Chaper 11

Macroscopic Lesions of the Respiratory Tract of Ruminants

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PART A: A GENERAL APPROACH TO RESPIRATORY SYSTEM PATHOLOGY

General Considerations

A thorough investigation of the respiratory tract is a major undertaking, although it can be accomplished with minimal equipment. A targeted investigation of respiratory disorders is greatly enhanced by prior knowledge of antemortem clinical disease. Knowledge of ante-mortem clinical signs also allows the prosector to reasonably assess risk of zoonotic disease, and the need for additional samples to isolate infectious agents. Many of the infectious causes of pneumonia are not distinctive on macroscopic examination, and often more than one pathogen is involved. There are well documented interactions between stressors, respiratory viruses, mycoplasma and bacteria, (*Figure 1*) and when outbreaks of infectious disease occurs in adults, these complex interactions should be investigated rather than assigning a diagnosis to a solitary pathogen.

Anatomy

The nasal cavity has distinctive regions both grossly and histologically. The ethmoid area is typically pigmented yellow-green and mucosal areas vary from stratified squamous, transitional, neurosensory and typical respiratory types (*Figures 2-4*).

Lungs were originally described according to major surface fissues, but the preferred nomenclature is based on the major bronchial branching patterns (*Figure 5*). The pleura is normally thicker over the dorsal aspects of the caudal lobes, (*Figure 6*) and the lungs are completely lobulated. As a consequence, there is no collateral ventilation between gas exchange units, and although Pores of Kohn increase in number in adult lungs, this only has a minor effect on collateral ventilation between alveoli within the same lung segment (*Figure 7*).

The pulmonary interstitium consists of 3 compartments, the bronchovascular, the alveolar septal and the interlobular. Interstitial involvement varies dependent on the disease process, and the terminology is confusing. *Interstitial emphysema* is common in cattle lungs and involves air trapping within the loose connective tissues of the interlobular interstitium. *Interstitial pneumonia* involves the alveolar interstitium, usually as a corollary to either alveolar epithelial or microvascular damage. The *bronchovascular interstitium* is typically the

first place that accumulates oedema fluid following hydrostatic causes of pulmonary oedema, but other interstitial compartments become affected with progressive oedema fluid accumulation.

Bronchiolar structure of ruminant lungs may lead to a particular susceptibility to injury at this level of the respiratory tract. The terminal bronchiole opens almost directly into gas exchange surfaces rather than through a series of respiratory bronchioles and alveolar ducts (*Figures 8-10*), and therefore alveoli that rupture may release air directly into the bronchovasacular interstitium. Similarly alveoli at the margins of the lobule may rupture and leak air into the interlobular interstitium. Traffic of leucocytes into the airways seems to occur most readily at this level of the bronchial tree. These features and the lack of collateral ventilatory channels mean that development of bronchiolar obstructive diseases and interstitial emphysema are relatively common.

Non-Lesions

Some changes at death may give a misleading impression of respiratory disease, and there are valid reasons for this.

- Nasal structures are delicate, yet difficult to expose adequately because of being totally enclosed in bone. Non-lesions include congestion of the mucosa and watery discharges at the external nares.
- Sinuses and eustachian tubes are convoluted spaces encased by bone and difficult to expose. Many cases of "shipping fever" in cattle have concurrent middle ear infections and some have sinusitis, but these are often missed because of inaccessibilty.
- The tracheobronchial tree may become intensely congested as a post mortem change, and distinction from a disease process become progressively more difficult. In general, disease processes produce a surface exudate, and there may be mucosal erosion or ulceration.
- Post mortem congestion of dependent regions of lung, with progressive accumulation of sanguineous fluid in the parenchyma is a particular problem in larger ruminant lungs, and may be very difficult to distinguish from early pneumonia. However, these lungs are generally soft, flabby and collapsed and not firm and turgid, as with early ante-mortem ling disease.
- Interstitial emphysema is a common non-lesion in adult cattle lungs, particularly in the caudal lobes, and in the absence of concurrent changes in the parenchyma is of no diagnostic significance.
- The dorsal aspects of the caudal lobes of both large and small ruminants have large subpleural networks of lymphatics, and these regions also have more fibro-elastic connective tissue than the remaining lung. Therefore, these areas appear pale to white compared to the remaining lung, but are normal. These areas are always elastic and therefore should not be confused with early pneumonic lesions or fibrinous pleuritis.

Establishing the display stage of dissection

There is no single best way to approach postmortem, but adoption of a standardised method of dissection is best, since familiarity with normal structures enables better detection of subtle changes.

Initial dissection

At this institution, ruminants are placed in left lateral recumbency. This enables best access for review of abdominal viscera, (except the spleen), since the entire left side of the abdomen is occupied by the rumen, but offers no particular advantage over other positions for examination of the respiratory tract. For smaller ruminants and young calves, animals may be placed in dorsal recumbency for dissection. With the animal placed in left lateral recumbency, a midline ventral skin incision from mandible to inguinal region is made, and the upper legs dissected free from the body. A V-shaped incision is then made in the ventral aspect of the mandible, dissecting along both sides of the tongue and the tongue "dropped". With the tongue pulled ventrally, enabling visualisation of the oral cavity, incisions are continued along the lateral walls of the pharynx, until the hyoid bones become palpable. Although the hyoid bones can be severed with bone cutters, good practice is to sever the hyoid bones at their cartilaginous attachments to the larynx, reducing the risk of stick injury from sharp bone ends. By gently pulling downwards on the tongue, the dorsal aspect of the pharynx can be visualised and severed, freeing the tongue and pharyngeal tissues from the skull. Deep dissection of the ventral aspects of the neck allows isolation and separation of the oesophagus and trachea from other ventral neck tissues. Once this is achieved, the trachea is occluded to ensure the lungs do not collapse upon opening the thorax. The means of occlusion is not important, and past practice at this institution was to have a range of large wooden stoppers, 10 to 15 cm in length and of varying diameters, which could be placed in the trachea via a tracheostomy incision, and then held firmly in place by heavy string ligatures. For various reasons, we have discontinued this practice, and now routinely clamp the trachea with 2 or 3 large gut clamps. This is much simpler and more effective at maintaining an adequate seal. Tracheal occlusion should take place near the thoracic inlet, avoiding structures in the proximal neck, such as the thyroids and salivary glands, or lymph nodes. At this stage of dissection, any gross lesions in the oral cavity, pharyngeal tissues, larynx, and the cervical trachea should be noted.

