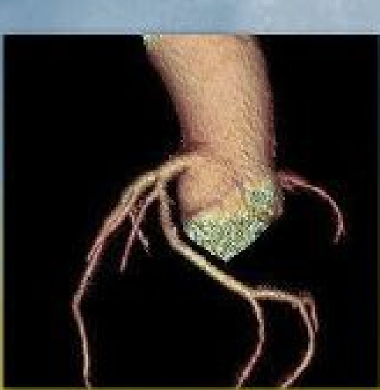
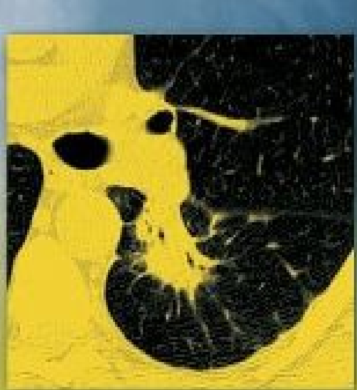
Thoracic Imaging

Pulmonary and Cardiovascular Radiology

THIRD EDITION

W. Richard Webb
Charles B. Higgins

Wolters Kluwer

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W. Richard Webb, MD

Professor Emeritus of Radiology and Biomedical Imaging
Department of Radiology and Biomedical Imaging
Emeritus Member, Haile Debas Academy of Medical Educators
University of California, San Francisco
San Francisco, California

Charles B. Higgins, MD

Distinguished Professor Emeritus of Radiology and Biomedical Imaging
Department of Radiology and Biomedical Imaging
University of California, San Francisco
San Francisco, California

Wolters Kluwer

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To Hideyo Minagi, my first teacher as a Resident, who taught me my most important lessons —to recognize what is real and what is not—and to understand that not everything unusual or abnormal is important. After that, it's all gravy.

and

J, an exceptional big sister, who has helped me grow up in many ways.

—W. Richard Webb

To the many fellows who have contributed to our progress in developing new cardiovascular imaging techniques.

—Charles B. Higgins

Contributors

Brett Elicker, MD

Associate Professor of Clinical Radiology
Chief, Cardiac and Pulmonary Imaging
Department of Radiology and Biomedical Imaging
University of California, San Francisco
San Francisco, California

Michael B. Gotway, MD

Consultant and Professor of Radiology
Mayo Clinic
Phoenix, Arizona
Clinical Associate Professor
Departments of Radiology and Biomedical Imaging and Pulmonary and Critical Care Medicine
University of California, San Francisco
San Francisco, California
Clinical Professor
University of Arizona College of Medicine, Phoenix
Phoenix, Arizona
Adjunct Professor
Department of Biomedical Informatics at Arizona State University
Tempe, Arizona

Charles B. Higgins, MD

Distinguished Professor Emeritus of Radiology and Biomedical Imaging
Department of Radiology and Biomedical Imaging
University of California, San Francisco
San Francisco, California

Michael D. Hope, MD

Associate Professor of Radiology
Department of Radiology and Biomedical Imaging
University of California, San Francisco
San Francisco, California

Clinton E. Jokerst, MD

Consultant and Professor of Diagnostic Radiology
Mayo Clinic
Phoenix, Arizona

Kimberly Kallianos, MD

Fellow, Cardiac and Pulmonary Imaging
Department of Radiology and Biomedical Imaging
University of California, San Francisco
San Francisco, California

Stefano Muzzarelli, MD

Privat Docent, Division of Cardiology
Cardiocentro Ticino
University of Zurich
Lugano, Switzerland
Privat Docent, Division of Cardiology
University of Lausanne
Lausanne, Switzerland

Karen Ordovas, MD, MAS

Associated Professor of Radiology and Medicine
Director of Cardiac Imaging
Cardiac and Pulmonary imaging
Department of Radiology and Biomedical imaging
University of California, San Francisco
San Francisco, California

W. Richard Webb, MD

Professor Emeritus of Radiology and Biomedical Imaging
Department of Radiology and Biomedical Imaging
Emeritus Member, Haile Debas Academy of Medical Educators
University of California, San Francisco
San Francisco, California

Preface

Our goal in writing *Thoracic Imaging: Pulmonary and Cardiovascular Radiology* has been to provide a single volume, with a comprehensive but easy-to-digest review of both pulmonary and thoracic cardiovascular imaging and to review the use and interpretation of both chest radiographs and computerized imaging techniques, such as spiral computed tomography, high-resolution CT (HRCT), CT angiography (CTA), magnetic resonance imaging (MRI), and magnetic resonance angiography (MRA). It is intended to provide the fundamentals of thoracic imaging for Medical Students and Residents and Fellows in Radiology, Pulmonology, Cardiology, and Cardiovascular Surgery.

We have tried to be thorough without being exhaustive. Rather than referencing specific studies and their results, which are now easily accessed via the Internet, we have summarized what we consider to be the most important and most pertinent information and have provided numerous tables to make key facts easily available to the reader. More than 2,500 illustrations demonstrate important imaging findings and the typical appearances of the various disease entities one might expect to encounter in clinical practice.

This, the third edition of our book, provides extensive updates of a number of important topics, including, but not limited to, the World Health Organization (WHO) classification of thoracic neoplasms, lymphoma classification, lung cancer screening, classification and diagnosis of diffuse lung diseases, pulmonary hypertension, pulmonary vasculitis, the idiopathic interstitial pneumonias, and the diagnosis of various cardiovascular diseases. Furthermore, an additional chapter regarding cardiac arrhythmias has been added, reflecting imaging advances in this field. Current references of value in further reading have been added wherever appropriate.

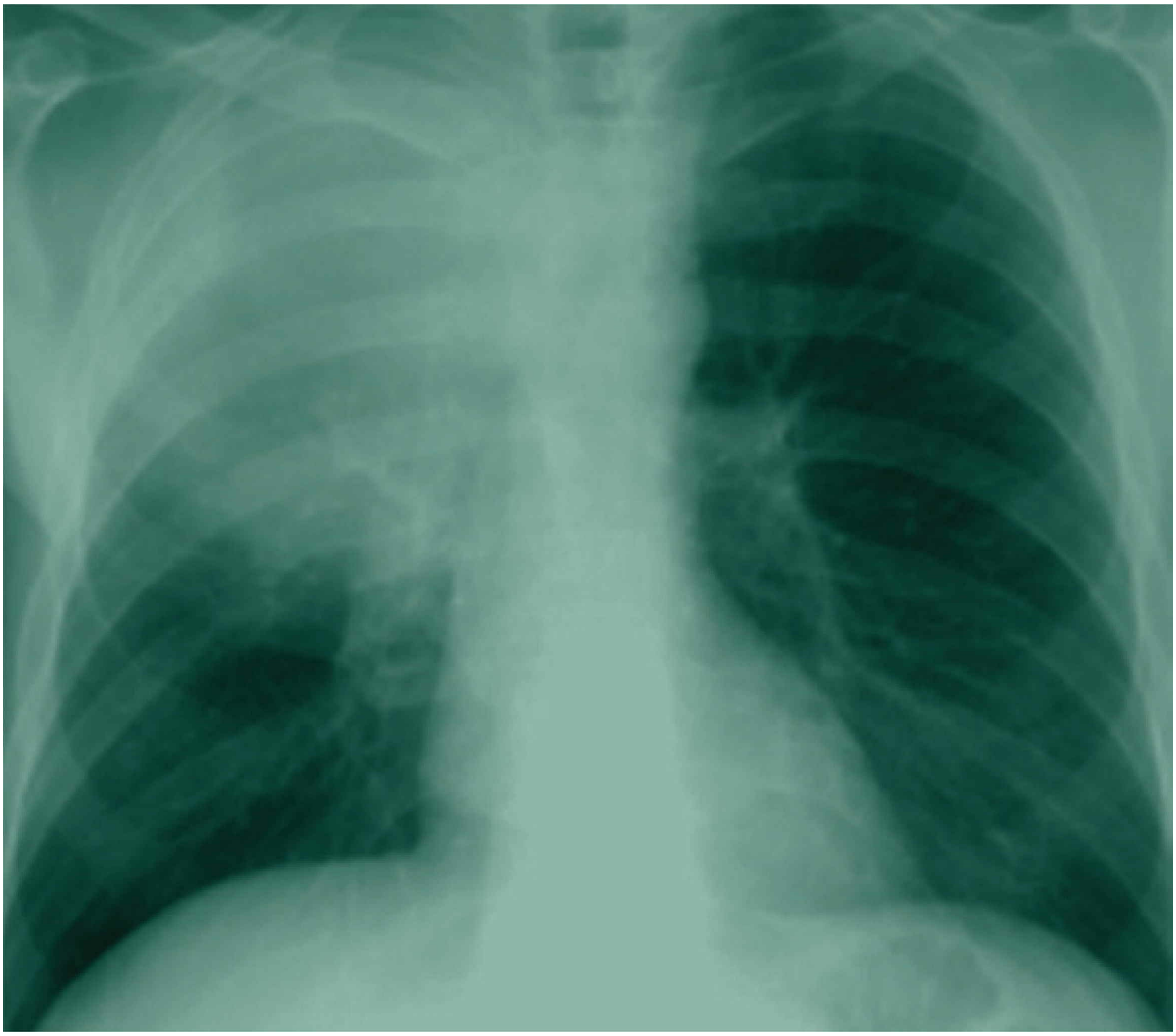
In this edition, we have grouped chapters in sections, related to key findings or fundamental clinical problems or diagnoses, in the hope that this may guide the reader to an organized understanding of disease and diagnosis. In the years since the prior edition, there has been considerable progress in understanding pulmonary and cardiovascular diseases, and many entities we discuss in our sections and chapters are newly defined or have been redefined, reclassified, or have had their diagnosis clarified. New tables and illustrations have been provided to summarize and illustrate these additions and changes.

W. Richard Webb, MD
Charles B. Higgins, MD
San Francisco, California

Contents

Section One

The Basics



CHAPTER 1

Lobar Anatomy, Air-space Consolidation, the Silhouette Sign, and Atelectasis

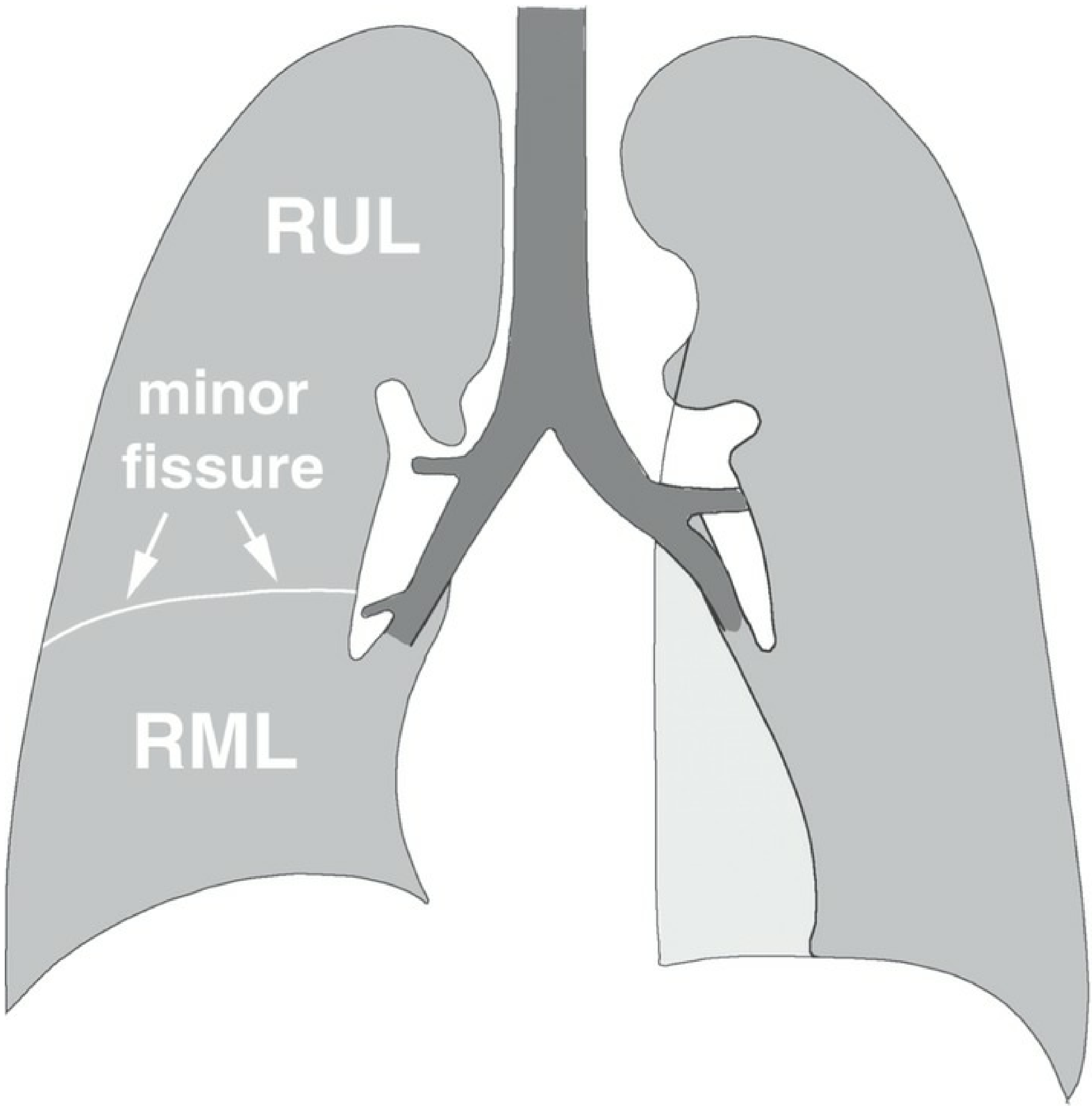
W. RICHARD WEBB

LOBAR ANATOMY AND THE INTERLOBAR FISSURES

The lung lobes are separated from each other by interlobar fissures, which may be incomplete in some cases. Accessory fissures, present in some patients, are discussed in Chapter 26.

Major (Oblique) Fissures

On the right, the major (oblique) fissure separates the upper and middle lobes from the lower lobe. On the left, it separates the upper lobe from the lower lobe. The major fissures are not normally seen on a frontal radiograph but are often visible on the lateral projection. The major fissures originate posteriorly above the level of the aortic arch, near the level of the fifth thoracic vertebra, and angle anteriorly and inferiorly, nearly parallel to the sixth rib (Fig. 1.1). Posteriorly, the superior aspect of the left major fissure is cephalad to the right in 75% of cases. They terminate along the anterior diaphragmatic pleural surface of each lung, several centimeters posterior to the anterior chest wall.



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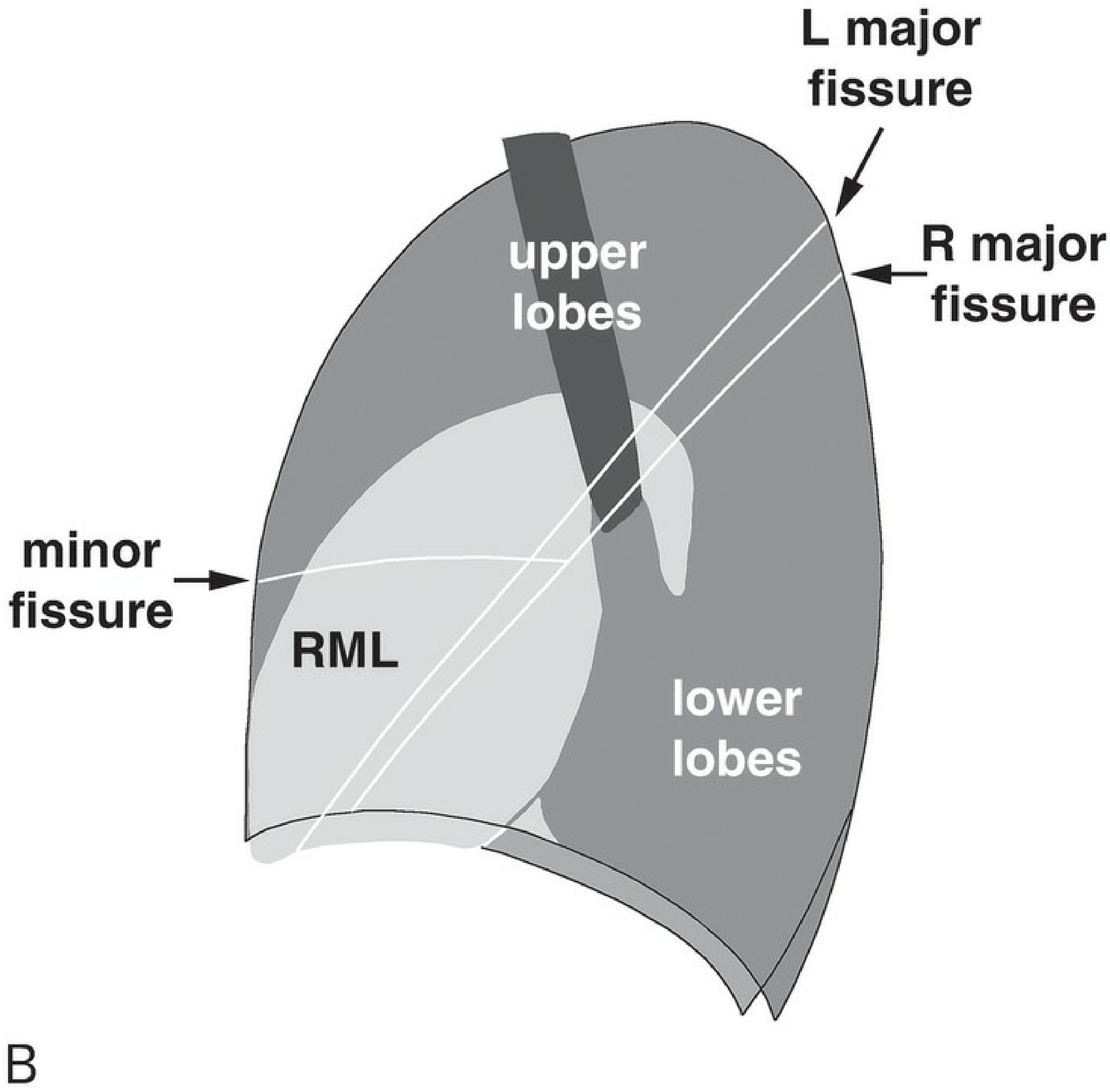
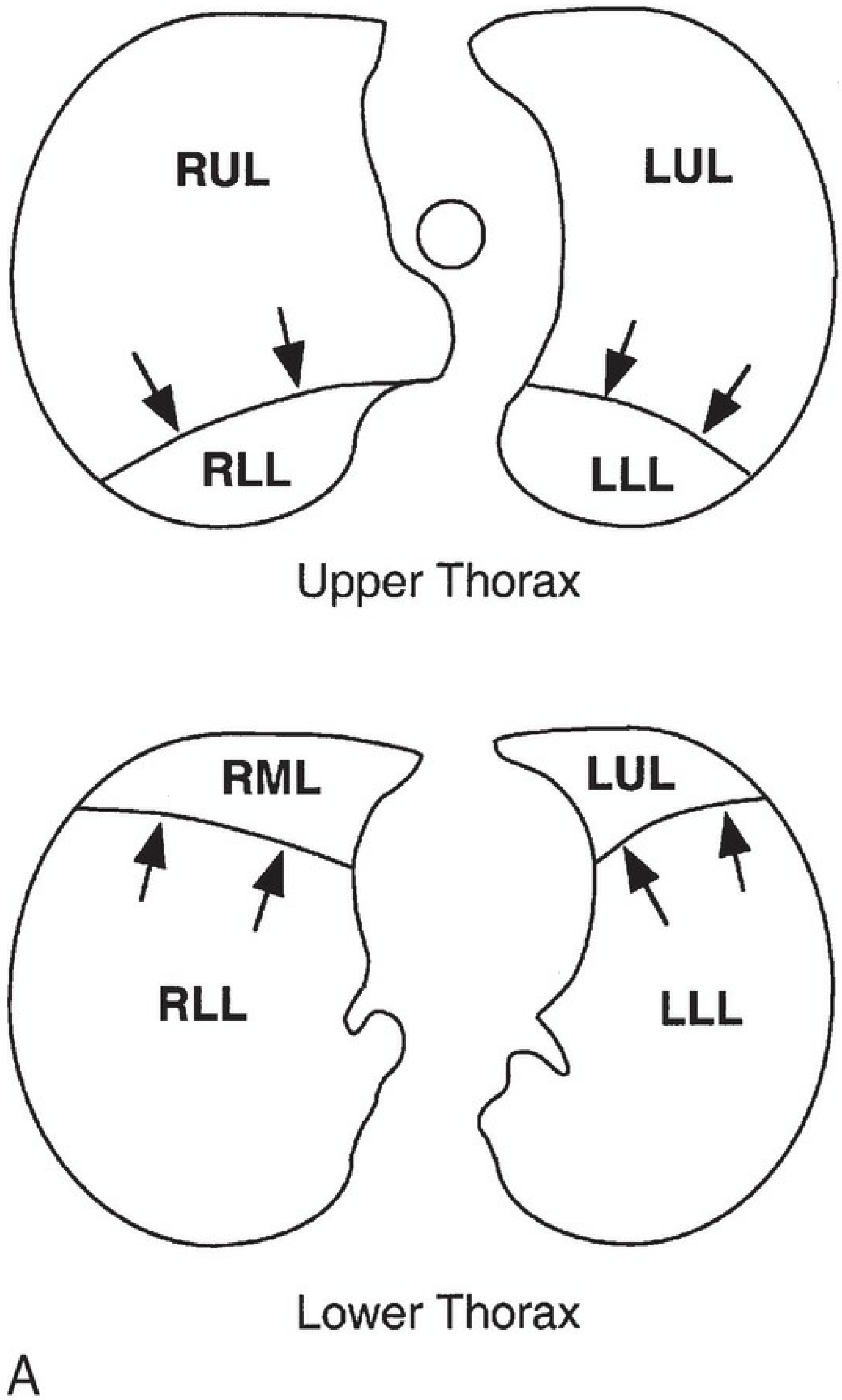


