EMERGENCY CARDIAC AND THORACIC RADIOLOGY

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In many cases, it may be difficult to distinguish whether cardiac or pulmonary disease or both are present in a critically ill small animal patient. Although thoracic radiographs should never be used in place of a careful and thorough physical examination, they are a useful tool in helping to determine the nature and severity of cardiac and pulmonary disease. Careful examination of thoracic radiographs can reveal the size and shape of cardiovascular structures, abnormalities of the pulmonary parenchyma and pleural space, mediastinal masses or hemorrhage, and fractures or disruption of the structures that form the thoracic cage. Thoracic radiographs should always be performed once a patient is stable, as there are inherent risks of stress and manipulation for proper positioning that can push a patient with cardiopulmonary disease over the edge, and thus be life-threatening.

Patient Positioning

Standard views for thoracic radiographs are lateral, ventrodorsal (VD), dorsoventral (DV) views taken at full inspiration for the best evaluation of the cardiovascular system and pulmonary parenchyma. The standard view for most accurate positioning of the heart is the dorsoventral (DV view), to ensure that the cardiac apex is in its normal anatomic position. Traditionally, changes in the cardiac silhouette are noted as compared with the face of a clock. In the DV view, the base of the heart is at the 12 o'clock position. On the VD view, the aortic arch is at the 12 o'clock position. All other structures are described in relation to their position as visualized on the face of a clock.

A standard right lateral radiograph with either a VD or DV view is usually sufficient to visualize normal and abnormal cardiac structures. When examining the thorax for suspected pulmonary parenchymal lesions such as neoplastic masses, however, both left and right lateral views should be performed, to avoid making a false negative diagnosis.

In some cases, the presence of pleural effusion and/or anterior mediastinal mass lesions can mask and overshadow the cardiac silhouette. In such cases, pleural fluid should be removed from the thorax via therapeutic and diagnostic thoracocentesis. Small dogs and cats can be positioned by stretching or scruffing the patient such that their hind end hangs onto the radiology table. The bucky is moved perpendicular to the thorax with the radiographic cassette positioned in a stand on the other side of the patient. The radiograph beam is shot through the patient to provide a "hanging lateral" radiograph. Such positioning will allow residual pleural fluid to move to the most gravity dependent areas of the thorax in the gutters adjacent to the diaphragm to aid in the visualization of cranial mediastinal mass lesions.

Normal Appearance of the Heart Within The Thorax

Lateral Radiograph: The cranial edge of the cardiac silhouette or cranial cardiac waist lies at approximately the level of the 3rd intercostal space. The caudal edge, or caudal cardiac waist, lies at approximately the 8th intercostal space. This position may vary slightly due to breed and shape of the individual patient's thorax. The cranial portion of the cardiac silhouette corresponds to the right heart, and the caudal edge of the cardiac silhouette corresponds to structures of the left heart. The dorsocranial edge of the cardiac silhouette on a lateral radiograph contains the aortic arch, pulmonary artery, and right auricular appendage. The lower two-thirds of the cranial cardiac silhouette contain the structures associated with the right atrium, the right ventricle, and the ventricular outflow tract. The cranial vena cava meets the right atrium at the slightly indented area known as the cranial cardiac waist. The right ventricle and cardiac apex of the left ventricle have sternal contact for a variable distance, depending on the height and width of the patient's thorax and the phase of the cardiac and respiratory cycle. The caudal border of the cardiac silhouette is composed of the left ventricle and left atrium. The left atrium merges with the left ventricle in a slightly indented are known as the caudal cardiac waist. Closely adjacent to the caudal cardiac waist is the caudal vena cava. The hyperlucent area over the heart base is the junction of the mainstem bronchi, an area known as the carina.

Dorsoventral Radiograph: On a DV view of the thorax, the right atrium is located at approximately 9 – 11 o'clock. The right ventricle is located from 5 to 9 o'clock. The main pulmonary artery is located at 1 to 2 o'clock. The left ventricle is located from 2 to 5 o'clock. The left auricle can be visualized between 2:30 and 3 o'clock. With proper patient positioning, the sternum and vertebral bodies should be superimposed on midline, and an equal amount of aerated lung fields should be visible on either side of the heart.