The next stage of dissection is to open the abdominal cavity, by a midline incision from paralumbar region down the ventral midline and along the rib margin. This exposes the right abdominal contents, and also then allows accurate visualisation of the diaphragm. The diaphragm should be domed cranially and should be inspected for any lesions such as fibrosis, adhesions to the liver or other abdominal viscera, or haemorrhages. Herniation of abdominal contents into the thorax should be obvious, perforations or tears will be apparent on the upper side of the diaphragm, but from this approach the left side of the diaphragm is unable to be assessed until the abdominal viscera are completely removed.

The next phase of dissection is to perforate the diaphragm, making a keyhole incision at the diaphragmatic attachment to the ribs. Normally, thoracic contents will be under negative pressure compared to atmospheric pressure, and air may be heard entering the thorax, accompanied by relaxation of the diaphragm back into the abdomen. In cases of pneumothorax, or severe pleuritis, where the thorax is not under negative pressure, the diaphragm may appear flaccid or domed into the abdomen. In order to review the lungs intact, it is important that the initial incision through the diaphragm is along the costal margin and not centrally. Perforation of the diaphragm centrally will almost invariably lead to laceration of the lungs. Once the diaphragm has been perforated, this costal incision should be extended from the level of the vertebra along the lateral attachments of the diaphragm to the sternum. At this point, the lungs can be visualised and an assessment for pleural disease made. After dissection of the musculature over the left thoracic wall, ribs are sectioned using large bone cutters adjacent to the vertebral bodies dorsally and adjacent to the sternum ventrally. In doing so, the upper thoracic wall is completely freed from the animal and can be removed. After assessment of the inner surfaces of the thoracic wall for evidence of pleural disease, this can either be discarded or, in field postmortems, the inside aspect of the ribs can be used as a satisfactory sterile surface for temporary storage of specimens while the postmortem proceeds. The lungs are then visible for inspection and if occluding the trachea has been successful, they should be a uniform pale pink colour to the upper lung with only a few ml of clear yellow fluid in the pleural cavity.

This concludes the "display stage of dissection", and at this stage, the objectives for postmortem evaluation for the respiratory tract should be reviewed, and if samples for microbiologic investigation have not already been taken, this is the most appropriate time to procure them. There is minimal risk of contamination up until this point of dissection, but contamination is likely after this stage.

Removal of the lower respiratory tract

By grasping the respiratory tract by the trachea at the level of the thoracic inlet, and applying tension to lift this out of the cadaver, anterior mediastinal tissues can be dissected free from the thoracic inlet. Ventral mediastinal attachments are removed including those adjacent to the pericardium, a ligature is placed around the oesophagus as it enters the diaphragm to prevent escape of ingesta from the rumen, and both the posterior vena cava and aorta are severed at the level of the diaphragm. The dorsal mediastinal attachments are separated so that the aorta is included, and the thoracic contents should now be free within the thoracic cavity and can be lifted from the cadaver. Because it is technically difficult to dissect the ventral mediastinal tissues away without rupturing the pericardial sac, it is best to open the pericardium while the thoracic contents are *in situ* in order to evaluate pericardial fluid.

Evaluation of tongue, pharynx and larynx

For this part of the respiratory tract, the process of evaluation does not differ from the pathologic investigation of any other organ system: -for solid structures, palpation and sectioning to allow visualisation of any lesions hidden beneath the surface, and for hollow structures, sectioning longitudinally to allow visualization. For the tongue and oropharynx, palpation and sectioning may lead to identification of lesions, but commonly, inflammatory lesions are best identified by the accumulation of exudate adherent to mucosal surfaces.

Evaluation of the tracheobronchial tree

Prior to opening the trachea by the sectioning of the trachealis muscle dorsally, the external appearance of these large airways should be assessed. Normally the tracheal cartilage rings are a rounded C-shape, and are springy to palpation. Lesions external to the airway are easily noted on routine dissection, but it takes some experience to recognise changes in the springiness of the cartilage rings or alterations in shape. In animals with mural obstructive defects or degeneration of tracheal cartilages, generally there is a loss of tone of the cartilage rings, reflected as excessive flattening of the tracheal profile. Mural or extramural causes for respiratory disease are unusual, and most abnormalities in the tracheobronchial tree reflect inflammatory processes. Typically in these cases, there is exudate in the airway, whose character depends on the type of inflammatory process. Catarrhal to mucopurulent exudates are the most common. A non-specific change common in the tracheobronchial tree is submucosal congestion, and may be so intense to appear haemorrhagic. However, careful evaluation will allow discrimination, because with postmortem congestion digital pressure will cause blanching of the affected area, and the mucosa is intact. Ideally, a thorough investigation of the tracheobronchial tree should include dissection of all the major branches of the bronchial tree. In practice, this rarely done, and if 6 to 8 major bronchial airways are followed to their distal extremities, this is usually adequate to gain a reliable impression as to the health of the major airways, provided major bronchi from both cranial and caudal aspects of the lung are dissected.

