Lung Expansion in the Diagnosis of Lung Disease

Kevin Winegardner, DVM
Peter V. Scrivani, DVM
Robin D. Gleed, BVSc, MRCVS
Cornell University
Ithaca, New York

ABSTRACT: The most common abnormality detected during thoracic radiography of patients with lung disease is increased opacity of the lungs. Although sensitive for lung disease, this finding alone is not specific for the cause of lung disease. Other conditions that increase lung opacity include technical complications and extrapulmonary lesions that compress the lung. Therefore, other radiographic signs are used to make a more definitive diagnosis. The size of the abnormally opaque lung lobe can be helpful in differentiating lung disease from other conditions. If the lung is normal to large in size, it is considered expanded. This situation always indicates disease. If the lung is small, it is considered incompletely expanded. This finding indicates pulmonary, thoracic wall, or pleural space disease or a technical complication. Common terms that are used to describe the volume of expanded or incompletely expanded lungs include infiltration, consolidation, collapse, and atelectasis. Although they are used as radiographic diagnoses, these terms should not be considered an endpoint analysis, and other radiographic signs must be sought to make a more definitive diagnosis.

The radiographic opacity of normal lungs is the result of a balance between air-filled spaces and pulmonary blood vessels. Other lung structures (e.g., bronchial walls, interstitium) are generally too small to be seen when normal. During disease, the opacity of the lungs is frequently altered. Therefore, it is important to be able to recognize the normal opacity of the lungs because abnormal opacity is a sign of lung disease. In veterinary medicine, most pulmonary diseases produce an increased opacity of the lungs (i.e., they appear more white), which is a significant finding but often is not specific for the cause of pulmonary disease. More specific tests for pulmonary disease rely on recognizing patterns of increased opacity and other radiographic signs. One of the most important signs, in combination with altered opacity, is the size of the affected lung. When a lung lobe is normal or increased in size, it is described as expanded. Infiltrated and consolidated are other terms that are used to describe this appearance. When the lung lobe is decreased in size, it is described as incompletely expanded. The terms collapsed and atelectatic are also used to describe this appearance.

Although commonly used in veterinary medicine, these other terms are sometimes controver-
Lung Expansion in the Diagnosis of Lung Disease

Figure 1. Interstitial versus alveolar pattern.

An example of a diffuse interstitial pattern, also called a diffuse air-space pattern, in a lateral thoracic radiograph from a geriatric cat with tachypnea. In the lungs, there is a moderate, diffuse increase in soft tissue opacity that partially silhouettes with pulmonary blood vessel margins. The differential diagnosis for this lesion is broad; in this case, the lung pattern was due to left congestive cardiac failure secondary to hypertrophic cardiomyopathy.

An example of a diffuse alveolar pattern, also called a diffuse air-space pattern, in a lateral thoracic radiograph from a middle-aged cat with severe respiratory distress. In the lungs, there is a severe, diffuse increase in soft tissue opacity that is worse centrally, completely obscures pulmonary blood vessel margins and adjacent heart margins, and creates air bronchograms. The differential diagnosis for this lesion distribution is also broad; however, the lung pattern in this case was also due to left congestive cardiac failure secondary to hypertrophic cardiomyopathy.

sial because they may be mistakenly used as an end-point analysis that does not sufficiently describe all the available radiographic information. Rather, they should be consid-
ered radiographic diagnoses that prompt the clinician to make a differential diagnosis. Therefore, we emphasize that differentiating whether the lung is expanded is only one step in the overall process of making a radiographic diagnosis. We also emphasize the need to understand the terminology used.

