Vet Clin Small Anim 37 (2007) 861–878
VETERINARY CLINICS
SMALL ANIMAL PRACTICE

Approach to the Respiratory Patient

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Several challenges arise when evaluating a dog or cat with respiratory disease. Most of the respiratory tract is encompassed within bony structures, making palpation and visual assessment difficult. The respiratory system also has a high degree of ventilatory reserve and some regenerative capability as well [1,2]. This can make respiratory diseases difficult to appreciate clinically until the disease is fairly severe. Additionally, diseases primarily affecting other organs can result in respiratory embarrassment even if the respiratory system is healthy. The history of patients with respiratory disease can be ambiguous, because some owners can have a difficult time in recognizing or describing respiratory abnormalities [3]. These are all challenges that a clinician faces when evaluating a patient with respiratory disease. There are some noninvasive diagnostics that aid in the diagnosis of respiratory disease; however, other more invasive tests can require anesthesia, which represents a potential hazard with a respiratory patient. This article focuses on reviewing the function of the respiratory system and how best to identify and diagnose cats and dogs with respiratory disease by implementing a thorough history and physical examination as well as appropriate diagnostic testing.

FUNCTIONAL ANATOMY OF THE RESPIRATORY TRACT

The anatomy of the respiratory tract is composed of a series of air passages with the primary goal of oxygen (O_2) delivery and carbon dioxide (CO_2) exchange at the level of the pulmonary capillaries. The respiratory tract begins at the nasal cavity, where the main functions are to humidify, filter, and warm inspired air. Particles greater than 20 μm are filtered within the nasal turbinates [4]. The lateral nasal glands also can aid in heat dissipation and thermoregulation in the dog [5,6]. The nasal cavity ends and the pharynx begins at the level of the choana, and it extends just rostral to the larynx at the intrapharyngeal ostium. The pharynx represents a defined area rather than an organized structure with obvious boundaries. It is considered part of the respiratory system as well as part of the gastrointestinal system. The overlapping function of the pharynx demonstrates why aspiration pneumonia is a relatively common occurrence [7].

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0195-5616/07/$ – see front matter
doi:10.1016/j.cvsm.2007.05.014

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The larynx is a complex musculocartilaginous structure that provides the primary protection for the trachea and lower airways from aspiration of food, water, secretions, or other debris. The rostral boundaries of the larynx are defined by the arytenoid cartilages and vocal folds (dorsal and lateral) and the epiglottis (ventral). The caudal boundaries are defined by the thyroid and cricoid cartilages. The area between the paired arytenoid cartilages is termed the *rima glottis*. The rima glottis is protected by folding over of the epiglottis and by adduction of the arytenoid cartilages during swallowing [7,8]. The larynx also functions in vocalization of cats and dogs. These respiratory structures (nasal cavity, pharynx, and larynx) are termed the *upper airways* [9].

The larynx is connected to the trachea, a noncollapsible, cartilaginous, tube-like structure that extends to the lungs. The lower airways begin at the level of the trachea [9]. The trachea is a series of C-shaped rigid cartilage rings. The dorsal aspect of these rings is bridged by the transversely oriented trachealis muscle. These rings are connected to each other by longitudinally oriented annular ligaments. The trachea serves mainly to conduct air to the lower airways by means of a low-resistance system [7]. The mucociliary tree of the tracheal epithelium consists of microscopic cilia that beat in the orad direction to aid in removing secretions and debris from the lower airways. The sensory nerves lining the tracheal and laryngeal epithelium aid in eliciting the cough reflex. None of the structures discussed here directly participate in gas exchange, with their primary roles including filtering and warming of air and protection of the more distal airways [10].

The trachea ends at the carina, where it branches into the right and left mainstem bronchi. These bronchi then branch into lobar bronchi. On the left side of the thorax, the lobar bronchi include the left cranial lung lobe (cranial and caudal aspects) and the left caudal lung lobe. On the right side, the principal bronchus gives rise to the right cranial lung lobe, the right middle lung lobe, the accessory lung lobe, and the right caudal lung lobe. Each lobar bronchus branches into segmental bronchi, which then undergo dichotomous branching to form the smaller bronchioles. Bronchioles give rise to alveolar ducts, alveolar sacs, and alveoli [7,10]. Gas exchange occurs at the level of the respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli [11].

O_2 and CO_2 are exchanged by means of passive diffusion generated by a pressure gradient. Gases must pass through the respiratory barrier composed of the alveolar epithelium, alveolar interstitium, and capillary endothelium. Conditions that lead to hypoxemia include (1) low inspired oxygen fraction (FIO_2), (2) hypoventilation, (3) thickening of the respiratory barrier, (4) shunting of pulmonary blood, and (5) physiologic dead space [12,13]. Shunting of pulmonary blood and physiologic dead space can be described as ventilation-perfusion inequality. Shunting of pulmonary blood occurs when there is not enough ventilation to oxygenate fully the blood flowing through the alveolar capillaries (ie, atelectatic lung, alveolar edema). Physiologic dead space occurs when ventilation of alveoli is normal but the alveolar blood flow is low, causing insufficient oxygenation of the alveolar blood (ie, pulmonary thromboembolus

[PTE], congenital cardiac shunts). A two- to threefold increase in the thickness of the respiratory barrier impairs O_2 diffusion [11]. This can occur with edema within the alveolar interstitium or fibrosis of the interstitium, although clinical signs are not apparent until disease is severe.

