RadioGraphics

Radiographic and CT Findings of Thoracic Complications after Pneumonectomy[1]

Eun Jin Chae, MD • Joon Beom Seo, MD • So Yeon Kim, MD
Kyung-Hyun Do, MD • Jeong-Nam Heo, MD • Jin Seong Lee, MD
Koun Sik Song, MD • Jae Woo Song, MD • Tae-Hwan Lim, MD

CME FEATURE

See accompanying test at http://www.rsna.org/education/rg_cme.html

LEARNING OBJECTIVES FOR TEST 4

After reading this article and taking the test, the reader will be able to:

- Describe the role of imaging in the diagnosis and management of postpneumonectomy complications.
- Recognize normal early postoperative alterations at chest radiography after pneumonectomy.
- Identify the radiologic and clinical features of early and late complications of pneumonectomy.

TEACHING POINTS

See last page

Pneumonectomy is the treatment of choice for bronchogenic carcinoma and intractable end-stage lung diseases such as tuberculosis and bronchiectasis, but it is often followed by postoperative complications, which account for significant morbidity and mortality. Knowledge of the radiologic features of such complications is of critical importance for their early detection and prompt management. Complications of pneumonectomy are classified as early or late, depending on when they occur in relation to the hospitalization period. Early complications of pneumonectomy include pulmonary edema, bronchopleural fistula, pneumonia of the contralateral lung, empyema, and adult respiratory distress syndrome, which may occur separately or in combination. Late postpneumonectomy complications include recurrent disease, infection, effects of radiation therapy or chemotherapy, and surgical complications such as late-onset bronchopleural fistula, postpneumonectomy syndrome, and esophagopleural fistula. Sequential examinations with chest radiography after pneumonectomy are an invaluable method of screening for these complications, especially in the early postoperative period. When the radiographic findings are inconclusive, computed tomography is helpful for establishing a diagnosis and obtaining detailed information about the disease process.

Abbreviations: ARDS = adult respiratory distress syndrome, BOOP = bronchiolitis obliterans with organizing pneumonia

RadioGraphics 2006; 26:1449–1467 • **Published online** 10.1148/rg.265055156 • **Content Codes:** CH CT

[1]From the Department of Radiology, Research Institute of Radiology, Asan Medical Center, University of Ulsan College of Medicine, 388-1, Poongnap-dong, Songpa-ku, Seoul 138-36, Korea. Presented as an education exhibit at the 2003 RSNA Annual Meeting. Received August 3, 2005; revision requested September 13 and received October 31; accepted October 31. All authors have no financial relationships to disclose. **Address correspondence to** J.B.S. (e-mail: *seojb@amc.seoul.kr*).

Introduction

The overall incidence of complications after pneumonectomy has been reported to be as high as 20%–60% (1–6), although the associated morbidity and mortality have decreased in recent decades. The nature of these complications differs according to the length of time between pneumonectomy and the onset of the complication. Complications that develop in the early postoperative period are largely related to the surgical procedure or a preexisting condition. Early and late complications of pneumonectomy, and their incidence as observed in a series of 273 consecutive patients who underwent pneumonectomy at our institution during a recent 5-year period, are shown in Tables 1 and 2.

Chest radiographs and CT scans obtained in patients who have undergone pneumonectomy show numerous normal alterations that are results of the surgical procedure. Many of the acute alterations are of little clinical significance, while others may herald major clinical problems. Therefore, familiarity with the clinical and imaging features of the expected alterations as well as the various possible complications after pneumonectomy is essential. In this article, the radiographic and CT features of postpneumonectomy complications are described and correlated with the clinical setting.

Teaching Point

Normal Postpneumonectomy Changes on Chest Radiographs

Initial chest radiographs after pneumonectomy should demonstrate a midline position of the trachea, slight congestion in the remaining lung, and a postpneumonectomy space that contains gas and fluid. The rate of accumulation of fluid in the postpneumonectomy space is extremely variable (7). In most cases, within the first 4–5 postoperative days, approximately half of the space is filled with fluid. After the 1st week, the air-fluid level gradually rises (Fig 1). Thereafter, the mediastinum either remains stationary or gradually shifts toward the postpneumonectomy space as a result of hyperextension of the remaining lung as gas from the surgical site is reabsorbed. Progressive mediastinal shift and lung herniation into the postpneumonectomy space indicate continuing fluid reabsorption (7–9). Total obliteration of the postpnemonectomy space usually takes weeks to months (7). As obliteration of the space occurs, the heart rotates toward the posterior, and the

Table 1
Complications in the Early Postoperative Period

Complication	No. of Patients*
Postpneumonectomy pulmonary edema	8 (2.9)
Bronchopleural fistula	7 (2.6)
Pneumonia of contralateral lung	6 (2.2)
Postpneumonectomy empyema	5 (1.8)
Postpneumonectomy ARDS	3 (1.1)
Other	6 (2.2)
Total	35 (12.8)

*Numbers in parentheses are percentages.
ARDS = adult respiratory distress syndrome.

Table 2
Complications in the Late Postoperative Period

Complication	No. of Patients*
Delayed surgical complications	27 (9.9)
Late-onset bronchopleural fistula	25 (9.2)
Postpneumonectomy syndrome	1 (0.3)
Esophagopleural fistula	1 (0.3)
Infections	23 (8.4)
Pneumonia	20 (7.3)
Late-onset postpneumonectomy empyema	3 (1.1)
Complications related to treatment	9 (3.3)
Radiation pneumonitis	4 (1.5)
Radiation-induced pleural and pericardial effusion	1 (0.3)
Radiation-induced BOOP	3 (1.1)
Chemotherapy-induced lung disease	1 (0.3)
Recurrence of primary disease	26 (9.5)
Tumor	23 (8.4)
Tuberculosis	3 (1.1)
Other	2 (0.7)
Total	87 (31.7)

*Numbers in parentheses are percentages.
BOOP = bronchiolitis obliterans with organizing pneumonia.

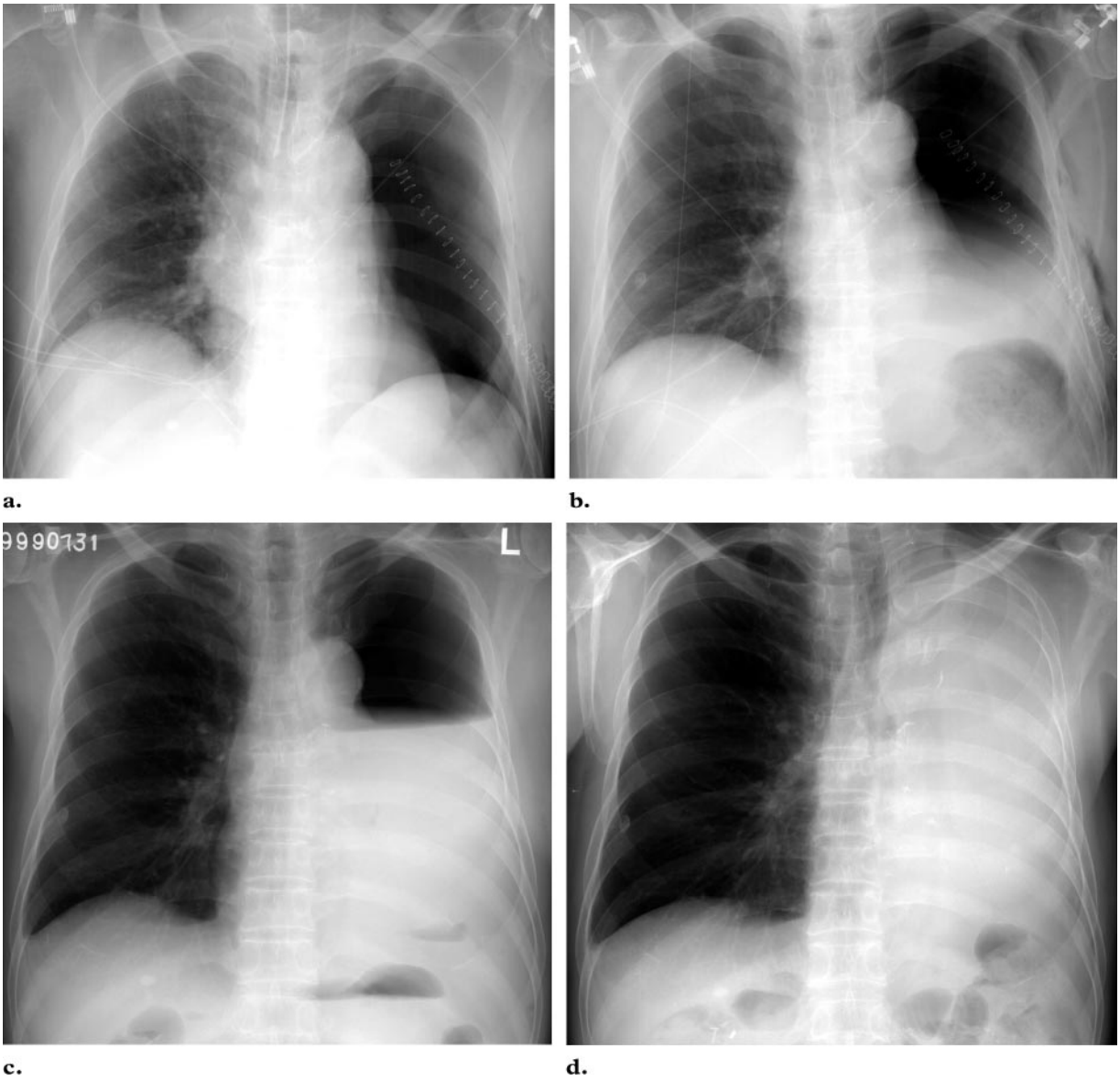


Figure 1. Normal postoperative anatomy at chest radiography in a 55-year-old man who underwent left pneumonectomy for squamous cell carcinoma. **(a)** Radiograph on postoperative day 1 shows pneumothorax in the postpneumonectomy space, a midline trachea, and slight congestion in the remaining right lung. **(b)** Radiograph on postoperative day 2 shows fluid in the lower one-third of the postpneumonectomy space. **(c)** Radiograph on postoperative day 14 shows that the air-fluid level has risen in the postpneumonectomy space. **(d)** Radiograph on postoperative day 30 shows total opacification of the postpneumonectomy space and elevation of the left hemidiaphragm.

remaining lung herniates across the midline to a position anterior to the heart and aorta (7). In the immediate postoperative period, a rapid mediastinal shift toward the remaining lung indicates atelectasis of the lung or an abnormal accumulation of air or fluid in the postpneumonectomy space, with the latter most often resulting from a bronchopleural fistula, hemorrhage, or empyema. In the late postoperative period, a mediastinal shift toward the remaining lung is indicative of a delayed complication (7,8,10). Familiarity with these chest radiographic findings is important because they are often the first indications of a complication, especially in the early postoperative period (7).