FIG. 1.1. Normal appearances of the fissures on chest radiographs. **A:** Frontal projection. The major fissures are not normally visible. The minor fissure is visible in 50% to 80% of cases, appearing as a roughly horizontal line, generally at or near the level of the anterior fourth rib. Medially, it arises at the level of the interlobar pulmonary artery, and its lateral part is often inferior to its medial part. **B:** Lateral projection. The major fissures originate posteriorly above the level of the aortic arch and near the level of the fifth thoracic vertebra. Posteriorly, the superior aspect of the left major fissure is cephalad to the right in 75% of cases. They terminate along the anterior diaphragmatic pleural surface of each lung, several centimeters posterior to the anterior chest wall.

On the lateral radiograph, the right and left major fissures may be distinguished in many patients by noting their relationships to the right or left hemidiaphragms or posterior ribs. The hemidiaphragms may be distinguished based on their relative positions or relationship to the stomach bubble and heart or by using the "big rib sign" (see below).

On computed tomography (CT), the orientation of the major fissures is clearly seen. Their positions vary at different levels. In the upper thorax, the major fissures angle posterolaterally from the mediastinum. Within the lower thorax, the major fissures angle anterolaterally from the mediastinum (Fig. 1.2A). The fissure may be seen as a linear opacity on thin slices. Alternatively, on thick slices, the location of the major fissures may be determined by recognizing a 1 to 2 cm thin, relatively avascular band (lung adjacent to the fissure contains only small vessels) having a typical orientation.



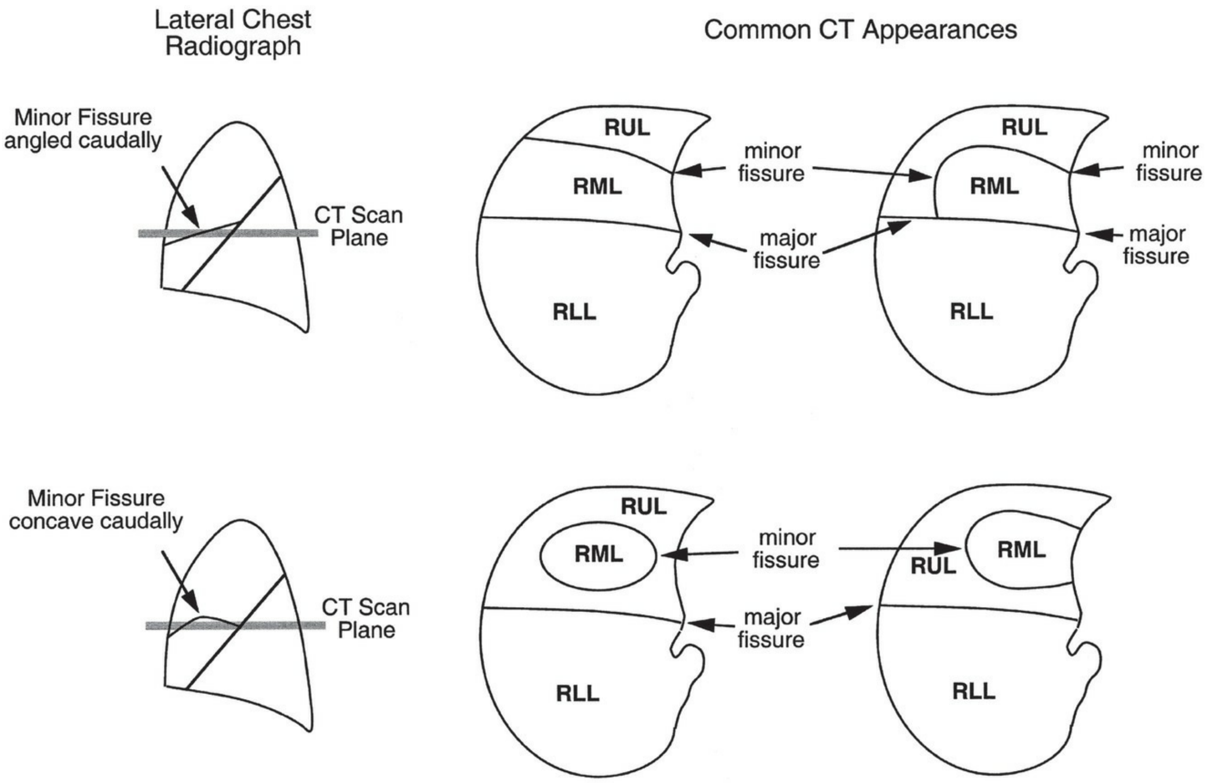


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FIG. 1.2. Normal appearances of the fissures on CT. **A:** Major fissures. In the upper thorax, the major fissures angle posterolaterally from the mediastinum. In the lower thorax, the major fissures angle anterolaterally. **B:** Minor fissure. The appearance of the minor fissure on CT is related to its orientation as seen on the lateral chest radiograph.

Distinguishing the Major Fissures and Hemidiaphragms (The "Big Rib Sign")

The right hemidiaphragm is most easily identified on a lateral radiograph by its association with the right ribs. The right ribs can be identified on a lateral radiograph because they are projected posterior to the left ribs and because they appear bigger than the left ribs (i.e., *the big rib sign*) (Fig. 1.3A). In the left lateral projection, the right ribs, being farther from the x-ray film or digital recording plate, are relatively magnified by the diverging x-ray beam (Fig. 1.3B). Also, the diverging x-ray beam, because of parallax, results in the right ribs being projected posterior to the left ribs, even on a perfectly positioned lateral view. Similarly, on the lateral radiograph, the left hemidiaphragm can be identified by its relationship to the left (more anterior and smaller) ribs (Fig. 1.3A).

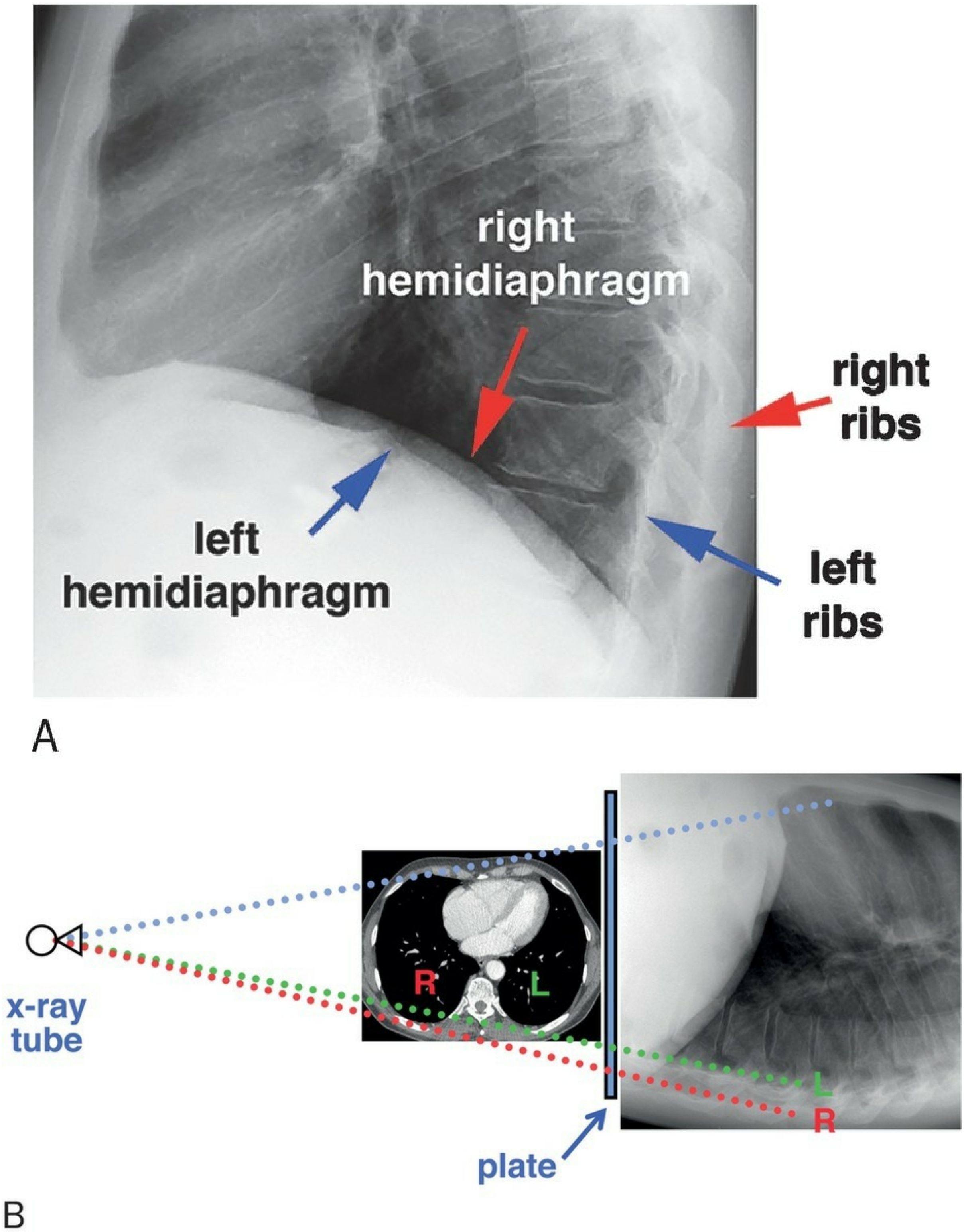


FIG. 1.3. The "big rib sign." **A:** Coned down view of a lateral chest radiograph. The posterior right ribs are projected posterior to and appear larger than the left ribs. The corresponding hemidiaphragms can be identified by their relation to the right and left ribs. Also, note that the right hemidiaphragm is visible anteriorly to the chest wall, while the left hemidiaphragm stops at the heart. **B:** Mechanism of the big rib sign. Because of the diverging x-ray beam, the right ribs being farther from the recording plate are projected posterior to the left ribs, even on a perfectly positioned lateral view, and are more magnified.

If the stomach is filled with air, the left hemidiaphragm may be identified by its close approximation to the stomach bubble. Although not always apparent, the right hemidiaphragm is often visible all the way to the anterior ribs, while the left hemidiaphragm often is invisible anterior to the point it contacts the heart (Fig. 1.3A).

Minor (Horizontal) Fissure

Right-sided consolidation anterior to the major fissure and inferior to the minor fissure involves the right middle lobe.

The minor or horizontal fissure separates the superior aspect of the right middle lobe from the right upper lobe. On frontal (PA or AP) radiographs, the minor fissure or a portion is visible in 50% to 80% of the cases, appearing as a roughly horizontal line, generally at or near the level of the anterior fourth rib (see Fig. 1.1B). Its contour is variable, but its lateral part is often visible inferior to its medial part. Medially, the fissure usually appears to arise at the level of the right hilum and interlobar pulmonary artery. On the lateral radiograph, the anterior part of the fissure often appears inferior to its posterior part. The posterior part of the fissure may be seen to end at the major fissure or may project posterior to it.

On CT, the minor fissure tends to parallel the scan plane and may be difficult to see with thick slices. In such cases, the position of the minor fissure can be inferred because of a broad avascular region in the anterior portion of the right lung, anterior to the major fissure, and at the level of the bronchus intermedius. With thin slices, the minor fissure may be seen as a discrete line, similar to the appearance of the major fissure.

When visible, the minor fissure is variable in appearance, depending on its orientation. Because the minor fissure often angles caudally, the lower lobe, middle lobe, and upper lobe may all be seen on a single CT scan (see Fig. 1.2B). If this is the case, the major and minor fissures can have a similar appearance, with the major fissure being posterior and the minor fissure anterior; in this situation, the lower lobe is most posterior, the upper lobe is most anterior, and the middle lobe is in the middle.

If the minor fissure is concave caudally, it can sometimes be seen in two locations or can appear ring shaped (Fig. 1.2B), with the middle lobe between the fissure lines or in the center of the ring and the upper lobe anterior to the most anterior part of the fissure.

Air-space Consolidation

Air-space consolidation is a common radiographic finding and represents replacement of alveolar air by fluid, blood, pus, cells, or other substances. *Consolidation*, *alveolar consolidation*, and *parenchymal consolidation* are synonyms. Recognizing and localizing consolidation is fundamental to an understanding of pulmonary radiology and also helps in describing lung and lobar anatomy. *Ground-glass opacity* is a similar abnormality but is less specific, and best diagnosed using high-resolution CT (HRCT); it is discussed in a later chapter.

Radiographic and CT Findings of Consolidation

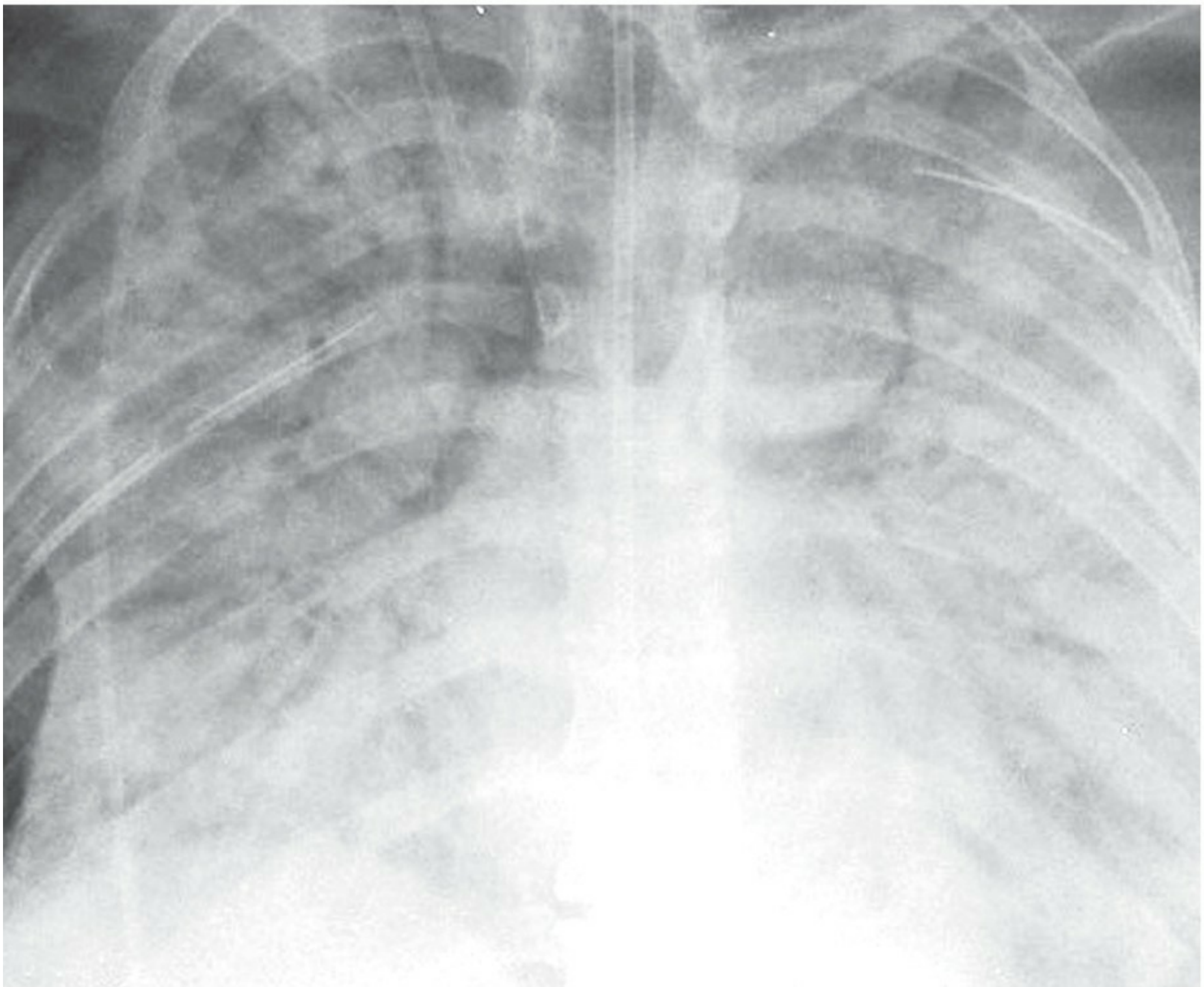
Radiographic and computed tomography abnormalities indicating the presence of air-space consolidation include the following:

- Homogeneous opacity obscuring vessels
- Air bronchograms

- Ill-defined or fluffy opacities
- “Air alveolograms”
- Patchy opacities
- “Acinar” or air-space nodules
- Preserved lung volume
- Extension to pleural surface
- “CT angiogram” sign

Homogeneous Opacity Obscuring Vessels

With complete replacement of alveolar air, homogeneous opacification of the lung results. Vessels within the consolidated lung are invisible (Fig. 1.4A).