Most of the O_2 in blood is carried bound to hemoglobin, and only 3% of the O_2 is in the dissolved state. CO_2 is carried by several different chemical forms, including, HCO_3 (70%), CO_2 (7%), and CO_2 bound to hemoglobin (23%). Through diffusion of CO_2 out of the respiratory tract, the lungs also play an important role in acid-base regulation [11,13]. An in-depth discussion of acid-base regulation is beyond the scope of this article, and the reader is referred to a multitude of excellent sources for a detailed discussion of acid-base respiratory physiology [11,14].

HISTORICAL FINDINGS

It is imperative that animals in respiratory distress be stabilized before time is taken to obtain a thorough history. Stabilization may include O_2 therapy, appropriate medications (ie, sedatives, bronchodilators, glucocorticoids, diuretics), and then a brief history. Once the patient is stabilized, a thorough history is crucial, because some respiratory patients can have a medical history that spans months to years. Other body systems can have marked effects on the respiratory system; thus, the history should also include questions regarding the patient's overall health. Most patients with respiratory disease present with a primary complaint of sneezing, nasal discharge, reverse sneezing, coughing, epistaxis, labored breathing, or exercise intolerance. Other less common complaints include syncope, regurgitation, dysphagia, dysphonia, collapse, or cachexia [3,15]. Because many fungal and parasitic diseases initially infect the respiratory system, a travel history is particularly relevant. Certain questions targeted at the respiratory system can help to narrow the list of differential diagnoses.

If labored breathing is a primary complaint, the owners should be asked to expand on this description. Some owners perceive panting or reverse sneezing as a form of labored breathing, and this can be misleading to the clinician. The clinician should discuss with the owner whether the patient's chest wall is actually moving more than normal and if the patient is tiring more than usual. A healthy cat or dog with normal respiratory effort has minimal movement of the chest wall during respiration at rest [16]. It is also important to determine when the labored breathing is noticed. Patients that experience more labored breathing with heat or excitement classically have diseases affecting the upper airways (eg, brachycephalic syndrome, laryngeal paralysis).

Many owner complaints focus on noisy breathing or a change in the bark or meow (dysphonia). The owner should describe the type of abnormal sound appreciated. A high-pitched raspy noise helps to describe stridor, whereas a gurgly low-pitched sound can describe snoring (stertor). Changes in voice suggest diseases of the upper airways, particularly laryngeal and pharyngeal diseases [3,7].

Some owners may complain of concurrent vomiting or regurgitation. The clinician should inquire whether the animal is coughing and then regurgitating (posttussive wretch) or whether it is truly vomiting. Some brachycephalic dogs may have a history of regurgitation or vomiting because of chronic respiratory disease [17,18]. The owner should also be asked to describe the nature, frequency, and circumstances of occurrence of a cough, if present. Laryngeal and tracheal diseases tend to cause a dry nonproductive cough, whereas airway or parenchymal diseases can produce a wet cough with a significant amount of secretions [3,7].

Because the respiratory system has a high ventilatory reserve, respiratory diseases may exist for much longer than is apparent to the owner or veterinarian. Some owners consider their pet's behavior as normal because it has been going on for so long. A bulldog that snores at night or a Yorkshire Terrier that coughs when excited, for example, may be interpreted as normal by the owner. Taking the time to ask specific questions about the respiratory history of the dog or cat can aid the clinician in determining the most likely disease responsible for clinical signs.

PHYSICAL EXAMINATION

The physical examination is extremely important in assessing respiratory health. Much can be learned simply by watching the animal breathe; certain abnormal breathing patterns can often aid in locating the anatomic position and nature of the disease. Even before approaching the animal, an attempt should be made to observe the animal while talking to the owner. This allows the clinician to appreciate any abnormalities that the owner is describing [7,19]. A dog or cat breathing at rest shows minimal movement of the chest wall. When the breathing becomes more labored, the ribs are pulled caudally and laterally by the diaphragm and chest wall muscles and the abdomen moves slightly outward. Labored breathing may be accompanied by recruitment of additional accessory chest wall muscles as well as nasal and pharyngeal dilator muscles. Flaring of the nostrils or contraction of the abdominal muscles indicates severe labored breathing [16].

Certain breathing patterns can be associated with disease at a specific location in the respiratory tract. Short shallow respirations with small tidal volumes are suggestive of stiff noncompliant lungs or restricted expansion of the lungs from pleural or thoracic wall diseases. Prolonged deep inspirations tend to be associated with laryngeal, pharyngeal, or cervical tracheal diseases, whereas prolonged inspiration and expiration are more compatible with a fixed obstruction. Because of the dynamic nature of respiration, narrowing of small airways has a much more profound effect on expiration than inspiration. Clinically, this appears as an expiratory or abdominal push. Some dogs may have hypertrophy of the abdominal muscles secondary to long-standing small airway disease. By watching and gaining experience in how the animal breathes, a clinician can already have narrowed the list of differential diagnoses before any diagnostics are performed. Orthopnea is defined as difficulty in

breathing, except in an erect sitting or standing position. This is usually present in animals with severe respiratory distress [7,16].