Early Postoperative Complications

Pulmonary Edema

Postpneumonectomy pulmonary edema is a life-threatening complication of pneumonectomy, with a reported prevalence of 2.5%–5% and an associated mortality rate of 80%–100% (11–13). The causal mechanism of this complication remains largely undetermined. Increased hydrostatic pressure and altered permeability of capillaries are probably contributing factors (12,14,15). Predisposing factors include an excessive perioperative fluid load, transfusion of fresh frozen plasma, arrhythmia, marked postsurgical diuresis, and low serum colloidal osmotic pressure (12). Postpneumonectomy pulmonary edema occurs more commonly after right pneumonectomy, probably because a larger amount of fluid in the post–right pneumonectomy space results in an increased pulmonary blood flow through the left lung, which normally receives only about 45% of the total pulmonary blood flow and contains approximately 45% of the total lymphatic capacity of the lungs (11,12). Postpneumonectomy pulmonary edema is diagnosed primarily through a process of exclusion; the diagnosis is valid only if there is no clinical or radiologic evidence of aspiration pneumonia, bacterial pneumonia, heart failure, thromboembolism, bronchopleural fistula, or other possible causes of ARDS (13). On serial chest radiographs, severe postpneumonectomy pulmonary edema appears as increased opacity identical to that seen in ARDS (Fig 2). In less severe cases, the imaging findings resemble those in hydrostatic pulmonary edema: The most frequently observed features include Kerley lines, peribronchial cuffing (ie, thickening of the bronchial wall), and ill-defined vessels. These features have a tendency to disappear within a few days, a tendency that strongly indicates that lesions of the capillary endothelial cells, if present, are mild in this form of the disorder (12).

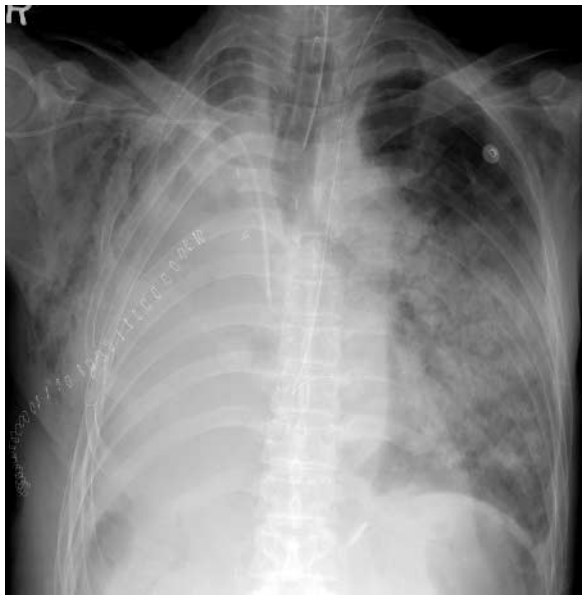


Figure 2. Pulmonary edema in a 58-year-old man after right pneumonectomy for multidrug-resistant tuberculosis. Chest radiograph on postoperative day 2 shows perihilar consolidation and an air bronchogram in the left lung.

Bronchopleural Fistula

Bronchopleural fistula is a potentially fatal complication of pneumonectomy, although its incidence has decreased over the years: An incidence of 0%–9% (16) and an associated mortality rate of 16%–23% (17) have been reported. The most common cause of death associated with this condition is aspiration pneumonia with subsequent ARDS (18). A bronchopleural fistula is more likely to occur after right pneumonectomy than after left pneumonectomy (10,17,18), probably because of the shorter length and less effective concealment of the bronchial stump, as well as the greater vulnerability to ischemia with blood supplied via a single bronchial artery, in right pneumonectomy (10,16). Other predisposing factors are uncontrolled preoperative pleuropulmonary infection, trauma, preoperative radiation therapy, postoperative positive ventilation, and faulty closure of the bronchial stump (16,17,19,20). The radiographic features suggestive of a bronchopleural fistula in the postpneumonectomy patient can be summarized as follows: failure of the postpneumonectomy space to fill; persistent or progressive pneumothorax despite adequate tube drainage; progressive subcutaneous or mediastinal emphysema; a 2-cm drop in the air-fluid level, with a shift of the mediastinum to the side opposite the postpneumonectomy space; consolidation in the remaining lung because of a transbronchial spill; and a sudden pneumothorax or reappearance of air in a previously opaque postpneumonectomy space (7,17) (Fig 3). A decrease in the height of the fluid level by 1.5 cm or more is indicative of a fistula (17). A minor decrease (<1.5 cm) may be due to differences in posture or in the degree of inspiration and should be ignored unless it is accompanied by a mediastinal shift away from the postpneumonectomy space (8,17). There is no good correlation between the extent of fluid filling and the length of the postoperative period. Therefore, because increased air and decreased fluid are cardinal signs of bronchopleural fistula, it is important to monitor changes in the air-fluid level in patients who have undergone a pneumonectomy (10).

Teaching Point

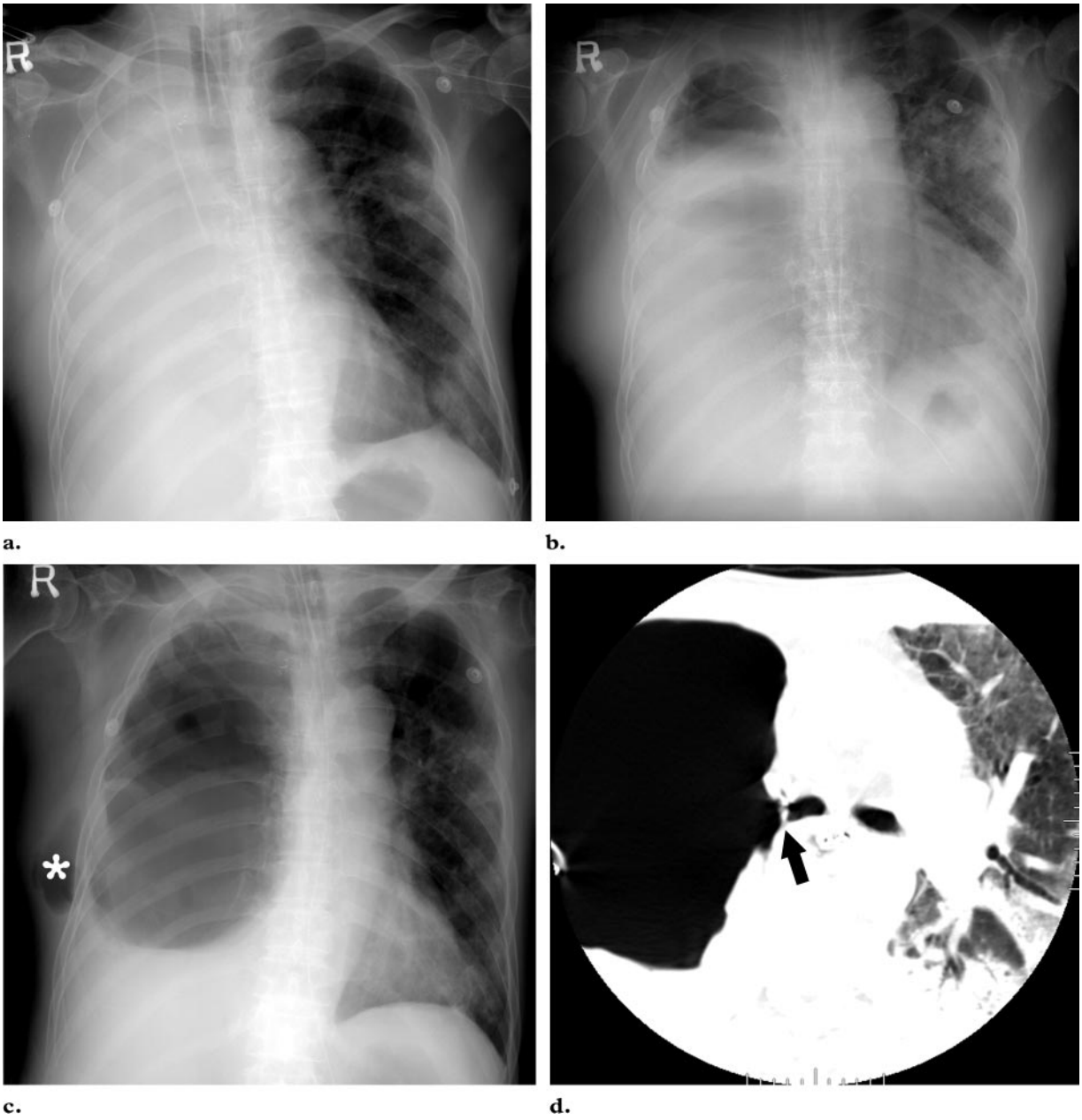
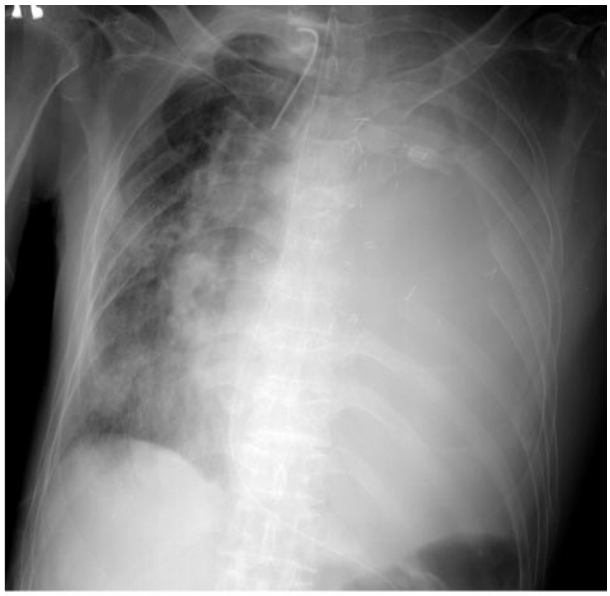


Figure 3. Bronchopleural fistula in a 65-year-old man after right pneumonectomy for large cell carcinoma. **(a)** Chest radiograph on postoperative day 18 shows near complete opacification of the postpneumonectomy space. **(b)** Chest radiograph on postoperative day 20 shows recurrent air-fluid levels in the middle of the postpneumonectomy space. **(c)** Chest radiograph on postoperative day 22 shows tension pneumothorax, subcutaneous emphysema (*), and a leftward shift of mediastinal structures, including the trachea. A chest tube subsequently was inserted for drainage. **(d)** Axial CT image demonstrates a fistula (arrow).

