Gross Pathology of Ruminants

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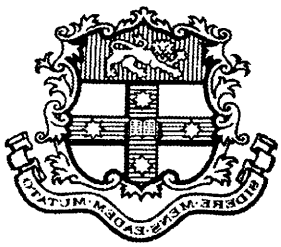

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He has supervised over 25 graduate students, many from overseas countries. His research collaborations included joint projects with Japanese researchers on the epidemiology of echinococcosis (hydatid disease); with PNG and Indonesian vets on the epidemiology of animal trypanosomiasis ("surra"); consultancies in PNG on parasitic diseases of farmed crocodiles; and

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Following graduation from the University of Sydney in 1963, Prof. Huxtable worked in mixed practice in NSW and the UK. Following this Clive began his PhD in the Department of Veterinary Pathology at the Univeristy of Sydney where he became interested in a career in pathology. Clive then spent time at Werribee working under KV Jubb and Peter Richards, and then moved to Murdoch Univeristy where he stayed for 23 years. Between 1980 and 1996 he made several extended visits to the College of Veterinary Medicine, Cornell University, where in 1999 he then accepted a 3 year contract as head of anatomoic pathology. This contract concluded in 2002, but Clive will be returning to Cornell as a visiting professor for three months in 2003 and possibly in 2004.

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Dr McKenzie graduated from the University of Queensland School of Veterinary Science in 1971. He is now a Senior Principal Veterinary Pathologist in the Queensland Department of Primary Industries' Animal Research Institute at Yeerongpilly where he has worked n diagnostic pathology and research on diseases of commercial livestock since 1973. He is a registered Specialist in Veterinary Pathology, Curator of the Queensland DPI Natural Toxins Database and holds an appointment as Part-Time Senior Lecturer at the University of Queensland where he presents the clinical toxicology course to veterinary undergraduates. He was awarded the Australian Veterinary Association Excellence in Teaching Award for 2002. He has authored over 100 scientific publications and earned the degree of Doctor of Veterinary Science from the University of Queensland in 1992 for his contributions to veterinary toxicology and pathology. Ross deals with over 300 enquiries on plant poisoning each year from the public and from professional colleagues. He has just personally published his lecture notes, Toxicology for Australian Veterinarians, (over 700 pages illustrated with coloured images of over 100 plants) on CD for students and veterinarians.

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Tony Ross BVSc MSc PhD

Tony is a registered specialist in veterinary pathology with 28 years experience in anatomical pathology of ruminants. He has worked in private practice, universities and government laboratories. His PhD studies were on intestinal carcinoma in sheep. He is currently senior veterinary research officer in the Regional Veterinary Laboratory, NSW Agriculture Menangle. In 1998 he received the AVA's Seddon Prize for a significant contribution to veterinary pathology.

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Prof. Ronald F. Slocombe BVSc Melb MVS PhD Mich SU ACVP MACVSc

Ron graduated at the University of Melbourne. He then spent two years in Canada, working in mixed practice, followed by a stint at Michigan State University for graduate work. He subsequently stayed on as a faculty member. He returned to the University of Melbourne in 1986 to a faculty position and assumed the Chair of Veterinary Pathology when Ken Jubb retired. Ron has published over 100 scientific articles with the majority of these involving pathology of the respiratory system.

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Keith Thompson BVSc PhD Diplomate ACVP

Keith is currently an Associate Professor and Head of the Pathobiology Section in the Institute of Veterinary, Animal & Biomedical Sciences at Massey University. He achieved a BVSc (1972) and PhD (1976) from Massey University and spent five years in North America (at Ontario Veterinary College and Texas A&M), during which time he became a Diplomate of the American College of Veterinary Pathologists. Although interested in all aspects of veterinary pathology, he has a special interest in skeletal diseases and has authored five book chapters related to this topic. As a weekend farmer, Keith and his wife have been running Angora goats, in addition to sheep and cattle, for the last 20 years, hence an interest in diseases of goats. In 1990 Keith was Technical Coordinator for the refresher course on Goat Health & Production run by the Post Graduate Foundation of Veterinary Science of the University of Sydney.