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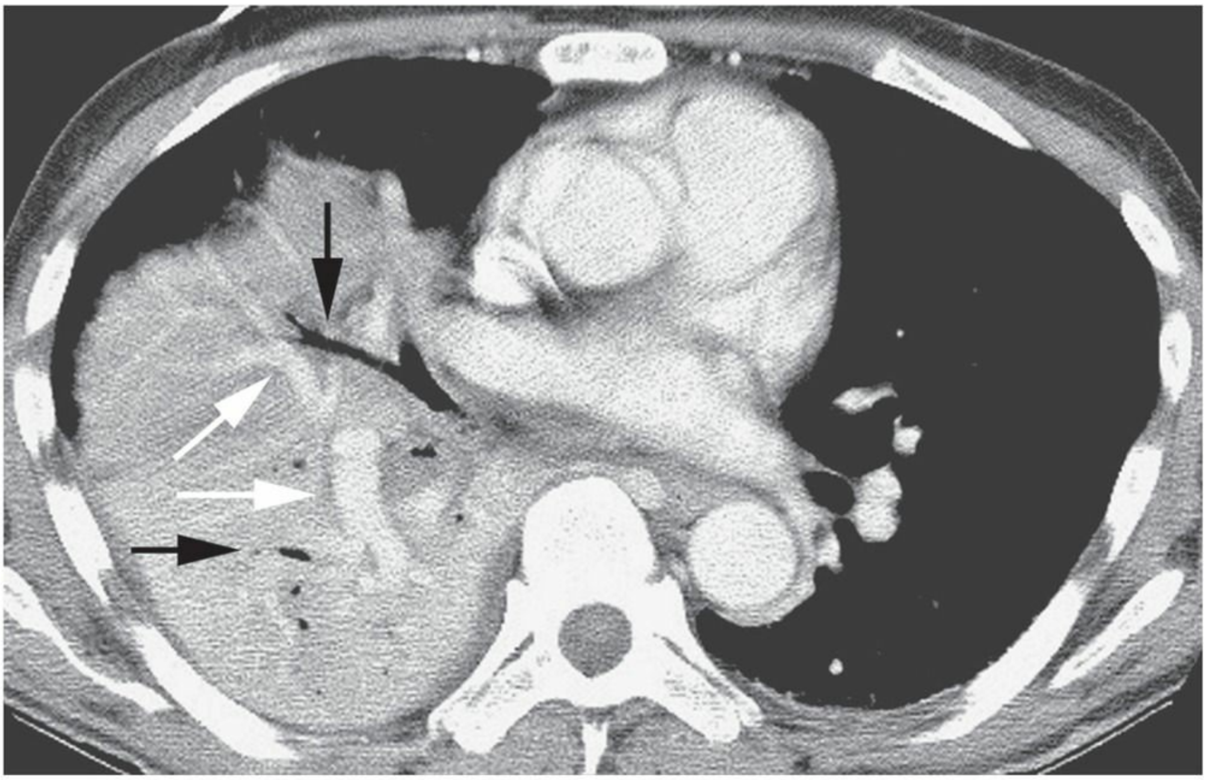

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FIG. 1.4. Consolidation: homogeneous opacity obscuring vessels, air bronchograms, and the CT angiogram sign. **A:** Right lung consolidation due to pulmonary edema. Air bronchograms are visible bilaterally within the consolidated lung, and pulmonary vessels are obscured. **B:** Enhanced CT in a patient with right middle and lower lobe pneumonia shows homogeneous consolidation, preserved lung volume, air bronchograms (*black arrows*), and opacified vessels (*white arrows*), appearing denser than surrounding consolidated lung (i.e., the "CT angiogram" sign).

Air Bronchograms

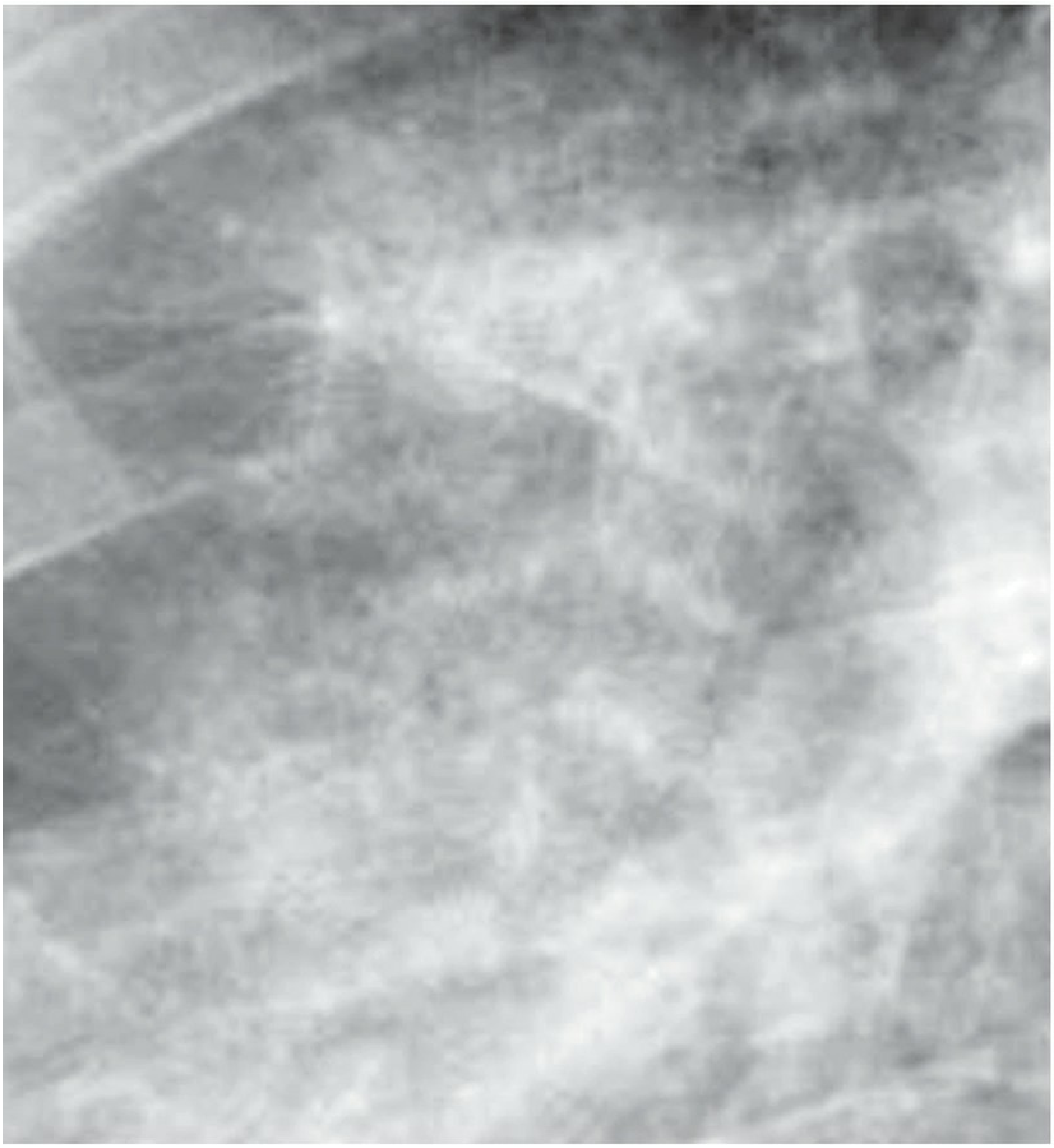
In patients with consolidation, air-filled bronchi are often visible on plain radiographs or CT, appearing lucent compared with opacified lung parenchyma (see Fig. 1.4). This finding is termed an *air bronchogram*. The bronchi usually appear normal in caliber, without evidence of displacement of distortion.

With some causes of consolidation, air bronchograms may not be visible. This usually occurs because of central bronchial obstruction (e.g., by cancer or mucus) or filling of bronchi in association with the underlying pathologic process. For example, pulmonary infarction often results in consolidation without air bronchograms because of blood filling the bronchi. In patients with bronchopneumonia, bronchi may be filled with mucus or pus.

If air bronchograms are visible within an area of consolidation, bronchial obstruction is unlikely (but not ruled out) as its cause. Although air bronchograms are considered a classic sign of air-space consolidation, they may also be seen in the presence of confluent interstitial disease and sometimes within a mass; in such cases, the bronchi may appear narrowed or displaced.

Ill-defined or Fluffy Opacities

Consolidation often results in opacities with ill-defined margins (Figs. 1.5 and 1.6), in contrast to the relatively sharp margins usually associated with a tumor or lung mass. Ill-defined margins result from patchy local spread of disease with variable involvement of alveoli at the edges of the pathologic process. When consolidation is bordered by an interlobar fissure, it may appear sharply marginated.



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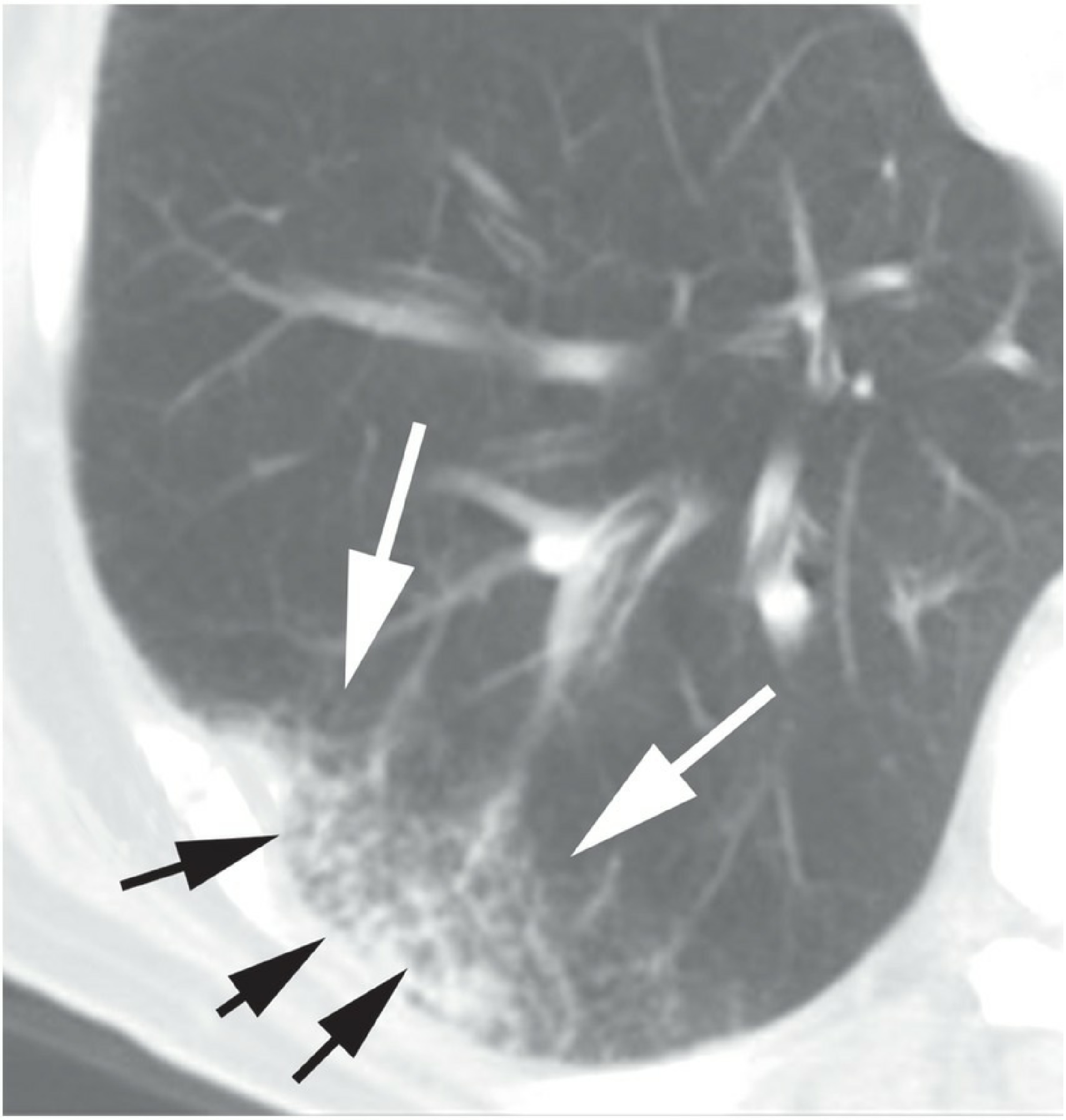

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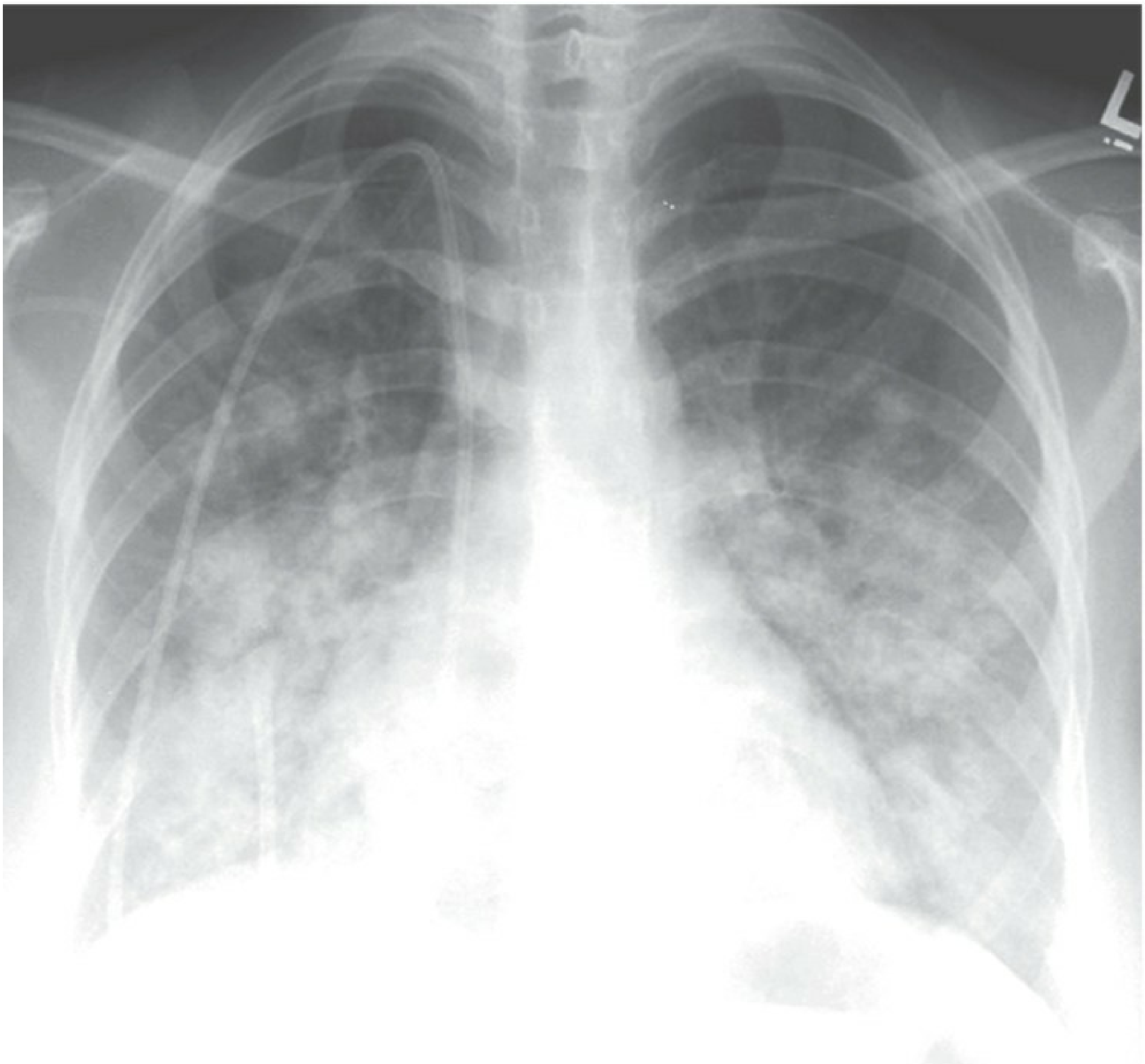
FIG. 1.5. Consolidation: ill-defined, fluffy opacities with “air alveolograms.” **A:** Detailed view of incomplete right lower lobe consolidation shows fluffy, ill-defined opacity containing small rounded lucencies. These lucencies have been termed air alveolograms, although they do not correspond to alveoli. **B:** Ill-defined fluffy consolidation (*white arrows*) is visible on CT in a patient with right lower lobe pneumonia. Small focal lucencies (*black arrows*) within the area of consolidation are “air alveolograms.”



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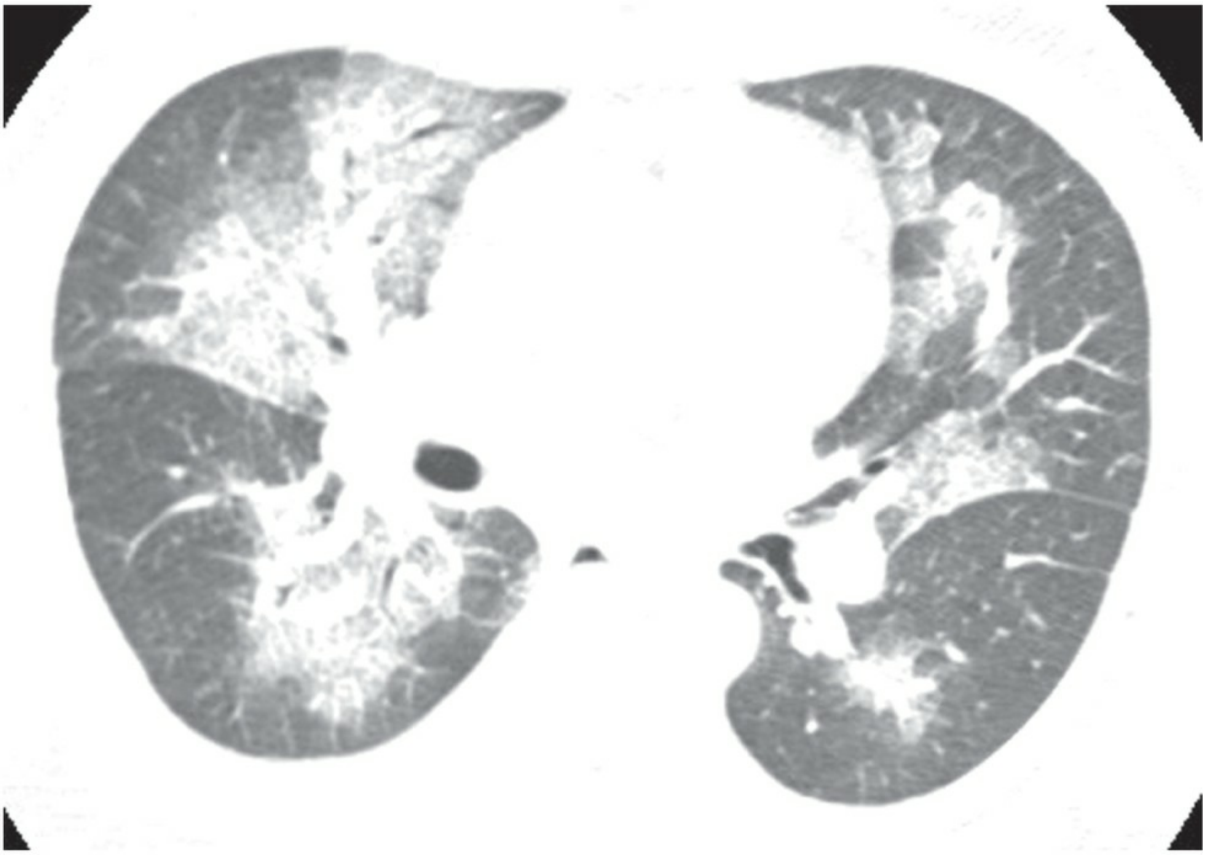
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FIG. 1.6. Consolidation: patchy opacities. **A:** Chest radiograph in a patient with pulmonary edema due to renal failure shows patchy perihilar consolidation. **B:** Patchy areas of fluffy consolidation are seen on CT. The fluffy margins are due to variable involvement of alveoli at the edges of the pathologic process.