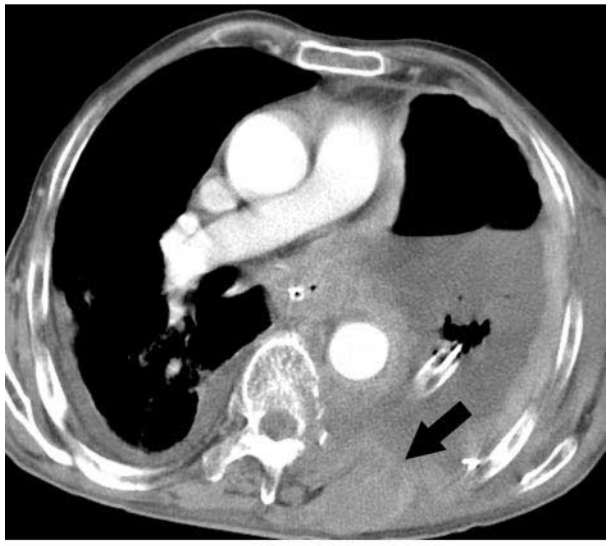
Empyema

Advanced surgical techniques and potent antibiotics have rendered empyema an uncommon complication of pneumonectomy. Its reported incidence varies between 1% and 10%, with most sources citing an incidence of less than 5% (7,21–23). However, empyema remains a potentially fatal complication of pneumonectomy. The infection may be manifested in the early postoperative period or may develop months or even years after surgery (22,24–26). Empyema in the early postoperative period is attributed to intraoperative contamination or residual infection in the pleural cavity, whereas hematogenous spread is the usual cause of infections that occur at a later time after

a.



b.



c.

Figure 4. Empyema in a 74-year-old man after left pneumonectomy for sarcomatoid carcinoma. **(a)** Chest radiograph on postoperative day 21 shows a midline position of the trachea, mediastinum, and tracheostomy tube and total opacification of the postpneumonectomy space. **(b)** Chest radiograph on postoperative day 50 shows a rightward deviation of the trachea with tracheostomy tube and of the mediastinum because of overexpansion of the postpneumonectomy space. **(c)** Axial CT image on postoperative day 52 shows irregular pleural thickening in the postpneumonectomy space and an abscess (arrow) in the posterior chest wall, findings suggestive of empyema. A chest tube was inserted for drainage.

surgery (22). Empyema most often occurs after completion pneumonectomy (pneumonectomy performed after a previous lobectomy), right pneumonectomy, preoperative irradiation, gross contamination of the pleura, surgery-related sepsis, mediastinal lymph node dissection, and postoperative mechanical ventilation. It also occurs more commonly in long bronchial stumps than in short ones (24). Those affected by empyema experience some degree of systemic toxicity, an elevated white blood cell count, and a general deterioration in status (23). The radiographic features of postpneumonectomy empyema include rapid filling of the postpneumonectomy space with fluid; a mediastinal shift toward the side opposite that of pneumonectomy; a decrease in the air-fluid level in the postpneumonectomy space, accompanied by communication to the outside via the bronchus or through the skin; and a new air-fluid level in a previously opacified postpneumonectomy space, indicative of a bronchopleural fistula or a gas-forming organism (7) (Fig 4). Chest radiographs may not be helpful in cases in which there is no change in the air-fluid level to provide a clue. CT is superior to radiography for assessing patients in whom the presence of postpneumonectomy empyema is suspected on clinical grounds. Postpneumonectomy empyema is characterized on CT images by an expansion of the postpneumonectomy space, with a mass effect; convexity or straightening of the normally concave mediastinal border of the postpneumonectomy space; irregularly increased thickening of the residual parietal pleura; and bronchopleural or esophagopleural fistula, which may either cause or coexist with empyema (27,28) (Fig 4).

Teaching Point

a. b.

Figure 5. ARDS in a 62-year-old man after right pneumonectomy for squamous cell carcinoma. **(a)** Chest radiograph on postoperative day 6 shows mild peribronchial cuffing and ill-defined nodular areas of opacity in the left lung. **(b)** Chest radiograph on postoperative day 19 shows increased opacification signifying progressive infiltration of the left lung. ARDS was diagnosed on the basis of clinical and radiographic findings.

ARDS and Acute Lung Injury

Postpneumonectomy acute lung injury is a recognized complication with a likely fatal outcome. The overall incidence of ARDS and acute lung injury has been reported to be approximately 5% (29–31). Patients who develop ARDS after pneumonectomy have a very poor prognosis, with mortality of more than 80%, compared with overall mortality of 65% for all patients with ARDS (29). Although the precise mechanism that causes ARDS or acute lung injury after pneumonectomy remains unclear, it has been postulated that increased postoperative blood flow through the remaining lung may disrupt the capillary endothelial cell–alveoli barrier (29). Alterations in respiratory mechanics during thoracic surgery, particularly in patients with compromised pulmonary function, also may contribute to the development and severity of lung injury (29–31). The diagnosis of ARDS or acute lung injury is largely based on the observation of the characteristic pulmonary opacity on chest radiographs and a pulmonary artery wedge pressure lower than 18 mm Hg. However, it is somewhat difficult to establish this diagnosis after pneumonectomy, when wedge pressure measurements may be falsely low (31). Serial chest radiographs show the rapid development of diffusely increased opacity in the remaining lung (Fig 5). CT depicts ground-glass opacity, increased visibility of interlobular septa, and an anteroposterior opacity gradient (32). ARDS also may develop in combination with other postpneumonectomy complications, such as pneumonia and bronchopleural fistula with or without empyema (33,34).

Pneumonia

The reported incidence of pneumonia in the remaining lung after pneumonectomy is 2%–15% (1,3–5,35). Pneumonia after pneumonectomy is associated with a mortality rate of 25% (4). Aspiration (overt or silent) of gastric secretions and bacterial colonization of atelectatic lung tissue are the most common causes of postoperative pneumonia (36). Intubation and mechanical ventilation may contribute to the prevalence of aspiration with subsequent pneumonia. The transbronchial spill of fluid via a bronchopleural fistula is another possible cause of aspiration pneumonia. As a rule, clinical signs and symptoms lead to the overdiagnosis of pneumonia in the postoperative setting. On the other hand, an overlooked (undiagnosed) case of pneumonia may be fatal. A lack of radiographic evidence does not rule out the possibility of postoperative pneumonia, because the radiologic signs of pneumonia often appear later than the clinical manifestations (18,35). Features on chest radiographs vary, from foci of

increased opacity or bronchopneumonia to lobar consolidation (Fig 6). Infection due to aspirated material may be manifested as necrotizing pneumonia or abscess formation (37,38). CT is especially useful for the evaluation of aspiration pneumonia caused by transbronchial spill in patients with a bronchopleural fistula, because CT images can directly depict the fistula.

Cardiac Herniation

Cardiac herniation is a very rare postpneumonectomy complication, and it requires urgent reduction. Most cases of cardiac herniation are the result of a prolapse of the heart muscle through the pericardial defect created for surgical exposure of the hilar vessels of the lung (39–41). The mortality rate among patients affected by this complication is 40%–50% (40,42). Patients typically manifest sudden hypotension, cyanosis, and circulatory distress (39). Although this complication usually has an immediate postsurgical onset or begins within 24 hours after pneumonectomy, late development and a gradual onset of symptoms also have been reported (39). The triggering event may be a change in the patient's position, coughing, extubation, or the connection of a chest tube to a negative pressure source (21,39).

Radiographic signs of cardiac herniation include the following: in herniation toward the left side, a hemisphere-shaped left border with an incisura between the great vessels and the more laterally herniated cardiac margin; in herniation toward the right side, displacement of the cardiac apex to the right hemithorax. The apex is found either in the lateral costophrenic sulcus or, if counterclockwise rotation has occurred, in the posterior costophrenic sulcus (43). Another radiographic sign of cardiac herniation is a pericardial sac containing air from an associated pneumothorax or the postpneumonectomy space (18,40,44). The immediate differential diagnosis includes massive intrathoracic hemorrhage, atelectasis of the remaining lung, and acute cardiac tamponade (42).

Other Early Complications

Other complications of pneumonectomy that may occur in the early postoperative period include hemothorax, chylothorax, wound infection or disruption, atelectasis, cardiac arrhythmia, and pulmonary embolism.

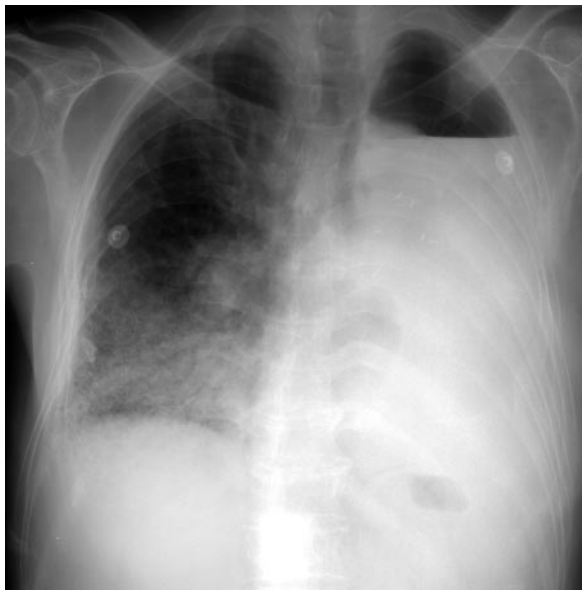


Figure 6. Pneumonia in a 72-year-old man after left pneumonectomy for adenocarcinoma. Chest radiograph on postoperative day 9 shows consolidation and an air bronchogram, findings suggestive of pneumonia, in the lower zone of the right lung. The patient had a productive cough, fever, and leukocytosis. Cultures of his sputum and blood grew a Gram-negative bacillus that was identified as *Enterobacter aerogenes*.

Late Postoperative Complications

Surgery-related Complications

Postpneumonectomy Syndrome.—Postpneumonectomy syndrome is a delayed complication seen primarily in children and young adults within a year after surgery (45–47). The syndrome is manifested in exertional dyspnea, inspiratory stridor, and recurrent pulmonary infections. Most cases of postpneumonectomy syndrome have been described as occurring after right pneumonectomy, when the powerful negative pressure of the involved hemithorax and overexpansion of the remaining lung move the mediastinum rightward. As the overexpanded lung further displaces the mediastinum toward the right side, the heart descends in the hemithorax and rotates counterclockwise along its main axis. The trachea also is displaced toward the right side, with resultant stretching of the left main bronchus, which is compressed downward by the aortic arch and the left main pulmonary artery (45). When tracheobronchomalacia occurs in combination with the classic symptoms of postpneumonectomy syndrome, the deleterious ef-