Assessment of the peripheral lung

Once lungs are removed from the thorax, both lung fields are visualised, and ready for analysis. Removal of the clamps from the trachea should cause the lungs to collapse further, and a failure to do so generally indicates the presence of lung disease. However, in autolysed cadavers, lung collapse may not occur. The lung parenchyma represents one of the most difficult tissues in the body to examine grossly. Its appearance is greatly influenced by the state of inflation, the amount of blood, the degree of preservation, and by lung disease. It is one of the few tissues where pathologists must rely more on palpation than appearance for clues as to the presence of lung disease. Hyperinflated or emphysematous lungs appear pale, swollen, and are soft and easily

distorted by palpation. Conversely, atelectic lungs are rubbery to firm, and if completely airless, are red to plum coloured. Pulmonary oedema is associated with pale, wet turgid lungs that fail to collapse, and generally frothy stable foam exudes from cut lung surfaces and is present within the airways.

The distribution of lesions is important in discriminating between different forms of pneumonia. Most bronchopneumonias are cranioventral in distribution, contain areas of parenchymal collapse, and typically have mucopurulent to suppurative exudates within airways. Exogenous lipid pneumonias have a similar distribution, and if uncomplicated by secondary sepsis, appear as swollen, pale, yellow to grey, waxy areas of lung. Gangrenous pneumonias also have a cranioventral distribution commonly, but typically are associated with grey to black necrotising lung lesions, pronounced fetid smell and severe pleuritis. Acute interstitial pneumonias, such as those associated with Gram negative septicemia's and acute viral infections often produce blotchy, oedematous, swollen lungs with scattered, variably sized haemorrhages. Upon section, lungs often ooze blood-stained fluid, but major airways are generally clear. In cases of chronic interstitial and bronchointerstitial pneumonia, often caudal lung lobes are mostly affected, these have variable regions of either atelectasis or hyperinflation and affected lungs regions are often pale, firmer than normal, and may have pleural adhesions. When bronchiolar injury is significant, lesions may be seen radiating away from small airways, best identified with cross-sections of lung parenchyma. Because of the large lung size in adult cattle, identifying small lung lesions deep to the pleura may be difficult, and careful palpation of the entire lung is necessary. Irregular regions of discolouration occur commonly as a postmortem change. Discoloured areas are not reliable indicators for good sampling sites for histopathology or microbiology. Therefore, if abnormalities can be detected by palpation, these are preferred to those where only visible changes are evident. Because of the complete lobulation of most ruminant lungs, it is possible to perfuse a sublobar bronchus and uniformly inflate an entire segment of lung. However, injecting formalin into airways under pressure may not produce a well fixed specimen for histopathology if airways are obstructed with exudates, and this mode of fixation induces "fixation artifact" in the interstitial tissues of the lung. Due to the large size of adult cattle lungs, the effects of postmortem congestion and gravitational compression means there are distinct differences between dorsal and ventral and left and right lung fields in typical postmortem specimens. Therefore, a comprehensive sampling technique should include both lung fields, with samples derived from cranial, middle and caudal aspects when no obvious gross lesions indicate a particular pattern of disease.

Pleural disease

Pleural disease is usually the consequence of sepsis, is usually characterised by fluid accumulation, fibrin exudation, adhesions and corresponding lung collapse. Often multiple microbial pathogens can be recovered on culture, especially if pleuritis is associated with gangrene or lung abscessation. Chronic fibrous scars are common on the pleural surfaces of the lungs of older animals.

Evaluation of the nasal cavity

In the laboratory, bisection of the skull along the midline to expose the nasal cavity is a simple matter, but in field postmortems this requires a stout saw or axe, and a strong arm. Once the skull has been bisected, the cartilaginous portion of the nasal septum is easily removed, allowing visualisation of the nasal turbinates. Tissues may require further dissection to evaluate the sinuses, except for the frontal sinus which is easily visualised after bisection of the skull. In postmortem specimens, typically the nasal mucosa is intensely congested, appearing dark-red to almost black. This is generally of no significance, unless there are mucosal lesions accompanying this change. Exudates within the nasal cavity, or focal lesions leading to destruction of turbinates are the usual indicators of nasal disease. The most common disorders include acute infectious disease, although these are generally not sufficiently severe to cause the animals death. Many acute bacterial and viral infections are not grossly distinctive and require additional microbiologic methods for confirmation of diagnosis. Other pathologic changes common to the nasal cavity include abscesses extending from the sinuses, traumatic lesions resulting from dehorning, and developmental anomalies. Neoplastic diseases of the respiratory tract are extremely rare in ruminants within Australia.

PART B: AN ILLUSTRATED GUIDE TO RESPIRATORY PATHOLOGY OF RUMINANTS

Nasal Cavity and Sinuses

Acute diffuse rhinitis/sinusitis

Initial injury results in sneezing and increased nasal discharge. This may be **serous, catarrhal** due to mucus hypersecretion, or **purulent** due to necrotic debris and leucocytes. Oedema and congestion of the epithelium may be pronounced and sufficient to obstruct the nasal cavity. Since there is normally a resident population of bacteria in the nose, and since clearance mechanisms are impaired by epithelial damage, all but the mildest of acute rhinitis cases lead to purulent discharge and bacterial involvement. Rapid and complete recovery is usual.

Causes

- Inhalation of irritant gases, (SO_2, smoke, ozone, pit gases, ammonia, rumen gas) or dusts.
- Respiratory viruses - Infectious bovine rhinotracheitis (IBR), Rhinovirus, Adenovirus, Coronavirus, Bovine virus diarrhea (BVD) (*Figures 11-13*)
- Other viruses - Orf, Papular stomatitis, Vesicular stomatitis, Ulcerative stomatitis, Ephemeral fever, Malignant catarrhal fever, Rinderpest, Bluetongue, FMD
- Bacteria - Pasteurella multocida, Mannheimia haemolytica, Haemophilus somnus, Arcanobacter pyogenes and A.bovis, Fusobacterium necrophorus, Mycoplasma mycoides, Mycoplasma bovis, Chlamydiophila, (*Figure 14*)

The most significant of these is probably IBR. Gross lesions of uncomplicated IBR are restricted to the upper respiratory tract, leading to intense, diffuse mucosal hyperaemia, occasionally fragile transient vesicles and pustules form, but more commonly there is erosion, accumulation of surface purulent exudates and mucosal sloughing. While IBR is mainly a disease of cattle, it can affect a wide range of ruminant species.