The Vertebral Scale System: For dogs, a standard general measure of normal cardiac size is 2.5 – 3.5 intercostal spaces on a standard lateral thoracic radiograph. Although this is good for a general rule, the technique has its limitations, based on proper positioning, phase of the respiratory cycle, and individual variations in thoracic conformation. More recently, measurements of the long and short axis of the heart were compared with measurements of the thoracic vertebrae. The vertebral heart size in dogs can be calculated by performing the following steps:

(1) Measure the long axis of the heart from the apex to the carina on the lateral view and mark the distance on a sheet of paper, placing the corner of the paper at the carina, and marking the distance to the apex on the lateral edge of the paper. This is the long axis measurement.

(2) Measure the length of the long axis in terms of vertebral bodies, starting with the corner of the paper at the cranial edge of the 4^{th} thoracic vertebra, and counting caudally, measure the number of vertebral bodies that are contained within the length of the long axis measurement.

(3) Measure the short axis of the heart starting at the caudal vena cava. This is the short axis of the heart, and is perpendicular to the long axis measurement.

(4) Repeat step 2, by measuring the short axis in relation to the number of vertebral bodies, starting at the cranial edge of the 4^{th} thoracic vertebra.

(5) Add the two numbers together to yield the vertebral heart size.

In dogs, a vertebral heart size greater than 10.5 is consistent with cardiomegaly. In cats, normal vertebral heart size is < 7.5. Interestingly, in cats, the short axis dimension corresponds to the length of 3.2 thoracic vertebrae, or roughly the width of 3 intercostal spaces. The measurement for vertebral heart size is obtained a little differently in cats than in dogs. On the VD or DV view, measure the maximum width of the heart, and then go back to the lateral thoracic view and measure from the 4^{th} thoracic vertebral body. Normal VHS in cats is 3.2 – 3.8. Using the vertebral heart size method is an efficient tool to evaluate for cardiomegaly, and to track changes in the heart size of a patient with known cardiac disease.

Congenital Heart Disease

Congenital cardiac disease should be suspected in any young dog or cat that presents to you with a cardiac murmur. Careful auscultation of the thorax to evaluate the location where the murmur is most intense and description of the quality of the murmur can increase your index of suspicion as to a specific condition, in some cases. Thoracic radiographs may demonstrate characteristic changes in the cardiac silhouette and/or pulmonary vasculature to support the diagnosis of a specific condition, although echocardiography may be required to make a definitive diagnosis.

Pulmonic stenosis: Pulmonic stenosis is defined as a narrowing of the outflow tract from the right ventricle to the pulmonary artery. As a result of impedance to outflow, an abnormal pressure gradient occurs from the right ventricle, across the stenotic area, to the pulmonary artery. Right ventricular hypertrophy occurs. Radiographically, right ventricular hypertrophy with a post-stenotic dilatation of the pulmonary artery may be visible. Right ventricular enlargement is easy to detect using the 2/5 to 3/5 rule. In a normal heart, draw a line from the carina to the apex; normally, 2/5 of the heart should lie to the left of the line, and 3/5 of the heart should lie on the right of the line. The cranial cardiac waist may be overshadowed by the dilatation of the pulmonary artery. On a DV view, right sided cardiomegaly may be apparent as a backward D shape, with a prominent enlarged pulmonary artery at 1 to 2 o'clock. Radiographic signs of pleural or peritoneal effusion may become apparent as right sided heart failure progresses.

Aortic stenosis: Aortic stenosis is a narrowing of the left ventricular outflow tract from the left ventricle to the aorta. The left ventricle must increase pressure to allow blood to flow past the stenotic narrowing. Left ventricular hypertrophy and a post-stenotic dilatation of the aorta occur. On plain radiographs, the cranial cardiac waist may be absent on a lateral thoracic view because of the post-stenotic dilatation of the aorta. Left ventricular hypertrophy may cause the caudal portion of the cardiac silhouette to become more vertical in appearance. Left atrial enlargement may become apparent as a loss of caudal cardiac waist with a so-called "backpack" sign. With severe cases and secondary left sided congestive heart failure, pulmonary interstitial to alveolar infiltrates may become apparent with the development of pulmonary edema.