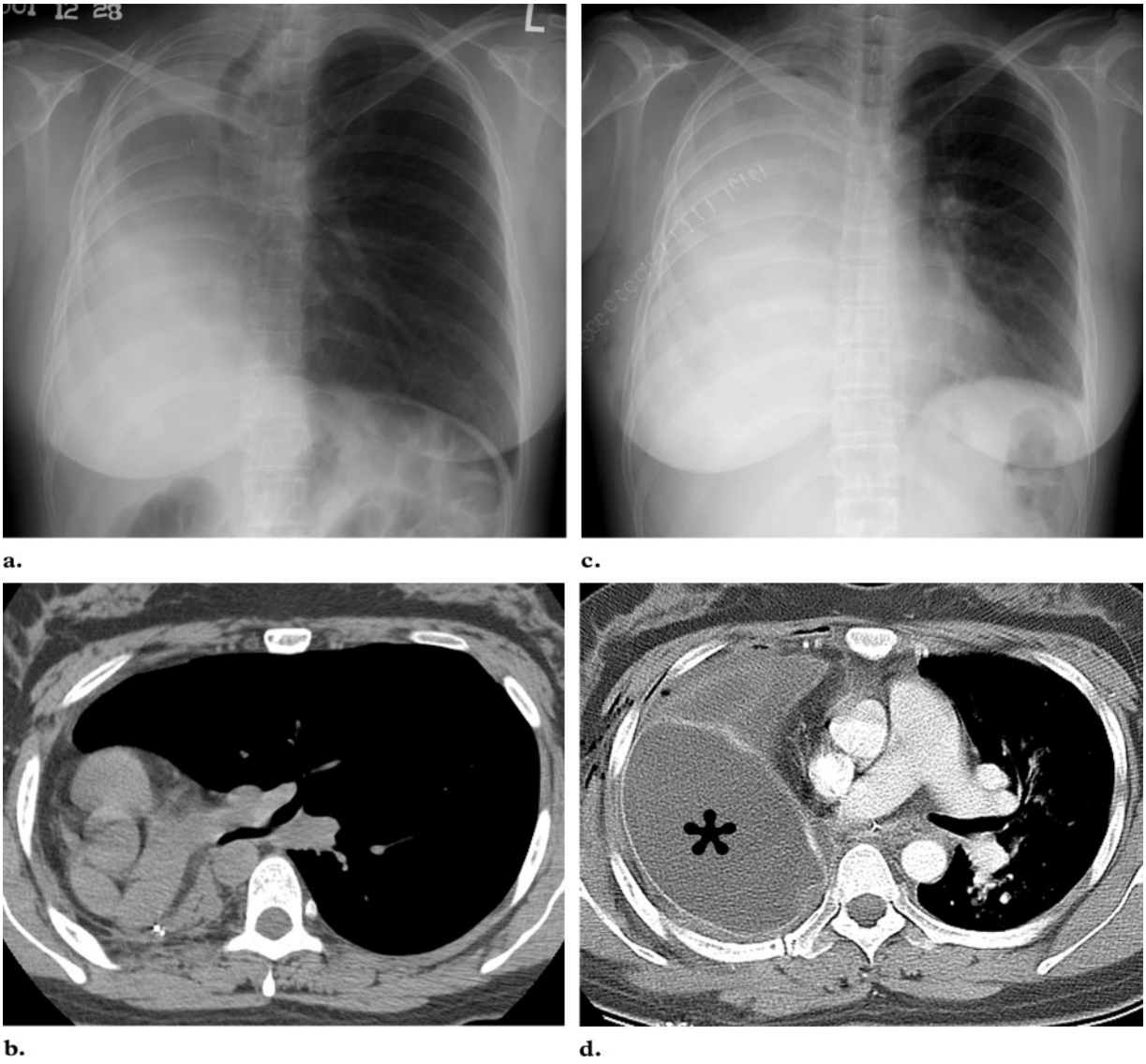
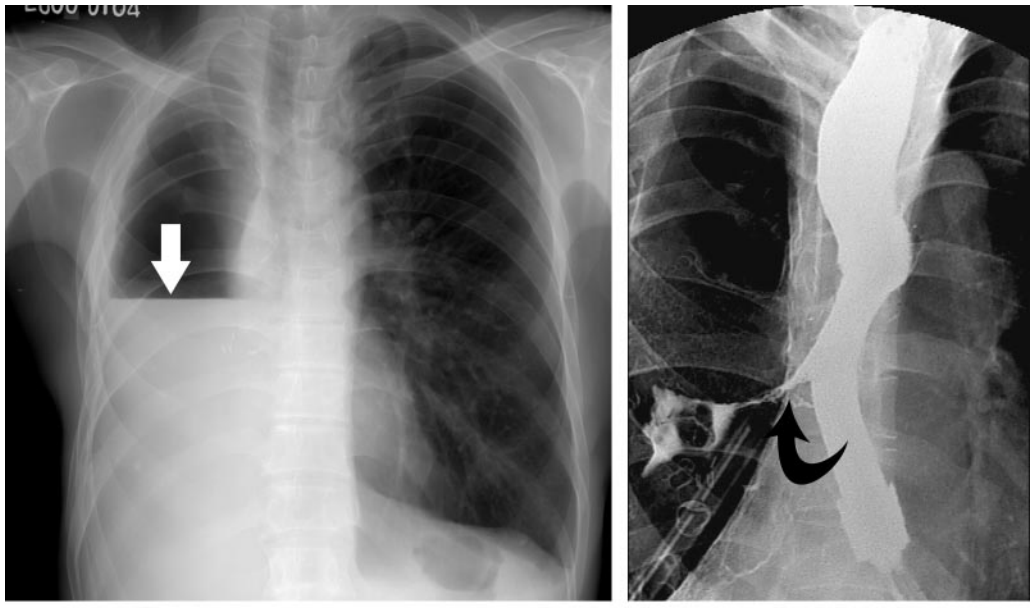


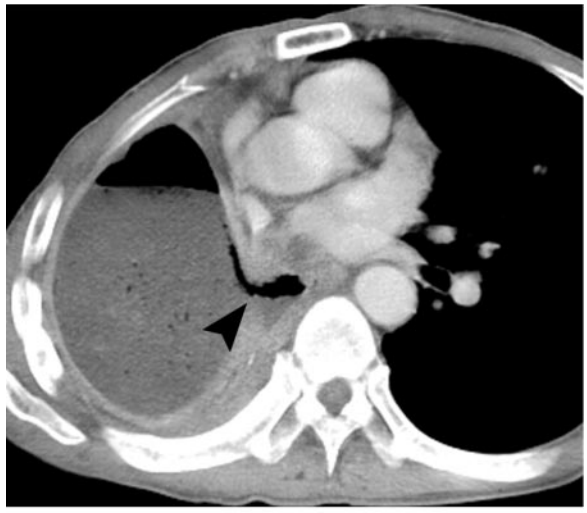
Figure 7. Postpneumonectomy syndrome in a 34-year-old woman after right pneumonectomy for multidrug-resistant tuberculosis. **(a)** Chest radiograph at 11-month follow-up shows overexpansion and anterior herniation of the left lung and rightward deviation of the trachea. **(b)** Axial CT image depicts stretching of the left main bronchus, which is visible between the left pulmonary artery and the vertebral body. **(c)** Chest radiograph obtained after silicone insertion shows normal locations of the trachea and the left lung. **(d)** Axial CT image obtained at the same time as **c** shows a patent left main bronchus and reexpansion of the postpneumonectomy space (*).

fects of bronchial compression are compounded (46). The frequency with which this syndrome occurs in infants, young children, and women is believed to be related to the increased elasticity and compliance of their lungs and mediastinum, compared with those of older patients and men (45–47). Chest radiographic findings include displacement of the heart and trachea toward the right side and the posterior. CT images show abnormal narrowing of the distal part of the trachea and the left main bronchus because of compression of the airway between the pulmonary artery anteriorly and the aorta and spine posteriorly (47) (Fig 7). Various surgical procedures have been used to reposition the mediastinum. Silicone breast implants have been used in the postpneumonectomy space to prevent rotational shifting after pneumonectomy in children, a method that has brought good results (45,48,49). In patients with a history of right pneumonectomy and subsequent dyspnea and recurrent pulmonary infection, a proper radiologic evaluation is crucial to

Teaching Point



a. c.

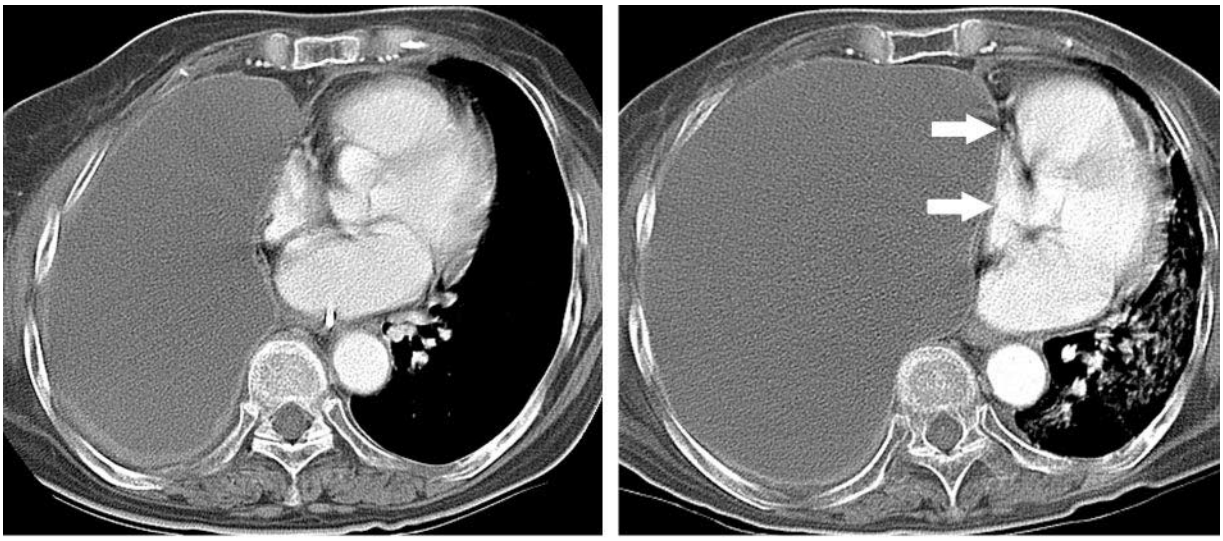


b.

Figure 8. Esophagopleural fistula in a 53-year-old man after right pneumonectomy for squamous cell carcinoma. **(a)** Chest radiograph 2 years after pneumonectomy shows a recurrent air-fluid level (arrow) in the postpneumonectomy space. **(b)** Axial CT image demonstrates a fistula between the esophagus and the postpneumonectomy space (arrowhead). **(c)** Esophagogram shows leakage of oral contrast material through the esophagopleural fistula (arrow).

establish a diagnosis of postpneumonectomy syndrome. CT is the best method for obtaining information about the status of the postpneumonectomy space; the position of the mediastinal blood vessels, bronchi, and thoracic spine; and the specific site of bronchial narrowing (18,48).

Esophagopleural Fistula.—Esophagopleural fistula is a devastating pathologic condition that occurs in 0.2%–1.0% of patients after pneumonectomy (50,51). Patients with esophagopleural fistula represent a very heterogeneous group because this condition can result from at least three different mechanisms: surgical injury, mediastinal cancer recurrence, and chronic infection (18,51). In the early postoperative period, the fistula is usually secondary to direct esophageal injury or compromise of the blood supply to the lower esophagus at the time of surgery (7). In the late postoperative period, a recurrent tumor or chronic inflammation with origins in the esophagus, the bronchial stump, or the surrounding tissues may be the causal mechanism (50,51). Like recurrent cancers, most esophagopleural fistulas occur within the first 2 years after cessation of cancer treatment (18,50,51). The diagnosis of an esophagopleural fistula may be confirmed with various investigations, including chest radiography, esophagoscopy, and bronchoscopy (50). The features of an esophagopleural fistula at chest radiography are similar to those of a bronchopleural fistula and include a decrease in the air-fluid level during the postoperative period and the reappearance of an air-fluid level in a previously opacified postpneumonectomy space. Esophagography is another potentially useful diagnostic modality; however, a barium swallow performed with the



a. b.