Chronic rhinitis/sinusitis

Chronic sinusitis readily develops because the drainage channels from the sinuses into the nose are easily occluded by inflammatory exudate, mucosal oedema and congestion and by contraction of scar tissue. Necrotic debris contained within the sinus, usually with large numbers of bacteria, leads to degeneration and atrophy of the mucosa, mucous cell hyperplasia, fibrosis of surrounding tissues and necrosis and atrophy of supporting bone. As a result there is often gross distortion of the facial bones.

Similarly chronic infections of the nasal cavity lead to mucous cell hyperplasia, squamous metaplasia and epithelial degeneration in the

mucosa. Turbinate bone necrosis, abscesses and atrophy may occur. Chronic granulomatous conditions typically result in proliferative nodular masses that obstruct the airways, cause necrosis of surrounding tissues and lead to distortion of the nose and face. Many chronic nasal conditions have a secondary bacterial component even though bacteria may not have initiated the nasal injury. Common sequelae to chronic nasal disease are

- Extension to the lower respiratory tract.
- Extension through the cribiform plate or sinuses into the brain.
- Emergence of neoplasms

Causes:

- Persisting bacterial infections - Pasteurella multocida, Mannheimia haemolytica,
- Arcanobacter pyogenes, Fusobacterium necrophorum, Actinobacillus ligneriesi, Actinomyces bovis, Histophilus ovis, and Salmonella spp. (*Figure 15*)
- Fungi – Aspergillus, Candida and zygomycetes, Rhinosporidium spp.
- Parasites- Oestrus ovis, Schistosoma nasalis, Syngamus nasicola (*Figure 16*)
- Allergy – chronic allergic rhinitis and nasal granulomata (*Figure 17,18*)

Miscellaneous conditions

- Congenital malformations of the nasal cavity occur sporadically. Craniofacial lesions occur with ingestion of Veratrum during early pregnancy, often leading to severe hypoplasia of naso-maxillary bones and concurrent cyclopia. Cleft palate occurs sporadically and apparently is not always associated with fatal aspiration pneumonia, as implied in the literature. Laterally deviated nasal bones are seen occasionally in goats. (*Figure 19*)
- Rhinitis and more particularly sinusitis arise as a consequence of teeth abscesses, facial trauma and dehorning wounds.
- Foreign bodies, including grass awns and blackberry stems may become lodged in the nasal cavity and are not uncommon in animals with allergic rhinitis.
- Trauma from repeated passage of nasogastric tubes is common in neonates
- Vitamin A deficient animals may develop plaques of squamous metaplasia in the nasal cavity and soft keratin plugs within submucosal glands.
- Primary neoplasms are rare in the nasal cavities of ruminants. However, enzootic ethmoid carcinomas are the exception, and are associated with retroviral infection. The condition is not seen in

Australia. Tumours are soft, fleshy and haemorrhagic and are locally infiltrative. (*Figure 20*)

- Inflammatory polyps, hamartomas and cysts occur sporadically in ruminants but much less so than other species.

Pharynx and Larynx

Acute inflammation of this region is caused by similar pathogens and elicits similar responses to that in the nasal cavity. (*Figure 21*) However, acute inflammation of this region induces fever, bilateral nasal discharge, dysphagia, coughing, alterations in voice, dyspnoea and may lead to suffocation, or aspiration pneumonia. Extension from the eustachian tube into the middle and internal ears leads to deafness, disturbances of balance and may lead to brain inflammation and abscess formation.

Necrotic laryngitis is a condition mainly of feeder calves, associated with distinctive bilateral, rapidly expanding areas of necrosis, usually with a perimeter of intense hyperaemia. (*Figure 22-24*) Animals are typically febrile, have stertorous respiration and may die from suffocation. Lesions are often associated with Fusobacterial infection, thought predisposed by forage containing sharp plant stems or awns. Survivors may recover completely but delays in prompt treatment lead to severe laryngeal scarring and chronic illthrift and dyspnoea.

Contact ulcers occur in feeder cattle and are thought to be initiated by paroxysmal coughing or vocalisation, possibly induced by mild respiratory viral infections or exposure to irritants such as very dusty environments. Superficial bilateral regions of laryngeal necrosis appear initially as grey plaques of devitalized mucosa that may progress to shallow ulcers. (*Figure 25,26*)

Trauma and foreign bodies to this region are common in young and weak animals, often following inexpert attempts at administration of medication by stomach tube or drenching gun. However, other foreign objects such as green apples or potatoes may become lodged in this region. Affected animals often drool saliva, are dysphagic, and may be febrile and toxic if foreign material is implanted retropharyngeally. Infected material may track from the retropharynx into the thorax and lead to fatal mediastinitis or pleuritis. (*Figure 27*)

Tracheo-Bronchial tree

Acute diffuse tracheo-bronchial disease is typically caused by the same agents that cause acute rhinitis, commonly respiratory viruses and bacteria. (*Figure 28-30*)

Chronic disease of conducting airways is frequently associated with Dictyocaulus infection. Sustained injury by worms or other causes leads to a chronic productive cough due to exudate accumulation in the airways. Chronic tracheo-bronchitis results in the gross appearance of

catarrhal to purulent mixed exudates in the airway lumens. (*Figure 31-33*) Abscesses may form in the wall of the airway or may develop pneumonia in the segment of lung supplied by the affected bronchus. (*Figure 34*) In addition, destruction of the airway wall can result in fusiform or saccular dilatations in the bronchial wall, leading to a condition known as bronchiectasis. *Bronchiectasis* (*Figure 35,36*) is an uncommon but serious respiratory condition. It always leads to chronic coughing due to failure to clear exudate from the dysfunctional portion of bronchus. As the area of bronchiectasis enlarges, inflammation spreads to the pulmonary parenchyma and may involve adjacent vasculature. Rupture of affected bronchi can lead to fulminant pneumonia or fatal haemorrhage. It is observed in a variety of bacterial pneumonias, especially tuberculosis and A. *pyogenes* infections, and also in some mycotic and lungworm infections.