Patent Ductus Arteriosus: During fetal life, blood in the cardiac circuit can bypass the deflated pulmonary circulation by the ductus arteriosus that is located in between the pulmonary artery and the aorta. At the time of birth and expansion of the alveoli, pressure gradients in the now-functional pulmonary circulation normally cause constriction then permanent of the ductus arteriosus within several weeks of birth. In some instances, the ductus remains open, allowing blood to shunt from the high pressure aorta through the pulmonary artery. This creates excess work for the right ventricle, and right ventricular hypertrophy and right atrial enlargement occur. Radiographically, right ventricular hypertrophy is evident as increased sternal contact and tracheal elevation. The cranial cardiac silhouette may be absent because of the superimposition of the aorta bulge in that area. The left-to-right shunt causes overcirculation of the pulmonary vasculature, which is evident on radiographs as enlarged cranial lobar arteries and veins. The enlarged pulmonary artery segment is often visible on the DV view between 1 and 2 o'clock. As the disease progresses, left sided congestive heart failure develops with acquired mitral insufficiency, left atrial and ventricular enlargement, and pulmonary edema.

Atrial Septal Defect: Small atrial septal defect may cause minimal changes in the appearance of the cardiovascular structures on thoracic radiographs. Large atrial septal defects can cause right atrial enlargement as blood from the left atrium is shunted back into the right atrium through the defect. Increased circulation of blood through the right heart can eventually cause right ventricular hypertrophy and dilation of the main pulmonary artery segment. Eventually, signs consistent with right heart failure including pleural and peritoneal effusion may develop.

Ventricular septal defect: Ventricular septal defects often cause increased work load for the right heart, as blood from the high pressure left ventricle is pushed through the rent in the ventricle to the right heart during ventricular systole. Radiographic signs are largely dependent on the size of the defect present, but may include right ventricular hypertrophy, and a subtle increase in the size of the pulmonary artery. Left ventricular and atrial enlargement may or may not be present, depending on the severity and chronicity of the condition

Tetralogy of Fallot: Tetralogy of Fallot is a rare congenital defect that is comprised of Pulmonic stenosis, right ventricular hypertrophy, overriding aorta, and a ventricular septal defect. Many animals will show clinical signs including exercise intolerance, cyanosis either at rest or after exercise, and stunted growth. Radiographically, the syndrome has right ventricular hypertrophy and a large aortic bulge in the cranial cardiac waist. A post-stenotic dilatation of the pulmonary artery may or may not be visible.

Pericardial-peritoneal diaphragmatic hernia: Congenital defects between the diaphragm and pericardium can cause infiltration of the pericardial sac with abdominal contents. In such cases, the cardiac silhouette appears enlarged, with a lack of demarcation in between the diaphragm and heart. Radiolucent densities may be present over the shadow of the heart if gas-filled viscera such as stomach and intestines are entrapped within the pericardial sac. Confirmation of the diagnosis is best made with ultrasound.

Acquired Cardiac Disease

Mitral Insufficiency: Fibrosis of the mitral valve (mitral valve endocardiosis), dilative cardiomyopathy, bacterial endocarditis, and rupture of the chordae tendinae can all cause mitral insufficiency or regurgitation. Mitral regurgitation or insufficiency is the most common acquired cardiac abnormality in dogs, and can lead to congestive heart failure. Radiographically, as mitral insufficiency progresses, enlargement of the left atrium at the level of the caudal cardiac waist becomes visible. This has been described as the “back-pack” sign. The caudal aspect of the cardiac silhouette becomes more vertical in appearance on a lateral thoracic radiograph due to left ventricular enlargement. Elevation of the trachea and increased sternal contact occur with the development of an enlarged right ventricle. If an animal has an acutely ruptured chordae tendinae, the cardiac silhouette may appear completely normal in size. Pulmonary edema is manifested as perihilar interstitial to alveolar infiltrates.