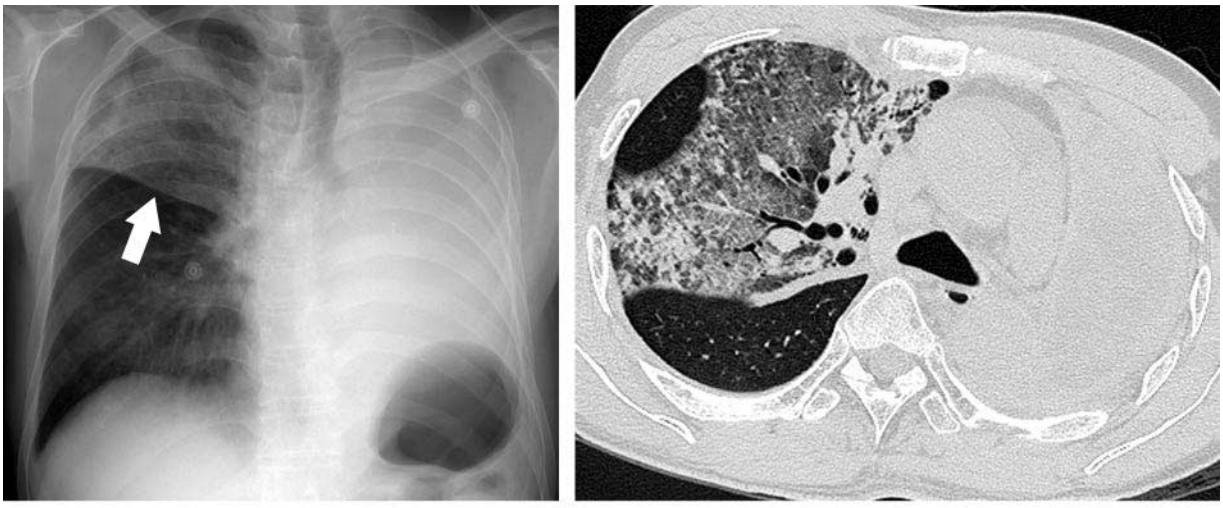
Figure 9. Late-onset empyema in a 69-year-old woman after right pneumonectomy for squamous cell carcinoma. **(a)** Axial CT image obtained at the time of discharge shows a slight leftward deviation of the heart. **(b)** Axial CT image obtained 8 months later shows marked leftward deviation of the heart due to overexpansion of the postpneumonectomy space (arrows) with a mass effect.

patient in the upright position may fail to opacify a tiny fistulous tract. CT can directly depict the fistula and any additional abnormalities, such as a recurrent tumor mass, inflammatory lymph nodes, empyema in the postpneumonectomy space, and aspiration pneumonia in the contralateral lung (Fig 8). Patients with an esophagopleural fistula must cease oral intake and undergo drainage of the pleural cavity and surgical closure of the fistula (51–53).

Late-Onset Bronchopleural Fistula.—Approximately half of all bronchopleural fistulas occur early, within the 1st postoperative week (24). Late-onset bronchopleural fistulas usually are due to an infection or a recurrent tumor in the bronchial stump. Radiologic findings in delayed-onset bronchopleural fistulas are the same as those in bronchopleural fistulas in the early period after pneumonectomy. The reappearance of an air-fluid level, a change in an existing air-fluid level, and the development of tension pneumothorax with or without subcutaneous emphysema are findings suggestive of air leakage into the postpneumonectomy space. Although such findings are usually verified with bronchoscopy, CT with a three-dimensional reconstruction technique is useful to identify the fistula and to provide additional information regarding the amount of residual fluid, pleural reaction, mediastinal abnormality, local tumor recurrence, and the state of the remaining lung.

Infections

Late-Onset Empyema.—Empyema may occur within 1 day or several weeks after pneumonectomy. Although postpneumonectomy empyema is usually diagnosed during the same hospitalization, some cases are not detected until months or even several years later (25,26). The pathogenesis of late-onset empyema is sometimes difficult to establish because of the many possible sources of infection of the postpneumonectomy space. In two-thirds of all patients who undergo pneumonectomy, the postpneumonectomy space remains fluid filled and marginated by a thickened pleura, whereas in the other one-third of patients the space is obliterated by fibrous tissue or normal mediastinal structures. The persistence of fluid in the postoperative space exposes patients to the risk of late-occurring empyema (9,26). Furthermore, late-onset postpneumonectomy empyema may be very difficult to diagnose. In cases of bronchopleural or esophagopleural fistula, multiple air-fluid levels in the postpneumonectomy space on chest radiographs are suggestive of the diagnosis of empyema or make it obvious (25,26). A sudden bulge in the postpneumonectomy space and a consequent mediastinal shift toward the opposite side, without the reappearance of an air-fluid level, also are suggestive of late-onset empyema (Fig 9). Postpneumonectomy empyema



a. b.

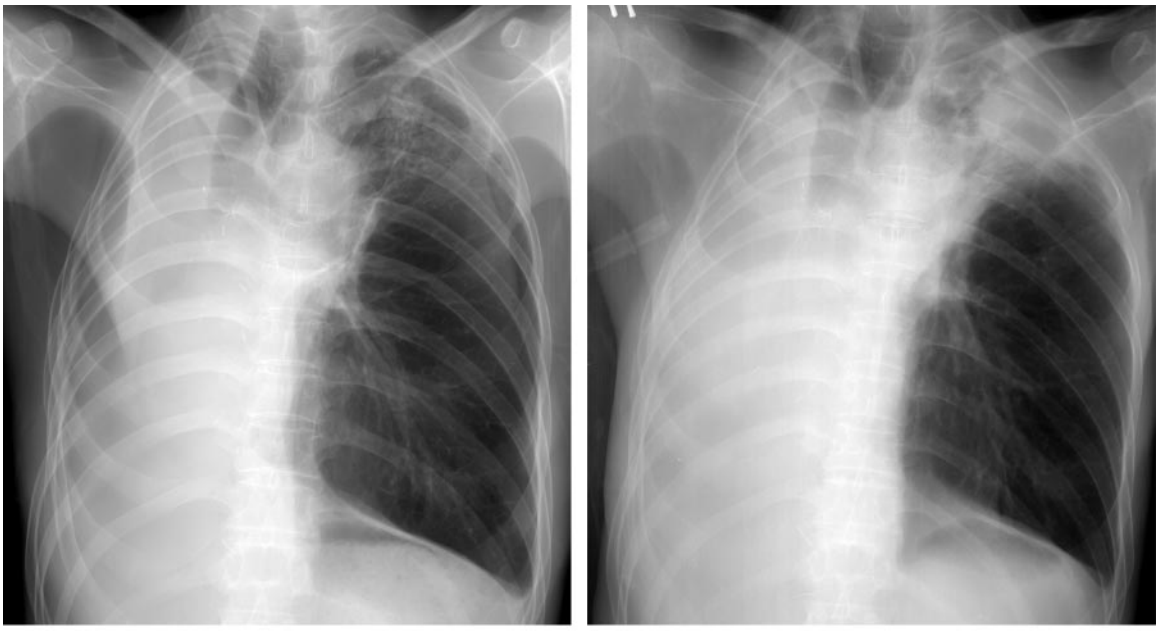
Figure 10. Pneumonia of the contralateral lung in a 62-year-old man after left pneumonectomy for squamous cell carcinoma. **(a)** Chest radiograph 8 months after surgery shows consolidation in the upper lobe of the right lung (arrow). **(b)** Axial CT image obtained at the same time as **a** shows areas of consolidation and ground-glass opacity in the upper lobe of the right lung. *Streptococcus pneumoniae* was cultured from the patient's sputum.

alone, in the absence of a bronchopleural fistula, may produce minimal changes on chest radiographs. CT in such cases may provide important diagnostic information. In addition, fluid in the postpneumonectomy space may be aspirated and the samples used to obtain cell counts, cultures, and cytologic analyses. In patients with a bronchopleural or esophagopleural fistula, CT can help identify the fistula and provide information about the position of the mediastinum, the amount of residual fluid and local pleural reaction, and the status of the remaining lung (24).

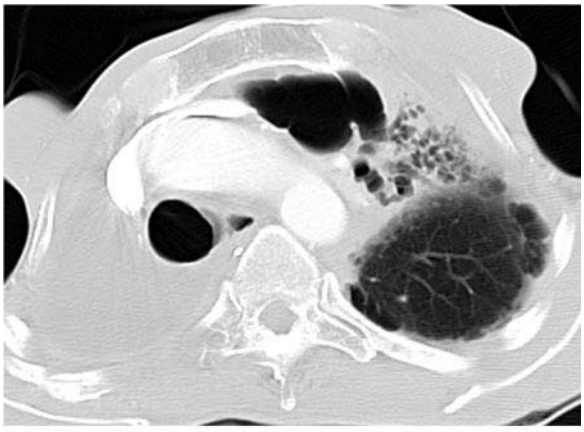
Pneumonia of the Contralateral Lung.—Pneumonia that is diagnosed after a patient's discharge following pneumonectomy is mainly community acquired (unlike that diagnosed in the early postoperative period, which is mainly due to aspiration). Newly developed opacity in the contralateral lung parenchyma is suggestive of this condition (Fig 10). The differential diagnosis includes radiation- and chemotherapy-induced increases in pulmonary opacity and recurrences of primary diseases such as cancer (metastases) or tuberculosis.

Treatment-related Complications

Radiation Pneumonitis.—The occurrence of radiation pneumonitis as a complication of mediastinal radiation therapy after pneumonectomy is not uncommon. According to the results of previous studies in patients with Hodgkin disease and non-Hodgkin lymphoma, mediastinal radiation therapy led to radiation pneumonitis in 6.4% of patients (54). Radiographic changes due to radiation pneumonitis are generally confined to the field of irradiation. Deviation of the mediastinum and lung toward the side of pneumonectomy is a familiar finding. The retrosternal shift may have a dual effect: A substantial portion of the lung volume may be inadvertently included within the "mediastinal" radiation port; in addition, the sternal and vertebral silhouettes may significantly obscure the radiographic manifestations of radiation pneumonitis (54). CT is helpful for evaluating this retrosternal pulmonary-mediastinal shift



a. b.