TERMINOLOGY AND DEFINITIONS

Infiltration is the migration of gas, fluid, or cells into a substance, cell, or tissue.1,2 Examples include deep soft tissue emphysema secondary to a tracheal tear and the accumulation of white blood cells in the prostate in response to infection. Consolidation can be considered solidification of tissue and is applied especially to inflam-
matory induration of a normally aerated lung by cellular exudates in the pulmonary alveoli; this process occurs in pneumonia, lung infarct, neoplastic infiltration, and other conditions.1–4 Both terms are used to describe the patho-
logic process that is suspected to be present when a lung of normal or increased size has increased radiographic opacity. Atelectasis is a decrease in, or complete loss of, air in the lung with resultant decreased volume of the initially expanded lung.1–4 The terms atelectasis and collapse are used synonymously and often according to personal preference; we use atelectasis in this article. When a neonate lung that never fully expanded is described, the term anectasis (also called primary atelectasis) is used. This situation is considered separate from atelectasis because it indicates that the lung never expanded after birth, not that it expanded and subsequently collapsed.1–3

The term unstructured interstitial pattern has been used to describe lungs that have increased opacity without complete effacement of pulmonary blood vessel margins. Unstructured interstitial pattern has also been used to describe lungs that are reduced in size (i.e., atelectatic) due to incomplete inhalation or to partial lung collapse caused by pleural fluid.1 However, the term interstitial pattern has classically indicated that there is infiltration of fluid or cells into the non–air-containing elements of the lung.3 Infiltration does not occur during incomplete inhalation or partial lung collapse; therefore, the term interstitial pattern is misleading in these cases because it does not precisely represent the underlying pathogenesis. Other descriptions of atelectasis use the term alveolar pattern.5–7 This description is more appropriate because an alveolar pattern is produced when a portion of the lung contains less than the normal volume of air due to either the collapse of or infiltration (cells or fluid) into the alveolar air spaces.5–7 In our experience, interstitial pattern and alveolar pattern have been used to describe differences in severity of reduced lung size.
Another reported descriptor used for lungs with increased opacity is air-space pattern. This term may be preferable because it can be modified to denote severity. For example, a mild air-space pattern would correspond with the use of interstitial pattern to denote less severe disease with partial obscuring of the pulmonary blood vessels, and a severe air-space pattern would correspond with the classic use of alveolar pattern to describe disease in which the pulmonary blood vessels are completely obscured (Figure 1). Alternatively, the lung may be described as having increased opacity that is further characterized by the use of other descriptors (e.g., distribution, lung size, air bronchograms, silhouetting of blood vessels, lines, and rings) to convey radiographic abnormalities with no mention of pattern.

**THE EXPANDED LUNG**
Consolidation or infiltration is recognized radiographically when a lung that is normal or increased in size has a relatively homogeneous soft tissue opacity characterized by effacement of pulmonary blood vessels and, sometimes, air bronchograms (Figure 2). Consolidation or infiltration always produces an air-space pattern because there is infiltration of the alveoli by fluid, cells, or both. Normal or increased lung size is detected by knowing the normal extent of lung lobes and identifying bulging pleural surfaces or displacement of structures (mediastinum, heart, adjacent unaffected lung) away from the affected lung lobe (i.e., mass effect). Although the term consolidation may imply that the lung is solid, the diseases that produce consolidation do not always advance to that degree. Therefore, there also is a continuum of the air-space pattern from mild to severe.

Recognizing that an abnormally opaque lung is normal or increased in size is important because this finding always indicates disease, and further evaluation using other imaging modalities (ultrasound, computed tomography), tissue sampling (transtracheal wash, bronchoalveolar lavage, percutaneous needle aspiration, biopsy), endoscopy, or surgery may be indicated.

**THE INCOMPLETELY EXPANDED LUNG**
In atelectasis, the volume of the lung is reduced because gas in the alveoli is absorbed and not replaced or because the lung is poorly ventilated. During thoracic radiography, the differential diagnosis for atelectasis
includes diseases and technical complications that limit expansion of the lung, such as airway obstruction, lung compression, incomplete inhalation, prolonged recumbency, and respiratory dynamics during anesthesia (Figures 2, 3, and 4). Although technical complications may be unrelated to disease, they may be mistaken for disease or obscure substantial pulmonary lesions. Therefore, it is important to recognize atelectasis because it may be an important diagnostic clue, an incidental finding, or a substantial distracter (Figures 5 and 6).