Dilative Cardiomyopathy: Dilative cardiomyopathy in dogs causes generalized cardiomegaly with enlargement of all 4 heart chambers. Although in some cases, the dog’s cardiac silhouette can appear globoid, it also appears more elongated and can have distinct left atrial enlargement on a lateral view of the thorax. This helps to distinguish between pericardial effusion, in which the cardiac silhouette appears round, with indistinct demarcation between cardiac chambers. Because both right and left sided heart failure can appear simultaneously in dogs with dilative cardiomyopathy, radiographic signs consistent with right- and left-sided failure, including pleural and peritoneal effusion/ascites, and pulmonary edema can be present, depending on the severity of the disease. Dilative cardiomyopathy in cats is usually associated with a deficiency of the essential amino acid taurine. Supplementation of taurine in many manufactured brands of cat food has made this disease entity extremely rare in clinical practice, but can still occur

Hypertrophic cardiomyopathy: Hypertrophic cardiomyopathy is a common disease in cats. Cardiomegaly and/or left atrial enlargement may be evident on a lateral thoracic radiograph. Dorsoventral or ventrodorsal views may reveal biatrial enlargement, or a so called "valentine-shaped" cardiac silhouette. Evidence of interstitial to alveolar pulmonary infiltrates or pleural effusion may be present due to left- or right-sided heart failure, respectively. In cats, cardiogenic pulmonary edema can appear anywhere in the lung fields, and is not restricted to the perihilar area. Restrictive or unclassified cardiomyopathy may reveal biatrial enlargement without evidence of left ventricular enlargement.

Heartworm Disease (Dirofilariasis): Dirofilariasis or heartworm disease occurs when adult heartworms colonize the pulmonary arteries, right ventricle, right atrium, and vena cavae. Radiographically, the pulmonary arteries appear enlarged and tortuous, and can appear blunted. The main pulmonary artery appears enlarged, and the cardiac silhouette appears as a backward "D" due to right ventricular hypertrophy on the DV view. Again, the 2/5 to 3/5 rule can be applied to look for right ventricular hypertrophy. Interstitial to alveolar pulmonary infiltrates may be present due to thromboemboli showering the lungs. Severe disease can result in pulmonary hypertension and eventual right-sided heart failure, or cor pulmonale.

Pericardial Effusion: Pericardial effusion is most commonly causes by a neoplastic process within the heart or pericardium, but can also be associated with intrapericardial cysts, inflammatory pericarditis, peritoneal-pericardial diaphragmatic hernia, and vitamin K antagonist rodenticide intoxication. If a heartbase or atrial tumor causes rapid hemorrhage into the pericardial sac, the patient may have clinical signs of weakness, cyanosis, tachycardia, or collapse before the pericardium has enough time to stretch and accommodate the fluid buildup. Clinical signs associated with pericardial tamponade, in such cases, may be present with a normal appearing cardiac silhouette on thoracic radiographs. In such cases, the use of ECG and echocardiography can help aid in making a diagnosis of pericardial effusion. More commonly, however, slow build-up of fluid within the pericardial sac allows stretching of the pericardium and a more globoid appearance to the cardiac silhouette.

Heartbase Tumor: Tumors located at the heartbase are usually chemodectomas or aortic body tumors. Thyroid, parathyroid, lymphatic, or connective tissue tumors have been documented at the heartbase, but are much less common. Radiographically, heartbase tumors can cause pericardial effusion, or can be visualized as a soft tissue density superimposed on the heart or great vessels. In some cases, the trachea will be displaced by the tumor.

Pulmonary Disease

It is often difficult to distinguish the difference between cardiac and respiratory disease with physical examination findings. Increased respiratory effort and distress can be associated with cardiac causes such as pleural effusion or pulmonary edema, but can also be associated with pulmonary parenchymal or bronchial causes, such as bronchitis, pneumonia, neoplasia, pulmonary hemorrhage, and tracheal collapse. Thoracic radiography can be useful in helping determine the extent of cardiac versus respiratory disease once the patient is stable enough to withstand handling.

Acute Respiratory Distress Syndrome: Acute respiratory distress syndrome (ARDS) is caused by the accumulation of inflammatory and proteinaceous debris in the alveoli of susceptible patients. The radiographic appearance of ARDS can differ, depending on the severity of the condition, and can include progressive patchy interstitial to alveolar infiltrates throughout the lung field.