Once observations have been made regarding the patient's respiratory rate, effort, pattern, and posture, the clinician should perform a complete physical examination of the entire respiratory system. Initially, the mucous membranes should be checked for any indication of cyanosis or pallor, which would indicate the need for immediate O_2 supplementation. Cyanosis becomes clinically apparent when the deoxygenated hemoglobin concentration reaches 5 g/dL and indicates that the patient is in true respiratory distress [20]. Both nares should be checked for air flow. This can be accomplished in several different manners. Suggestions include listening for air flow through the nares with a stethoscope, placing a frozen glass slide in front of the nares and watching for condensation, or placing the examiner's ear next to the animal's nares to listen for normal air flow. Facial symmetry should be noted as well. The patient's mouth should be opened to evaluate for any hard or soft palate abnormalities as well as to evaluate the upper dental arcade for evidence of oronasal fistulas or tooth abscessation. Some patients may allow the clinician to get a brief look at the larynx, but this should not be considered a sufficient evaluation of the laryngeal and pharyngeal area. Note any excessive reverse sneezing, which could indicate inflammation or irritation to the nasopharynx [7,21,22].

The cervical trachea should be digitally palpated. Abnormalities that might be encountered include an easily compressible trachea, a hypoplastic trachea, or a cervical mass that may be compressing the trachea. Tracheal sensitivity can be evaluated by applying mild to moderate digital compression of the cervical trachea. When a cough is easily elicited (increased tracheal sensitivity), generalized airway inflammation or irritation should be presumed. If a cough is elicited with tracheal palpation, the clinician should note whether the cough is dry or wet in nature, because most parenchymal diseases produce secretions and a wet cough [3,7].

Physical examination of the pulmonary parenchyma is more limited than that of other areas of the respiratory tract, given that it is completely encompassed within the thoracic cavity. The thoracic cavity should be palpated for any defects or masses that could be affecting the respiratory system. The clinician's only tools to evaluate the lower airways on the physical examination are by observing the rate, pattern, and nature of the animal's breathing as well as lung auscultation. Lung auscultation was first introduced by Laennec in 1819 as a way of describing the explosive and musical sounds heard within the lungs when listening with a stethoscope. Until the 1950s, lung sound terminology was confusing and unclear. It included such terms as rales (moist, mucous, sonorous, sibilant, and crackling), rhonchi (dry and wet), and wheezes to describe adventitious lung sounds. These definitions became more unclear with time, which led to the proposal by Robertson and Coope in 1957 to divide adventitious lung sounds into two new and simple groups. These two new groups include continuous sounds (wheezes) and intermittent sounds

(crackles). Wheezes are defined as musical sounds that are primarily classified according to pitch (high and low) and timing (inspiratory and expiratory) [23]. Wheezes are thought to be generated primarily by airway narrowing, stenosis, or obstruction. Crackles are defined as short, explosive, nonmusical sounds and are primarily defined by pitch (high and low) and timing (inspiratory and expiratory). Crackles are typically produced by a delayed opening of small airways attributable to an abnormal fluid-air interface (ie, pneumonia, pulmonary edema, bronchitis) (Table 1). Normal breath sounds in the dog and cat include soft low-pitched airway sounds that are generally only appreciated on inspiration. In some cats, it may be difficult to appreciate normal inspiratory breath sounds [3]. When these sounds become loud or prominent on expiration, the descriptive term used most frequently is increased breath sounds or increased bronchovesicular sounds. Sounds generated in the upper airways can often be auscultated within the lungs (referred airway sounds). These can be differentiated from true lung sounds by auscultating over the cervical trachea and larynx and determining where the sound is the loudest. The sound is generated from the spot where it is the loudest [7,19,22].

Stridor is used to describe upper airway noise. It is described as a harsh high-pitched respiratory sound and is often associated with laryngeal obstruction. Stertor is defined as snoring or sonorous breathing and is often associated with pharyngeal or nasopharyngeal disease. Because these are both sounds associated with the upper airways, they are often easy to detect during physical examination. Occasionally, these sounds can only be appreciated with auscultation over the larynx and cervical trachea [3,7,12,24]. Although auscultation is a useful tool, the sensitivity and specificity are largely understudied in veterinary medicine. One study demonstrated good correlation between abnormal adventitious sounds and thoracic trauma; however, other studies are lacking

Table 1
Classification of respiratory sounds in small animal veterinary medicine

Description	Definition
Breath sounds	These are the normal, faint, low-pitched sounds heard through the chest wall of a healthy patient These sounds are louder on inspiration and are sometimes barely perceptible in cats
Crackles	Short, explosive, nonmusical sounds primarily defined by pitch (high and low) and timing (inspiration versus expiration)
Wheezes	Musical sounds primarily described by pitch (high and low) and timing (inspiration versus expiration)
Stridor	Harsh high-pitched respiratory sound, often associated with laryngeal obstruction
Stertor	Act of snoring or sonorous breathing, often associated with pharyngeal or nasopharyngeal disease

Data from Corcoran B. Clinical evaluation of the patient with respiratory disease. In: Ettinger SJ, Feldman EC, editors. Textbook of veterinary internal medicine. 5th edition. Philadelphia: WB Saunders; 2000. p. 1035; and Forgacs P. Terminology. In: Lung sounds. London: Baillere Tindall; 1978. p. 1–6.