Atelectasis is a radiographic diagnosis made when the lung is reduced in size. The radiographic signs of atelectasis include displacement of interlobar fissures, pulmonary blood vessels, or bronchi because of reduced lung volume. Decreased lung size is typically also recognized by identifying increased lung opacity, cranial displacement of the diaphragm, displacement of the mediastinum and heart toward the affected lung, compensatory overinflation of the adjacent lung, bronchial rearrangement, and rib displacement (crowding). These signs are related to the fact that a fixed thoracic volume must be maintained. If the lung collapses, then other structures must compensate for the loss of volume either by shifting position or increasing volume. Some or all of these signs may be detected, depending on the severity of atelectasis (Figures 2 and 3).

Usually, a reduction in lung volume is accompanied by increased lung opacity because of the change in the balance of gas-filled spaces to blood vessels (i.e., in a unit of lung tissue, there is less gas for the same amount of visible soft tissue structures). The degree of lung collapse may be minimal to severe; thus, the degree of increased opacity (air-space pattern) is also variable. When atelectasis is more severe, a silhouette sign, lobar sign, or air bronchogram may be detected. However, increased opacity is not necessary to diagnose atelectasis because mild volume loss and pleural fissure displacement can occur without detectable increased opacity.

In humans, clinically important pleural fissure displacement without detectable increased lung opacity is a
**Key Points**

- A critical initial step in the diagnostic approach to any patient undergoing pulmonary radiography is to determine whether both lungs are fully or incompletely expanded.
- If a radiographically abnormal lung is normal to large in size, it is considered *expanded*, indicating pulmonary disease.
- If a radiographically abnormal lung is small, it is considered *incompletely expanded*, indicating pulmonary disease, nonpulmonary thoracic disease, or a technical complication.
- The terms *infiltration, consolidation, collapse, and atelectasis* can be used to describe lungs regardless of degree of expansion; however, other radiographic signs must be sought to make a more definitive diagnosis.

Sign of atelectasis in postanesthesia patients. Also in humans, patterns of atelectasis associated with disease are categorized based on derangements of normal physiologic mechanisms: passive (relaxation), resorption (obstructive), adhesive, and cicatrizing. When a radiographic pattern of atelectasis is detected, all types of atelectasis generally need to be considered (Table 1). In some instances, it may be possible to refine the differential diagnosis by noting other radiographic signs, such as the distribution of the atelectasis (i.e., focal, locally extensive, or diffuse). A focal lesion might suggest a local problem such as a foreign body, radiation pneumonitis, or recumbency. A diffuse distribution might suggest diseases that produce cicatrizing atelectasis or incomplete inhalation. Further characterization of atelectasis is only possible when the underlying pathogenesis can be determined.

**Relaxation or Passive Atelectasis**

The normal lung has an inherent elasticity and a natural tendency to collapse. This tendency to collapse at rest is normally opposed by the rigid shape of the thoracic wall and the sealed thoracic cavity. These opposing forces produce negative pressure in the pleural space. Therefore, any process that allows the normally negative intrapleural pressure to approach atmospheric pressure (either completely or partially) results in lung collapse and relaxation atelectasis. Relaxation atelectasis most often is due to
pleural diseases such as fluid accumulation or pneumothorax, but it may also result from impaired function of the thoracic wall musculature or diaphragm. Large thoracic wall lesions, severe cardiomegaly, pulmonary lesions that occupy substantial intrathoracic volume, or diaphragmatic hernia with cranial displacement of abdominal organs also may produce relaxation atelectasis. In mild cases of pneumothorax or pleural fluid accumulation, the only detectable sign may be reduced lung volume because the ratio of gas-filled space to blood vessels is not altered enough to result in increased opacity.