Chronic Bronchitis: Chronic bronchitis can be present in both cats and dogs. Bronchitis is an inflammation of the airways. Radiographically, small airway inflammation can be seen as donuts when seen in cross-section, or tram-lines when a bronchus is seen longitudinally on thoracic radiographs. In some cases, subtle changes may not be readily apparent when viewing the entire thoracic radiograph from afar. Making a small window in a piece of paper, then moving the window over the radiograph such that the window allows visualization of only a small area of the lung field at one time may aid in making a diagnosis of subtle bronchial markings. In cats, bronchitis (asthma) also can show a flattening or tenting of the diaphragm on the lateral and VD views, respectively. More than 10% of cats with chronic bronchitis have atelectasis or consolidation of the right middle lung lobe. Severe cases can be associated with ruptured bullae, pneumothorax, pneumomediastinum, and pneumoperitoneum. In dogs, bronchiectasis, or widening of the mainstem bronchi may become apparent with chronic bronchial disease.

Neoplasia: The radiographic appearance of pulmonary and pleural neoplasia can be manifested in a variety of manners, depending on cause. Solitary large mass lesions within the pulmonary parenchyma are characteristic of bronchogenic adenocarcinoma. Small nodules scattered throughout the lung fields are more characteristic of neoplasia such as hemangiosarcoma that has metastasized from a distant site. Soft tissue densities in the mediastinum can be associated with heartbase tumors, thyroid or parathyroid tumors, thymomas, or lymphoma. Pleural effusion with lytic or sunburst lesions of the ribs in young dogs are often associated with osteosarcoma or osteochrondrosarcoma of the ribs. Feline lymphoma with mediastinal mass lesions often present with pleural effusion and elevation of the trachea and caudal displacement of the carina due to a cranial mediastinal mass. Malignant histiocytosis of Bernese Mountain Dogs can appear as perihilar lymphadenopathy, pulmonary parenchymal soft tissue nodules to masses, and pleural effusion.

Pleural effusion: Fluid accumulation in the pleural space is known as pleural effusion. Pleural effusion can be caused by intrapleural hemorrhage, neoplasia, cardiac disease, diaphragmatic hernia, inflammation or damage to the thoracic duct, and trauma. The radiographic appearance of pleural effusion varies depending on the amount of fluid present, and chronicity of the problem. Pleural effusion usually will be located in the most gravity dependent areas of the thorax. Pleural effusion appears as a soft tissue density superimposed over the lung field. Fissure lines may be present in between lung lobes if only a small amount of fluid is present and are best seen on the VD view. With excessive fluid accumulation, the lungs will be pushed dorsally and caudally, and will be outlined by the fluid. On a VD or VD view, scalloping or rounding of the lung edges surrounded by fluid are suggestive that the process is chronic in nature.

Pneumonia: Pneumonia can occur in any portion of the lung field, depending on the cause. Radiographically, aspiration pneumonia usually appears as patchy interstitial to alveolar infiltrates in the dependent portion of the lung fields, in the right and left cranial and right middle lung lobes. Depending on the position of the patient at the time of aspiration, however, pneumonia can be present in any area of the lung field. Interstitial pneumonia appears as more of a patchy increased interstitial pattern throughout the lung field. Fungal pneumonias are more common in the Midwest and Southwest geographical regions of the United States. Fungal pneumonia caused by histoplasmosis and blastomycosis usually appears as patchy foamy interstitial nodules of varying sizes scattered throughout the lung field. Coccidioidmycosis can be manifested as perihilar lymphadenopathy or a perihilar interstitial pattern or as a diffuse miliary or diffuse interstitial pattern with small nodules throughout the lung field. Because of this, taking a thorough travel history and performing a careful physical examination to rule out a cardiac murmur is helpful when trying to distinguish between cardiac and pulmonary disease.