Acute Bronchiolitis

Bronchioles are tethered to surrounding lung tissue by fibro-elastic attachments arising in lung parenchyma. They are pulled open as the lung expands and close when the lung collapses. Acute bronchiolitis is a common disease. Grossly, the lung may have focal emphysema or atelectasis, depending on the degree of bronchiolar obstruction. Bronchiolitis is able to be determined grossly in fresh lung specimens as lesions radiating out from the smallest airways discernible by the naked eye, and the presence of watery to foamy exudates within these airways. (*Figure 37-38*)

Causes

- Noxious gases that are inhaled.
- Viral infections, Parainfluenza 3 (cattle, sheep), Bovine respiratory syncytial virus
- Haemophilus somnus and Mycoplasma spp.

Chronic bronchiolitis

Leads to the accumulation of debris and catarrhal exudate in airway lumens, peribronchiolar inflammation and fibrosis. When initial lesions are necrotizing, as with BRSV and Haemophilus infections, granulation tissue may obstruct airway lumens leading to *bronchiolitis obliterans.* Chronic bronchiolitis is a common respiratory injury with mycoplasma infections and lungworm infections with Protostrongylus rufesecens and dictyocaulus spp. Areas of lung affected by bronchiolitis usually have absorbtion atelectasis and low grade pneumonia.

"Sick cilia" (immotile cilia syndromes) are defects in the structure of cilia leading to poorly motile cilia and impaired mucociliary clearance. Affected animals suffer from chronic accumulation of mucus especially in more dependent areas of lung, leading to repeated episodes of obstructive bronchiolitis, pneumonia and eventual severe bronchiectasis. These signs are not specific, but some affected animals may have situs

inversus of thoracic viscera and males have immotile sperm. The syndrome is not recognized in ruminants, but varying degrees of cilial abnormality can be found in every species thus far examined.

Disorders of Alvolar Inflation

Atelectasis

This is partial or complete collapse of the lung due to reduction in the normal amount of air within alveoli. Affected areas are depressed below that of surrounding tissue, dark red, with a rubbery pliable texture.

- *Foetal atelectasis* - Normal in the foetus and to some extent just after birth. Failure of adequate surfactant in premature neonates leads to extensive atelectasis. Lung tissue will not float in fluid. Also seen in stillbirths where the animal is dead prior or during parturition. Grossly, lung is rubbery, plum colored and may be oedematous. (*Figure 39*)
- *Compression atelectasis* - occurs particularly in pleural disease where the pleural space is filled with transudates, blood, exudates, air, or neoplasms or where the thoracic space is reduced because of diaphragmatic hernia or bloat. Mechanical collapse occurs due to lung elastic recoil not being opposed by the thoracic wall preventing collapse.
- *Obstructive atelectasis* (absorbtion atelectasis) occurs with airway blockage by exudates, parasites, or aspirated foreign material, especially in species with poorly developed collateral ventilation to lung lobules. Gas in alveolar segments downstream to an airway obstruction is absorbed. It also occurs with ventilation problems during anaesthesia especially when animals have breathed 100% oxygen. If ventilation becomes inadequate, oxygen is absorbed and the alveoli collapse.

Emphysema

- *Alveolar emphysema* is a permanent, abnormal enlargement of any part of the respiratory acinus accompanied by destruction of alveolar septal tissue and is *rare* in animals. It appears grossly as crepitant pale pink to clear bubbles and cystic spaces in lung tissue. The loss of pulmonary parenchyma tends to be progressive because it hastens premature closure of bronchioles further contributing to air entrapment during exhalation. In humans, it is often associated with protease activity that digests away lung elastic structural elements, but in animals obstructive bronchiolar disease is more common. (*Figure 40*)
- *Interstitial emphysema* - This form describes the escape of air from ruptured alveoli in the interstitial spaces of the perilobular and peribronchial spaces. It is a feature of acute interstitial

pneumonia of cattle caused by allergic or toxic influences, and also seen commonly along with alveolar emphysema in lungworm infections. Air in interlobular septa tracks beneath the pleura, through to the mediastinum at the lung hilus, and finds its way to subcutaneous tissues of the brisket, shoulder or dorsal thoracic regions. (*Figure 41,42*)

- *Bullous emphysema* - In this form there are large cystic cavities that develop in peripheral lung fields usually as a result of local obstructive lung disease.
- *Hyperinflation* is a common lesion where alveoli are overdistended with air as a result of either gas trapping (implies airway obstruction) or compensatory inflation because other areas of lung are unable to receive their full share of the tidal volume. It differs from emphysema in that destruction of the alveolar connective tissue is not the primary mechanism for development of overinflated regions of lung. Hyperinflation is a frequent lesion in animals unlike emphysema, which is uncommon.

Pulmonary Odema

In its least severe form, oedema is a protein free transudate that is exceedingly difficult to diagnose histologically, and is best diagnosed from the gross specimen. With increasingly severe injury, loss of protein and/or blood cells into the lumens occurs and the lumens become filled with a protein rich exudate. If the process is not immediately fatal, washout of surfactant occurs and atelectasis ensues.