Dependent portions of the lung may have decreased alveolar expansion and increased perfusion because of the effects of gravity. These conditions change the ratio of gas-filled spaces to blood vessels, resulting in increased attenuation of x-rays during radiography or computed tomography. The resulting appearance has been termed gravity-dependent atelectasis. Although they are normal physiologic changes, gravity-dependent effects on the lung can exacerbate relaxation atelectasis caused by hypoventilation. Hypoventilation is frequently encountered during general anesthesia or diffuse neuromuscular disease because the diaphragm and thoracic wall are inactive. During general anesthesia, relaxation atelectasis can be easily overcome by increasing ventilation; ordinarily, this is accomplished by compressing the rebreathing bag on the patient’s breathing system to mimic maximal spontaneous inspiration (vital capacity maneuver). Relaxation atelectasis also may occur in cases of diaphragmatic hemiparesis.

Atelectasis at the edge of a focal lesion is thought by some to result from the normal elasticity of the surrounding lung and is therefore regarded as a variant of relaxation atelectasis. It is radiographically detectable only if the focal lesion is gas filled (e.g., bulla) because if the focal lesion is of soft tissue consistency, the lesion and atelectatic lung will form a silhouette. In some texts, atelectasis adjacent to a parenchymal space-occupying lesion (neoplasm, bulla) has been termed compressive atelectasis because of the idea that an enlarging focal lesion “compresses” the adjacent lung. Compressive atelec-

![Figure 6. Two sets of orthogonal thoracic radiographs of a 7-year-old, spayed domestic shorthaired cat.](image)

In these images, obtained while the cat was awake, the lungs are decreased in volume and have diffuse, mildly increased opacity. Based on the cranial location of the diaphragm and a diffuse distribution, these radiographs most likely were obtained during exhalation.

![In these images, obtained while the cat was under general anesthesia with positive-pressure ventilation, the lungs are well expanded, demonstrating that the increased opacity in the initial images was the result of a technical artifact rather than disease.](image)

Resorption or Obstructive Atelectasis

Air must flow into the lungs to allow them to expand. Diseases that obstruct the airways (primary bronchus, multiple small bronchi, or bronchioles) produce resorption atelectasis because gas exchange in the alveoli continues despite the obstruction, causing any gas in the lung downstream to the obstruction to be
If a lung has reduced size, increased opacity, and no air bronchograms, either a complete bronchial obstruction is present or an underlying disease that could secondarily occlude the airways with fluid or cells (e.g., pneumonia, neoplasm, asthma) or severe lung fibrosis (in which the airways are collapsed secondary to fibrotic change) should be suspected. Resorption atelectasis may or may not be present. In humans, resorption atelectasis is not usually considered when air bronchograms are detected. This is because an obstruction of a large bronchus that is severe enough to result in absorption of gas from the alveoli should also cause absorption of gas from the bronchial tree downstream from the obstruction. If only the small bronchi are obstructed (e.g., mucus accumulation) in the periphery of the bronchial tree, air bronchograms are typically present because the larger airways remain patent.