Pneumothorax: Pneumothorax can be diagnosed on physical examination with a history of trauma, the presence of external injuries, tachypnea, a shallow, restrictive respiratory pattern, and muffled lung sounds on thoracic auscultation. Therapeutic thoracocentesis should be performed prior to taking radiographs, to help stabilize the patient and decrease morbidity and mortality associated with the stress of handling. When air escapes from the pulmonary parenchyma and bronchi, the lungs collapse and appear consolidated. On a lateral thoracic radiograph, the heart is raised above the sternum, and thus, has decreased sternal contact. The outline of the lungs themselves can be observed, surrounded by hyperlucent areas in the periphery. Evaluation of the pulmonary vasculature revealed a lack of vessels in the periphery. Lateral and DV radiographs should be obtained, whenever possible without causing undue patient stress, in order to localize the area of pneumothorax and concurrent thoracic injuries.

Pulmonary Contusions: Pulmonary contusions are caused by direct impact and shearing forces when an animal is struck by a blunt object such as a cattle hoof or motor vehicle. Contusions are simply a bruise within the pulmonary parenchyma that may be apparent radiographically for up to 24 – 36 hours after the incident. Patchy to consolidated interstitial to alveolar infiltrates are characteristic of pulmonary contusions. Careful evaluation of the entire radiograph is necessary to diagnose concurrent injuries such as rib or spinal fractures, pneumothorax, pleural effusion, and diaphragmatic hernia.

Pulmonary edema: cardiogenic and noncardiogenic: Pulmonary edema is often associated with left-heart failure and increased pressure in the pulmonary vasculature. Cardiogenic pulmonary edema often starts in the perihilar region. Noncardiogenic pulmonary edema should be on the list of differential diagnoses in any patient with a history of seizure, choke, upper airway obstruction or electrocution that later develops clinical signs of respiratory distress. Noncardiogenic pulmonary edema is characterized by interstitial to alveolar infiltrates in the dorsocaudal lung fields.

Pulmonary hemorrhage: Pulmonary hemorrhage may be caused by rupture of a neoplastic mass lesion, or from Vitamin K antagonist rodenticide intoxication. Depending on the severity and cause, pulmonary hemorrhage can be manifested radiographically as patchy interstitial to alveolar infiltrates anywhere throughout the lung field. Mediastinal hemorrhage with widening of the cranial mediastinum is common in small animal patients that have ingested Vitamin K antagonist rodenticide. In such cases, a careful history, combined with coagulation screening tests such as a prothrombin time or activated clotting time, is useful in determining the cause and appropriate treatment of vitamin K antagonist rodenticide intoxication.

Pulmonary Hypertension: Pulmonary hypertension can occur due to chronic bronchitis, pulmonary thromboembolic disease, Dirofilariasis, left-to-right shunts, chronic obstructive pulmonary disease, or chronic hypoxia. Pulmonary hypertension is manifested on thoracic radiographs as prominent irregular tortuous pulmonary vessels on a lateral view. Evaluation of the pulmonary artery that feeds the right cranial lung lobe is larger that the proximal portion of the 4th rib. Depending on the cause of pulmonary hypertension, pulmonary infiltrates due to small pulmonary emboli and atelectasis and chronic bronchitis may obscure the pulmonary vasculature in the caudal lung fields.

Pulmonary thromboembolism: The diagnosis of pulmonary thromboembolic disease is often difficult to make on the basis of radiographs alone. In some cases, enlargement of the pulmonary arteries may be observed on thoracic radiographs. Patchy peripheral interstitial to alveolar infiltrates may be present, or consolidation of one or more lung lobes. Most often, the lungs also may appear normal on thoracic radiographs, making a diagnosis very difficult without concurrent use of nuclear scintigraphy scans and echocardiography to document an acute onset of tricuspid insufficiency in a previously normal patient.

Tracheal collapse: Tracheal collapse is a dynamic process that may be difficult to document, depending on the phase of respiration and the location of the problem. For this reason, fluoroscopy is more efficient than flat radiographs when attempting to document tracheal collapse in some patients. Lateral thoracic radiographs are preferred over VD or DV radiographs to document tracheal collapse, because the trachea most often collapses in a dorsoventral, rather than lateral plane. Redundant trachealis muscle may also be visible as a soft tissue density within the tracheal lumen. Cervical tracheal collapse occurs during inhalation, and intrathoracic tracheal collapse occurs during exhalation. Superimposition of fat or the esophagus over the trachea may obscure the trachea in obese patients.

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