Nontraditional Interpretation of Lung Patterns

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KEYWORDS

• Lung • Radiography • Computed tomography
• Atelectasis • Dog • Cat

In the 1970s and 1980s, a series of case reports, review articles, and text books established what may be considered as the traditional approach to radiographic interpretation of lung disease in veterinary medicine.[1–16] In the past decade, our group has proposed a modified approach that is referred to as an alternate appraisal or a nontraditional approach.[17–19] It is a work in progress, and we keep modifying the basic premise as new information is gathered. The fundamentals of either approach are very similar, but the major difference is where the emphasis is placed. For example, our group emphasizes that, in most patients, the three most important radiographic signs for prioritizing the differential diagnosis are the opacity of the lung, the degree of lung expansion, and the macroscopic distribution of lung lesions. Additional signs (including the more traditionally emphasized ones), however, are extremely important and still used to prioritize the differential diagnosis. Another difference between the two approaches is that we try to incorporate terminology that reflects current usage in human medicine, which has advanced at a more substantial pace than veterinary medicine—especially with the extensive use of thoracic computed tomography and histopathologic correlation that has aided radiographic interpretation.[20]

To simplify the description for this article, discussion of pulmonary blood-vessel alterations are relegated to the cardiovascular system and therefore discussed only minimally. Additionally, since it is well known that improperly exposed radiographs or unacceptably positioned patients may unfavorably affect radiographic interpretation, assumptions are made that abnormalities detected on thoracic radiographs are localized to the lung (not merely superimposed) and neither due to technical complications nor age-related changes. Herein, describing a lung lesion also implies that the viewer thinks that lung pathology is present. This approach to the radiographic description is reasonable when the radiologic study is considered as if it were

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a scientific test.[21] If, for example, we assume a "null hypothesis" and anticipate that the radiographic findings will fall within the expected range of normal for the given population, then it is necessary to describe only those findings that are abnormal and disprove the null hypothesis—these findings are referred to as positive findings.[21] The exception occurs when a clinical question implies the possible presence of a specific abnormality and introduces a positive hypothesis that the findings will document the questioned abnormality.[21] In this case, normal findings that refute the presence of the questioned abnormality should be described and are referred to as pertinent negatives.[21]

OPACITY OF THE LUNG AND DEGREE OF LUNG EXPANSION

Altered opacity of the lungs is one of the most common radiographic signs associated with pulmonary disease. Therefore, detecting altered opacity is frequently the first positive finding that the lungs are abnormal. The altered opacity may be either increased (more opaque) or decreased (more lucent), but the majority of pulmonary diseases in dogs and cats produce an increased opacity. Negative findings are possible, because some diseases may produce no alteration of opacity due to the pathogenesis of that particular disease, disease severity, or stage of the disease. In addition, whereas detecting altered opacity of the lung is a sensitive test for lung disease, it is often not specific for the type of lung disease. Therefore, this finding is generally combined with other signs to form a pattern of the disease. One of the most important signs to help further classify the pattern of lung disease is the size of the lungs or lobes, which may be decreased, normal, or increased. Lungs that have decreased size are described as incompletely expanded. Lungs that have normal or increased size are fully expanded.

An incompletely expanded lung that has an increased opacity that completely or partially obscures the margins of pulmonary blood vessels and airway walls is called *collapse* or *atelectasis*. Atelectasis is reduced inflation of all or part of the lung. It is important to differentiate an abnormally opaque lung lobe that is incompletely expanded from one that is fully expanded lung, because this latter pattern always implies pulmonary disease and atelectasis implies either disease or a technical complication that is incidental or may obscure a real lesion. The radiographic signs that alert the viewer to reduced lung volume are a mediastinal shift toward the abnormal appearing lung, crowding and reorientation of pulmonary blood vessels, crowding of ribs, compensatory hyperinflation of other lung lobes, bronchial rearrangement, cardiac rotation, displacement of interlobar fissures, displacement of the diaphragm, change in location of abnormal structures, and rounded pulmonary margins. Not all need to be present to recognize atelectasis (**Fig. 1**).

In some patients, atelectasis may be the most important indicator of disease and not just a technical complication to be dismissed without further consideration. Additionally, if it is just a technical complication associated with prolonged recumbency, anesthesia (**Fig. 2**), or not taking a deep breath, it may be severe enough to obscure an important lesion. There are several types of atelectasis: relaxing, obstructive, adhesive, and cicatrizing.[22] The different types relate to the mechanism for which the lungs cannot inflate. Relaxation atelectasis is due to the unopposed tendency of the lung to collapse due to inherent elasticity. Diseases that may produce this type of atelectasis are pneumothorax, pleural fluid, space-occupying lesion, and gravity-dependent and shallow breathing.[22] Obstructive atelectasis is due to absorption of alveolar gas without replacement due to airway obstruction. The differential diagnosis includes neoplasm (**Fig. 3**), foreign body, mucous plugging (eg, asthma), infectious