Table 1. Differential Diagnoses Associated with Radiographic Findings

<table>
<thead>
<tr>
<th>Radiographic Pattern</th>
<th>Type</th>
<th>Pathogenesis</th>
<th>Abbreviated Differential Diagnosis</th>
</tr>
</thead>
</table>
| Incompletely expanded (collapsed, atelectatic) | Relaxation | Unopposed tendency of lung to collapse due to inherent elasticity | • Pneumothorax  
• Pleural fluid  
• Space-occupying lesion  
• Gravity dependent  
• Shallow breathing |
| Obstructive | Absorption of alveolar gas without replacement due to airway obstruction | • Neoplasm  
• Inhaled foreign body  
• Mucus plugging (asthma)  
• Infectious bronchitis or pneumonia  
• Ciliary dyskinesia |
| Adhesive | Lumen surfaces of alveoli stick together due to surfactant abnormality | • Neonatal respiratory distress syndrome  
• Acute respiratory distress syndrome  
• Pulmonary embolism |
| Cicatrizizing | Lungs do not increase in volume under normal respiration due to reduced compliance | • Chronic idiopathic fibrosis  
• Chronic immune-mediated lung disease  
• Chronic pneumonia  
• Radiation pneumonitis |
| Expanded (infiltrated, consolidated) | NA | Infiltration of lung with fluid, cells, or both | • Pneumonia  
• Neoplasm  
• Hemorrhage  
• Edema (severe)  
• Fungal disease  
• Immune-mediated disease  
• Lung-lobate torsion |

aThese terms are commonly used in human medicine but may be useful in refining radiographic diagnoses in veterinary patients.
Adhesive Atelectasis

Normally, as an alveolus decreases in volume, pulmonary alveolar surfactant reduces surface tension in an effort to keep the alveolus open. If a surfactant abnormality is present, the luminal surfaces of the alveolar walls can stick together and generalized alveolar collapse, called **adhesive atelectasis**, can occur. Another proposed mechanism for adhesive atelectasis is that alveolar collapse disrupts surfactant function. Adhesive atelectasis may occur in association with pulmonary embolism and is thought to relate to decreased surfactant production. However, the exact cause of surfactant derangements seen with pulmonary embolism is not fully understood. Atelectasis may be an important radiographic sign of pulmonary thromboembolism; however, atelectasis in these patients may be transient.4 Atelectasis is reportedly seen in many patients with pulmonary embolism (i.e., the presence of a foreign object, such as a bone fragment or air bubble, that lodges in a pulmonary artery) but is nonspecific for thromboembolism (i.e., the presence of a blood clot in a pulmonary artery).12–14 Surfactant function may remain altered despite reopening of the collapsed air spaces.15

Cicatrizing Atelectasis

Lung volume depends on a balance of applied forces resulting in negative intrathoracic pressure and the opposing elastic forces of the lung. The ability of the lungs to stretch and change in volume relative to an applied change in pressure is called **pulmonary compliance**. The normal lung is more compliant in a low-volume state and becomes less compliant as the volume increases. Diseases that reduce lung compliance prevent the lungs from increasing in volume during normal respiration; this is termed **cicatrizing atelectasis**. Lung compliance most often is reduced by fibrosis, which produces a “stiffer” lung, or by scar tissue. Increased radiographic opacity may be the result of fibrosis and the inability to expand the alveoli with gas. In animals, fibrosis and scar formation are most often caused by chronic pneumonia, immune-mediated disease (e.g., chronic obstructive pulmonary disease), and radiation pneumonitis. Chronic idiopathic pulmonary fibrosis of West Highland White terriers is a reported disease entity. In this small population of dogs, diffuse cicatrizing atelectasis may be present as a secondary change; however, such conclusions have not been reported.16,17

CONCLUSION

The terms atelectasis, collapse, infiltration, and consolidation are commonly used to describe pulmonary radiography findings; however, other radiographic signs must be sought to make a more definitive diagnosis. Although many of the diseases that produce consolidation can also produce atelectasis, it is important to differentiate the two conditions when possible. Recognizing that an abnormally opaque lung is normal or increased in size is important because this finding always indicates disease.

Atelectasis (increased radiographic opacity and decreased size of the lung) may be an essential diagnostic clue, an incidental finding, or a substantial distracter. Although increased opacity is a common radiographic finding in
atelectasis, it is not necessary to make this radiographic diagnosis; detecting reduced lung size is all that is necessary. When a radiographic pattern of atelectasis is detected, then all types of atelectasis generally need to be considered. In some instances, it may be possible to refine the differential diagnosis by noting other radiographic signs. Further characterization of atelectasis is only possible when the underlying pathogenesis can be determined.