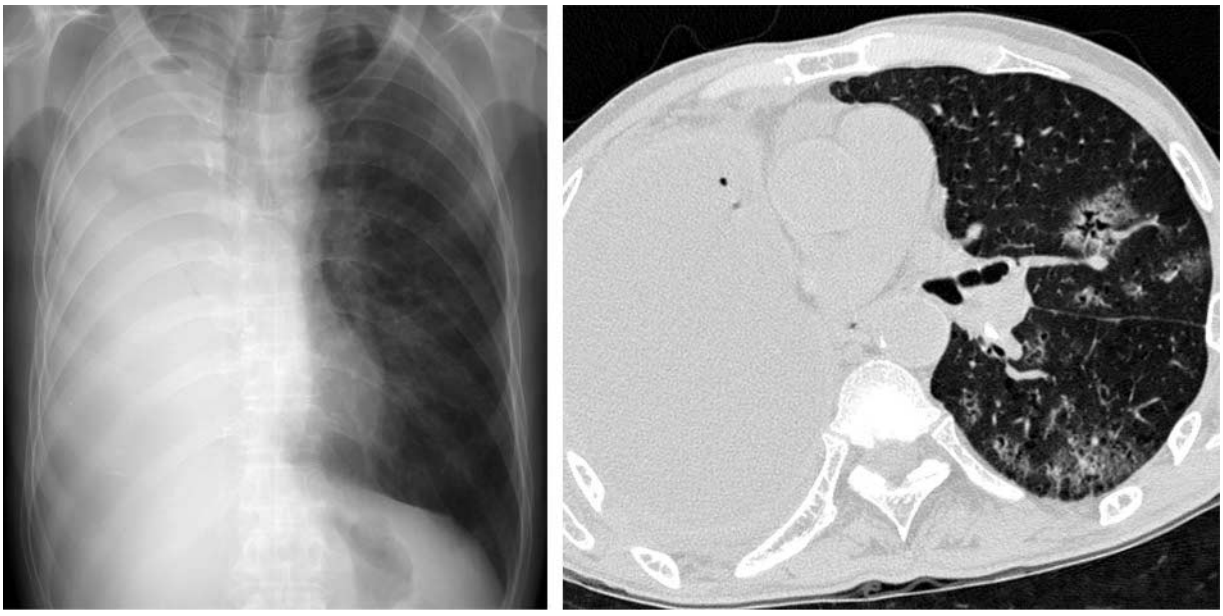


c.

Figure 11. Radiation pneumonitis in a 43-year-old man after right pneumonectomy for squamous cell carcinoma. **(a)** Chest radiograph obtained 5 months after completion of radiation therapy shows fibrosis and nodular areas of opacity with a volume decrease in the upper lobe of the left lung. **(b)** Chest radiograph obtained 8 months after completion of radiation therapy shows progression of fibrotic change. **(c)** Axial CT image obtained at the same time as **b** shows fibrotic consolidation and bronchiectasis in the area of fibrotic change.

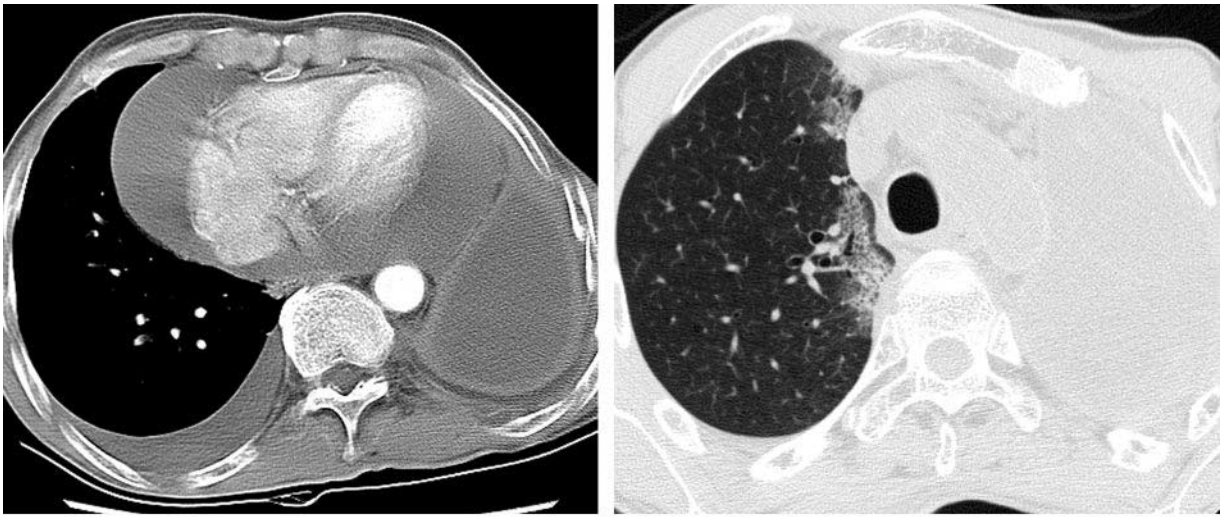
as well as associated radiation pneumonitis. Radiation pneumonitis usually occurs approximately 4–12 weeks after completion of radiation therapy. Fibrous changes take 6–24 months to evolve but usually remain stable after 2 years. The imaging characteristics of radiation pneumonitis, including ground-glass opacity or consolidation in the acute phase and traction bronchiectasis, volume loss, and consolidation in the later phase, are well described in the literature (55–57) (Fig 11).

Radiation-induced BOOP.—BOOP differs from classic radiation pneumonitis because of the migration of the alveolar areas of increased opacity and the absence of significant sequelae (55). BOOP usually occurs within 6 weeks to 10 months after radiation therapy (55). The most common feature at chest radiography and CT is multiple bilateral areas of patchy consolidation or ground-glass opacity, frequently in subpleural or peribronchial locations, with a characteristic migratory pattern on serial chest images (55) (Fig 12).



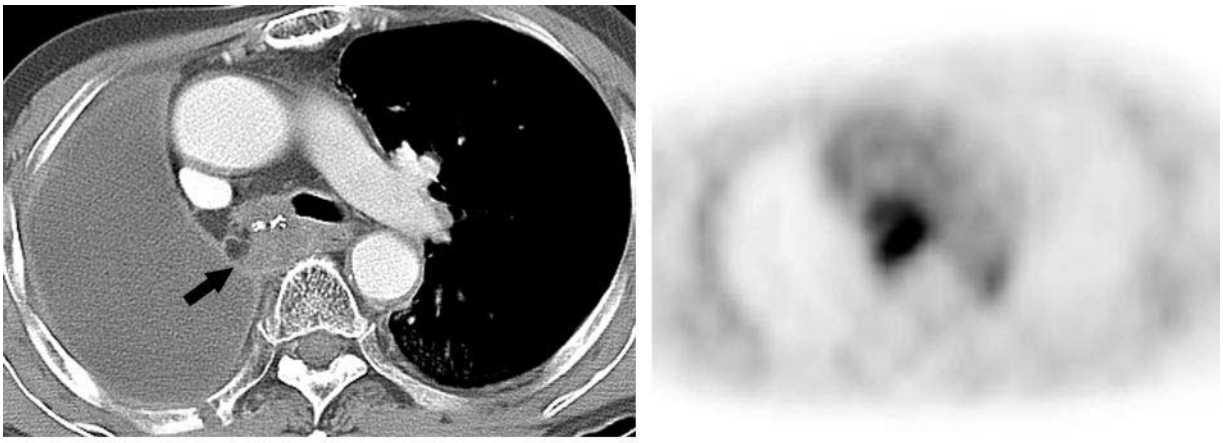
a. b.

Figure 12. Radiation-induced BOOP in a 69-year-old man after right pneumonectomy for squamous cell carcinoma. **(a)** Chest radiograph obtained 1 month after completion of radiation therapy shows multiple foci of patchy increased opacity in the left lung. **(b)** Axial CT image shows multiple foci of patchy consolidation along the bronchovascular bundle in the left lung. The results of a video-assisted thoracoscopic lung biopsy showed a BOOP reaction in the left lung.



a. b.

Figure 13. Radiation-induced pericarditis and pleuritis in a 63-year-old man after left pneumonectomy for squamous cell carcinoma. **(a)** Axial CT image obtained with a mediastinal window setting 4 months after completion of radiation therapy shows extensive pericardial and pleural effusion in the right hemithorax. **(b)** Axial CT image obtained with a lung window setting at the same time as **a** shows combined radiation pneumonitis in the upper paramediastinal zone of the right lung.



a. b.

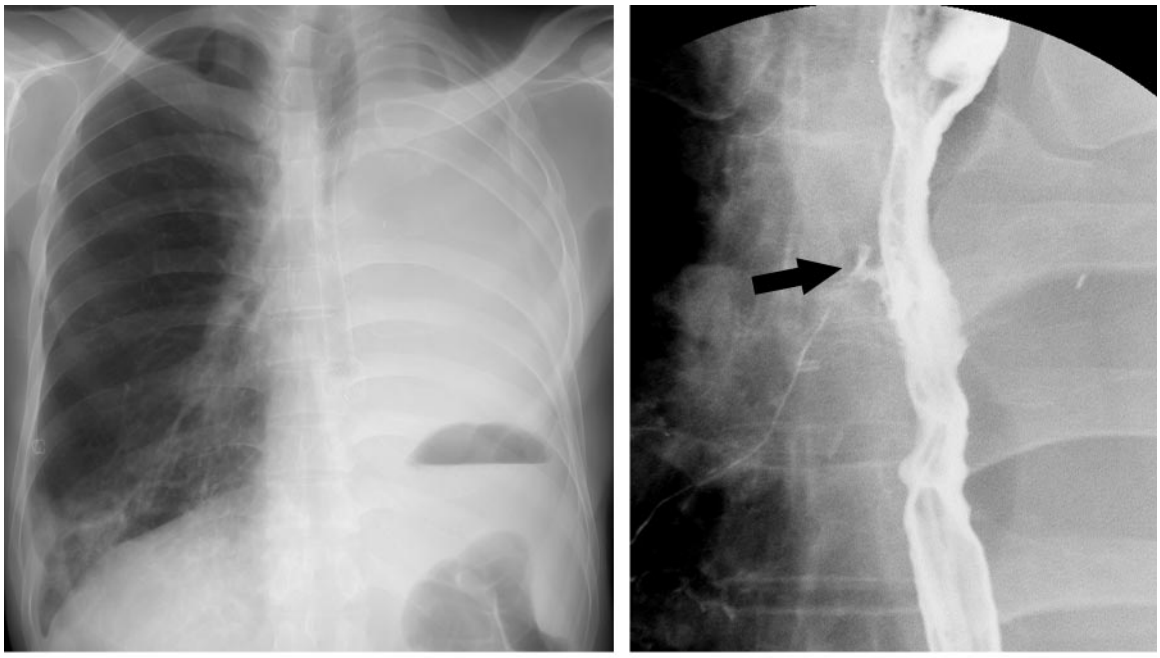
Figure 14. Recurrent tumor in a 52-year-old man after right pneumonectomy for squamous cell carcinoma. **(a)** Axial CT image shows a newly developed soft-tissue mass (arrow) with a diameter of 3 cm that surrounds the surgical clip at the bronchial stump site. **(b)** Image from fluorine 18 fluorodeoxyglucose positron emission tomography shows a hypermetabolic lesion that corresponds to the soft-tissue mass in **a**. The results of a bronchoscopic biopsy confirmed the recurrence of squamous cell carcinoma at the stump site.