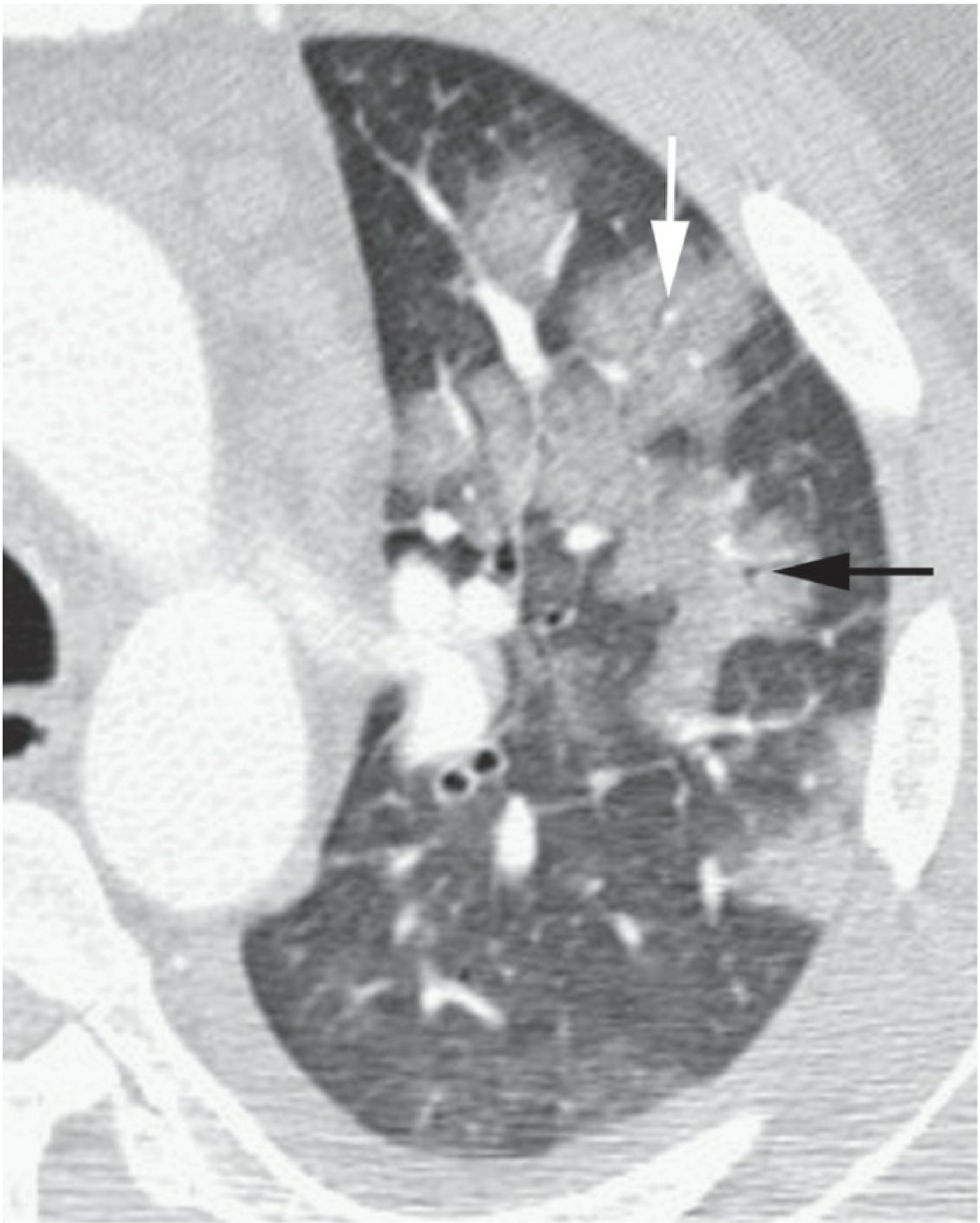
"Air Alveolograms"

If lung consolidation is not confluent and homogeneous, small focal lucencies representing regions of uninvolved lung may be visible within the abnormal area (see Fig. 1.5). These have been termed "air alveolograms," but this is somewhat of a misnomer as individual alveoli are too small to see radiographically or on CT. However, patchy consolidation surrounding clusters of normal alveoli result in this appearance.

Patchy Opacities

Variable consolidation in different lung regions results in patchy areas of increased opacity (Fig. 1.6). Pulmonary vessels may be obscured or poorly defined.

Patchy consolidation visible on chest radiographs sometimes appears to be lobular or multilobular on CT (i.e., involving individual pulmonary lobules; Fig. 1.7). Some lobules appear abnormally dense, while adjacent lobules appear normally aerated.



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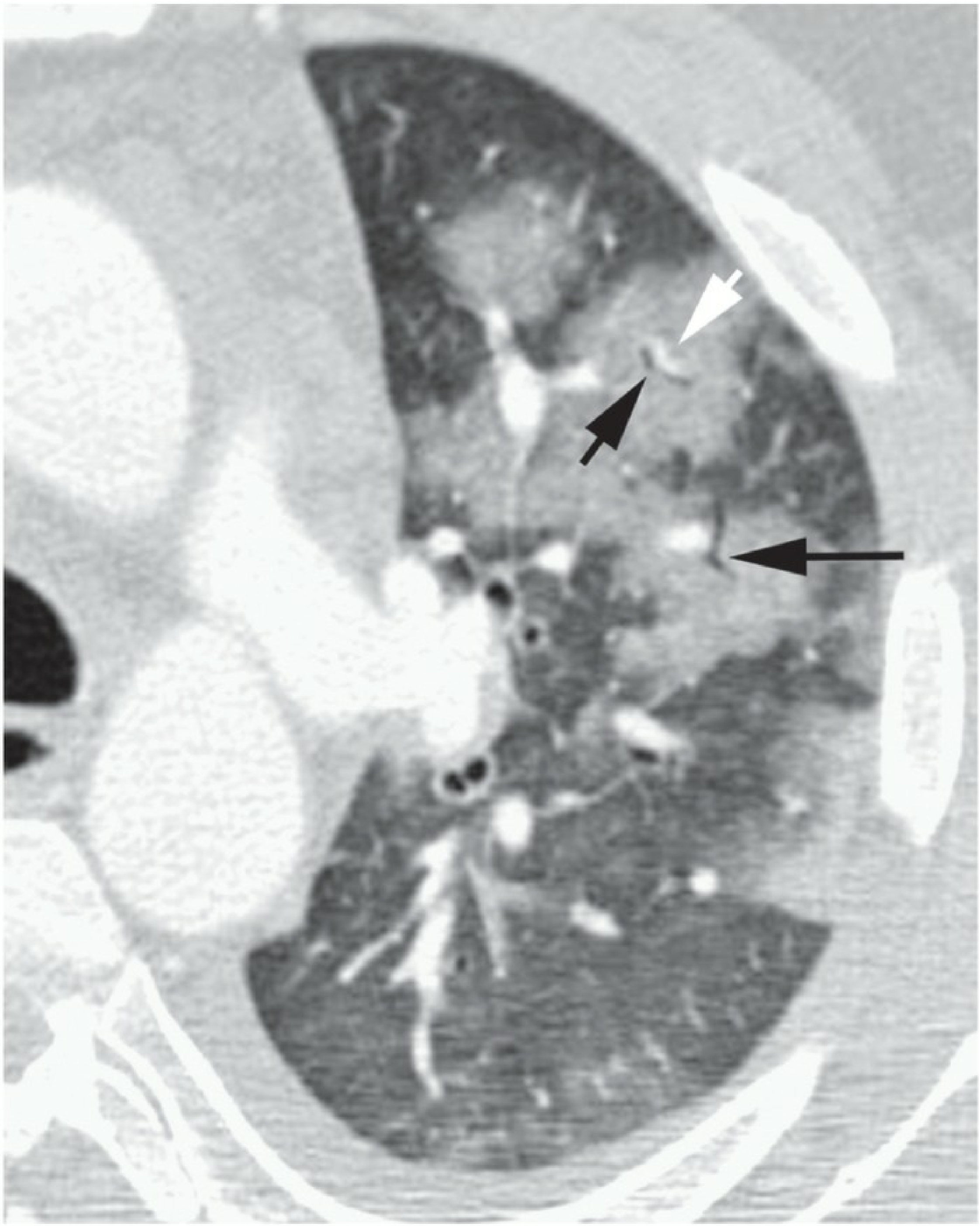

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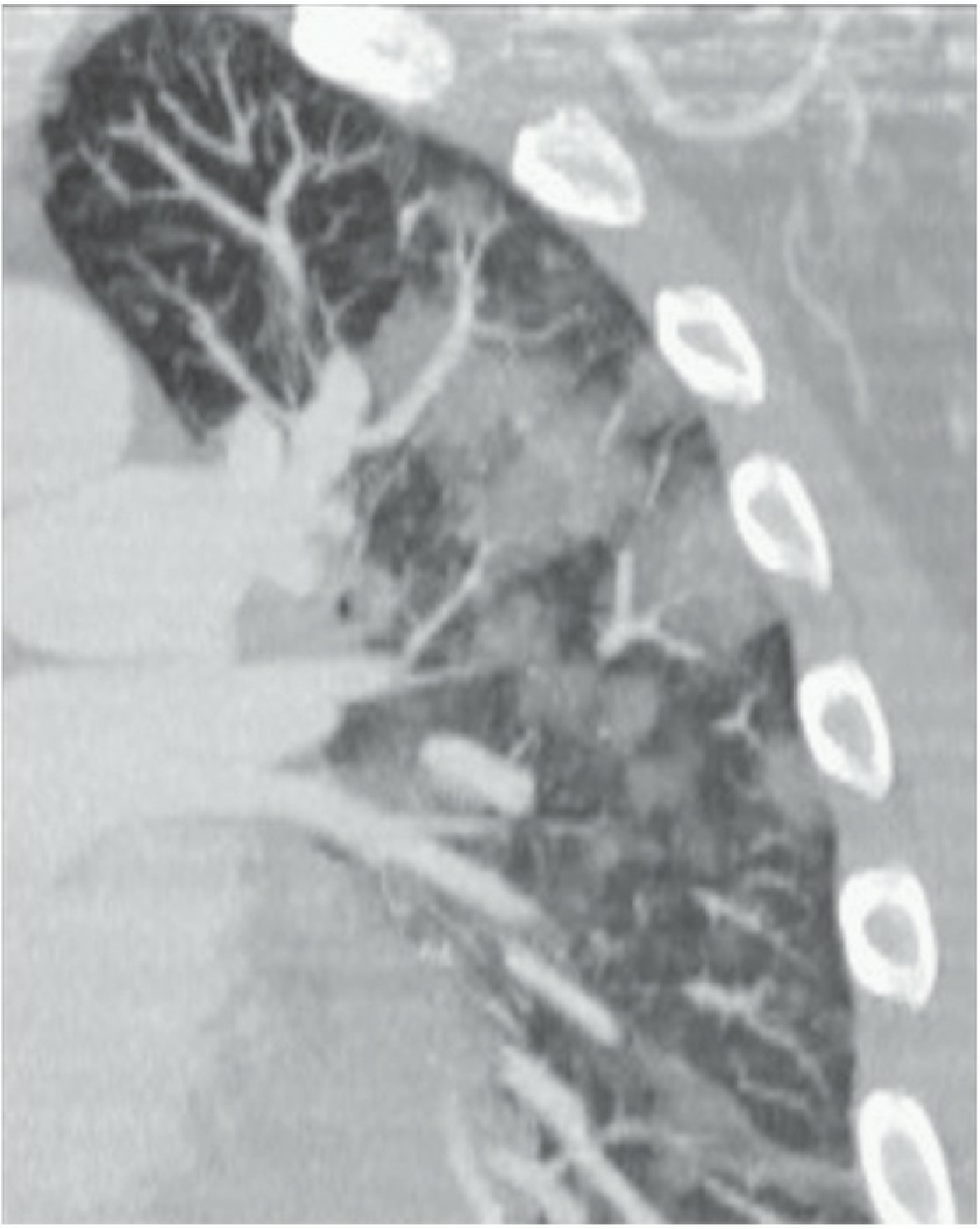

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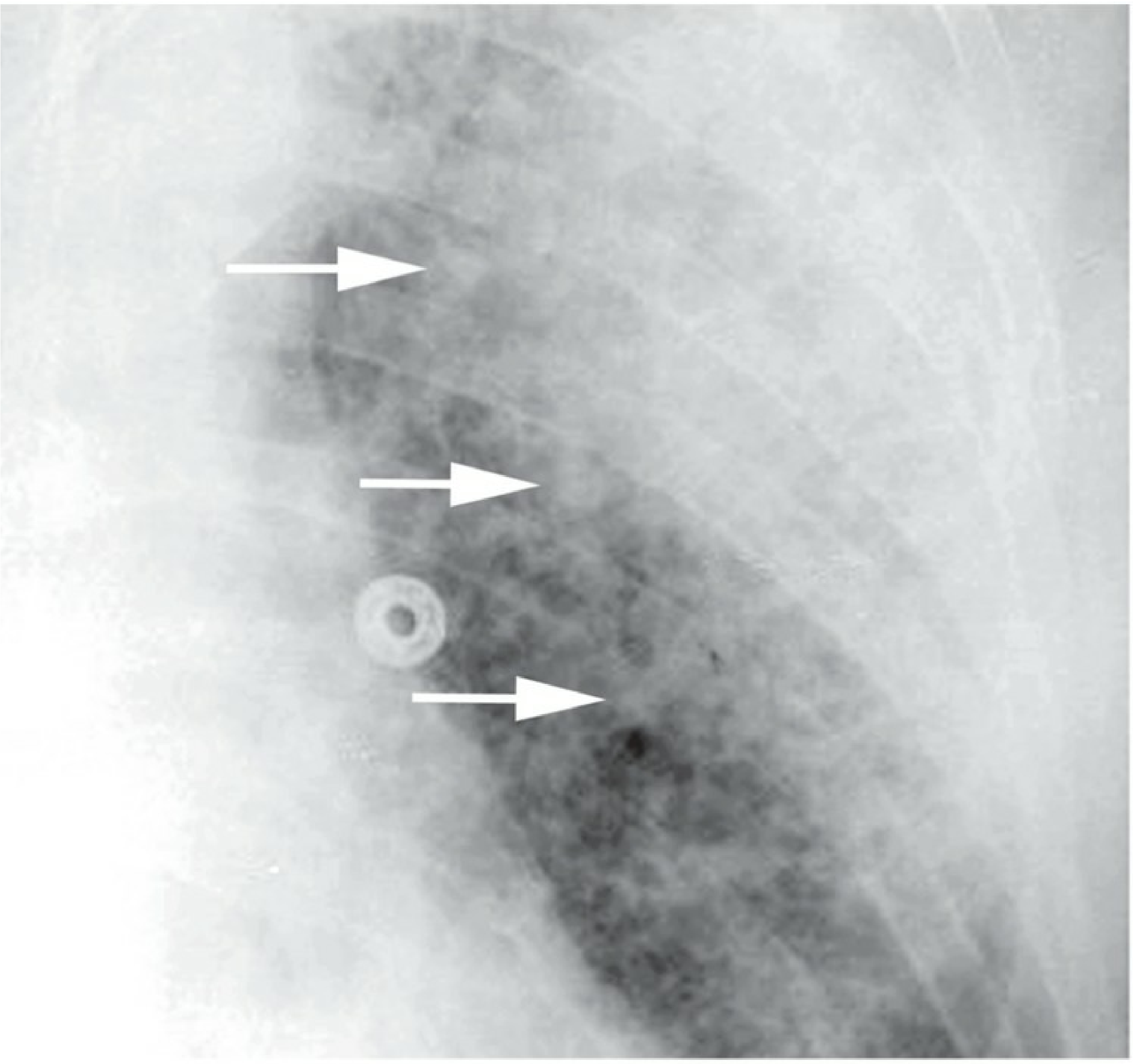
FIG. 1.7. Consolidation: patchy opacities with lobular consolidation. **A, B:** Contrast-enhanced HRCT in a patient with bronchopneumonia and lobular consolidation. Individual lobules are consolidated, while others appear normal. Centrilobular arteries (*white arrows*) and bronchi (*black arrows*) are visible within consolidated lobules. **C:** Coronal reconstruction also shows the lobular distribution of the patchy lung opacities.

"Acinar" or Air-space Nodules

An acinus is the largest unit of the lung in which all airways participate in gas exchange. Anatomically, it is located distal to a terminal bronchiole and is supplied by a first-order respiratory bronchiole. Acini average 7 to 8 mm in diameter.

The terms *acinar nodule* and *air-space nodule* are used to describe poorly marginated rounded opacities, usually 5 to 10 mm in diameter, that occur due to focal consolidation (Fig. 1.8). Although these nodules approximate the size of acini, they are often centrilobular and peribronchiolar rather than acinar. They may be seen as the only finding of consolidation or may be seen in association with larger areas of opacified lung.