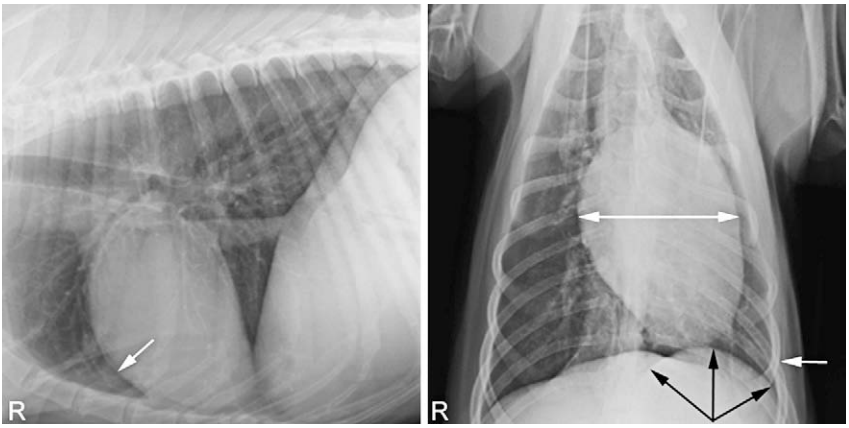

Fig. 1. Orthogonal thoracic radiographs of a 9-year-old, neutered, male Weimaraner with atelectasis. On the lateral view, note the increased opacity that obscures the margins on pulmonary blood vessels (*white arrow*). On the ventrodorsal view, note the mediastinal shift of the heart to the left (*double-headed white arrow*), rib crowding (*white arrow*), and cranial displacement of the left crus of the diaphragm (*black arrows*).

bronchitis or pneumonia (**Fig. 4**), or ciliary diskinesis.[22] Whereas pneumonia typically produces lung consolidation, atelectasis may occur when the lung lobe is not completely filled with pus and exudates obstruct some of the airways, preventing refilling of alveolar gas. Adhesive atelectasis is due to lumen surfaces of alveoli sticking together due to surfactant abnormality. Diseases include neonatal respiratory distress syndrome, acute respiratory distress syndrome, and pulmonary thrombosis.[22] Cicatrizing atelectasis occurs when the lungs do not increase in volume under normal

Fig. 2. Ventrodorsal thoracic radiographs of a 7-year-old, FS, Australian shepherd with difficulty breathing due to a pharyngeal mass. The radiograph on the left was obtained while the patient was awake. The radiograph on the right was obtained a day later while the patient was under general anesthesia. Note that, during general anesthesia, the rib cage is not as well expanded, there is a mediastinal shift to the left, and the left lung is small and increased in opacity. The results of that study are indeterminate for lung disease—atelectasis may be due to primary lung disease, secondary to some other disease, or may be a technical complication that is incidental or may obscure a real lesion.

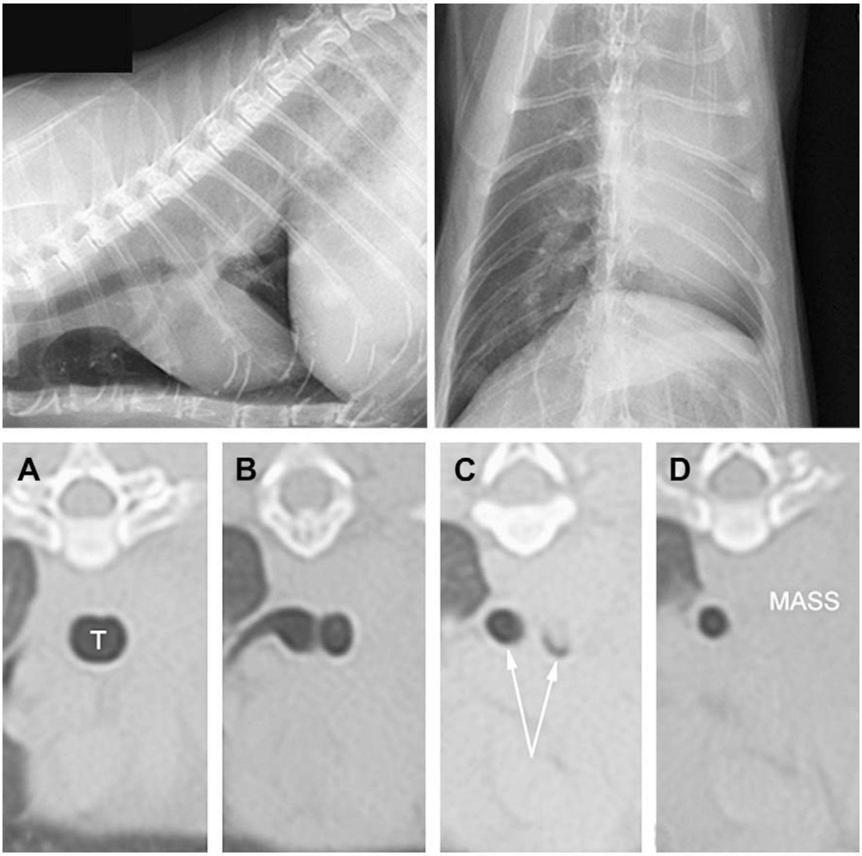

Fig. 3. Orthogonal thoracic radiographs (*top row*) and sequential thoracic CT scans (*bottom row*) of an 11-year-old, neutered, male, domestic longhair cat with left-lung atelectasis due to tumor. The left lung is severely small, causing a mediastinal shift of the heart to the left; the remaining lung is hyperinflated. In this case, atelectasis is due to a mass growing into the left-principal bronchus. On the CT scans, note the two principal bronchi (*arrows*) that are caudal to the tracheal (T) bifurcation. The lung mass extends into and completely obscures the lumen of the left bronchus (the right bronchus remains air filled). The four CT scans are obtained in sequential order from cranial to caudal (*A–D*).