[25]. Even with normal lung sounds, diagnostics should be pursued if there is historical or physical evidence to suggest respiratory embarrassment.

DIAGNOSTIC TESTING

Many diagnostic aids are available to the clinician to help identify and describe the type of respiratory disease present. Some of these tests also help in quantifying the degree of respiratory disease present. It is imperative with respiratory patients that the potential hazard of any test be considered, because minor stress can lead to decompensation of these patients [12].

Hematology, Biochemistry, and Serology

Patients that have a respiratory disease often have hematology and biochemical profiles that are unremarkable or show nonspecific changes. The most important contribution of hematology and biochemistry profiles is to uncover any systemic or metabolic diseases that might be affecting the respiratory system (ie, acid-base imbalance, anemia). Some relatively common hematology findings associated with respiratory disease include polycythemia from chronic hypoxia, leukocytosis with respiratory infections, or eosinophilia with pulmonary infiltrates with eosinophils (PIE) or parasitic lung infections. Basophilia can also be suggestive of heartworm infection [3]. Eosinophilia can be seen in cats with bronchial disease; however, there is no absolute association with disease [26]. Cats with respiratory distress and eosinophilia should not be presumed to have feline asthma or bronchopulmonary disease. Whenever hemoptysis or unexplained respiratory distress is present, a coagulation profile should be performed to rule out warfarin toxicity [3,27]. Serology can be beneficial in the diagnosis of pulmonary mycotic diseases, particularly coccidioidomycosis or cryptococcosis. In cats, serology for feline leukemia virus (FeLV) and feline immunodeficiency virus (FIV) can aid in ruling out any underlying immune deficiency [3,28].

Radiography

Thoracic radiography is an invaluable tool for investigating respiratory disease. Even so, diagnostic information may be limited by poor radiographic technique, poor patient cooperation, and an inherently low diagnostic sensitivity and specificity. The reader is referred to several excellent veterinary resources that explain the details of thoracic radiographic technique [29,30]. Three views of the thorax are often recommended to maximize lesion detection and to minimize superimposition of thoracic structures. The importance of sedation or general anesthesia should be emphasized as a tool to aid in proper patient positioning. Patient rotation may cause normal thoracic structures to appear abnormal or may hide abnormalities within the thorax because of superimposition of other structures. Always keep in mind that thoracic radiology does have low specificity and that it is rare to form a definitive diagnosis from thoracic radiographs alone. Thoracic radiography, however, is useful in leading to a working list of potential differential diagnoses. Specific radiographic signs can suggest certain diseases and narrow the list of differential diagnoses [29].

The assessment of any radiograph should follow a set procedure and should be consistent for the reader. This ensures that subtle radiographic changes are not overlooked and prevents misdiagnosis caused by not reading the entire radiograph. Most clinicians find it beneficial to evaluate the structures outside the pulmonary parenchyma first to prevent inadvertently focusing only on the pulmonary system. All bony structures should be evaluated for abnormalities, including lysis, proliferation, osteoporosis, or fractures. The diaphragm and mediastinum should also be checked for anatomic abnormalities. The position and size of the cardiac silhouette, great vessels, and associated structures should be assessed, and the radiograph should be reviewed for sternal or hilar lymphadenopathy [29].

The trachea should then be evaluated for narrowing, compression, or deviations in the cervical and intrathoracic region. An undulating or deviating trachea can be a normal variant or a result of improper patient positioning. Elevation of the trachea at the level of the carina can indicate a mediastinal or cardiac mass [31]. Occasionally, static radiographs can detect changes in the luminal diameter of the mainstem bronchi.

Within the pulmonary parenchyma, pulmonary vessels can be visualized and the airways are seen between the paired artery and vein. Bronchial walls are not normally visible, except in the central area or if they are calcified (an age-related change). If the walls become thickened because of inflammation, end-on ring structures (doughnuts) or parallel line markings (tramlines or train tracks) can be visualized. These findings are thought to reflect pathologic change. An interstitial pattern can be described as linear densities that give a hazy appearance to the lung field and obscure visualization of the vasculature. This pattern can be difficult to discern and is highly sensitive to obesity or changes in radiographic technique. An alveolar pattern appears as a soft tissue density in the lung containing air bronchograms, airways outlined by infiltrated pulmonary parenchyma (Fig. 1). These appear as air-filled structures (often branching) against the soft tissue opacity of the lung. An alveolar pattern without the presence of air bronchograms can occur with pulmonary masses, atelectasis, lung lobe torsion, or pulmonary granuloma. The patterns described are generalizations, and several different patterns or a spectrum of the patterns can often be found on thoracic radiographs [29,32]. These patterns describe where the pathologic change is located (bronchioles, interstitium, or alveoli) but do not provide a definitive diagnosis.