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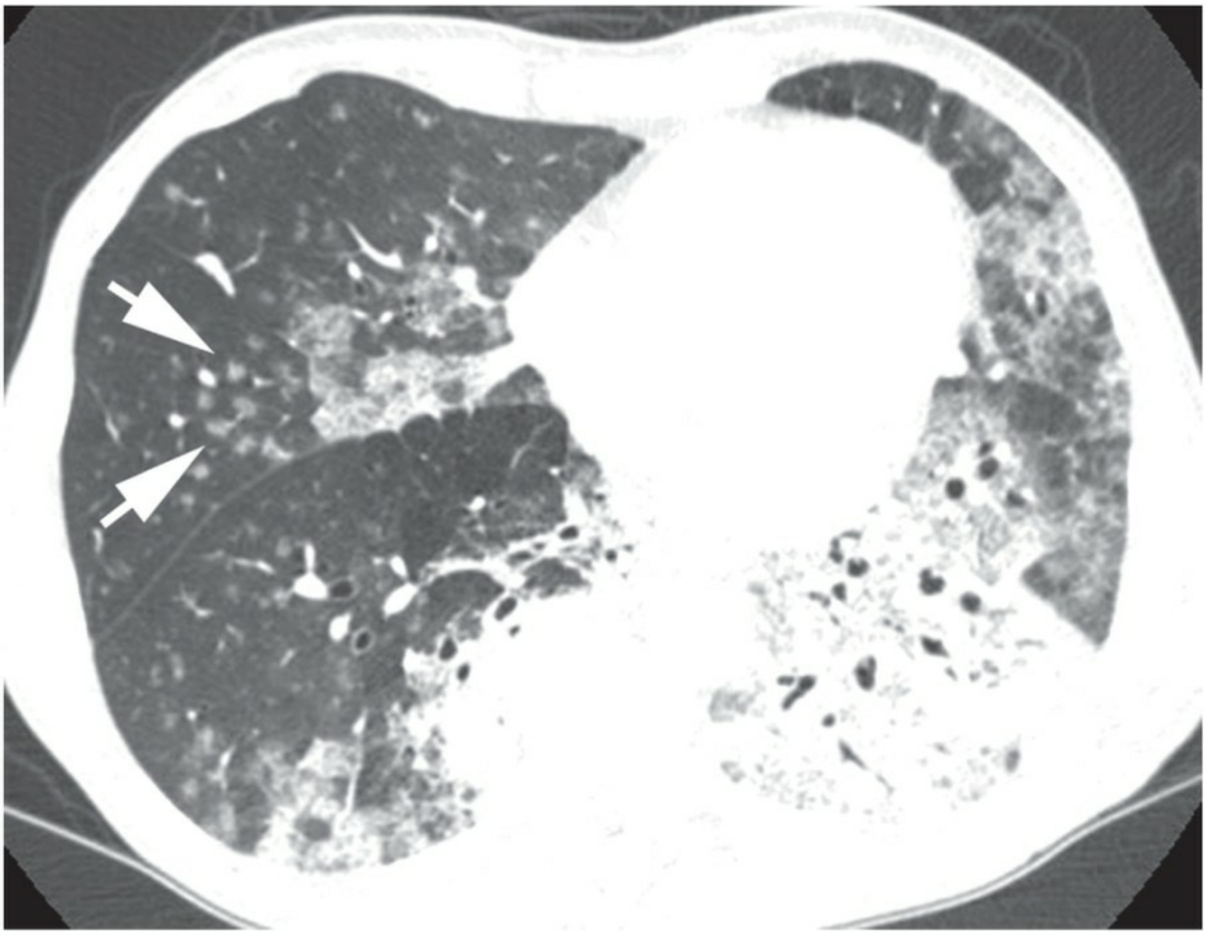

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FIG. 1.8. Consolidation: acinar or air-space nodules. **A:** Chest radiograph shows a patchy left upper lobe pneumonia. Ill-defined nodular opacities less than 1 cm in diameter (*arrows*) are visible on the edge of the area of denser consolidation. These represent air-space or acinar nodules. **B:** CT (5-mm slice thickness) in a patient with bilateral consolidation. Air bronchograms are visible in the left lower lobe. Patchy consolidation and ground-glass opacities are present. Air-space nodules are visible in the right middle lobe (*arrows*) and the right lower lobe. These nodules are ill defined, 5 to 10 mm in diameter, and centrilobular in distribution.

These nodular opacities are more easily seen on HRCT than on chest radiographs. On HRCT, their centrilobular location is usually discernable. This appearance is described further in Chapter 10.

Preserved Lung Volume

In the presence of consolidation, because alveolar air is replaced by something else (e.g., fluid), the volume of affected lung tends to be preserved (see Fig. 1.4B). Although some volume loss may be seen in patients with consolidation, it is usually of a minor degree. Alternatively, in some patients with consolidation, a lobe may appear expanded.

Extension to Pleural Surfaces

Pathologic processes resulting in consolidation often spread from alveolus to alveolus until reaching a fissure or pleural surface (see Fig. 1.8B). The pleural surface prevents further spread. When extension to a pleural surface occurs, the abnormality may appear lobar, as in lobar pneumonia.

CT Angiogram Sign

A unique finding seen on CT in patients with consolidation is the “CT angiogram” sign. This sign is present if normal-appearing opacified vessels are visible within the consolidated lung following infusion of intravenous contrast (see Figs. 1.4B and 1.9). Although opacified vessels are sometimes seen within a lung mass, they usually appear compressed or distorted. The CT angiogram sign is the vascular equivalent of an air bronchogram.

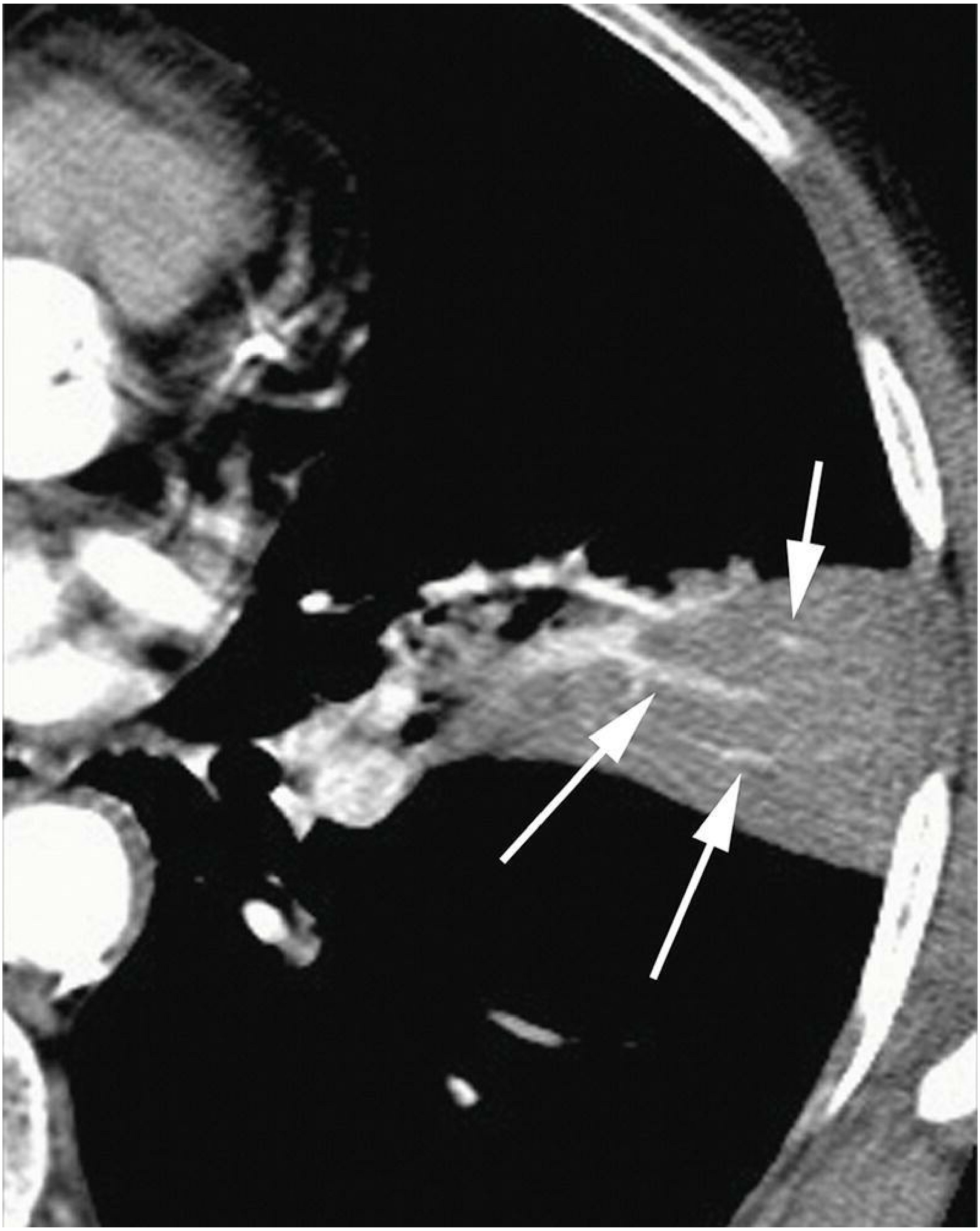


FIG. 1.9. Consolidation: the CT angiogram sign. Contrast-enhanced CT in a patient with pneumonia shows focal consolidation. Opacified arteries (*arrows*) appear denser than does consolidated lung (i.e., the CT angiogram sign). The consolidation borders on the major fissure posteriorly and appears segmental.

Differential Diagnosis of Consolidation

A wide variety of pathologic processes can result in air-space consolidation. In general, the differential diagnosis is based on a consideration of what may be replacing alveolar air:

1. Water (e.g., the various types of pulmonary edema)
2. Blood (e.g., pulmonary hemorrhage)
3. Pus (e.g., pneumonia)
4. Cells (e.g., pulmonary adenocarcinoma, lymphoma, eosinophilic pneumonia, organizing pneumonia [OP])
5. Other substances (e.g., lipoprotein in alveolar proteinosis, lipid in lipoid pneumonia)

Patterns of Consolidation

Based on the radiographic or CT pattern of abnormalities, patients with consolidation may be divided into two primary groups for the purpose of differential diagnosis: those with diffuse or bilateral consolidation and those with focal consolidation.

Diffuse or Extensive Consolidation

Diffuse consolidation has a number of possible causes (Table 1.1), and the clinical history is often more important than the radiographic findings in making the diagnosis. Several patterns or distributions of diffuse consolidation may suggest possible causes.

TABLE 1.1 Differential Diagnosis of Diffuse Consolidation

Water (Edema) (See Chapter XX)

Hydrostatic (cardiogenic) pulmonary edema
- Heart failure
- Left atrial or pulmonary venous obstruction
- Volume overload
- Low intravascular oncotic pressure
- Hypoalbuminemia
- Liver disease
- Renal failure

Increased permeability (noncardiogenic) pulmonary edema
- With diffuse alveolar damage (acute respiratory distress syndrome [ARDS])
  - Acute interstitial pneumonia
  - Aspiration of gastric acid
  - Drugs
  - Fat embolism
  - Infection and sepsis
  - Near-drowning
  - Pneumonia
  - Radiation
  - Shock
  - Toxic fumes or gases
  - Trauma
- Without diffuse alveolar damage
  - Any cause of ARDS, in a mild form
  - Drug reactions
  - Hantavirus pulmonary syndrome
  - Transfusion reaction

Mixed types of edema
- Air embolism
- High-altitude pulmonary edema
- Neurogenic pulmonary edema
- Posttransplantation edema
- Postpneumonectomy
- Reexpansion edema
- Reperfusion edema
- Tocolytic therapy
- Hydrostatic and permeability edema

Blood (hemorrhage) (see Chapter XX)
- Aspiration of blood
- Bleeding diathesis
  - Anticoagulation
  - Chemotherapy
  - Leukemia
  - Low platelets
- Collagen-vascular disease and immune complex vasculitis
  - Systemic lupus erythematosus most common
  - Behçet's syndrome
  - Henoch-Schönlein purpura
  - Antiphospholipid syndrome
- Goodpasture's syndrome
- Idiopathic pulmonary hemosiderosis
- Trauma
- Vasculitis
  - Granulomatosis with polyangiitis (Wegener's granulomatosis)
  - Churg-Strauss granulomatosis
  - Microscopic polyangiitis

Pus (pneumonia)
- Bacterial pneumonia
- Pneumonia in an immunosuppressed patient
- Tuberculosis
- Nontuberculous mycobacteria
- Fungal pneumonia (histoplasmosis, aspergillosis most common)
- Atypical organisms
  - Virus
  - *Pneumocystis*

Cells
- Neoplasm
  - Pulmonary adenocarcinoma
  - Lymphoma and other lymphoproliferative diseases
- Eosinophilic pneumonia or other eosinophilic diseases
- Organizing pneumonia (OP)
- Idiopathic interstitial pneumonias
  - Nonspecific interstitial pneumonia
  - Desquamative interstitial pneumonia
- Sarcoidosis

Other substances
- Alveolar proteinosis (lipoprotein)
- Lipoid pneumonia (lipid)

Perihilar "Bat-Wing" Consolidation

Perihilar "bat-wing" consolidation shows central consolidation with sparing of the lung periphery (Figs. 1.10 and 1.11). It is most typical of pulmonary edema (hydrostatic or permeability). This pattern also may be seen with pulmonary hemorrhage, pneumonias (including bacteria and atypical pneumonias such as *Pneumocystis jiroveci* pneumonia [PCP] and viral pneumonia), and inhalational lung injury. In patients with pulmonary edema, a perihilar distribution is most often present when rapid accumulation of fluid has occurred. Relative sparing of the lung periphery has been attributed to better lymphatic clearance of edema fluid in this region, although the exact mechanism is unclear and undoubtedly varies with the disease.

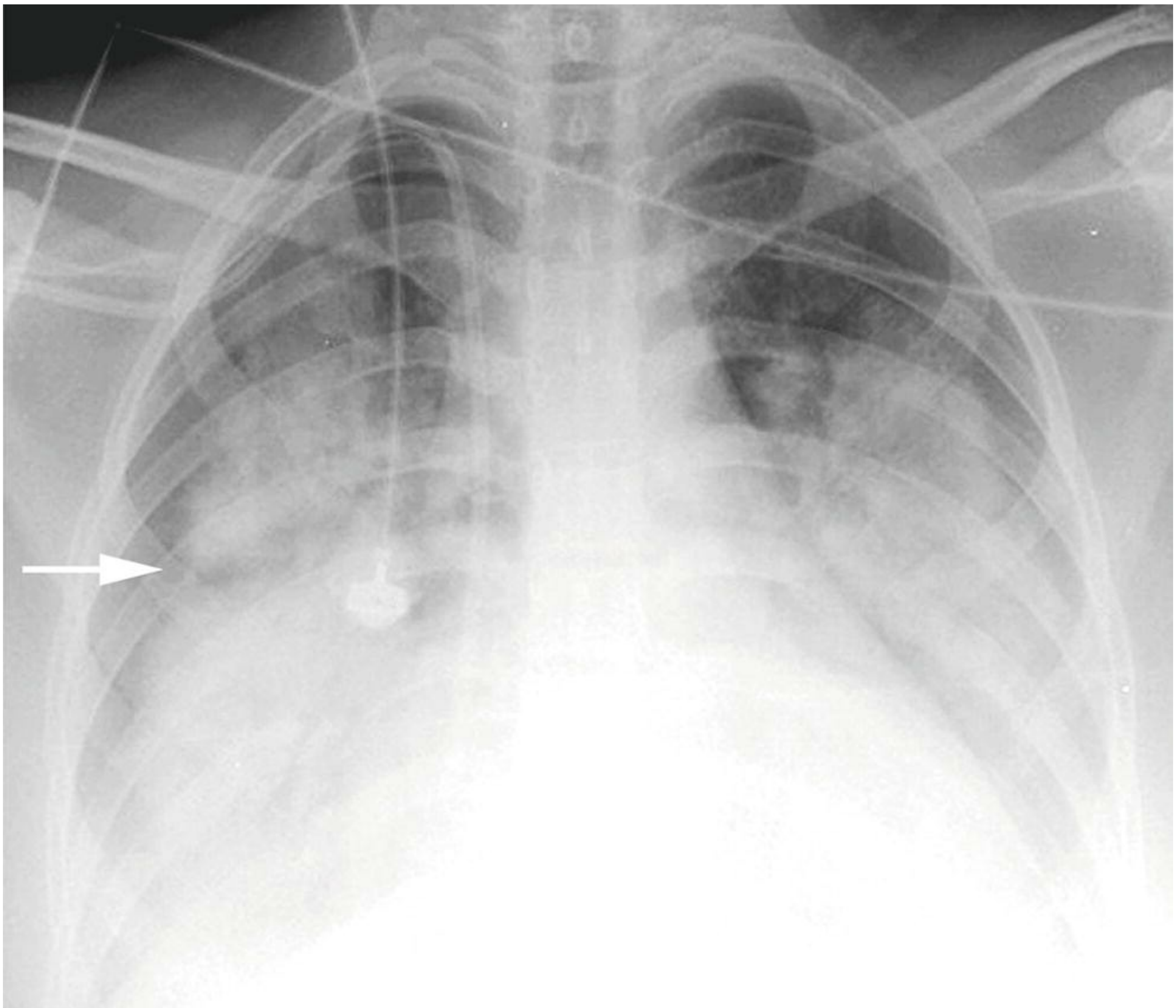
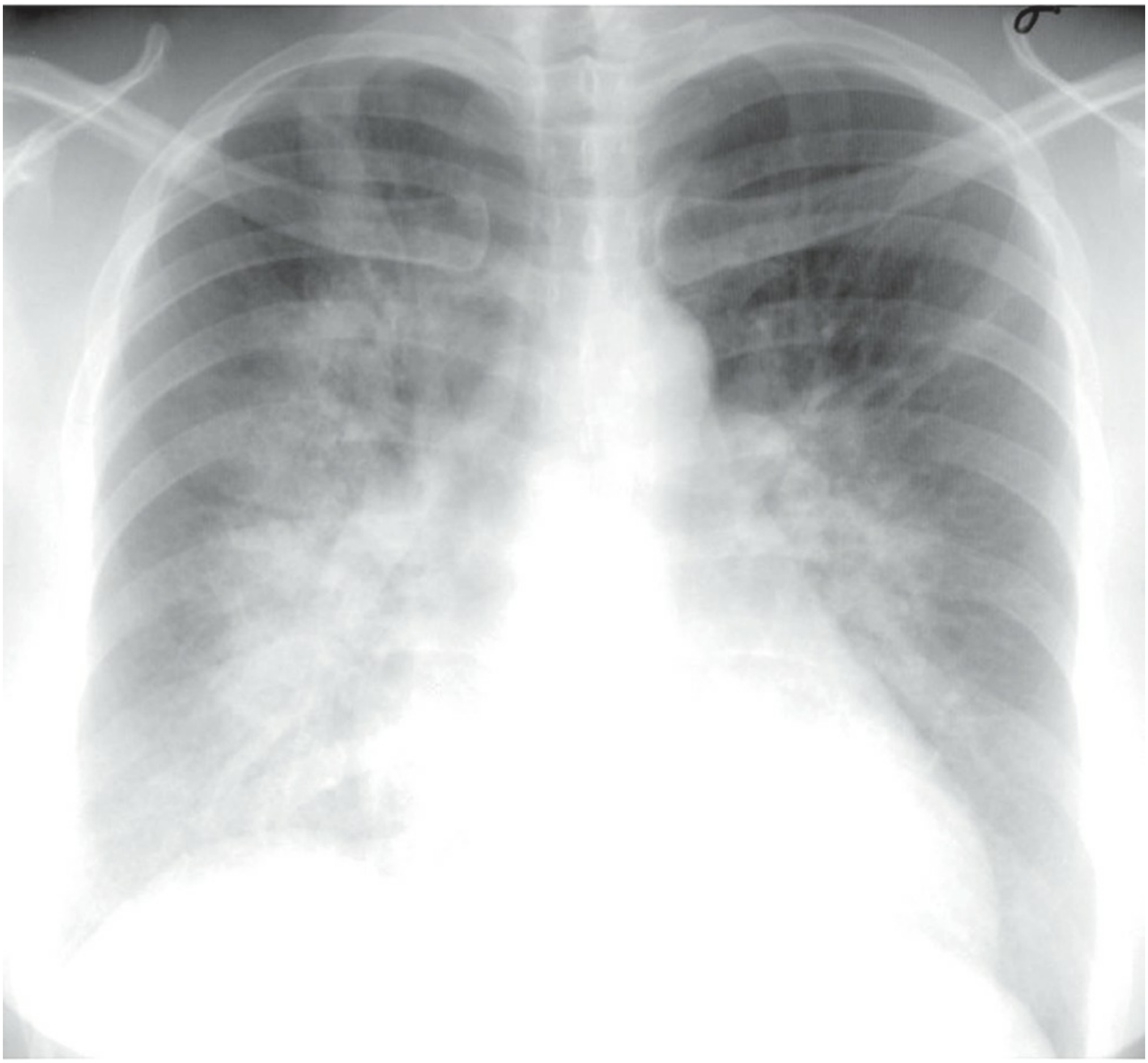


FIG. 1.10. Perihilar "bat-wing" consolidation in pulmonary edema. Chest radiograph in a patient with pulmonary edema due to renal failure (note the dialysis catheter in the right atrium) shows a distinct perihilar bat-wing pattern of consolidation. The lung periphery is spared. Note the lucency at the level of the minor fissure (*arrow*) because of sparing of peripheral lung adjacent to the fissure.