Radiation-induced Pericarditis and Pleuritis.—The prevalence of radiation-induced pericarditis is 2%–6% in patients receiving radiation therapy after pneumonectomy (55). Radiation-induced pericarditis usually is manifested 6–9 months after therapy, and nearly all cases occur within 18 months after radiation therapy (55,58). Acute and chronic variants occur with equal frequency. Constriction of the cardiac chambers is observed in 15%–20% of patients with pericarditis, but it also may occur in the absence of pericardial disease (55). The typical appearance of radiation-induced pericarditis is symmetric enlargement of the cardiac silhouette (Fig 13). Pericardial effusion and thickening are best evaluated with CT or MR imaging (59–61). The major consideration in the differential diagnosis is a malignant pericardial effusion (58). The identification of eccentric pericardial thickening or adjacent mediastinal lymph nodes may aid in the diagnosis of malignancy (58).

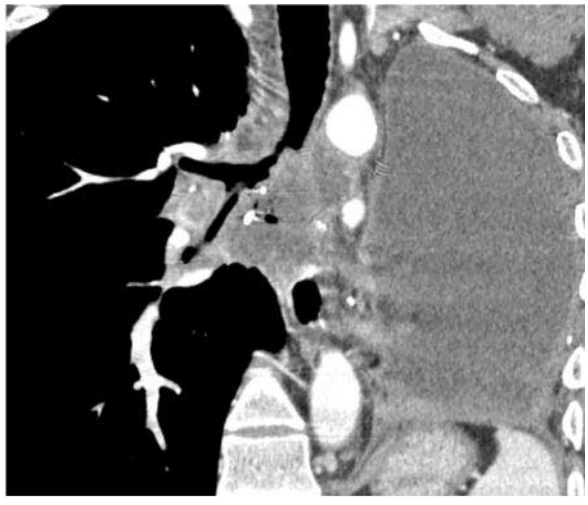
Pleural effusions also may develop, and this usually occurs within 6 months of completion of therapy (58). Distinguishing a radiation-induced pleural effusion from a malignant pleural effusion can be difficult. If effusions do not spontaneously resolve, thoracentesis may be required; unfortunately, a cytologic analysis is not always diagnostic (58). Decreased pulmonary venous return due to radiation-induced constrictive pericarditis may be the cause of pleural effusion in patients with concomitant pericardial and pleural effusions (62).

Recurrence of Primary Disease

Tumors.—The recurrence of lung cancers and metastases after a curative resection suggests the presence of micrometastases that were not recognized at any examination at the time of surgery. The recurrence rate at the bronchial stump is 2.2%–37% for all resected lung cancers, according to previous reports (63,64). Most such recurrences take place within 2 years after surgery (63,64). The detection of recurrent tumors at postpneumonectomy chest radiography has been difficult. One of the most sensitive indicators of a recurrent tumor in the postpneumonectomy space or mediastinum is a lateral shift in the position of the mediastinum on chest radiographs; however, this finding may be subtle and not easily detected (65). CT images depict a recurrent tumor as a soft-tissue mass at or near the bronchial stump (65,66) (Fig 14). CT also can help detect



a. b.

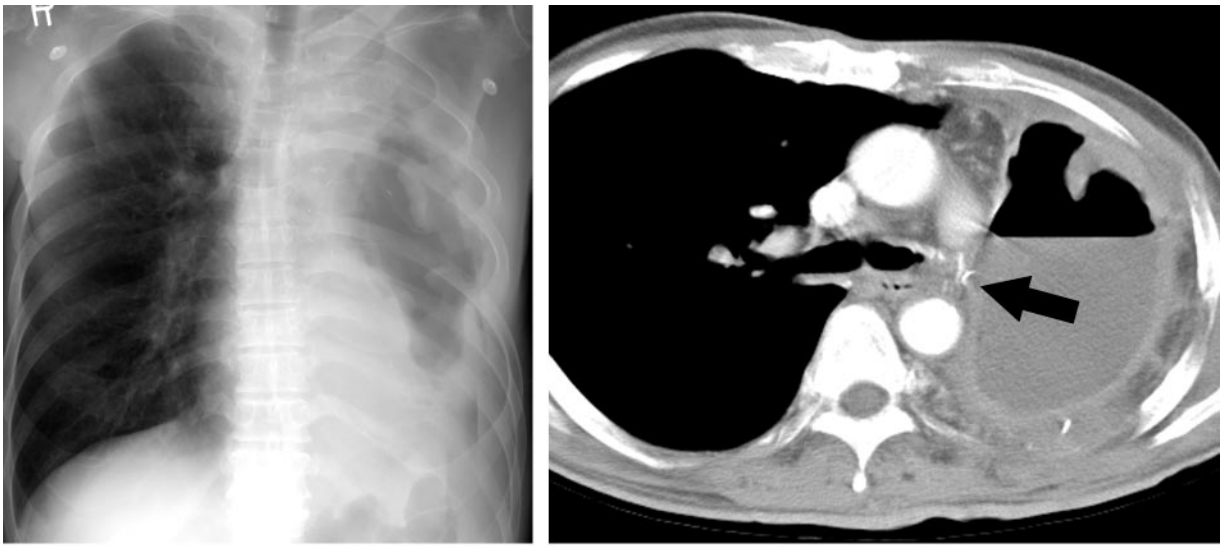


c.

Figure 15. Recurrent tumor in a 39-year-old man after left pneumonectomy for squamous cell carcinoma. **(a)** Chest radiograph shows segmental consolidation that was presumed to be due to aspiration pneumonia in the lower lobe of the right lung. **(b)** Esophagram shows a thin linear area of contrast material (arrow) that has leaked from the esophagus at the level of the carina. **(c)** Coronal CT image depicts a necrotic lymph node, which is indicative of recurrent metastatic carcinoma, and a resultant esophago-nodo-bronchial fistula at the carina.

abnormalities such as pleural seeding and enlarged mediastinal lymph nodes (Fig 15). Almost all patients with a postpneumonectomy local tumor recurrence undergo radiation therapy, especially if they did not undergo previous postoperative irradiation. CT is helpful in accurately delineating the extent of recurrent disease in patients who have undergone previous postoperative radiation therapy and is useful for assessing the extent of tumor regression after repeated radiation therapy.

Tuberculosis.—Pneumonectomy is a high-risk procedure in patients with a chronic infectious disease such as tuberculosis, and many surgeons recommend that indications for this surgery be strictly defined and carefully considered (67–70). However, there are conditions in which pneumonectomy or pleuropneumonectomy is the only curative treatment modality; these include massive destruction of the lung tissue, significant hemoptysis, stenosis of the main bronchus, and multidrug-resistant infection. Bronchopleural fistula and empyema, because they are fairly common complications after pneumonectomy and are associated with high rates of morbidity and mortality, have been well studied. In contrast, to our knowledge, studies of recurrent tuberculosis after pneumonectomy have been infrequent. In one small case series, long-term follow-up data were available for 33 patients who underwent lung resection (either lobectomy or pneumonectomy) (67). According to these results, only 5% of the patients tested positive for tuberculosis at long-term follow-up sputum analyses, and the reactivated infection in these patients was easily controlled with further treatment (67). In our patient series, serial chest radiography played an important role, in conjunction with sputum testing, in



a. b.

Figure 16. Recurrent disease in a 57-year-old man after left pneumonectomy for multidrug-resistant tuberculosis. **(a)** Chest radiograph obtained 7 months after pneumonectomy shows irregular pleural thickening in the postpneumonectomy space. **(b)** Axial CT image depicts a newly developed soft-tissue lesion (arrow) near the surgical clip at the bronchial stump site. Clinical findings were indicative of combined bronchopleural fistula and empyema. The results of a bronchoscopic biopsy indicated recurrent pulmonary tuberculosis at the bronchial stump site.

helping detect postpneumonectomy reactivation of tuberculosis in the remaining lung parenchyma. Occasionally, an initial manifestation of reactivation at the bronchial stump may mimic a bronchopleural fistula or empyema on chest radiographs. Lymph node necrosis due to reactivated tuberculosis also may occur and may lead to an esophago-nodo-bronchial fistula. CT best depicts these findings, with the use of axial source images and three-dimensional reconstructions (Fig 16).

Summary

In our experience, the most common complications in the early period after pneumonectomy are pulmonary edema, bronchopleural fistula, and pneumonia of the contralateral lung. An understanding of the normal postsurgical alterations at serial chest radiography after pneumonectomy is essential for detecting complications during this period. Sequential examinations with chest radiography after pneumonectomy are an invaluable method of screening for complications, especially in the early postoperative period. When radiographic findings are subtle or equivocal, CT may be used to obtain more detailed diagnostic information. The most common complications in the late postpneumonectomy period, in our experience, are delayed surgical complications and recurrences of primary disease. In the late postoperative period, CT is often superior to chest radiography for detecting complications.

Teaching Point

The radiologist plays a major role in the diagnosis of complications after pneumonectomy. Recognition of the clinical and radiologic features of the various complications that may occur after pneumonectomy is imperative to achieve prompt and accurate diagnoses that may help reduce morbidity and mortality.

References

1. Duque JL, Ramos G, Gastrodeza J, et al. Early complications in surgical treatment of lung cancer: a prospective, multicenter study. Ann Thorac Surg 1997;63:944–950.
2. Dyszkiewicz W, Pawlak K, Gasiorowski L. Early post-pneumonectomy complications in the elderly. Eur J Cardiothorac Surg 2000;17:246–250.
3. Harmon H, Fergus S, Cole FH. Pneumonectomy: review of 351 cases. Ann Surg 1976;183:719–722.
4. Nagasaki F, Flehinger BJ, Martini N. Complications of surgery in the treatment of carcinoma of the lung. Chest 1982;82:25–29.
5. Mitsudomi T, Mizoue T, Yoshimatsu T, et al. Postoperative complications after pneumonectomy for treatment of lung cancer: multivariate analysis. J Surg Oncol 1996;61:218–222.
6. Romano PS, Mark DH. Patient and hospital characteristics related to in-hospital mortality after lung cancer resection. Chest 1992;101:1332–1337.
7. Goodman LR. Postoperative chest radiograph. II. Alterations after major intrathoracic surgery. AJR Am J Roentgenol 1980;134:803–813.
8. Wechsler RJ, Goodman LR. Mediastinal position and air-fluid height after pneumonectomy: the

