interlobular fissures. Air-space consolidation is seen less frequently. Hilar and mediastinal adenopathy may be present but are less common findings in patients with the disseminated form of histoplasmosis [22].

**Viral infections.** Of the viral pathogens, cytomegalovirus (CMV) may cause significant morbidity and mortality among bone marrow transplant recipients and solid-organ transplant recipients. Approximately 70% of renal transplant recipients will develop infection with CMV. CMV is the most potentially lethal pathogen that infects bone marrow transplant recipients in the first 6 months after transplantation. The mortality has been reported to be as high as 90% in this population [23].

In a recent study [2], the most common computed tomographic finding for patients with CMV pneumonitis was described as small nodules surrounded by areas with a ground-glass appearance, which correlates pathologically with peripheral hemorrhage (figure 11); air-space consolidation is also seen.

Herpes simplex pneumonitis may present as localized or disseminated pneumonia [23]. Radiographs demonstrate non-specific bilateral air-space consolidation with diffuse nodules (3–20 mm in diameter) that can be seen on CT scans. Patchy areas of ground-glass attenuation are also seen on the CTs [2].

**Tuberculosis.** The incidence of TB in the United States has been increasing since 1985. The reasons for this rise include increasing drug abuse, an increased number of homeless persons, an increased number of individuals in long-term facilities (prisons and nursing homes), and a higher rate of immigration from countries where TB is endemic. However, the AIDS epidemic is the primary cause of the rising incidence of TB. In one study in New York City, 82% of persons in minority groups who had TB tested positive for antibodies to HIV [24].

Computed tomography has become an important tool in the diagnosis and management of TB. First, more patients with lung disease are being evaluated with use of computed tomography. Second, this technique may be helpful in confirming or detecting the presence of subtle adenopathy or an infiltrate. In addition, small cavities are better visualized on CTs [21].
Figure 12. Tuberculosis in a 42-year-old male. A: Right middle-lobe cavity with thickened, irregular wall; right lower-lobe infiltrate and consolidation are seen. B: Tiny nodules in the right upper lobe are seen with miliary dissemination; right lower-lobe infiltrate is apparent.

Miliary TB occurs when host defenses are overcome by hematogenously spread organisms. Miliary TB may not become evident on plain chest radiographs until ≤6 weeks after dissemination has occurred [21]. McGuinness et al. [25] reported that 50% of chest radiographs that documented miliary disease initially showed no abnormalities. Thus, CTs demonstrate miliary dissemination much earlier. Computed tomography depicts early miliary disease as discrete, diffusely scattered nodules that are 1–2 mm in diameter [21, 25, 26] (figure 12). HRCT reveals a profusion of both sharply defined and poorly defined nodules that are 1–3 mm in diameter, nodular beaded septa, irregular vessels, and subpleural dots [26].

Tuberculous lymphadenitis is seen in primary or reactive disease in adults and in primary disease in children. The right paratracheal region, the right tracheobronchial region, and the subcarinal nodal regions are most commonly affected [21, 26], which probably reflects nodal drainage from commonly affected areas of the lung. Left paratracheal adenopathy is unusual [27].

Im et al. [27] studied 23 patients with use of CT who had tuberculous lymphadenitis. These investigators found that tuberculous nodes generally enhanced peripherally, with the majority demonstrating central low attenuation after administration of contrast media. Of the patients in their study, 85% were found to have centers of low attenuation only after injection of the contrast medium. All tuberculous nodes enhanced; some had multiple septations, while others showed central low attenuation (figures 13 and 14). Some of these nodes showed homogeneous attenuation. Obliteration of perinodal fat was noted for most of these nodes (except for one group with homogeneous enhancement).