- *Cardiogenic* Left sided heart failure leads to increased pulmonary venous pressure. This leads to oedema. There are many causes for left sided or bilateral heart failure, and in dogs a common cause is endocardiosis of the mitral valves. Occasionally chordae tendinae of the mitral valve in racehorses will rupture, leading to massive acute pulmonary oedema; froth bubbles out the mouth and the animals essentially drown in foamy oedema fluid. As oedema develops, it washes surfactant out of alveoli and this increases the risk of alveolar collapse and accelerates the rate of fluid formation in affected alveoli.
- *Permeability oedema* In this form of oedema, the underlying mechanism is damage to the alveolar wall leading to increased permeability. Causes include noxious gases, neurogenic reflexes, anaphylaxis, endotoxaemia, uremia, and oxidative toxins such as paraquat, ANTU and indols.
- *Acute oedema* - causes red, heavy, wet swollen lungs with stable frothy fluid in the airways. The lobular pattern of lung parenchyma is typically accentuated by interlobular oedema. Oedema is also an early component of peracute pneumonias, especially those with concurrent endotoxic injury to the vasculature. (*Figure 43*)

- *Chronic* oedema - lungs become firm and bronze in colour due to interstitial fibrosis and haemosiderosis. Oedema is generally not marked in these cases and lungs are firm rather than wet. Non-cardiogenic causes of chronic diffuse lung oedema are rare.

Congenital Pulmonary Disease

- *Hypoplastic lungs* - These occur occasionally in most species and some are associated with in utero viral infections such as BVD in lambs, and influenza virus infection in pigs. (*Figure 44*)
- *Pulmonary anomalies* - These occur with low frequency. Sometimes lungs develop with missing lobes or abnormal lobation. These are generally of little consequence but sometimes leads to emphysema, atelectasis or pneumothorax due to abnormal relationships between the airways and the lungs.
- *Bronchopulmonary dysplasia* - This is a rare disorder of lungs mainly described in cattle, horses and children. A failure of airway growth into the lung mesenchyme during embryogenesis results in abnormal persistence of embryonic bronchioles which do not form alveoli. Affected portions of lung are solid to cystic with oedematous glandular parenchyma of similar appearance grossly to salivary gland. They may remain asymptomatic but sometimes they become infected, or cystic areas continually expand until they occupy so much of the thorax that they cause cardio-respiratory compromise. (*Figure 45*)

Cor Pulmonale

Although really a cardiovascular condition, vascular remodeling leading to cor pulmonale is a common sequel to lung disease where hypoxia persists. The condition is more common in cattle than other ruminants due to the reactivity of the pulmonary vasculature to hypoxia, and familial susceptibilities also influence the course of the clinical disease. Pulmonary hypertension develops in response to hypoxia, either through chronic lung disease, or from low environmental oxygen tensions encountered when animals graze at high altitude. Affected animals have right sided congestive heart failure, brisket oedema, dilated right hearts and attenuation and thickening of pulmonary arterioles.

Common Types of Pneumonia

Bronchopneumonia

Histologically, inflammation extends from bronchi, down bronchioles, into alveolar lumens leading to clusters of lobules affected by the disease process, hence the associated name of lobular pneumonia. These pneumonic lesions typically reflect the consequence of aerosolized pathogens that affect all levels of the lobule. Often lobular pneumonias are associated with foci of different ages because exudates are coughed up and aspirated into other lobules.

Acute Bacterial Bronchopneumonias

- Usually caused by inhalation of pathogens
- Usually affects lobules of the cranial, middle, accessory, or cranio-ventral aspects of the caudal lobes.

Initially

(i) Heavy red, purplish lungs exuding a frothy purulent to haemorrhagic fluid on incision. Acute inflammatory reaction comprising intra-alveolar edema and haemorrhage accompanied by bacteria and a few macrophages and toxic neutrophils. Edema of interlobular connective tissue with parenchymal areas of necrosis surrounded by degenerate inflammatory cells takes ~ 8-24hours. (*Figure 46-47*)

Within a day or so

(ii) "Red hepatisation" - firm, red, swollen, airless lungs with pink stained froth in airways. (*Figure 48*) Fibrinous pleurisy, with necrotic regions in the parenchyma, mixed with fibrin and pus in alveoli, together with macrophages and neutrophils which may be degenerate to form "oat-shaped" cells, red cells and bacteria. Necrotic foci may eventually become bronchogenic abscesses or form sequestra.

Within a week

(iii) "Grey hepatisation" - fibrinous exudate over pleura, affected areas of lung are firm, airless, swollen, grey and oedematous. Reduced congestion, distended airways and parenchyma full of fibrin and degenerate polymorphs.

After a week

(iv) Resolution (8-10 days) - may be residual fibrous thickening of pleura with adhesions, or residual lung abscesses. (*Figure 49*)

Cattle:

"Shipping fever" Mannheimia haemolytica (*Figure 51-55*) and Pasteurella multocida, Haemophilus somnus
Arcanobacter pyogenes – often abscesses, typically mixed infections.

Sheep

Mannheimia haemolytica ("acute enzootic pneumonia").
Mycoplasma ovipneumoniae ("summer pneumonia")

Chronic bronchopneumonias

Regions of residual chronic bronchopneumonia are common in ruminants following episodes of acute disease. These often progress to regions of bronchiectasis, and bronchogenic abscesses. Sensitive organisms such as Mannheimia may die out when trapped in pus or necrotic material and these organisms may be replaced by anaerobes and Arcanobacterium pyogenes. Therefore cultures may not necessarily give an accurate idea of the initiating cause, even when pathogens are recovered. (*Figure 56*)

Tuberculosis

Mycobacterial infection of the lungs of large ruminants caused by M.bovis remains a global problem, particularly where domestic animals cohabit with feral ruminants that serve as reservoirs of infection. Multifocal granulomatous lesions are found in the lungs and lymph nodes, and these appear grossly as variably-sized yellow, firm foci that contain caseous debris and often visible flecks of mineral. In small ruminants, mineralization may not be as obvious. Tuberculous pneumonia is often seen as solitary to several large primary lesions and scattered daughter lesions or military secondary foci. One explanation for this is that primary lesions often erode into airways and disseminate by aspiration of infected material. In humans, fulminant tuberculosis with severe haemorrhage can occur via similar mechanisms, particularly if major pulmonary blood vessels become eroded. (*Figure 57-60*)

Differential diagnosis includes parasitic granulomas, usually abherrant fluke or cestode larvae, actinomycosis, actinobacillosis or mycotic infections, and Corynebacterium ovis in sheep. (*Figure 61*)