respiration because of reduced compliance due to such things as chronic idiopathic fibrosis, chronic immune-mediated lung disease, chronic pneumonia, and radiation pneumonitis.[22]

It may not be possible to differentiate between the different types of atelectasis simply by observing certain radiographic signs. The cause of atelectasis, however, may be prioritized by noting if the atelectasis is distributed regionally or diffusely. A regional lesion might suggest a local problem such as a foreign body, radiation pneumonitis, or recumbency.[19] A diffuse distribution might suggest diseases that produce cicatrizing atelectasis or incomplete inhalation.[19] Further characterization of atelectasis is probably possible only when the underlying pathogenesis can be determined.

Whereas an incompletely expanded lung lobe may or may not be due to disease, a fully expanded lung that has altered opacity is abnormal and indicates pulmonary disease. If enlarged, the lung lobe may have a convex surface, a rounded contour,

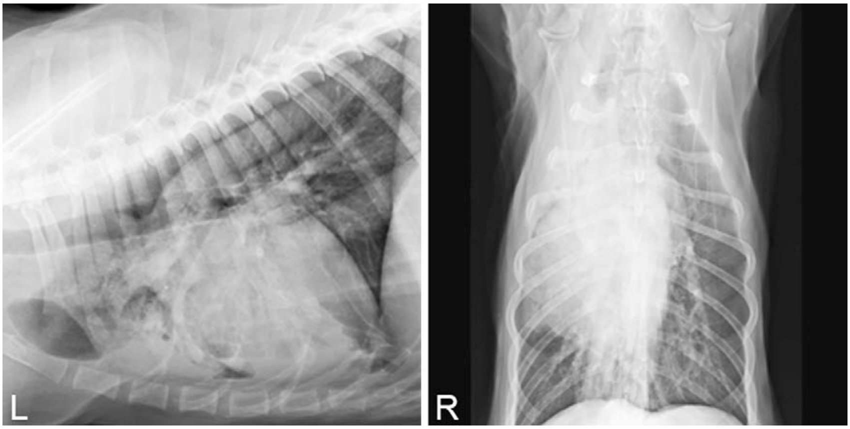

Fig. 4. Orthogonal thoracic radiographs of an 11-year-old, FS, Akita with vomiting, fever, and difficulty breathing attributed to pneumonia. Note that the right-cranial and right-middle lung lobes have an increased opacity that completely obscures pulmonary blood vessels and creates air bronchograms. Additionally, these lung lobes are not fully inflated, as the heart is shifted to the right, and the left-cranial lung lobe is hyperinflated, crossing midline more than normal. In this case, the atelectasis is attributed to aspiration pneumonia.

or displace structures away from it. A fully expanded lung that has a homogeneous increased opacity that obscures the margins of pulmonary blood vessels and airway walls is called *consolidation*: air bronchograms may or may not be present (**Fig. 5**).[20] Consolidation is not an end-point diagnosis but rather refers to a condition where an exudate or other product of disease replaces alveolar air, rendering the lung solid.[20] A fully expanded lung that has a hazy increased opacity that only partially obscures the margins of pulmonary blood vessels and airway walls is called *ground-glass opacity*.[20] This finding is caused by partial filling of air spaces, interstitial thickening (due to fluid,

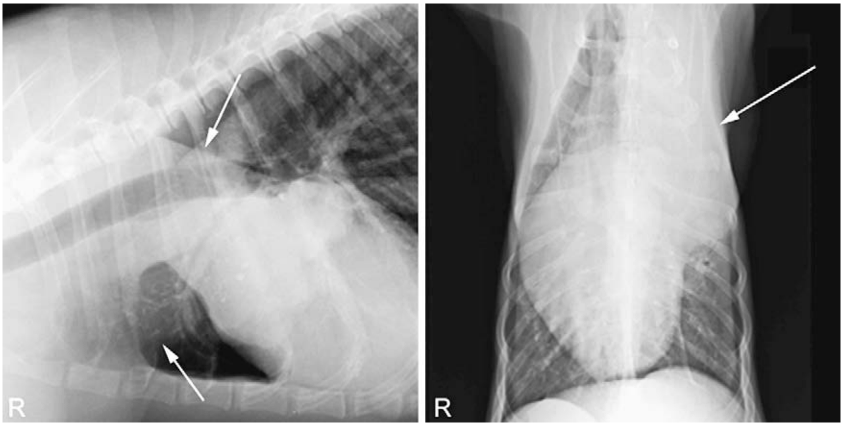

Fig. 5. Orthogonal thoracic radiographs of a 10-year-old, neutered female greyhound with a consolidated cranial part of the left-cranial lung lobe (*arrows*). Note that the abnormal lung lobe is fully expanded and enlarged, displacing the heart away from the abnormal lung lobe (to the *right*).

cells, or fibrosis), increased capillary blood volume, or a combination of these, the common factor being displacement of air.[20] The differential diagnosis for increased opacity in a fully expanded lung includes such diseases as pneumonia, neoplasia, hemorrhage, pulmonary edema, and immune-mediated diseases (**Fig. 6**).