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Keith Walker BVSc, PhD
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Gross Pathology of Ruminants

9-11 April 2003
Elizabeth Macarthur Agricultural Institute

Wednesday 9 April 2003

9.00am – 10.00am Keith Thompson

Alimentary Tract

This lecture will be an illustrated review of gross lesions of infectious and non-infectious diseases of the alimentary tract in cattle, sheep and deer. The emphasis will be on diseases of importance to Australia and New Zealand. The selection of samples for laboratory testing will also be discussed.

10.00am – 10.30am Morning Tea

10.30am – 11.10am Keith Thompson

Bones/Joints

The diagnosis of skeletal diseases is perhaps more dependent on gross examination than is the case for any other organ system. This lecture will present a review of the gross lesions of a range of infectious and non-infectious diseases of bones and joints, including discussion of inherited skeletal diseases. The selection of appropriate samples for laboratory testing will also be discussed.

11.10am – 11.50am Phil Ladds

Lymphorecticular System

Although all elements of the lymphoreticular system will be covered, emphasis will be on lymph nodes, largely because of their significance in traditional meat inspection. Important gross features of the "normal" lymph node will first be addressed, noting the effect of age, then general reactions, non-infectious/non-neoplastic changes, lymphadenitis, and neoplasia, will be considered.

11.50am – 12.30pm Roger Cook

Cardiovascular System

A systematic approach to gross examination of the cardiovascular system and lesions associated with specific diseases will be illustrated.

12.30pm – 1.30pm Lunch

1.30pm – 2.30pm Roger Kelly

Liver

"Liver lesions are very common; clinical illness due to liver disease is relatively rare". I think I once used this statement as the basis for a searching undergraduate examination question and, in consequence, had to wade through an awful lot of irrelevant verbiage from students who had missed the point. But during these workshops I think the quote will serve better to highlight the problems of distinguishing incidental from significant gross liver pathology. A practical session using abattoir material will help reinforce the principles that will be presented.

2.30pm – 3.30pm Keith Walker

Practical Session

The Post Mortem – Technique, equipment and collection of samples, demonstration and practice *3.30pm – 4.00pm Afternoon Tea*

4.00pm – 5.00pm

Practical Session Continued..
Examination of the alimentary tract and collection of samples for Johne's Disease - Keith Thompson and Keith Walker
The Liver – Roger Kelly
Examination of the Heart – Roger Cook

Thursday 10 April 2003

9.00am – 10.00am Phil Ladds

Reproductive Tract

Included in the lecture will be a discussion on how best to obtain the reproductive tract at a necropsy or slaughter, followed by a description of a standardised procedure for dissection and examination of both male and female tracts. Also, covered will be a consideration of what specimens need to be collected, and in what manner, to permit further laboratory investigations.

10.00am – 10.30am Morning Tea

10.30am – 11.10am Roger Cook

Foetal and Neonatal Diseases

The gross lesions associated with diseases of the foetus and neonate will be illustrated

11.10am – 11.50am Keith Walker

Skeletal Muscles

This session will focus upon the gross pathological findings in congenital, degenerative, inflammatory and neoplastic diseases of ruminant skeletal muscle. Photographs and fresh specimens will be used to illustrate key points.

11.50am – 12.30pm Tony Ross

Skin

A large diagnostic potpourri of developmental, deficiency, toxicological, bacterial, fungal, viral, parasitic, photobiological, neoplastic and foreign body conditions of the skin of sheep, goats, cattle, deer and camelids including the important vesicular diseases will be presented.

12.30pm – 1.30pm Lunch

1.30pm – 2.30pm Deborah Middleton

Exotic Diseases

Australia prides itself upon its freedom from many major diseases of economic livestock. If any of these diseases gain entry to the country, early recognition by field veterinarians will be of paramount importance in our efforts at eradication. The information and pictorial material presented during this session will greatly enhance your ability to recognise these diseases in the paddock on the farm.

2.30pm – 3.30pm Ron Slocombe

Respiratory System

Respiratory diseases can cause major economic losses in different livestock production systems, particularly the cattle feedlot industry. Important diagnostic clues can often be obtained by a detailed gross examination of the respiratory tract. During this session, an exciting interactive learning process will considerably hone your skills in this area.