Fibrinous Pneumonia

Frequently this represents the catastrophic expression of fulminant bronchopneumonia. As a consequence of extensive exudation, usually induced by necrotizing diseases, copious fluid spreads rapidly to large areas of lung parenchyma, often involving entire lobes. ***This is therefore also known as lobar pneumonia.*** Typically fibrinous pneumonias have marked interstitial lymphatic thrombosis and the reaction extends to the pleura leading to extensive pleuritis. Causes are often acute bacterial infections, and the potency of bacterial toxins and leukocyte products leads typically to extensive areas of lung necrosis, infarction and often rapid death. If the animal recovers, necrotic infarcted tissue may eventually form a **sequestrum.** Because of the relative resistance of the larger airways to necrotizing toxins and infarctive processes, often the larger airways are relatively well preserved (although filled with exudate) and necrosis begins at the level of the bronchioles. (*Figure 62-64*)

Cattle:
"Shipping fever", Mannheimia haemolytica and Pasteurella multocida in cattle, often complicated by prior viral infections, IBR, BVD, PI_3 and BRSV.
Haemophilus somnus
Mycoplasma mycoides sub mycoides (small colony), occasionally Mycoplasma bovis,

Contagious bovine pleuropneumonia (CBPP) produces a condition similar to the fibrinous pleuropneumonia and pleuritis seen in pneumonic pasteurellosis. However, marbling of the lung is more pronounced due to multiple stages of lobular pneumonia being present, the disease may present more in caudal lung fields, and deposits of fibrin interstitially may be more pronounced. Unlike the leukotoxins, known to be important in

the pathogenesis of pasteurellosis, the pathogenesis of the necrosis in CBPP is thought related to immune-mediated vasculitis.

Sheep:
Pneumonic pasteurellosis also predisposed by prior viral or chlamydial infection.
Mycoplasma ovipneumoniae

Goats:
Similar bacterial pathogens to those of sheep and also Mycoplasma mycoides sub mycoides (large colony)

This condition, contagious caprine pleuropneumonia, causes a respiratory disease similar to CBPP of cattle, as well as polyserositis. However, not all isolates appear similarly pathogenic and the disease does not seem to spread in herds with the same capacity as CBPP does in cattle herds.

Interstitial Pneumonias

Acute interstitial pneumonias - are typically diffuse, lungs fail to collapse properly and are discoloured with blotchy red to grey areas firm areas.

Causes

- Viral diseases including IBR, PI_3 and BRSV. Recently BVD infections leading to interstitial lung disease have been described in cattle.
- Acute bacterial septicaemias (salmonella, listeria, pasteurella, streps and coliforms) particularly in young stock, chamydiophila
- Acute protozoal infection, toxoplasmosis.
- Acute hypersensitivity to lungworm *Dictyocaulus viviparus* larvae in alveoli, or visceral larval migrans of ascarids especially following reinfection. Eosinophils in alveolar exudate, and often eosinophilic bronchiolitis. (*Figure 65*)
- Toxic injury to the alveolar lining, including 3-methyl indole, paraquat, 4-ipomeanol from mouldy potatoes, perilla ketones from purple mint, stinkwood, and brassica species, pyrrolizidines, endotoxaemia and septic shock.

Atypical Interstitial Pneumonia
In cattle, conversion of tryptophan to indols from rumen fermentation occurs. 3-methyl indol is metabolized mainly by type 2 alveolar cells leading to acute dyspnoea, epithelial cell necrosis, oedema, interlobular emphysema, and hyaline membranes. Lungs grossly have widespread areas of red, collapsed, airless and oedematous lobules and pronounced interstitial oedema and emphysema. (*Figure 66-69*) In animals that recover, proliferation of Type 2 cells, fibrosis of hyaline membranes, and chronic inflammation eventually leads to fibrosis. (*Figure 70*)

Chronic interstitial pneumonias
Chronic interstitial lung disease is also usually diffuse and lungs tend to be rubbery to firm, often discolored tan, pale yellow to white, and are often heavy and fail to collapse. In long-standing interstitial disease due to uraemia, lungs may be gritty and white due to extensive dystrophic mineralisation. A similar but rare disorder called **"pumice lung"** occurs when there is extensive mineralization and ossification of lung parenchyma leading to a white inflexible porous lung with the texture and appearance of volcanic pumice.

Causes:

- *Viral diseases*

  Maedi-visna in sheep and CAE in goats. These are lentiviral interstitial pneumonias, Maedi currently exotic to Australia. They are characterized by chronic debilitating lung disease, and affected animals have heavy wet swollen lungs, enlarged lymph nodes and yellow-grey soft consolidation of the parenchyma. In goats infected with CAE, alveolar proteinosis is a distinctive and consistent histologic feature. (*Figure 71-74*)

  Systemic pox infection of sheep and goats - also produce a proliferative interstitial pneumonia. These pox viral infections are exotic to Australia and are distinct from Orf.

  Pulmonary adenomatosis of sheep. (Jaagziekte) This condition is mentioned here because of its similar gross appearance to Maedi. Sheep are affected by a proliferative pneumonia where there are papillary growths of the bronchiolar and alveolar epithelium and diffuse granulomatous inflammation. These epithelial proliferations become neoplastic and may metastasize. The disease is caused by a retrovirus. Jaagtziekte differs from CAE and Maedi (which are also proliferative interstitial pneumonias) in that it is principally a neoplastic process. However, both Maedi and Jaagtziekte may occur in the same animal. Grossly Jaagsiekte resembles Maedi in that lungs are swollen and oedematous due to accumulation of epithelial secretions, and pale, grey to white soft multifocal areas of consolidation are present, representing areas of chronic granulomatous pneumonia and sites of epithelial proliferation.