A fully expanded lung that has a decreased opacity (**Fig. 7**) may be due to retention of air in the lung downstream to the obstruction (ie, *air trapping*), reduced pulmonary blood volume (ie, *oligemia* or *hypoperfusion*), or permanently enlarged air spaces downstream to the terminal bronchiole with destruction of the alveolar walls (ie, *emphysema*).[20] Compensatory hyperinflation following collapse or removal of a lung lobe may also appear in this manner.

MACROSCOPIC DISTRIBUTION OF LUNG LESION

The next radiographic sign to incorporate for defining a pattern of lung disease is the macroscopic distribution of the lesion. We emphasize this sign as important, because it is extremely helpful for generating a prioritized differential diagnosis list, easier to teach and learn, and correlates well with gross pathology. Additionally, in people, several lung diseases have been classified using histologic criteria, but the macroscopic distribution of the lesion during computed tomography (CT) is distinct and linked to a specific clinical syndrome.[23] We currently use the following descriptions of macroscopic distribution of lung lesions: cranioventral, caudodorsal, diffuse, lobar, focal, locally extensive, multifocal, and asymmetric. With increasing use of CT, other distributions may be important (eg, central versus peripheral within a lung lobe).

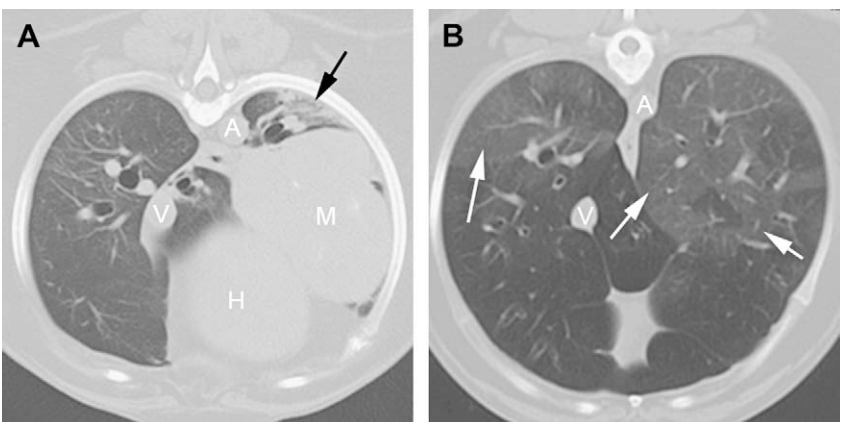

Fig. 6. Thoracic CT Scans of a 14-year-old, neutered female Cocker spaniel (*A*) and a 3-year-old, neutered female West Highland terrier (*B*). In A, note the atelectasis in the left-caudal lung lobe (*black arrow*)—this lung lobe is incompletely inflated and has an increased opacity that partially to completely obscures pulmonary blood vessels. Immediately ventral to this lung lobe there is a lung mass (M). In this situation, the abnormal lung is consolidated, because it is fully inflated, and the increased opacity completely obscures the bronchovascular margins. When atelectasis and consolidation occur concurrently within the lungs, it may be problematic, especially during radiography, to differentiate the conditions. In B, the left- and right-caudal lung lobes have ground-glass opacity, (*arrows*) because the lungs are fully inflated, and bronchovascular margins are only partially obscured. The aorta (A) and caudal vena cava (V) are identified.

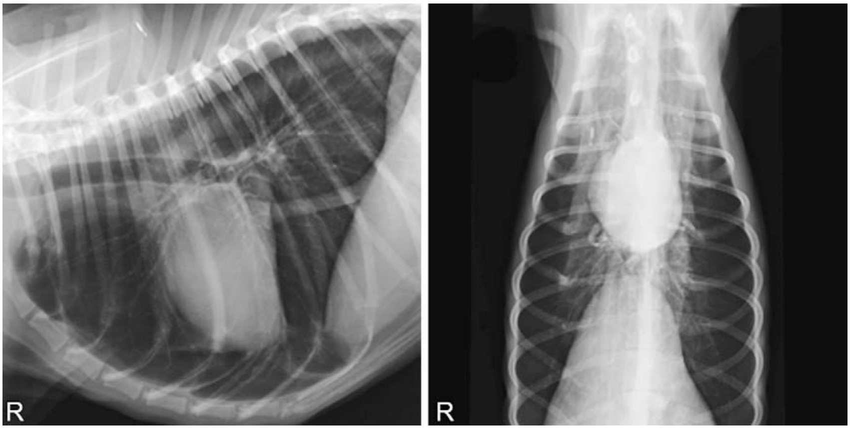

Fig. 7. Orthogonal thoracic radiographs of a 5-year-old, FS, standard poodle with hypovolemia. Note that the lungs are fully expanded and reduced in opacity due to small pulmonary blood vessels.