CT/Thoracic Ultrasound/Fluoroscopy

Many of the previous uses for fluoroscopy in small animal medicine are presently being replaced by the use of CT and thoracic ultrasound. Fluoroscopy is still used in some specialty private practices and academic institutions to detect tracheal or airway collapse. The dynamic nature of fluoroscopy makes it much more sensitive and specific for tracheal collapse than thoracic radiographs. The extent of the trachea involved can be accurately assessed as well as the dynamic change in the tracheal diameter [29].

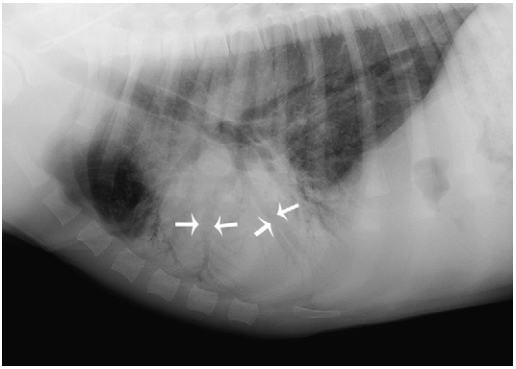

Fig. 1. Example of an alveolar pattern with branching air bronchograms (*arrows*). This lateral radiograph is from a young dog with severe bronchopneumonia. Air bronchograms represent air in the bronchial lumen surrounded by a relatively homogeneous increase in lung opacity.

Thoracic ultrasound has emerged as a relatively new tool in thoracic imaging. Thoracic ultrasound is best used if preceded by thoracic radiographs so as to define the location of the lesion. Structures within the lungs that are surrounded by aerated lung are not accessible with thoracic ultrasound. The modality is most useful when evaluating cardiac or mediastinal masses (the ventral portion of the mediastinum), consolidated or collapsed lung lobes, pleural effusion, or thoracic wall masses or when looking for diaphragmatic hernias. If the lesion can be visualized, a fine-needle aspirate or biopsy can be attempted with sedation or general anesthesia, depending on the ultrasonographer's comfort level with the appearance of the mass [29,33].

The introduction of thoracic CT in veterinary medicine has allowed subtle changes within the thoracic cavity to be more easily detected and described. This is attributable to CT's inherent superiority in contrast resolution as compared with radiography [34]. It is also used commonly for planning radiation therapy for nasal neoplasia. CT can also be valuable when thoracic radiographs are normal, although lung pathologic change is still suspected. CT angiography is being introduced in veterinary medicine to detect PTE [35]. In experimentally induced PTEs in dogs, the PTE was detected in 64% to 76% of the dogs, although detection depends highly on user experience. In human patients, CT angiography has replaced ventilation:perfusion ($\dot{V}/\dot{Q}$) scintigraphy as the diagnostic tool used with PTEs [29]. CT has also been used with variable results in dogs with spontaneous pneumothorax, in which the underlying lung lesion can be difficult to see at the time of exploratory thoracotomy [36]. For a more complete description of the role of CT in respiratory disease, see the article by Johnson elsewhere in this issue.

Rhinoscopy and Bronchoscopy

Endoscopy is the best tool to visualize the entirety of the respiratory tract. In addition to direct visualization, endoscopy (rhinoscopy and bronchoscopy)

allows for collection of tissue and fluid samples and removal of foreign bodies. Initially, the caudal nasal chamber and nasopharynx are visualized using a flexible fiberoptic endoscope or videoendoscope (5-mm bronchoscope or 7.9-mm gastroscope is most common) (Fig. 2). A multipurpose, rigid, 2.7-mm telescope is most useful when evaluating the rostral nares. This allows visualization of the dorsal, middle, and ventral meatuses and assessment of turbinate quantity and health [37–39]. When significant turbinate destruction is present, the frontal sinuses may also be visualized. Biopsies are most easily obtained when visualization is achieved with the rigid scope. Rhinoscopy and nasal biopsy can cause significant epistaxis, and the patient should be monitored for several hours at least before leaving the hospital.

Bronchoscopy in small animal patients is performed in sternal recumbency to minimize lung atelectasis and subsequent hypoxia. Bronchoscopy is most commonly performed with a 5.0-mm flexible fiberoptic bronchoscope or videoendoscope, although a 2.5-mm scope may be preferable in cats to limit obstruction of exhaled air. Bronchoscopy should begin by first evaluating the larynx (see section on laryngoscopy). The scope is then passed into the proximal trachea, with the endoscopist making sure not to contaminate the scope with the oral bacterial flora. The normal tracheobronchial mucosa has a light pink color, and mucosal vessels are readily visible (Fig. 3). Edema causes blanching of the mucosa and obscure visualization of the vessels. The trachea should be evaluated for the presence of mucus, hyperemia, or dynamic collapse. In some cases of chronic airway inflammation, nodules can be seen along the more distal tracheal and bronchial mucosa, indicating the chronicity of disease. Beyond the level of the carina, the endoscopist should be aware of the appropriate orientation of all lobar bronchi to determine the precise location within the bronchial tree. Airway anatomic nomenclature has been well described for the dog and aids in describing the location of specific lesions [40]. This aids in describing the location of any abnormalities found during bronchoscopy.