effect of the respiratory cycle. AJR Am J Roentgenol 1985;145:1173–1176.
9. Biondetti PR, Fiore D, Sartori F, Colognato A, Ravasini R, Romani S. Evaluation of post-pneumonectomy space by computed tomography. J Comput Assist Tomogr 1982;6:238–242.
10. Lams P. Radiographic signs in post-pneumonectomy bronchopleural fistula. J Can Assoc Radiol 1980;31:178–180.
11. Turnage WS, Lunn JJ. Postpneumonectomy pulmonary edema: a retrospective analysis of associated variables. Chest 1993;103:1646–1650.
12. Gluecker T, Capasso P, Schnyder P, Gudinchet F. Clinical and radiologic features of pulmonary edema. RadioGraphics 1999;19:1507–1531.
13. Deslauriers J, Aucoin A, Grégoire J. Postpneumonectomy pulmonary edema. Chest Surg Clin N Am 1998;8:611–631.
14. Waller DA, Gebitekin C, Saunders NR, Walker DR. Noncardiogenic pulmonary edema complicating lung resection. Ann Thorac Surg 1993;55: 140–143.
15. Mathru M, Blakeman B, Dries DJ, Kleinman B, Kumar P. Permeability pulmonary edema following lung resection. Chest 1990;98:1216–1218.
16. Hubaut JJ, Baron O, Al Habash O, Despins P, Duveau D, Michaud JL. Closure of the bronchial stump by manual suture and incidence of bronchopleural fistula in a series of 209 pneumonectomies for lung cancer. Eur J Cardiothorac Surg 1999;16:418–423.
17. Lauckner ME, Beggs I, Armstrong RF. The radiological characteristics of bronchopleural fistula following pneumonectomy. Anaesthesia 1983;38: 452–456.
18. Kim EA, Lee KS, Shim YM, et al. Radiographic and CT findings in complications following pulmonary resection. RadioGraphics 2002;22:67–86.
19. Friedman PJ, Hellekant CAG. Radiologic recognition of bronchopleural fistula. Radiology 1977; 124:289–295.
20. Wright CD, Wain JC, Mathisen DJ, Grillo HC. Postpneumonectomy bronchopleural fistula after sutured bronchial closure: incidence, risk factors, and management. J Thorac Cardiovasc Surg 1996;112:1367–1371.
21. Tsukada G, Stark P. Postpneumonectomy complications. AJR Am J Roentgenol 1997;169:1363–1370.
22. Kirsh MM, Rotman H, Behrendt DM, Orringer MB, Sloan H. Complications of pulmonary resection. Ann Thorac Surg 1975;20:215–236.
23. Shields TW. General features and complications of pulmonary resections. In: Shields TW, ed. General thoracic surgery. 4th ed. Vol 1. Philadelphia, Pa: Williams & Wilkins, 1994; 401–414.
24. Wain JC. Management of late postpneumonectomy empyema and bronchopleural fistula. Chest Surg Clin N Am 1996;6:529–541.
25. Kerr WF. Late-onset post-pneumonectomy empyema. Thorax 1977;32:149–154.
26. Kutty CP, Varkey B. Empyema seven years after pneumonectomy: detection by gallium 67 scan. JAMA 1979;242:2322–2324.
27. Choe DH, Lee JH, Lee BH, Kim KH, Chin SY, Zo JI. Postpneumonectomy empyema: CT findings in six patients. Clin Imaging 2001;25:28–31.
28. Heater K, Revzani L, Rubin JM. CT evaluation of empyema in the postpneumonectomy space. AJR Am J Roentgenol 1985;145:39–40.
29. Hayes JP, Williams EA, Goldstraw P, Evans TW. Lung injury in patients following thoracotomy. Thorax 1995;50:990–991.
30. Jordan S, Mitchell JA, Quinlan GJ, Goldstraw P, Evans TW. The pathogenesis of lung injury following pulmonary resection. Eur Respir J 2000; 15:790–799.
31. Kutlu CA, Williams EA, Evans TW, Pastorino U, Goldstraw P. Acute lung injury and acute respiratory distress syndrome after pulmonary resection. Ann Thorac Surg 2000;69:376–380.
32. Padley SP, Jordan SJ, Goldstraw P, Wells AU, Hansell DM. Asymmetric ARDS following pulmonary resection: CT findings—initial observations. Radiology 2002;223:468–473.
33. Deb S, Fonseca P. Respiratory distress following pneumonectomy. Chest 1999;116:1461–1463.
34. Bethea MC, King TC, Carberry DM, Hutchinson JE. Acute respiratory distress associated with postpneumonectomy bronchopleural fistula. Chest 1976;70:567.
35. Ferdinand B, Shennib H. Postoperative pneumonia. Chest Surg Clin N Am 1998;8:529–539.
36. Schweizer A, Perrot MD, Hohn L, Spiliopoulos A, Licker M. Massive contralateral pneumonia following thoracotomy for lung resection. J Clin Anesth 1998;10:678–680.
37. Franquet T, Giménez A, Rosón N, Torrubia S, Sabaté JM, Pérez C. Aspiration diseases: findings, pitfalls, and differential diagnosis. RadioGraphics 2000;20:673–685.
38. DePaso WJ. Aspiration pneumonia. Clin Chest Med 1991;12:269–284.
39. Asamura H. Early complications: cardiac complications. Chest Surg Clin N Am 1999;9:527–541.
40. Arndt RD, Frank CG, Schmitz AL, Haveson SB. Cardiac herniation with volvulus after pneumonectomy. AJR Am J Roentgenol 1978;130:155–156.

41. Goldstraw P. Pneumonectomy and its modifications. In: Shields TW, ed. General thoracic surgery. 4th ed. Vol 1. Philadelphia, Pa: Williams & Wilkins, 1994; 415–427.
42. Dippel WF, Ehrenhaft JL. Herniation of the heart after pneumonectomy. J Thorac Cardiovasc Surg 1973;65:207–209.
43. Gurney JW, Arnold S, Goodman LR. Impending cardiac herniation: the snow cone sign. Radiology 1986;161:653–655.
44. Tschersich HU, Skorapa V, Fleming WH. Acute cardiac herniation following pneumonectomy. Radiology 1976;120:546.
45. Mehran RJ, Deslauriers J. Late complications: postpneumonectomy syndrome. Chest Surg Clin N Am 1999;9:655–673.
46. Quillin SP, Shackelford GD. Postpneumonectomy syndrome after left lung resection. Radiology 1991;179:100–102.
47. Shepard JA, Grillo HC, McLoud TC, Dedrick CG, Spizarny DL. Right pneumonectomy syndrome: radiologic findings and CT correlation. Radiology 1986;161:661–664.
48. Valji AM, Maziak DE, Shamji FM, Matzinger FR. Postpneumonectomy syndrome: recognition and management. Chest 1998;114:1766–1769.
49. Jansen JP, Brutel de la Riviere A, Alting MP, Westermann CJ, Bergstein PG. Postpneumonectomy syndrome in adulthood: surgical correction using an expandable prosthesis. Chest 1992;101:1167–1170.
50. Lauwers P, Van Schil P, Schroyens W, Fierens H, Vanmaele R, Eyskens E. Oesophagopleural fistula: a rare sequel of pneumonectomy. Thorac Cardiovasc Surg 1996;44:266–270.
51. Massard G, Ducrocq X, Hentz JG, et al. Esophagopleural fistula: an early and long-term complication after pneumonectomy. Ann Thorac Surg 1994;58:1437–1440.
52. Richardson JK, Campbell D, Trinkle JK. Esophagopleural fistula after pneumonectomy. Chest 1976;69:795–797.
53. Efthimiadis M, Xanthakis D, Primikyrios N, Papadakis G, Aligizakis CJ. Late esophagopleural fistula after pneumonectomy for bronchial carcinoma. Chest 1974;65:579–580.
54. Shulimzon T, Apter S, Weitzen R, Yellin A, Brenner HJ, Wollner A. Radiation pneumonitis complicating mediastinal radiotherapy postpneumonectomy. Eur Respir J 1996;9:2697–2699.
55. Mesurolle B, Qanadli SD, Merad M, et al. Unusual radiologic findings in the thorax after radiation therapy. RadioGraphics 2000;20:67–81.
56. Choi YW, Munden RF, Erasmus JJ, et al. Effects of radiation therapy on the lung: radiologic appearances and differential diagnosis. RadioGraphics 2004;24:985–997.
57. Park KJ, Chung JY, Chun MS, Suh JH. Radiation-induced lung disease and the impact of radiation methods on imaging features. RadioGraphics 2000;20:83–98.
58. Libshitz HI, DuBrow RA, Loyer EM, Charnsangavej C. Radiation change in normal organs: an overview of body imaging. Eur Radiol 1996;6:786–795.
59. Wang ZJ, Reddy GP, Gotway MB, Yeh BM, Hetts SW, Higgins CB. CT and MR imaging of pericardial disease. RadioGraphics 2003;23(Spec Issue):S167–S180.
60. Glockner JF. Imaging of pericardial disease. Magn Reson Imaging Clin N Am 2003;11:149–162.
61. Rienmuller R, Groll R, Lipton MJ. CT and MR imaging of pericardial disease. Radiol Clin North Am 2004;42:587–601.
62. Yamamoto N, Noda Y, Miyashita Y. A case of refractory bilateral pleural effusion due to post-irradiation constrictive pericarditis. Respirology 2002;7:365–368.
63. Miura H, Konaka C, Kato H, Kawate N, Taira O. Recurrence at the bronchial stump after resection of lung cancer. Ann Surg 1994;219:306–309.
64. Spjut HJ, Mateo LE. Recurrent and metastatic carcinoma in surgically treated carcinoma of the lung. Cancer 1965;18:1462–1466.
65. Glazer HS, Aronberg DJ, Sagel SS, Emami B. Utility of CT in detecting postpneumonectomy carcinoma recurrence. AJR Am J Roentgenol 1984;142:487–494.
66. Peters JC, Desai KK. CT demonstration of postpneumonectomy tumor recurrence. AJR Am J Roentgenol 1983;141:259–262.
67. Kim YT, Kim HK, Sung SW, Kim JH. Long-term outcomes and risk factor analysis after pneumonectomy for active and sequela forms of pulmonary tuberculosis. Eur J Cardiothorac Surg 2003;23:833–839.
68. Tsunezuka Y, Sato H, Hiranuma C. Surgical outcome of mycobacterium other than mycobacterium tuberculosis pulmonary disease. Thorac Cardiovasc Surg 2000;48:290–293.
69. Ashour M. Pneumonectomy for tuberculosis. Eur J Cardiothorac Surg 1997;12:209–213.
70. Moran JF, Alexander LG, Staub EW, Young WG Jr, Sealy WC. Long-term results of pulmonary resection for atypical mycobacterial disease. Ann Thorac Surg 1983;35:597–604.

This article meets the criteria for 1.0 credit hour in category 1 of the AMA Physician's Recognition Award. To obtain credit, see accompanying test at http://www.rsna.org/education/rg_cme.html.

Radiographic and CT Findings of Thoracic Complications after Pneumonectomy

Eun Jin Chae, MD et al

RadioGraphics 2006; 26:1449–1467 • **Published online** 10.1148/rg.265055156 • **Content Codes:** CH CT

Page 1450
Familiarity with the clinical and imaging features of the expected alterations as well as the various possible complications after pneumonectomy is essential.

Page 1452
Because increased air and decreased fluid are cardinal signs of bronchopleural fistula, it is important to monitor changes in the air-fluid level in patients who have undergone a pneumonectomy.

Page 1454
Postpneumonectomy empyema is characterized on CT images by an expansion of the postpneumonectomy space, with a mass effect; convexity or straightening of the normally concave mediastinal border of the postpneumonectomy space; irregularly increased thickening of the residual parietal pleura; and bronchopleural or esophagopleural fistula, which may either cause or coexist with empyema.

Page 1457
CT images show abnormal narrowing of the distal part of the trachea and the left main bronchus because of compression of the airway between the pulmonary artery anteriorly and the aorta and spine posteriorly.

Page 1465
Sequential examinations with chest radiography after pneumonectomy are an invaluable method of screening for complications, especially in the early postoperative period.