The cranioventral distribution generally conforms to the region of the left-cranial, right-cranial, and right-middle lung lobes (**Fig. 8**). Not all parts of this region need to be affected to determine that a cranioventral distribution is present. This designation tends to imply that gravity has an effect on the distribution of the lesion, although that is not necessary. If the disease is severe, then a lesion may extend into the ventral part of caudal lung lobes. It is important to note that on the lateral view, the cranioventral lung field actually extends into the caudoventral portion of the thorax and is superimposed on the heart. The caudodorsal distribution generally conforms to the region of the left-caudal, right-caudal, and accessory lung lobes. When severe, this distribution tends toward being diffuse. A *diffuse* distribution implies that all parts of all lung lobes are abnormal (**Fig. 9**). These distributions tend to imply that the lesion is distributed by a hematogenous route or by the airways. On the ventrodorsal view, the cranioventral

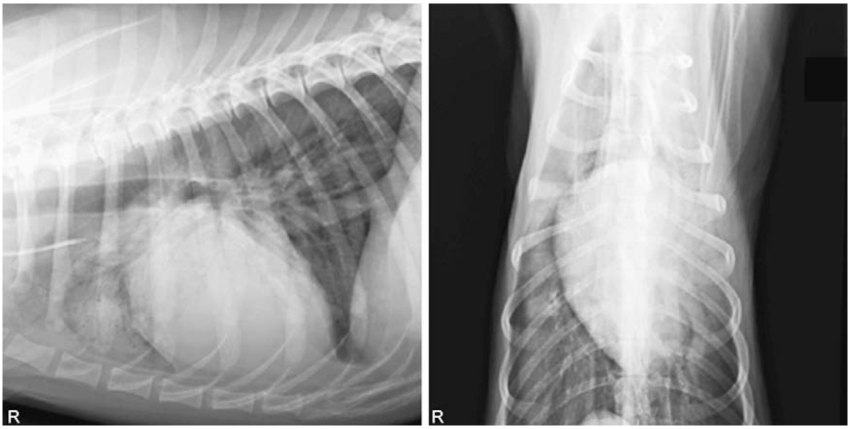

Fig. 8. Orthogonal thoracic radiographs of an 8-year-old, intact, male poodle with pneumonia. Note the cranioventral distribution of the increased opacity, which is worse on the left.

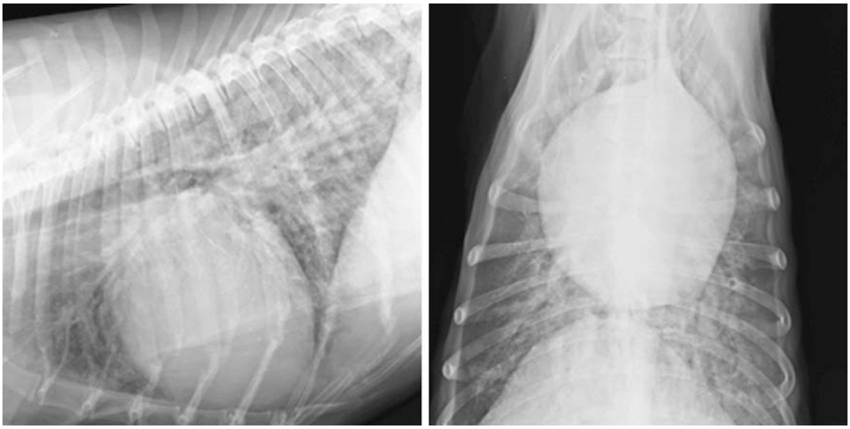

Fig. 9. Orthogonal thoracic radiographs of a 9-year-old, neutered, male, mixed-breed dog with left-sided, congestive heart failure. Note that the increased opacity is distributed in all parts of the lungs but worse caudodorsally (caudodorsal-to-diffuse).

and caudodorsal lung fields overlap at the level of the heart, and it may not be possible to differentiate where the lesion is located without the orthogonal view.

If the lesion is discretely localized to an entire lung lobe, then the term *lobar* may be used (see **Fig. 5**). The term *focal* is used to describe a single lesion that is usually is well defined and discrete and tends to imply diseases like a neoplasm, abscess, granuloma, cyst, hematoma, cavity, bleb, or bulla. If the focus is more of a poorly defined patch, then the term *locally extensive* may be used. The margins may be poorly defined if the adjacent lung is collapsed or if the lesion is more infiltrative. The term *multifocal* is used when there is more than one lesion in one, multiple, or all lung lobes (**Fig. 10**). If all lung lobes are involved, the term multifocal is used when there is some normal lung between lesions (ie, the distribution is not diffuse). These lesions are usually discrete but, alternatively, may be poorly defined patches that have a random distribution.