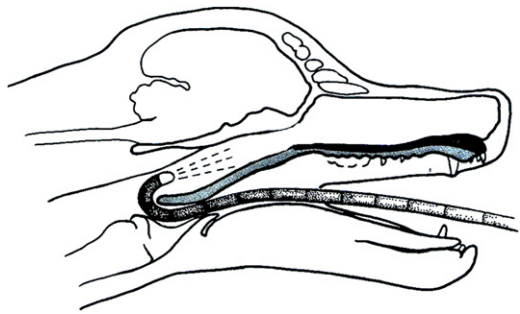

Fig. 2. Schematic representation of retrograde rhinoscopy using a flexible fiberoptic endoscope to examine the nasopharynx of a dog. (*Adapted from* Pook HA, Meric SM. Caudal nasal cyst in a dog: retrograde rhinoscopic management. J Am Anim Hosp Assoc 1990;26(2):170; with permission.)

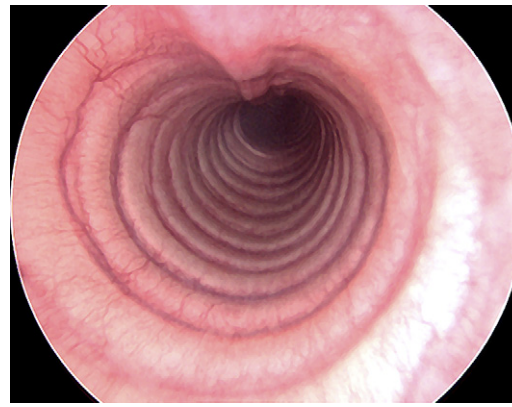

Fig. 3. Appearance of a normal canine trachea during tracheoscopy. There should be minimal secretions within the trachea. The tracheal mucosa appears light pink, with the capillary blood vessels easily visualized.

Fig. 4 demonstrates the positioning of the right and left mainstem bronchi as well as the location of the lobar bronchi. The amount of secretions, mucosa color, and dynamic collapse of any airways should be noted at this level as well. Widening of the carina can indicate hilar lymphadenopathy. The endoscope should be manipulated throughout all the lobar bronchi and branches until it can no longer be safely advanced [41].

Once all lobes have been evaluated, bronchoalveolar lavage (BAL) should be performed in several different areas, including the lung appearing to be the most diseased. The author prefers BAL over transtracheal washes or bronchial brushings because it allows collection of fluid from a specific site and is thought to

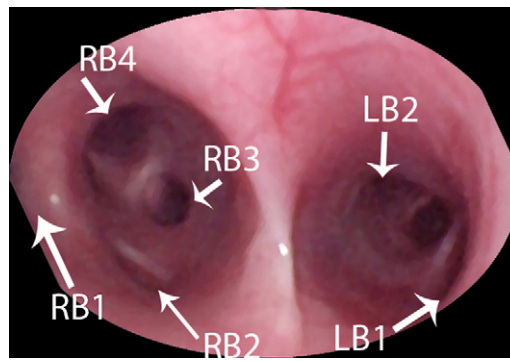

Fig. 4. Appearance of the carina during bronchoscopy. From this view, the branching pattern into lobar bronchi can be recognized. LB1, left cranial lobe; LB2, left caudal lung lobe; RB1, right cranial lung lobe; RB2, right middle lung lobe; RB3, accessory lung lobe; RB4, right caudal lung lobe.

represent the cells from the distal small airways and interstitium of the lung best. BAL is the only technique for which normal differential cell counts have been established for dogs and cats (Table 2) [41]. Because oral bacterial contamination can lead to false-positive culture results in BAL fluid, after gross visualization of the airways has been completed, the endoscope should be removed from the airways and cleaned by suctioning with sterile saline and air. The endoscope is then returned to the area chosen for BAL [41,42]. If no diseased area is recognized, the right middle lung lobe and caudal portion of the left cranial lung lobe are usually sampled because of their ventral orientation. BAL is performed when the scope is in a wedged position, and 10- to 20-mL aliquots of sterile saline are instilled into the airways depending on the size of the animal. The sample should then be immediately aspirated back into the same syringe, and a 40% to 90% return of the volume instilled can be expected. Lavage is generally performed twice in the same location, because greater fluid return is usually obtained on the second sample. The fluid can then be evaluated for total cell counts, cell differentials, cytology, and quantitative culture. Cytology not only helps to determine if inflammation is present but can aid in diagnosing infection, neoplasia, parasitic disease, or some fungal diseases. True bacterial infection is characterized by the presence of intracellular bacteria on cytology and bacterial growth of greater than 1.7×10^3 colony-forming units (CFUs) [43]. Smaller bacterial numbers are likely consistent with normal airway colonization.