Patients with low-attenuation centers had constitutional symptoms more often than did those without central low attenuation. This low attenuation may be helpful in the differentiation of mediastinal masses. Lymphoma, the most common mediastinal mass, rarely has central low attenuation (except in cases of Hodgkin’s disease, where adenopathy is prevascular rather than pretracheal). The adenopathy associated with sarcoidosis is usually hilar; however, other infectious agents (e.g., _H. capsulatum_) can cause nodes with low attenuation [27]. Fibrosing mediastinitis also occurs in patients with TB [21].

Cavitary disease is seen on the CTs of patients with reactive tuberculosis. Cavities result when areas of caseating necrosis erode into the bronchial tree, releasing liquid infectious debris into the airways. Computed tomography is sensitive in detecting cavitary disease, especially in difficult-to-visualize areas such as the lung bases or apices or in paramediastinal or retrocardiac locations. CT scans may reveal cavities that are thick or thin, smooth or irregular, and walled [21, 24, 26] (figure 7, figure 12). In the distorted or fibrotic parenchyma, computed tomography can delineate cavities that may be hidden on plain films. Air-fluid levels are sometimes seen and raise the suspicion of superimposed bacterial or fungal disease [21].

Tuberculous involvement of the pleurae occurs when a subpleural caseous nodule ruptures into the pleural space, usually 3–7 months after a primary parenchymal infection. However, pleurisy can develop at any stage of infection. Tuberculous effusions contain few tubercle bacilli and, indeed, are usually serous exudates that develop as a result of hypersensitivity to _Mycobacterium tuberculosis_ proteins. Plain films and decubitus chest films may reveal little except for the existence of a pleural effusion; however, computed tomography can play an important role in the diagnosis of tuberculous pleurisy.

Focal subpleural cavities, which often are not discernible on a chest radiograph, can be more clearly seen on CTs. In addition, the detection of mediastinal adenopathy may help establish the diagnosis. Tuberculous pleurisy is usually self limited, with clinical and radiological findings subsiding after several weeks. However, 65% of untreated patients have active pulmonary and/or extrapulmonary TB within 5 years [28].

Incomplete medical therapy and resistant organisms can result in chronic tuberculous pleurisy—i.e., grossly purulent
pleural fluid containing tubercle bacilli. Fibrothorax forms when these pleural effusions fibrose and calcify: they appear as a pleural rind on CTs. However, in the absence of calcification, tuberculous empyema may look like any other pleural effusion.

Computed tomography is useful in detecting fluid within a fibrothorax, which is indicative of active disease [28]. Fibrocalcific scars, which often appear in the upper lobes, form with the resolution of parenchymal chest disease and

---

**Figure 13.** Tuberculosis in a 35-year-old male. **A, B:** Pulmonary windows demonstrate right upper-lobe focal masslike infiltrates. **C:** Soft-tissue windows reveal enhancing right hilar adenopathy.

---

**Figure 14.** Tuberculous adenitis in a 37-year-old female with AIDS. Rim-enhancing lymph nodes represent **(A)** paratracheal adenopathy and **(B)** right hilar and subcarinal adenopathy. The perinodal fat is obliterated.
result in contraction and distortion of the lung with bronchiectasis, atelectasis, and adjacent emphysema [21]. Computed tomography is useful in these cases, as the scarring can look masslike and is sometimes indistinguishable from carcinoma. Computed tomography is helpful in establishing stability or eliminating or establishing the presence of a tumor in these cases [21]. Where necessary, computed tomography can be used to guide percutaneous biopsy when a tumor is suspected.

**Conclusion**

Chest infection is a common occurrence, particularly in immunocompromised or debilitated patients. The superior discriminatory capability of computed tomography for two-dimensional imaging and soft-tissue imaging makes it an excellent tool for the study of chest infections and their complications. HRCT is particularly useful for the early detection of pneumonia in the febrile immunocompromised patient. The capacity for staging disease and identifying complications that might necessitate a change of treatment or interventional therapy makes computed tomography a valuable study for immunocompetent patients. Localization for interventional and diagnostic procedures is also facilitated with use of this technique.

**References**