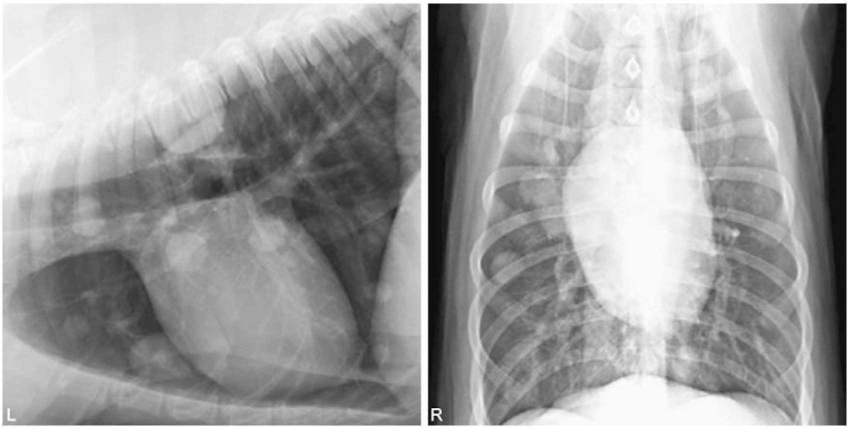

Fig. 10. Orthogonal thoracic radiographs of a 6-year-old, neutered, male Bernese mountain dog with pulmonary metastasis of a prostatic transitional cell carcinoma. In the lungs, there are multiple, well-defined, soft-tissue nodules with a multifocal distribution.

The term *asymmetric* is used to describe lesion distributions that do not conform to one of the other categories (**Fig. 11**). With this designation, there may be one or more lesions that are usually patchy, locally extensive, and poorly defined (but not necessarily); often there is left-right asymmetry. This distribution tends to imply diseases that may occur at random locations within the lungs (eg, cancer, trauma, inflammatory).

APPEARANCES OF INCREASED OPACITY WITHIN THE LUNG

The traditional lung patterns applied to disseminated pulmonary diseases initially were believed to signify in part the microscopic distribution of lesions within the alveoli, interstitium, or bronchi.[1] This idea of describing diffuse pulmonary disease based on histologic classifications, however, is no longer considered reliable or accurate in human medicine, which is one of the reasons we prefer using more wide-ranging terminology.[24–25]

The *interstitium* consists of a continuum of connective tissue throughout the lung, comprising three subdivisions: (1) the bronchovascular interstitium, surrounding and supporting the bronchi, arteries, and veins from the hilum to the level of the respiratory bronchiole; (2) the parenchymal interstitium, situated between alveolar and capillary basement membranes; and (3) the subpleural connective tissue.[20] In people, but not in dogs and cats, the interstitium distinctly also extends into interlobular septa, which may create distinctive lines when abnormal. Since the alveoli and parenchymal interstitium are superimposed on each other in the radiograph, increased thickness of the interstitium, partial filling of the alveoli with fluid or cells, or partial collapse of the alveoli will result in the same amount of attenuation of the x-ray beam. Therefore, simply detecting an increased opacity in the lung does not correlate to a specific microscopic anatomic location. Therefore, more generic terms such as ground-glass opacity and consolidation are preferable, because they do not specify a microscopic anatomic location. Furthermore, many diseases affect multiple microscopic distributions at the same time.

Likewise, the airway wall and bronchovascular interstitium attenuate the x-ray beam as a unit that forms a silhouette on the radiograph; therefore, if the unit is thick, one

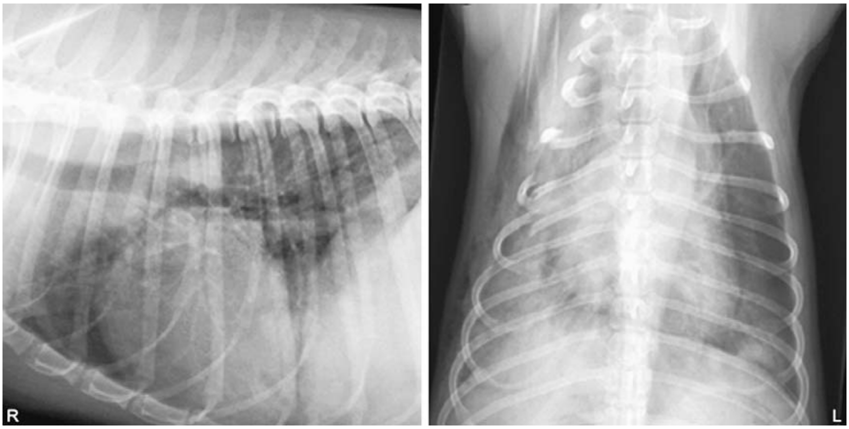

Fig. 11. Orthogonal thoracic radiographs of a 2.5-year-old, neutered, female Jack Russell terrier with pulmonary contusions (hemorrhage) and rib fractures. The distribution of the lung lesions does not conform to any of the described distributions, as it is located in the entire right lung (both cranially and caudally) and focally in the left-caudal-lung lobe.