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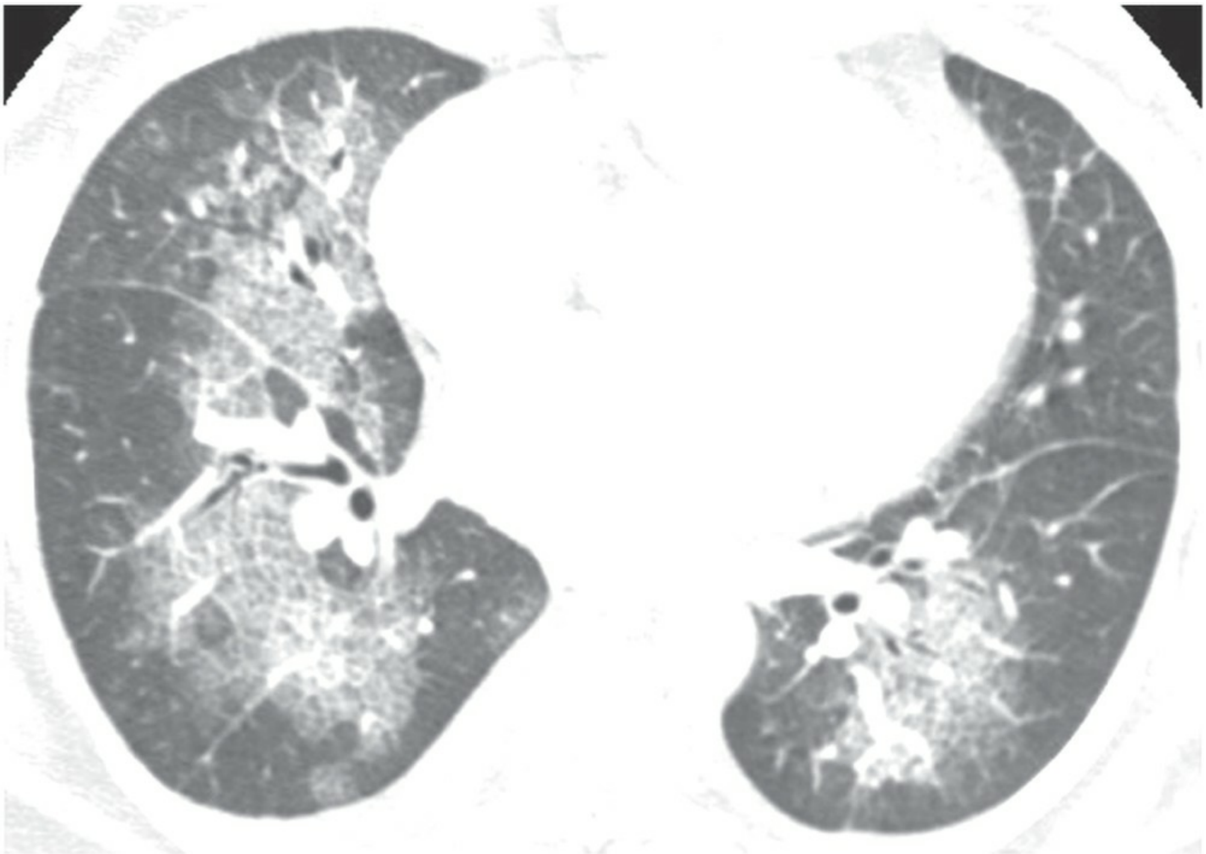
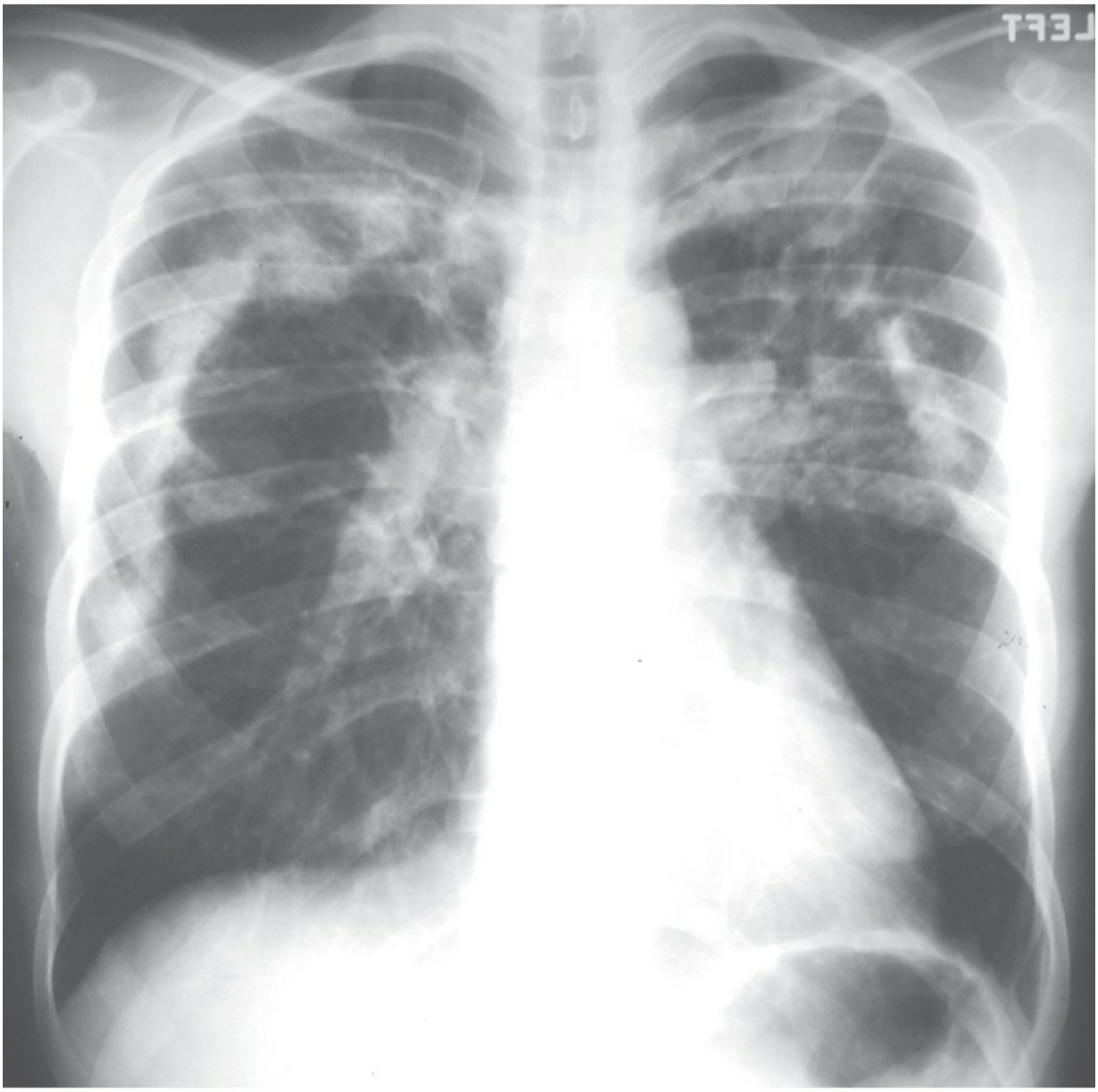


B

FIG. 1.11. Perihilar “bat-wing” consolidation in pulmonary edema. **A:** Chest radiograph shows a distinct perihilar predominance of consolidation. The heart is enlarged. **B:** CT shows sparing of the lung periphery.

Peripheral or Subpleural Consolidation

Peripheral or subpleural consolidation is the opposite of a bat-wing pattern (i.e., a reverse bat-wing pattern). Consolidation is seen adjacent to the chest wall, with sparing of the perihilar regions. It is most often seen in patients with a chronic lung disease (also the reverse of what is true of a bat-wing pattern). It is classically associated with eosinophilic lung diseases, particularly eosinophilic pneumonia (Fig. 1.12A), but may also occur with OP (see Fig. 1.12B), sarcoidosis, radiation pneumonitis, lung contusion, or mucinous adenocarcinoma. Peripheral consolidation need not always appear peripheral on the frontal (posteroanterior [PA] or anteroposterior [AP]) radiograph; it may be peripheral in the anterior or posterior lung and overlie the parahilar regions.



A

B

FIG. 1.12. Peripheral subpleural (reverse bat-wing) consolidation. **A:** Chest radiograph in a patient with chronic eosinophilic pneumonia shows areas of consolidation in the subpleural lung. The perihilar regions are spared. **B:** CT in a patient with OP shows patchy areas of consolidation in the subpleural lung.

Diffuse Patchy Consolidation

Diffuse patchy consolidation (Fig. 1.13) may be seen with any pneumonia (bacterial, mycobacterial, fungal, viral, PCP), pulmonary edema (see Fig. 1.6A) (hydrostatic and permeability), acute respiratory distress syndrome (ARDS), pulmonary hemorrhage syndromes, aspiration, inhalational diseases, eosinophilic diseases, and invasive mucinous adenocarcinoma. The patchy opacities may correspond to consolidation of lobules, subsegments, or segments.

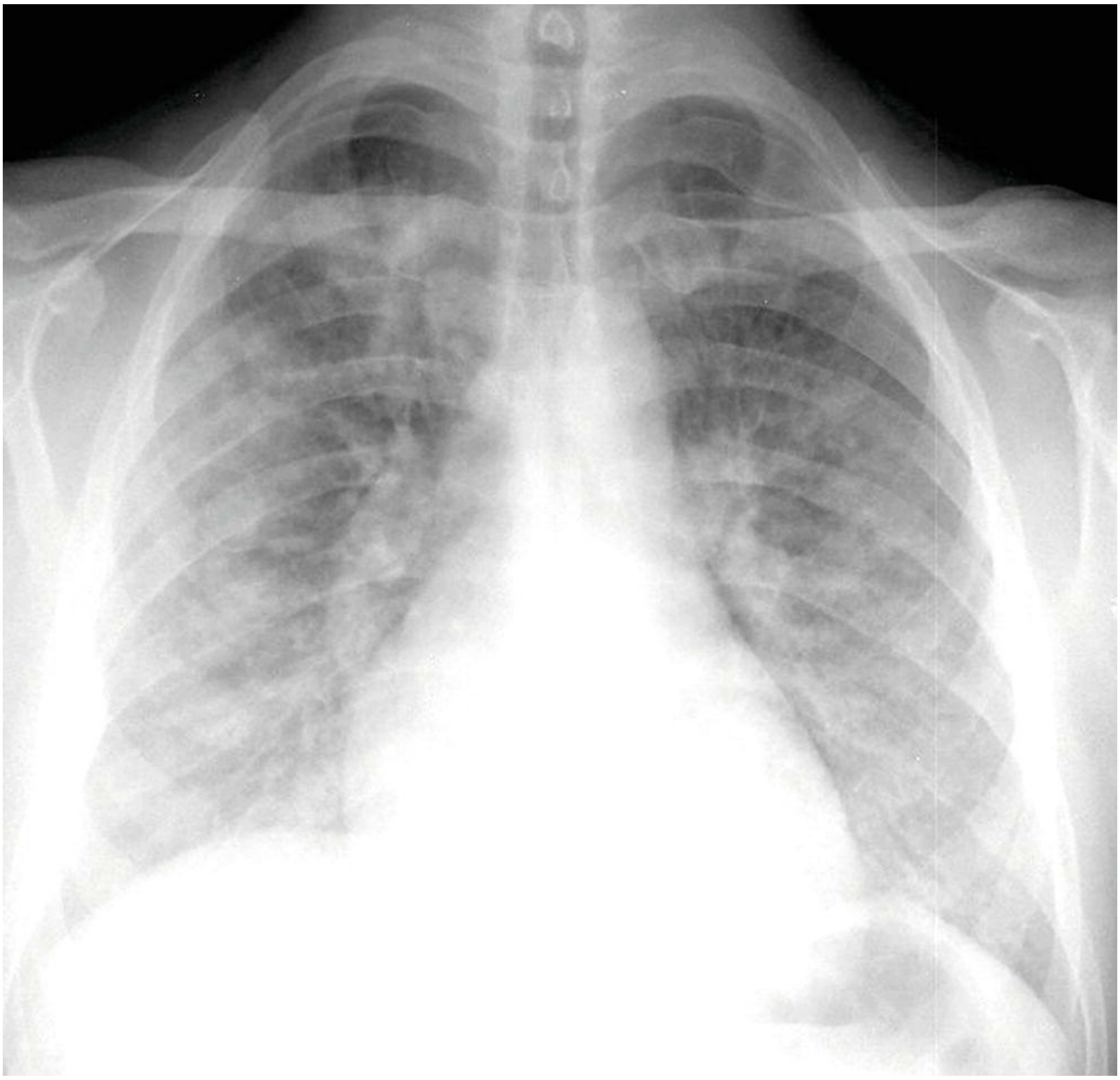


FIG. 1.13. Diffuse patchy consolidation in a patient with viral pneumonia.

Diffuse Air-space Nodules

Diffuse air-space nodules as a prominent feature of consolidation are typical of endobronchial spread of disease (Fig. 1.14). This appearance is seen in patients with endobronchial spread of infection such as tuberculosis (TB) or *Mycobacterium avium* complex (MAC), bacterial bronchopneumonia, viral pneumonia (cytomegalovirus [CMV], measles), invasive mucinous adenocarcinoma with endobronchial spread, pulmonary hemorrhage, or sometimes aspiration.

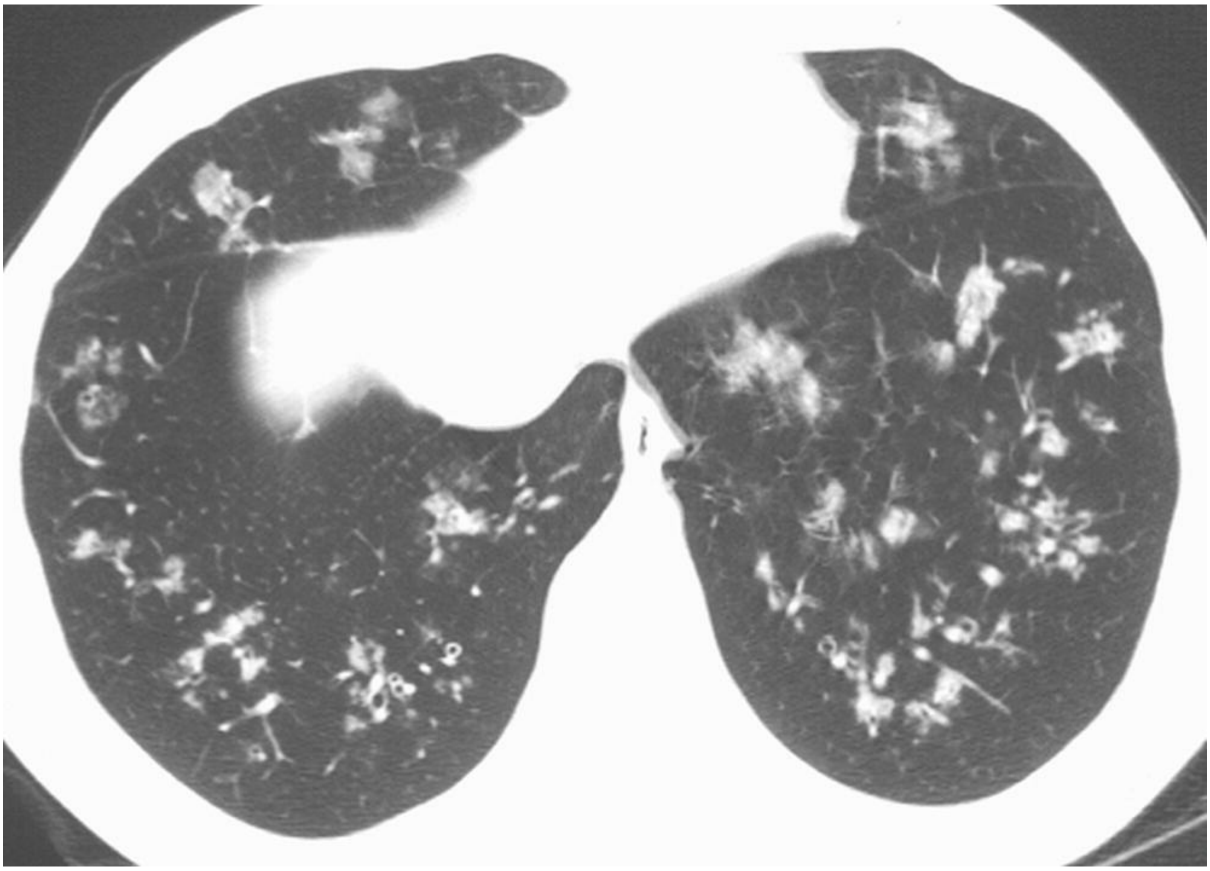


FIG. 1.14. Diffuse air-space nodules in bronchopneumonia. Multiple small nodular opacities are typical of spread of infection through the airways. This represented a bacterial bronchopneumonia, but other organisms such as TB, MAC, fungus, or viruses may be involved.

Diffuse Homogeneous Consolidation

Diffuse homogeneous consolidation is most typical in patients with pulmonary edema, ARDS, pulmonary hemorrhage, pneumonias (including viral and PCP), alveolar proteinosis, and extensive atelectasis.

Focal or Localized Consolidation

The most likely causes of focal consolidation include pneumonia, atelectasis with or without bronchial obstruction, and neoplasm, while pulmonary edema and hemorrhage are much less likely than in patients with diffuse abnormalities.