DIAGNOSTICS FOR AIRWAY FUNCTION

Laryngoscopy

Laryngoscopy allows direct visualization of the larynx and associated structures and also provides the best assessment of laryngeal function. The cervical

Table 2
Differential cell counts from bronchoalveolar lavage fluid from normal dogs and cats

Study	Scott et al[a]	Rebar et al[b]	Padrid et al[c]	King et al[c]
Species	Canine	Canine	Feline	Feline
Number	46	9	24	11
Total cell count/mL	Not reported	516	303 (±126)	241 (±101)
% Macrophages	75 (27–92)	83	64 (±22)	70.6 (±9.8)
% PMNs	3 (0–30)	5	5 (±3)	6.7 (±4)
% Eosinophils	3 (3–28)	4.2	25 (±21)	16.1 (±6.8)
% Lymphs	10 (1–43)	5.7	4 (±3)	4.6 (±3.2)
% Mast cells	1 (0–5)	2.3	<1 (±<1)	Not reported
% Epithelial cells	Not reported	Not reported	2 (± 2)	Not reported
% Goblet cells	Not reported	Not reported	<1 (±<1)	Not reported

Abbreviation: PMNs, polymorphonuclear cells.
[a]Values are median obtained from the second lavage performed in a lobe.
[b]Values are mean (range) from six lung lobes from all dogs.
[c]Values are mean (±SD) obtained from these cats.
Adapted from McKiernan BC. Bronchoscopy. In: McCarthy TC, editor. Veterinary endoscopy for the small animal practitioner. St. Louis: Elsevier; 2005. p. 224.

trachea can also be easily evaluated with a rigid 5-mm telescope to look for evidence of tracheal collapse. The normal laryngeal mucosa should be a light pink with readily visible blood vessels (Fig. 5). If laryngeal edema is present, the mucosa appears blanched and vessels are difficult to see. There should be minimal secretions within the larynx and cervical trachea in a normal dog or cat. The arytenoid cartilages should normally abduct symmetrically during inspiration. Dogs and cats with laryngeal paralysis show minimal to no abduction of the larynx on inspiration. It is imperative that the endoscopist be able to appreciate when the phase of inspiration occurs so as to confirm that abduction occurs at that time [41]. Laryngeal paralysis is most commonly bilateral in the dog and cat but can be unilateral [44]. It is well known that general anesthesia can dampen laryngeal movement, thus causing false-positive and false-negative diagnoses of laryngeal paralysis. It is suggested to use doxapram (Dopram-V) at a rate of 2.2 mg/kg administered intravenously during laryngoscopy to maximize laryngeal movement and to uncover any subtle changes in laryngeal function [45,46].

Arterial Blood Gas

An arterial blood gas measurement allows direct assessment of gas exchange, and thus is the most definitive assessment of overall pulmonary function. Most analyzers directly measure pH, PO_2, and PCO_2; HCO_3 and base excess are then calculated from these direct measurements. The femoral artery is most commonly used in dogs to obtain an arterial blood gas measurement, although alternatives include the dorsal metatarsal, carotid, brachial, and auricular

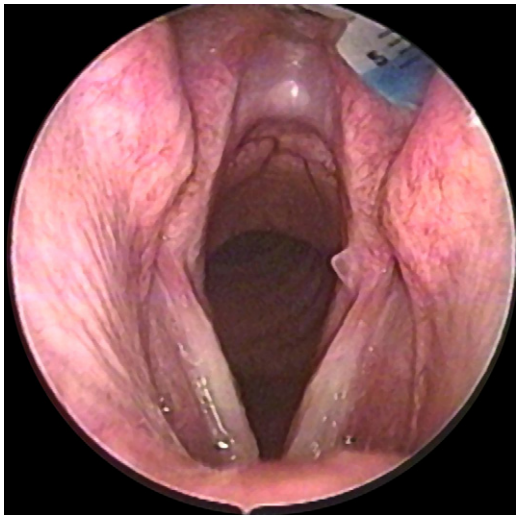

Fig. 5. Appearance of a normal canine larynx during laryngoscopy. The laryngeal mucosa should be light pink, with the blood vessels easily seen. The use of doxapram hydrogen chloride increases laryngeal movement to uncover subtle changes in laryngeal motion.

arteries [16,47]. Small-gauge needles (23–25 gauge) on 1- to 3-mL syringes are recommended, and a small volume of heparin (1000 U/mL) is drawn into the syringe to coat the needle hub and barrel. Arterial blood gas measurement in the cat is extremely difficult unless an indwelling catheter has been placed. To obtain an arterial sample in the canine patient, the patient should be placed in lateral recumbency. When using the femoral artery, the artery pulse is palpated with two fingers as high up in the inguinal area as possible. The needle is then directed into the palpated artery at an angle of 60°. Once a flash is seen within the hub of the needle, the needle should be kept completely still while the syringe is allowed to fill (if a preset syringe) or is aspirated back. It is best to use commercially available preset syringes that fill without aspiration and contain a filter through which air is displaced. These syringes also contain an anticoagulant to allow for the blood to be properly stored temporarily. To minimize any source of error, the sample should be kept on ice until analysis and analyzed as soon as possible [16,47,48].