cannot differentiate a thick airway from thick bronchovascular interstitium. Therefore, the term *bronchocentric* is preferred, as it applies to diseases that are conspicuously centered on macroscopic bronchovascular bundles but does not differentiate between microscopic structures (**Fig. 12**). Previously, we used the term "airway" to describe this radiographic appearance.[18] An increased opacity within the lungs that has a bronchocentric location may be differentiated from increased opacity within the air space, because they have a different appearance. The *air space* is the gas-containing part of the lung, including the respiratory bronchioles but excluding purely conducting airways such as terminal bronchioles. (Bronchioles are non–cartilage-containing airways.)[20] This term is used in conjunction with consolidation, ground-glass opacity, nodules, and masses. Note that there are strong similarities between the radiographic appearances of alveolar, interstitial, and bronchial patterns and consolidation, ground-glass, and bronchocentric opacities. The difference in terminology, however, better suits current understanding of the pathogenesis of these radiographic appearances.

Focal, approximately spherical, discrete lesions may be further characterized by their opacity and size. A *bleb* is a small gas-containing space that is not larger than 1 cm in diameter and located within the visceral pleura or in the subpleural lung.[20] A *bulla* is an air space that is more than 1 cm in diameter, sharply demarcated by a thin wall.[20] A *cavity* is a gas-containing space of unspecified size within pulmonary consolidation, a mass, or a nodule that is usually produced by expulsion or drainage of a necrotic part of the lesion via the bronchial tree (**Fig. 13**).[20] A *nodule* is a rounded, soft-tissue opacity, well or poorly defined, that is up to 3 cm in diameter.[18,20] A tiny nodule (not larger than 3 mm) may be described as a micronodule (or miliary when profuse).[20] A *mass* is any lesion that is larger than 3 cm in diameter without regard to contour, border, or density characteristics.[18,20] Note that these size recommendations are made for humans, and clinical judgment should be exercised when applying these criteria to dogs and cats that have variable body sizes. Nevertheless, it is useful to know that the differentiation between these descriptions is often based on differences in size and opacity.

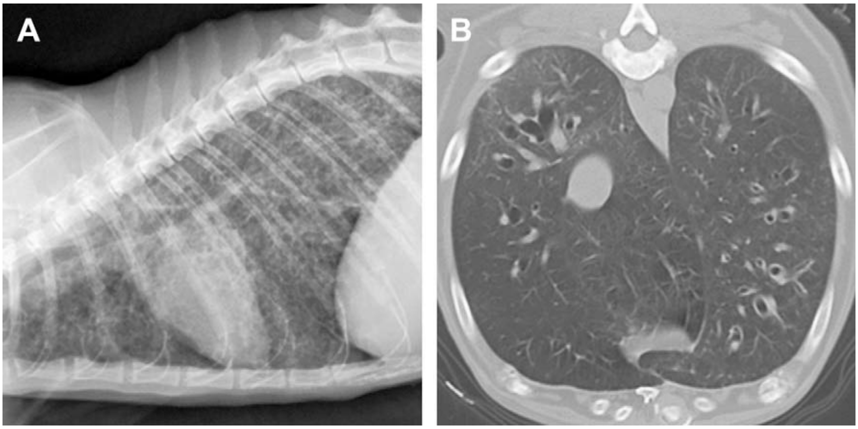

Fig. 12. Lateral thoracic radiographs of a 15-year-old, neutered, female, domestic shorthair cat (*A*) and thoracic CT scan of a 12-year-old, neutered female, Labrador retriever (*B*). In both cases, note the bronchocentric distribution of the increased opacity that forms an excessive number of enlarged lines and rings, especially near the periphery of the lungs.

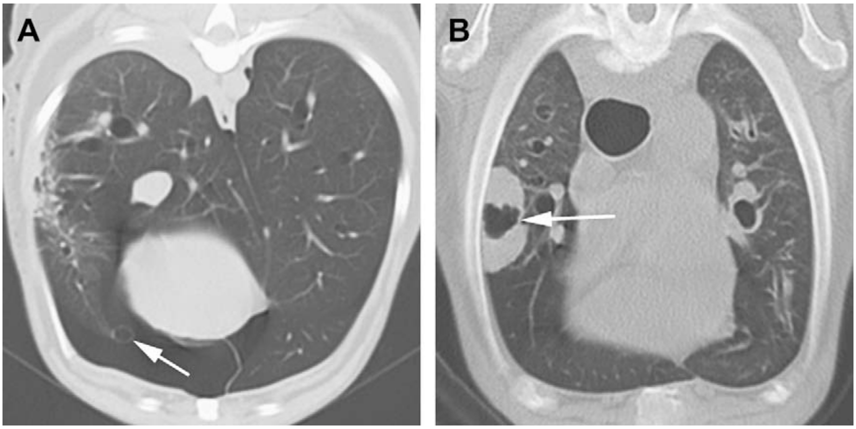

Fig. 13. Thoracic CT scans of a 7-year-old, neutered male poodle (*A*) with pneumothorax and a bleb (*arrow*) and of a 12-year-old, neutered female, Labrador retriever (*B*) with a cavity (*arrow*) in a soft-tissue mass (additional images of this dog are in **Fig. 11**).