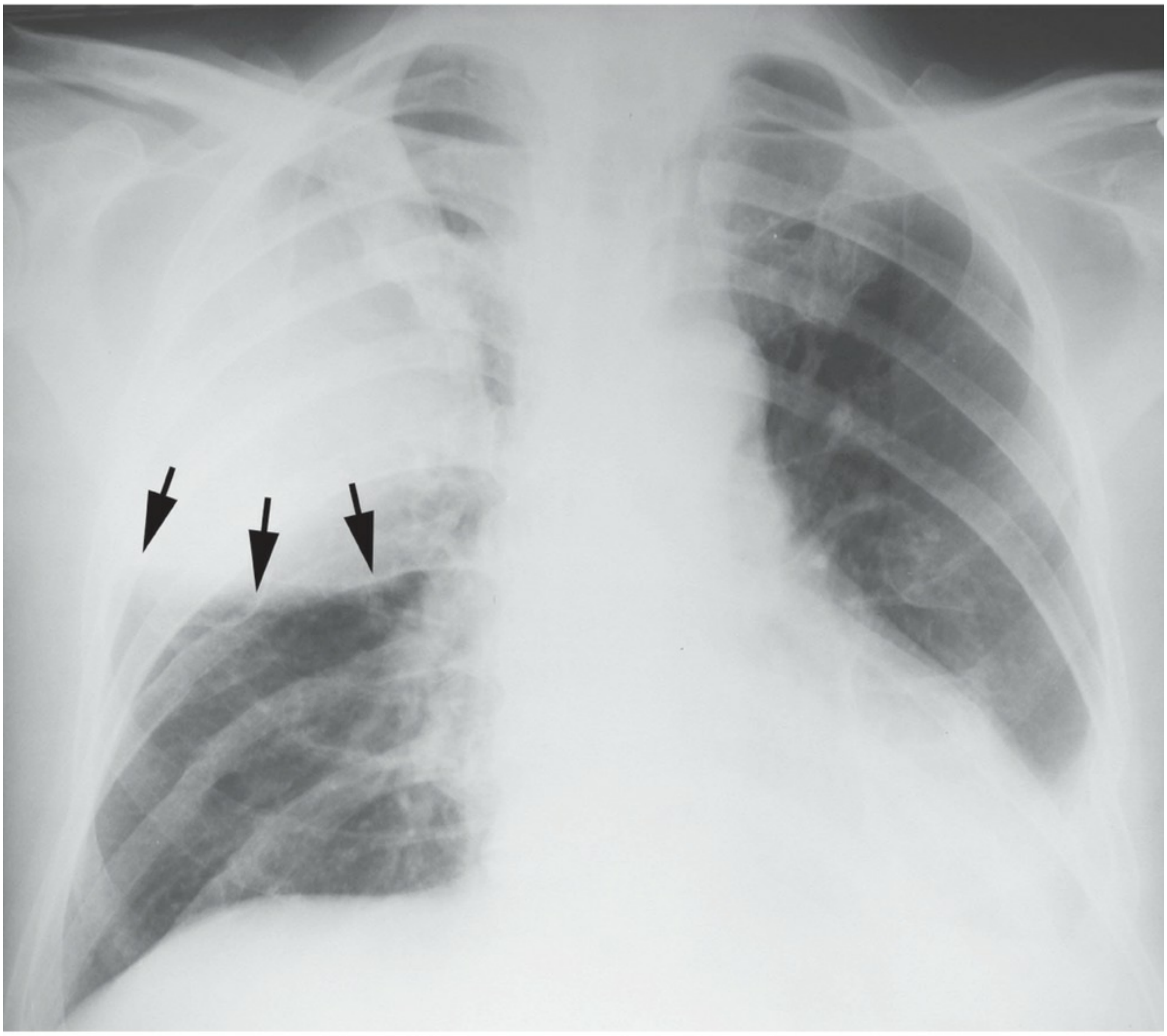
Focal consolidation (Table 1.2) may represent pneumonia; postobstructive pneumonia; aspiration; pulmonary adenocarcinoma; lymphoma or other lymphoproliferative disease; infarction; hemorrhage due to trauma, pulmonary embolism, or diseases such as granulomatosis with polyangiitis (GPA) formerly known as Wegener's granulomatosis; pulmonary infarction; radiation pneumonitis; organizing pneumonia; eosinophilic pneumonia; atelectasis; or rarely focal edema. The appearance of focal consolidation may also result from confluent interstitial disease, as in patients with sarcoidosis. The appearance or pattern of focal or multifocal consolidation may be helpful in differential diagnosis.

TABLE 1.2 Differential Diagnosis of Focal Consolidation

Water (Edema) (Uncommon)
Papillary muscle rupture with mitral prolapse (right upper lobe)
Edema in a patient with
Pulmonary artery obstruction (e.g., pulmonary embolism)
Hypoplastic pulmonary artery
Swyer-James syndrome
Decubitus position
Reexpansion edema
Pulmonary vein occlusion
Systemic to pulmonary artery shunt (congenital or acquired)
Bland aspiration
Atelectasis with drowned lung
Blood (hemorrhage)
Contusion
Infarction
Aspiration of blood
Vasculitis
Pus (pneumonia)
Bacterial
Tuberculosis or nontuberculous mycobacterial
Fungal
Virus (uncommon)
Pneumocystis (uncommon)
Aspiration pneumonia
Atelectasis with postobstructive pneumonia
Cells
Neoplasm
Pulmonary adenocarcinoma
Lymphoma and other lymphoproliferative diseases
Eosinophilic pneumonia or other eosinophilic diseases
Organizing pneumonia (OP)
Sarcoidosis
Other substances
Lipoid pneumonia (lipid)

Lobar Consolidation

Consolidation involving a single (or more than one) lobe is most typical of pneumonia (including *Streptococcus pneumoniae*, *Klebsiella* (Fig. 1.15A), *Legionella*, and TB) and abnormalities associated with bronchial obstruction. Consolidation can be localized to one or more lobes if its relationship to a specific fissure or fissures is apparent on either frontal or lateral radiographs, or on CT.



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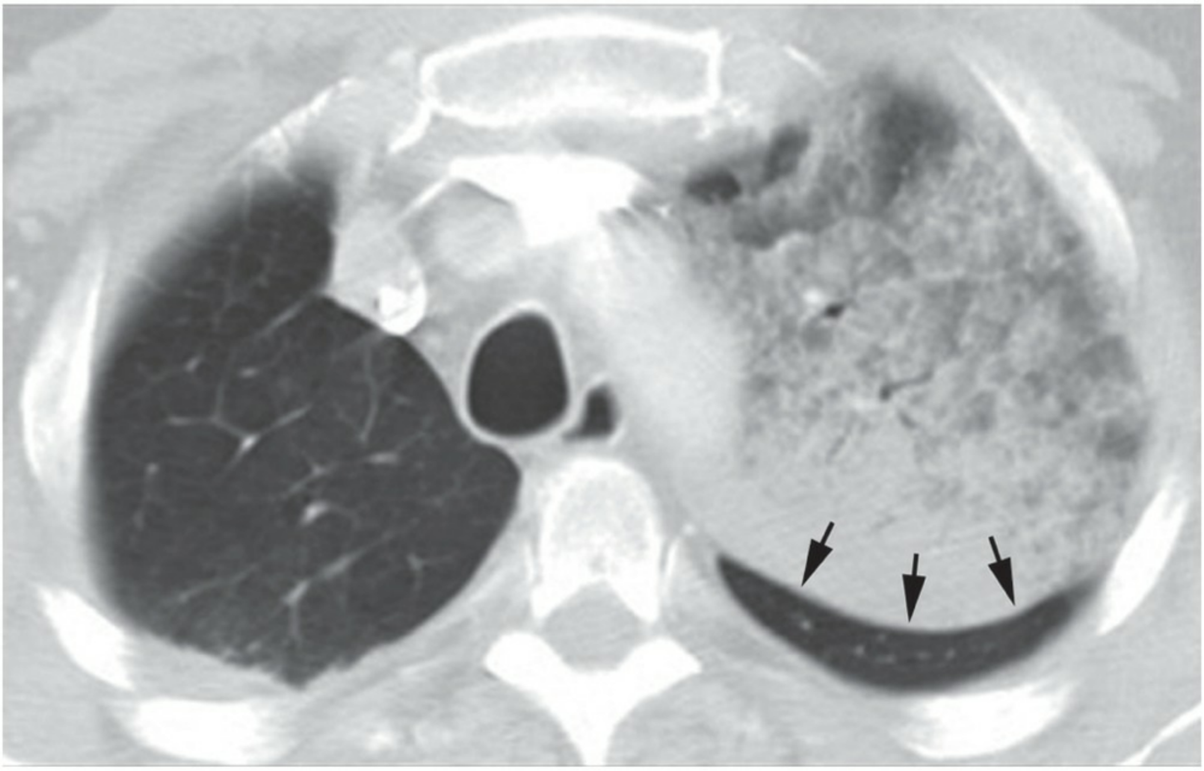


B

FIG. 1.15. Lobar consolidation with expansion. **A:** A patient with right upper lobe consolidation due to *Klebsiella* pneumonia shows downward bowing of the minor fissure (*arrows*) because of lobar expansion. **B:** Invasive mucinous adenocarcinoma involving the left upper lobe with posterior bulging (*arrows*) of the left major fissure.

Lobar consolidation with pneumonia often occurs because of interalveolar spread of disease via the *pores of Kohn* (small holes in the alveolar walls). This type of spread continues until a fissure or pleural surface is reached. Organisms associated with spread of pneumonia via the pores of Kohn are characterized by thin secretions (thus passing easily through the pores). The presence of an incomplete fissure may lead to a lobar pneumonia becoming bilobar (or trilobar) (see Fig. 1.15B).

Lobar consolidation resulting from interalveolar spread of disease can also be seen with lymphoma and invasive mucinous adenocarcinoma (see Fig. 1.15B). The term *lepidic growth* is used to describe the local spread of tumors such as nonmucinous or mucinous pulmonary adenocarcinoma, using alveolar walls as a scaffold.

Bronchial obstruction with postobstructive pneumonia or atelectasis also commonly results in lobar consolidation. The differential diagnosis is that of bronchial obstruction and includes neoplasm, lymph node enlargement, inflammatory lesions, stricture, and foreign body.

Lobar consolidation is uncommonly the result of vascular abnormalities. Right upper lobe consolidation representing pulmonary edema may occur in patients with acute myocardial infarction resulting in papillary muscle rupture and mitral valve prolapse; it occurs because a jet of regurgitant blood is directed into the right superior pulmonary vein. Focal pulmonary hemorrhage may lead to a lobar consolidation. Lobar consolidation is uncommon with pulmonary embolism.

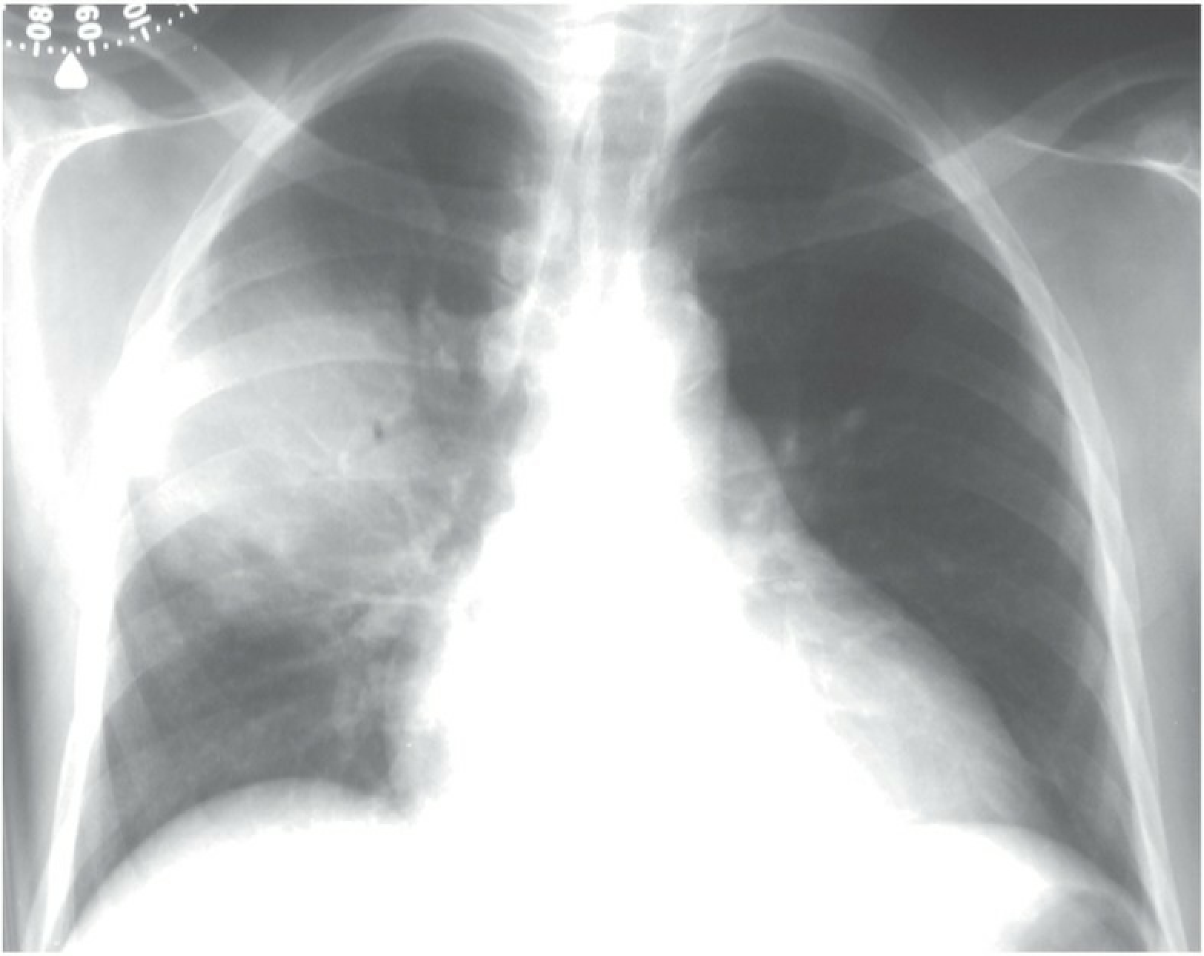
Lobar expansion in association with lobar consolidation suggests infection, particularly by *Klebsiella* (see Fig. 1.15A) or *Pneumococcus*, TB, bronchial obstruction with postobstructive pneumonia, or consolidation associated with neoplasm (see Fig. 1.15B).

Lobar consolidation can be localized by attention to the interlobar fissures. Simply stated, consolidation on the right (seen on the frontal view), which is posterior to the major fissure on the lateral view, is located in the lower lobe. Right-sided consolidation anterior to the major fissure may be in the upper lobe or middle lobe, depending on whether it is above (thus involving the upper lobe) or below the minor fissure (involving the middle lobe). On the left, consolidation anterior to the major fissure is in the upper lobe, while consolidation posterior to it is in the lower lobe. The inferior half of the left upper lobe roughly corresponds to the lingula (lingular segments of the left upper lobe).

Round or Spherical Consolidation

Round or spherical consolidation is most typical of pulmonary adenocarcinoma (nonmucinous or mucinous), lymphoma or lymphoproliferative disease, or pneumonia (i.e., *round pneumonia*). A round or spherical pneumonia is typical of organisms that spread via the pores of Kohn and progress to being lobar, such as *S. pneumoniae*, *Klebsiella*, *Legionella*, or TB (Fig. 1.16). Such diseases begin in at a single site and result in an enlarging ill-defined sphere of consolidation as more and more alveoli become involved. As the growing sphere reaches a pleural surface or fissure and cannot spread further, it becomes lobar.

A



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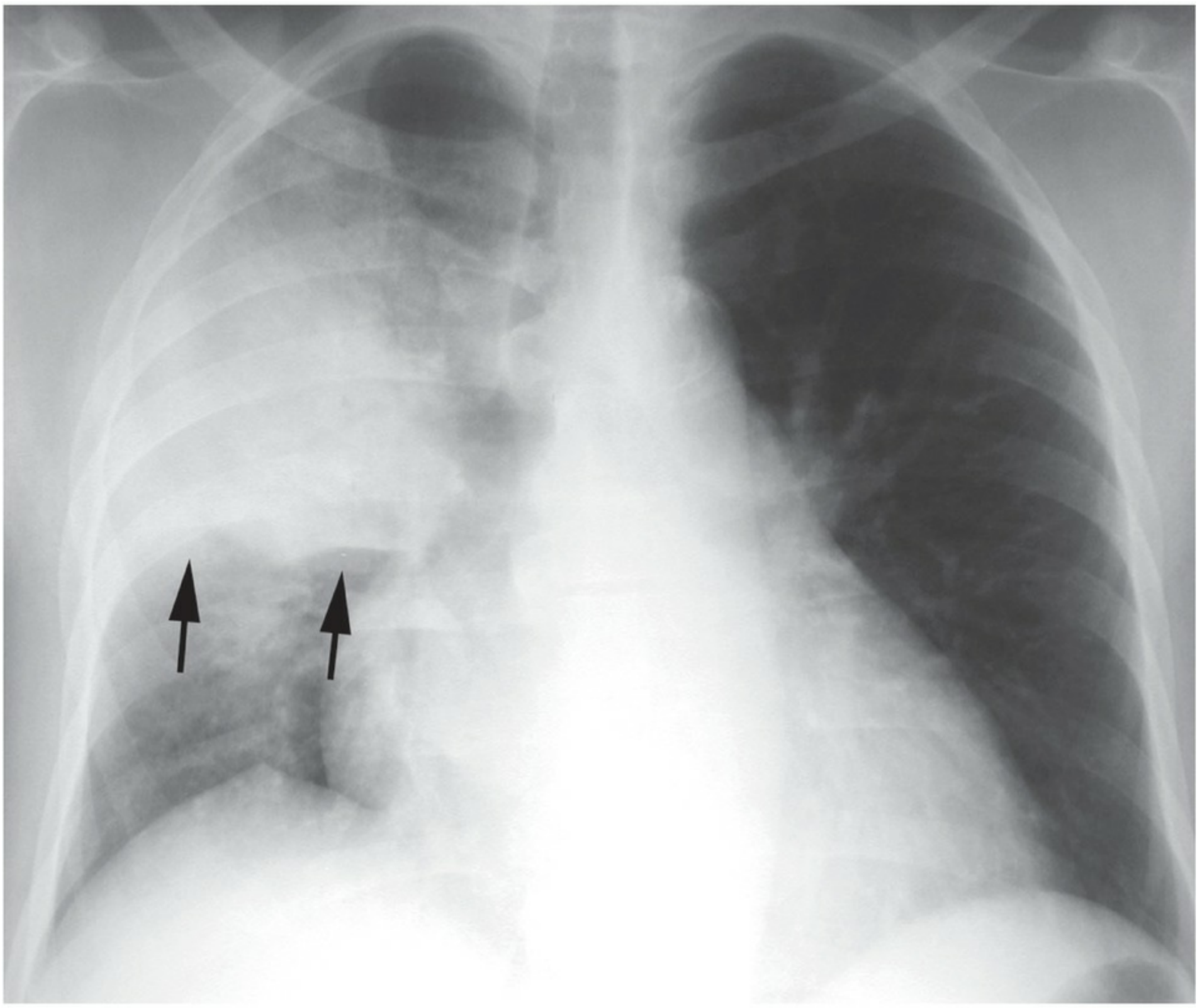