The PO_2 obtained from an arterial blood sample (PaO_2) represents O_2 that is bound to hemoglobin and dissolved in the blood. PaO_2 in a normal animal at sea level should be greater than 80 mm Hg, although values are slightly lower at high altitudes. A decrease in PaO_2 can occur with hypoventilation, with a decrease in the partial pressure of atmospheric O_2 (high altitude), or with venous admixture. Venous admixture is perhaps the most common reason for hypoxemia and can occur with venous shunting (ie, lung atelectasis, pneumonia) or physiologic dead space (ie, PTE). If there is thickening of the lung interstitium, there can also be a diffusion barrier for O_2; however, this is fairly rare, given O_2's great reserve for diffusion [16,47,48].

As stated previously, hypoxemia can occur from high altitude or hypoventilation, neither of which is a cause of lung dysfunction. It is imperative when evaluating hypoxemia to compare the PaO_2 with the $PaCO_2$. The alveolar-arterial O_2 gradient gives an estimate of the effectiveness of gas transfer and is independent of the effect of ventilation. The gradient is calculated by first estimating the partial pressure of O_2 in the alveoli (PAO_2), using the alveolar gas equation:

$$PAO_2 = FIO_2(P_b - P_{H2O}) - PCO_2/RQ$$

where FIO_2 is the fractional inspired O_2 concentration, P_b is barometric pressure, P_{H2O} is the saturated water vapor pressure at body temperature, and RQ is the respiratory quotient (typically 0.9 at sea level). Measured arterial PaO_2 is then subtracted from the estimated alveolar PAO_2. Normal values in dogs are less than 10 to 15 mm Hg [13,16]. This equation includes the measurement of $PaCO_2$, and thus removes the possibility of hypoxemia induced by hypoventilation.

Pulmonary Lung Function Testing and Lung Mechanics

The function of the airways can be assessed by measuring resistance and compliance within the airways. Compliance (Cdyn) is the inverse of elastance,

which is defined as the amount of elastic recoil within the lung. Cdyn is calculated as the change in lung volume divided by the change in transpulmonary pressure at two points of zero air flow. Resistance is a measurement that describes impedance to air flow, which is mostly frictional resistance of air currents against the walls of the airways. Resistance is defined as the pressure difference between the alveoli and the mouth divided by the flow rate of air [49].

Tidal breathing flow-volume loops (TBFVLs) were introduced into veterinary medicine to help bypass the need for patient cooperation or general anesthesia to evaluate air flow. Loops are generated by placing a pneumotachograph with a tight-fitting face mask over the patient's muzzle and measuring flow over time. The loops can then be evaluated for shape, respiratory rate, and tidal volume. Specific flow measurements and specific changes in the appearance of the loops can be obtained to help identify evidence of disease (Fig. 6). TBFVLs have been used in the diagnosis of laryngeal paralysis, brachycephalic syndrome, and chronic bronchitis in the dog [16,47,49]. For additional information on pulmonary function testing in small animal medicine, see the article by Hoffman elsewhere in this issue.

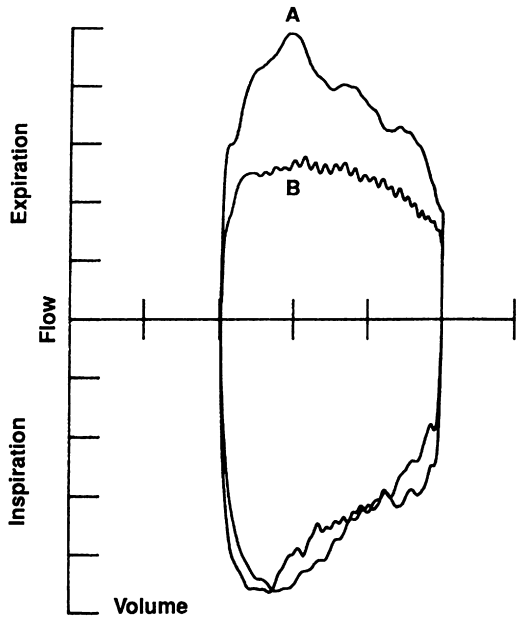

Fig. 6. A comparison of tidal breathing flow-volume loops (TBFVLs) obtained from a single healthy cat (*A*) and one bronchitic cat (*B*). Differences in expiratory flow (but not inspiratory flow) are readily apparent between the two loops. (*From* McKiernan BC, Dye JA, Rozanski EA. Tidal breathing flow-volume loops in healthy and bronchitic cats. J Vet Intern Med 1993:7(6):392; with permission.)

SUMMARY

The respiratory system provides many challenges by inherently being difficult to examine. The clinician must integrate history and physical examination findings to determine which diagnostic procedures are likely to be most effective in each case. Certain diagnostic tests (radiographs, CT, and bronchoscopy) provide extremely useful information when evaluating respiratory disease but do not provide any quantitative measurement of the disease. Other diagnostics (laryngoscopy, arterial blood gas, and TBFVLs) can help to quantify the degree of respiratory disease present.

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