CLINICAL INTEGRATION

The above Roentgen signs of altered opacity, degree of expansion, macroscopic distribution of the lesion, and appearance of the opacity may be combined to form radiographic patterns of lung disease. Some examples of radiographic patterns of lung disease are listed.

- Cranioventral air space pattern
- Consolidated lung lobe
- Caudodorsal-to-diffuse air space pattern
- Diffuse bronchocentric pattern
- Focal lung nodule (soft tissue)
- Multifocal lung nodules (soft tissue)

Fig. 14. Orthogonal thoracic radiographs of a 12-year-old, neutered, female German shepherd dog. Note the mixed-lung pattern, which is composed of an increased opacity that is diffuse bronchocentric and multifocal nodular (soft-tissue).

- Focal bleb or bulla
- Multifocal blebs or bullae
- Focal lung cavity
- Multifocal lung cavities
- Diffuse hyperlucent lung pattern
- Atelectasis (regional)
- Atelectasis (diffuse)
- Asymmetric air space pattern
- Mixed lung pattern

Suggested differential diagnoses for some of these patterns are available.[17,18] For example, the differential diagnosis for a cranioventral air space pattern includes aspiration or bronchopneumonia, hemorrhage, or cancer. The differential diagnosis for a caudodorsal-to-diffuse air space pattern includes such things as congestive left heart failure, toxin inhalation, some viral or parasitic infections, strangulation, near drowning, fibrosis, thermal injury, septicemia and endotoxemia, disseminated intravascular coagulation, and some cancers (eg, lymphoma). The differential diagnosis for a diffuse bronchocentric pattern includes all causes of bronchitis (eg, allergic, immune-mediated, infectious, viral, bacterial, parasitic), lymphatic spread of cancer, or early left-sided congestive heart failure. Differential diagnoses may be prioritized by incorporating other information such as signalment, history, and results of other tests.

Oftentimes, lung disease does not produce a radiographic pattern that can be neatly categorized, because there is a mixture of findings. Identifying a mixed pattern, however, is not helpful unless the different components are equally important. Most often, it is simply most efficacious to identify only the most important pattern, because that is what will help better define the cause of the problem. When multiple findings are equally important and it is appropriate to conclude a mixed pattern, then the disease may be due to one or multiple causes, and differential diagnoses for all patterns should be considered (**Fig. 14**).

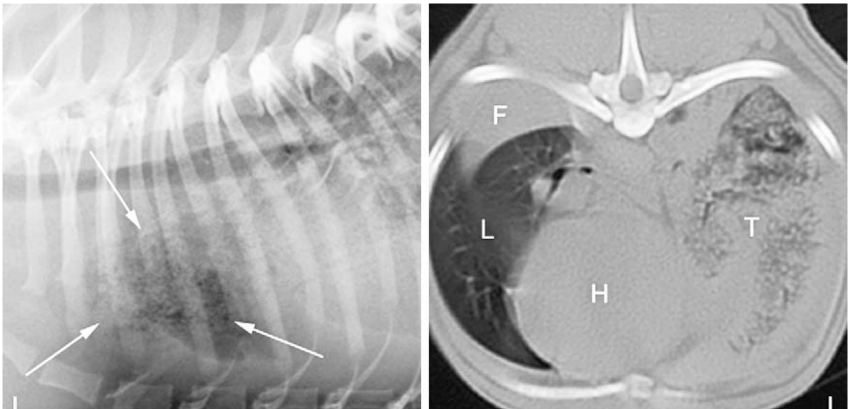

Fig. 15. A lateral thoracic radiograph and CT scan of a 3-year-old, neutered male Pug with a left-cranial-lung-lobe torsion. Note that the left-cranial lung lobe is fully expanded with locally extensive increased opacity that contains innumerable, small, gas bubbles (*arrows*, T). This combination of signs is consistent with lung-lobe torsion with lung necrosis. The heart (H), lung (L) and pleural fluid (F) also are indicated.

SUMMARY

It is important to acknowledge that the description in this article is incomplete. For example, the term *bronchiectasis*, which is irreversible, localized, or diffuse bronchial enlargement usually resulting from chronic infection, upstream airway obstruction, or congenital bronchial abnormality, was not mentioned.[20] Also, diseases that produce mineralization were not discussed. Therefore, the previous description should be considered as a starting point that may be useful for diagnosing commonly encountered pulmonary diseases. There are other signs (eg, bronchial foreign body) or patterns of lung disease that were not described and necessary to make other diagnoses. For example, a pattern of a fully expanded lung lobe with increased opacity that obscures pulmonary blood vessels and contains multiple gas bubbles may be observed in some dogs and cats with lung-lobe torsion; signs of pleural fluid may also be present (**Fig. 15**).[18,26]

Pulmonary radiography is a complex process that is most effective when it combines clinical experience with scientific knowledge and is able to change with newly gathered information. Additionally, there is a need for radiologists to seek evidence that the proposed methods (whether traditional or non-traditional) actually improve patient care.

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