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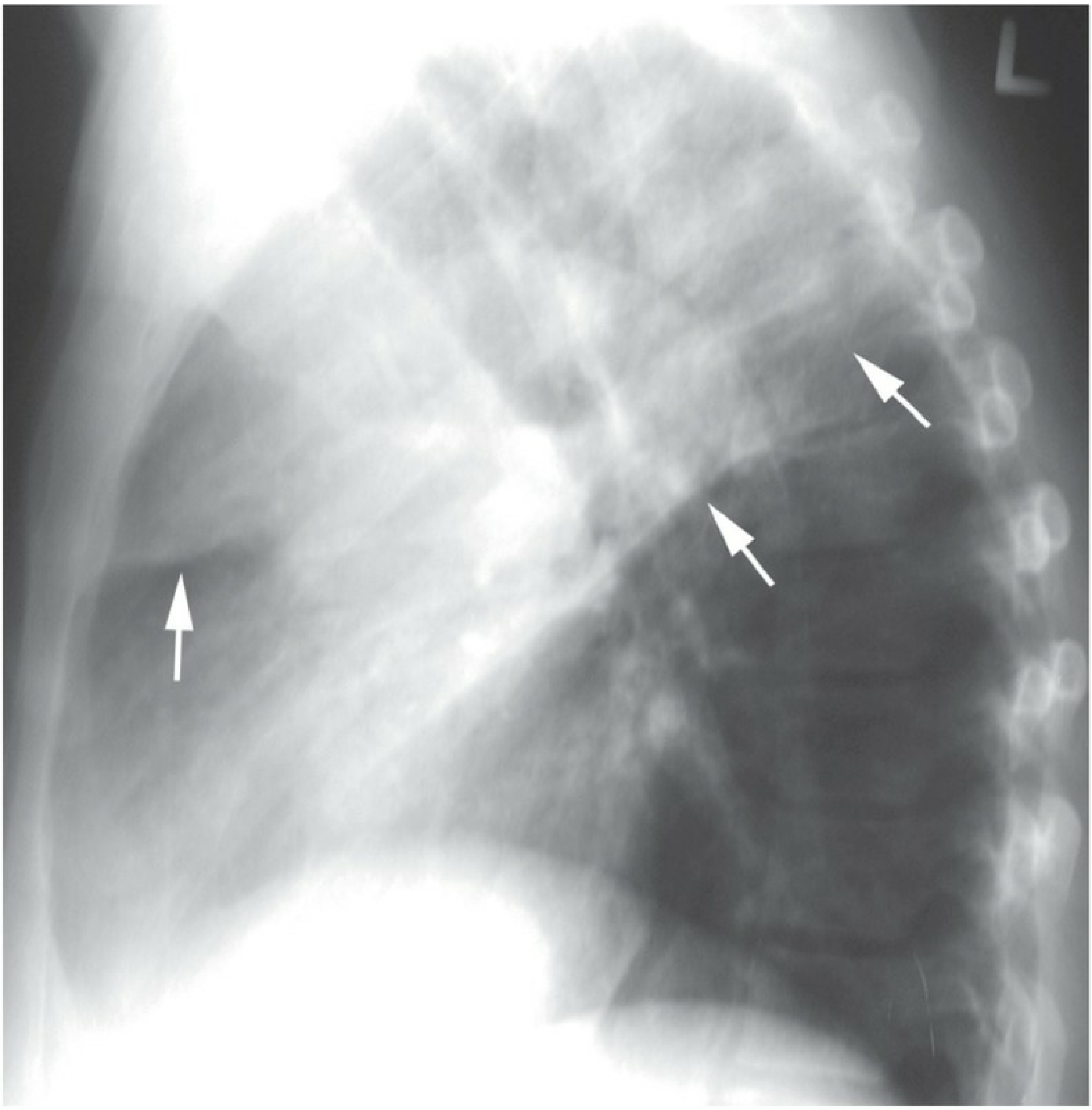


D

FIG. 1.16. Spherical consolidation due to pneumonia. **A:** On the initial radiograph, a patient with *Legionella* pneumonia shows a poorly defined area of consolidation (*arrows*) in the right upper lobe. This may be termed "round pneumonia." **B:** Over the next several days, the spherical consolidation increases in size because of local interalveolar spread. This appearance may be seen in the early stages of lobar pneumonias. **C:** Further progression results in consolidation of the right upper lobe, marginated by the minor fissure (*arrows*). **D:** A lateral view at the same time as (**C**) shows upper lobe consolidation marginated by the major and minor fissures (*arrows*). Partial right middle lobe consolidation is also present.

Segmental (or Subsegmental) Consolidation

Segmental (or subsegmental) consolidation may be diagnosed if a wedge-shaped opacity of more than a few centimeters in size is visible with the apex of the wedge pointing toward the hilum (see Figs. 1.9 and 1.17). This finding suggests an abnormality related to a segmental (or subsegmental) bronchus or artery, such as bronchial obstruction due to mucus or tumor, bronchopneumonia, focal aspiration, or pulmonary embolism with infarction.

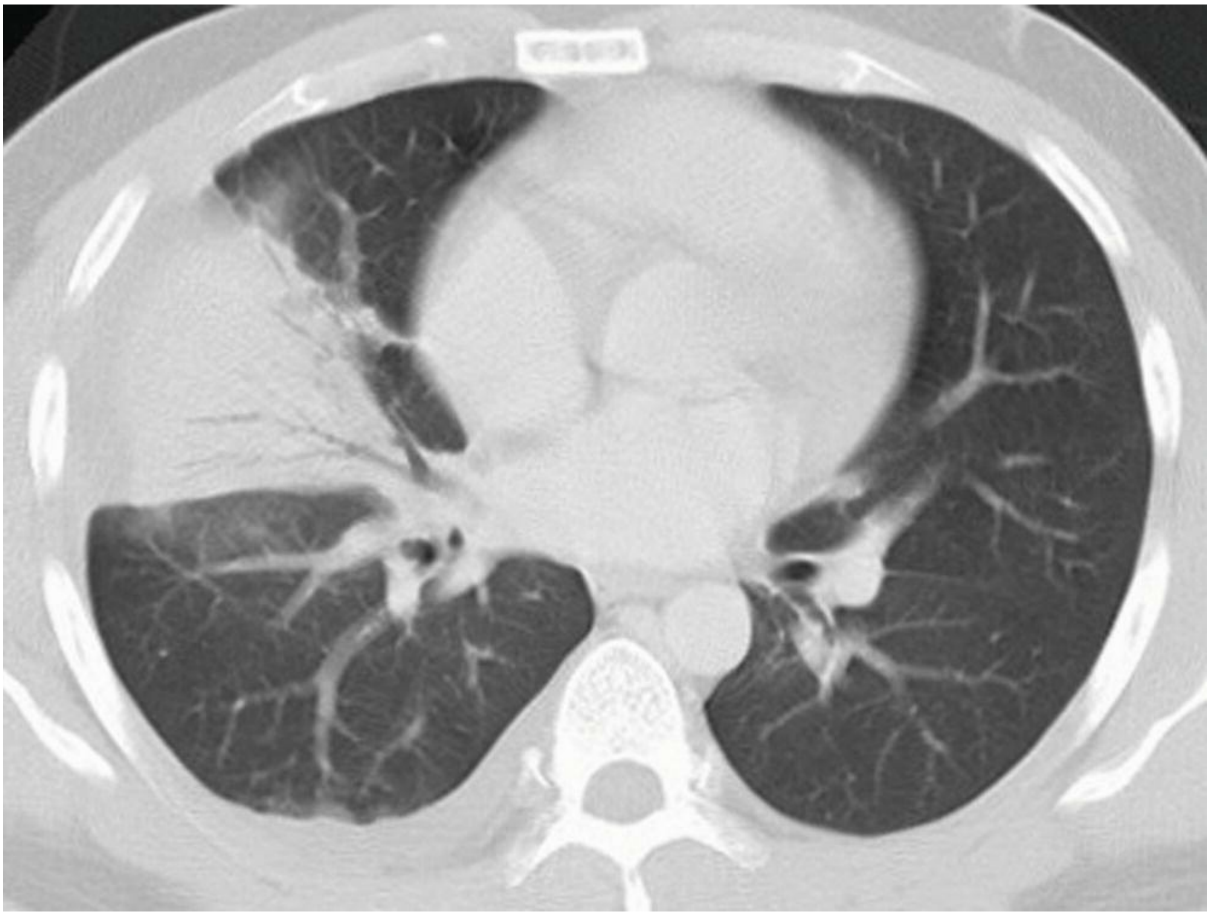


FIG. 1.17. Segmental consolidation. A patient with pneumonia shows consolidation of the lateral segment of the right middle lobe. The segmental bronchus is seen within the consolidated lung as an air bronchogram. The medial segment, adjacent to the right heart border, is normally aerated. The consolidated segment borders posteriorly on the major fissure.

Focal Patchy Consolidation

Focal patchy consolidation is typical of pneumonias, endobronchial spread of TB, or endobronchial spread of tumor such as mucinous carcinoma (see Fig. 1.6). CT may show a pattern of lobular consolidation. Centrilobular nodules are seen in some cases (see Fig. 1.7).

Patchy consolidation is typical of bronchopneumonia. Pneumonias associated with this pattern (e.g., *Staphylococcus, Haemophilus, Pseudomonas*) are characterized by thick and tenacious secretions and spread via airways rather than the pores of Kohn. Infected secretions are typically present within the bronchi. Bronchopneumonia is also known as *lobular pneumonia* because of its tendency to involve individual lobules. *Mycoplasma pneumonia* often results in this pattern.

Differential Diagnosis of Consolidation Based on Time Course

The time course over which consolidation develops, or the duration of symptoms in a patient presenting with consolidation on radiographs or CT, is important in differential diagnosis.

The likely diagnoses associated with acute symptoms or progression of radiographic abnormalities (hours, a few days, or a week or two) are quite different than those associated with a subacute, chronic, or progressive symptoms (a few weeks or months or years).

Rapidly Appearing Consolidation or Consolidation with Acute Symptoms

Rapidly appearing consolidation (a few hours) or consolidation associated with acute symptoms suggests atelectasis with drowned lung, aspiration, pulmonary edema, pulmonary hemorrhage, pulmonary embolism with infarction, or rapidly progressing pneumonia, particularly in an immunocompromised host. Of these, only pulmonary edema and drowned lung may clear quickly. Occasionally, a lymphoproliferative neoplasm progresses within hours.

Long-standing Consolidation or Consolidation with Chronic Symptoms

Long-standing (chronic) consolidation (4 to 6 weeks or longer) with little change suggests eosinophilic pneumonia, organizing pneumonia, mucinous adenocarcinoma, lymphoma, lipoid pneumonia, or some indolent pneumonias such as those caused by fungal organisms. Recurrent processes (e.g., recurrent pulmonary edema, pulmonary hemorrhage, or aspiration) may appear to be chronic if radiographs are obtained only during the acute episodes.

Localizing Consolidation: The Silhouette Sign

The borders of soft tissue structures such as the mediastinum, hila, and hemidiaphragms are visible on chest radiographs because they are outlined by adjacent air-containing lung. When consolidated lung (or a soft tissue mass) contacts one of these structures, its border becomes invisible or is poorly marginated. This is termed the "silhouette" sign. The silhouette sign is used on radiographs to diagnose the presence of a lung abnormality (i.e., consolidation, atelectasis, mass) and localize it to a specific lobe or lung region. It should be used in conjunction with identification of the interlobar fissures or may be used when the fissures are not clearly seen. However, keep in mind two caveats regarding the silhouette sign: (1) it does not always work and it should be correlated with other findings and (2) the presence of volume loss (i.e., atelectasis) may alter specific anatomic relationships.

The Silhouette Sign on the Frontal Radiograph

On the frontal (PA or AP) radiograph, obscuration (in radiologic parlance, "silhouetting") of specific contours may be related to abnormalities (e.g., consolidation or mass) involving specific lobes. Obscuration of specific contours and their correspondence to specific lobes are listed below and illustrated in Figure 1.18:

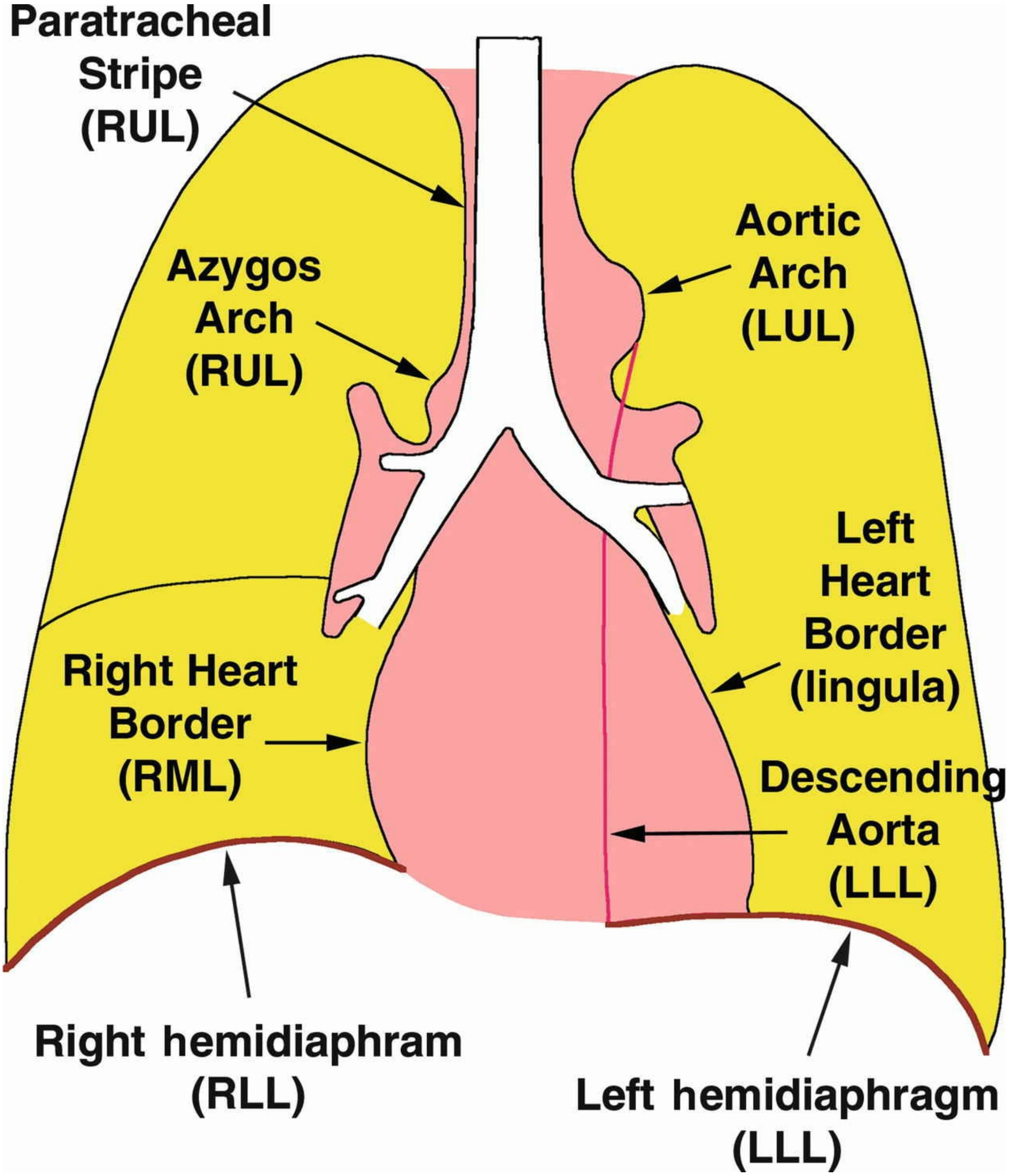
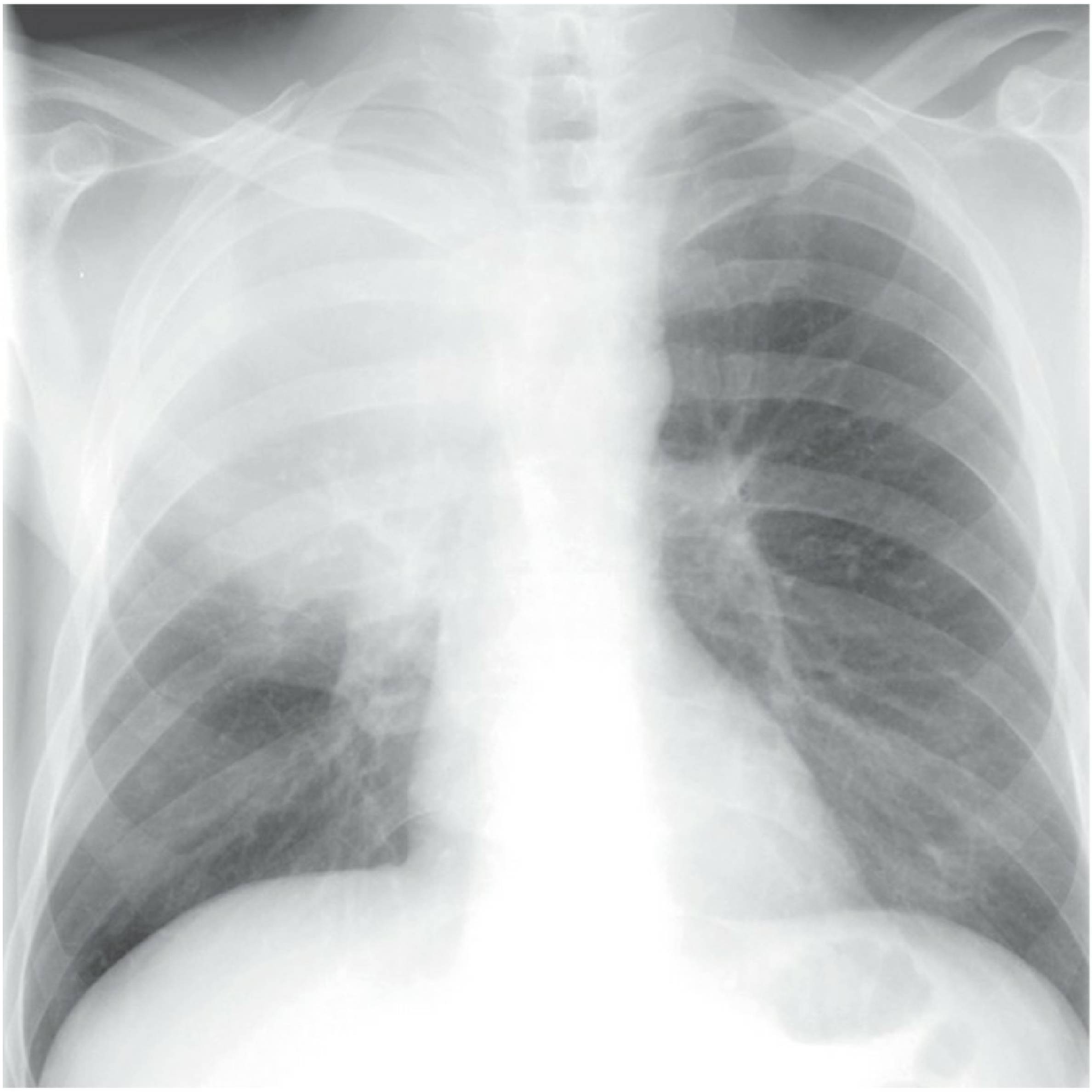


FIG. 1.18. Anatomic relationships and the silhouette sign on a frontal radiograph. Obscuration of the borders shown in this diagram is associated with consolidation of the listed lobes. RUL, right upper lobe; RML, right middle lobe; RLL, right lower lobe; LUL, left upper lobe; LLL, left lower lobe.

Right superior mediastinum (i.e., superior vena cava [SVC]) = right upper lobe (see Fig. 1.19)



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