- *Farmers lung.*
  Chronic hypersensitivity reactions leading to interstitial pneumonias are most common in mature dairy cattle, probably induced by hyper-responsiveness to thermophilic mould spores. Similar conditions have been attributed to recurrent BRSV infections in cattle and allergic reactions to Dictyocaulus viviparus larvae. Affected individuals have solid, often multifocal areas of grey lung tissue corresponding to noncaseating granulomas and lymphoid infiltrates. (*Figure 75-76*)

- *Interstitial parasites* such as Muellerius capillaris in sheep and goats

- *Pneumoconiosis* from silica or other inhaled lung irritants

- Persisting lesions from acute interstitial pneumonias.
- Chronic congestive heart failure.

Broncho-Interstitial Pneumonia

This is also commonly called "cuffing pneumonia", because cellular infiltrates inolve the smaller airways and the lesions extend into lung parenchyma affecting alveolar walls as well as some exudation into alveolar lumens. The histologic lesions are distinct from the typical inflammatory reactions seen in the suppurative bronchopneumonias commonly seen in ruminants.

Causes
These types of pneumonic reactions are typically seen with uncomplicated mycoplasmal infections, (*Figure 77-79*) also less severe Haemophilus somnus infections, with BRSV infection and lungworm. (*Figure 80*)

> **Bovine respiratory syncitial virus infection.** - BRSV may be indistinguishable from a number of other infectious causes of respiratory disease, but sometimes it produces rather characteristic gross lesions. Cranioventral lung regions are often meaty, reddish-brown and airless. Careful close examination on sectioning may show a necrotizing bronchiolitis with radiating areas of pneumonia (broncho-interstitial pattern). In contrast, caudal lung lobes are often red, swollen and oedematous, often with severe interstitial to bullous emphysema. (*Figure 81-84*) Bronchiolitis obliterans may be a feature of both BRSV and Haemophilus somnus infected lungs during resolving phases, but is not a typical feature of other causes of broncho-interstitial pneumonia.

Embolic Pneumonia

Pathogenic material arriving via the pulmonary circulation will not pass through the lungs if it exceeds 12µm. Pasteurella septicemia in lambs, and streptococcal septicemias lodge in the lungs because bacteria clump together, enmeshed in fibrin. With acute septicemic salmonellosis in calves and pigs, localization is probably due to phagocytosis by intravascular macrophages. These lesions are typically diffuse if bacterial emboli are small,fragile and easily dispersed. Under other circumstances, embolic lesions tend to be multifocal to miliary, distributed mainly to the caudal lung fields and may be acute or chronic. Embolic lung disease lesions are typically those of intrapulmonary haemorrhage and necrosis, abscess or granuloma formation and occasionally extension to the pleura. (*Figure 85-86*)

Postcaval syndrome in cattle illustrates this type of process, where contents of ruptured liver abscesses embolise in the lungs. (*Figure 87, 88*) Generally this does not lead to lung infarction, because the lungs have a dual blood supply and are relatively resistant to vascular

compromise. However septic emboli cause destruction of local blood vessels and alveolar walls leading to severe haemorrhage. Other common causes of embolic pneumonia in ruminants occur following jugular phlebitis, valvular endocarditis or mycotic rumenitis. (*Figure 89, 90*)

Gangrenous Pneumonia

This lesion is often the sequel to acute aspiration and the initial lesion is severe bronchopneumonia. (*Figure 91-94*) However, the presence of putrefactive bacteria in the aspirate extends the lesion causing necrosis, cavitation and gangrene. (*Figure 95-96*) Not all cases of aspiration pneumonia turn gangrenous, but typically aspirated ingesta in ruminants causes gangrene. Occasionally, penetrating wounds, aspirates from necrotic upper airway lesions or penetration from the reticulum in ruminants leads to gangrenous pneumonia. Grossly, gangrenous lesions appear as lobar pneumonias with blue, cyan or black discoloured areas with necrosis, foul smell, cavitation, emphysema, and copious fibrinous, purulent to bloody effusions in the pleural cavity.

Lipid Pneumonia

Gelatinous gray to white areas of interstitial pneumonia occur in lungs with lipid pneumonia, provided that the lipid is of vegetable origin. Mineral and animal derived lipids tend to produce more inflammation, and because lipid typically arrives by aspiration, lesions are usually cranioventral and sometimes gangrenous, because of concurrently aspirated bacteria. However, sometimes endogenous lipid pneumonias occur, mostly following emboli of bone marrow subsequent to fractures in ruminants.

Foetal Pneumonia

The normal foetal lung is red, airless and rubbery and the larger airways contain clear to slightly sanguinous viscous fluid. Mostly, foetal pneumonias are bronchopneumonias due to inhalation of infected amnion. Exaggerated respiratory movements probably draw amnion into the lungs in excessive amounts when foetuses are hypoxic or stressed. In addition, foetal distress may cause contamination of the amnion with meconium. Bronchopneumonias in fetuses do not have a cranial distribution. Gross lesions may be very subtle and easily missed. In addition to this mechanism, haematogenous infection also leads to foetal pneumonia. Tiny multifocal areas of necrosis or microabscesses may be evident in lung parenchyma, sometimes there are widespread petechia and in a few cases, purulent to fibrinous exudates are evident in the larger airways. (*Figure 97-98*)

Causes

- *Viruses*, IBR, PI_3, and some of the exotics
- *Bacteria*, Brucella spp., Listeria, Campylobacter, Salmonella, Chlamydiophila and Arcanobacterium

- *Fungi*, Aspergillus and Mortierella
- *Protozoa*, toxoplasma, sarcocystis and neospora

Verminous Pneumonias

Infestation with nematodes produces distinctive lesions in the lungs of ruminants as previously described. Abherrant fluke or cestode larvae usually produce gritty subpleural granulomas that may contain green caseous material. Over time these may shrink down and mineralize extensively. Hydatids also produce distinctive lesions with viable cysts often lined by translucent membranes (*Figure 99, 100*) while degenerate parasites form granulomas and fibrous scars.

Pleuritis

This is common in ruminants, usually secondary to infectious causes of pneumonia, or following aspiration and gangrene, or in cattle associated with hardware disease.

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