3.30pm – 4.00pm Afternoon Tea

4.00pm – 5.00pm Keith Thompson

Goats

Many goat farmers in Australia and New Zealand do not feel well served by the veterinary profession. In fact, some of them consider that they know as much about goat diseases as their veterinarian. Whether or not this is true, it is fair to say that most veterinarians are less familiar with diseases of goats than with diseases of other ruminants. Furthermore, the

published literature is not always helpful. Goats are more susceptible to some diseases than sheep and cattle, and less susceptible to others. They also have some diseases of their own. This lecture will present an illustrated review of goat diseases by a pathologist, who has been farming goats for the last 20 years.

Friday 11 April 2003

9.00am – 10.00am Clive Huxtable

Nervous System

The illustrated presentation will cover the diseases of the brain and, to a lesser extent, those of the spinal cord. Amongst others, "old favourites" such as polioencephalomalacia, focal symmetrical encephalomalacia, bacterial meningoencephalitis and phalaris staggers, will be included. The session will commence with a demonstration of how to locate key landmarks in the brain. Discussion then will focus upon where lesions may be found, how they may be recognised and how they reflect the nature of the disease process.

10.00am – 10.30am Morning Tea

10.30am – 11.10am Roger Kelly

Systemic Conditions Such As Anthrax, Tick Fever And Clostridial Diseases

Gross post-mortem findings in severe systemic diseases such as septicaemias, tick fevers and clostridial toxaemias are often confusingly non-specific. This is in part due to the acute nature of these conditions, which allows insufficient time for more localised and specific lesions to develop. Another reason is the final common pathways of circulatory shock and disseminated intravascular coagulation that help kill the animal. This presentation will offer a deductive approach to interpretation and diagnosis of these cases, and will attempt to demonstrate how this approach can influence decisions about their subsequent management.

11.10am – 11.50am Clive Huxtable

Urinary Tract

The location and recognition of important lesions and the nature of the underlying disease process will be addressed. Amongst the conditions to be covered will be urolithiasis, acute nephrotoxicity, nephritis, "white spotted kidney", amyloidosis, enterotoxaemia and lymphoma.

11.50am – 12.30pm Stephen Love and Gareth Hutchinson

Parasitic Diseases

The presentation will concentrate upon the gross pathology and diagnosis of gastrointestinal helminthosis in ruminants, with special emphasis on the economically important parasites of sheep, goats and cattle. Descriptions of the diseases will be augmented by transparencies/images, and by demonstrations in a practical session.

12.30pm – 1.30pm Lunch

1.30pm – 2.30pm Ross McKenzie

Plant Poisonings

Plant poisonings are often the last resort of the diagnostically destitute but they can cause spectacular losses amongst grazing ruminants. This session will cover most of the major plant toxicoses found in Australasia. Gross pathological findings will be highlighted but some information on pathogenesis and identification of plants also will be covered.

2.30pm – 3.30pm

Practical Session

Field parasitology techniques – Steven Love

Examination of lungs – Ron Slocombe

3.30pm – 4.00pm Afternoon Tea

4.00pm – 5.00pm

Practical Session Continued

Examination of reproductive tracts – Phil Ladds
Removal of brains for TSE exclusion – Roger Cook

Table of Contents

Chapter 13

The Nervous System

Clive Huxtable

Chapter 14

Acute Systemic Conditions: Diagnosis and Management of Sudden Death in Ruminants

Roger Kelly

Chapter 15

The Urinary System

Clive Huxtable

Chapter 16

Pathology and Diagnosis of Internal Parasites in Ruminants

Stephen Love & Gareth Hutchinson

Chapter 17

Necropsy Findings in Ruminant Poisonings by Plant, Fungal, Cyanobacterial and Animal-Origin Toxins in Australia

List of Figures

Figure

List of Tables

Table

List of Images (Chapter 11)

18. Nasal granuloma, ox. Large polypoid masses are evident in this case, either side of the nasal septum. **(page 222)**

19. Cleft palate ox. Note the granulomatous rhinitis in the nasal tissues above the defect. This specimen was an aged cow, that had apparent lived a relatively normal life, despite the severity of this defect. **(page 222)**

20. Enzootic ethmoid carcinomas, sheep. Image from Ellis and Rosadio, Comp. Cont. Ed. Prac Vet. February, Intranasal tumour in a ewe, 6: S61-S63, 1984. **(page 223)**

21. Acute erosive laryngitis, IBR. **(page 223)**

22. Symmetrical ulcero-necrotic lesions, necrotic laryngitis, calf. **(page 224)**

23. Intense congestion and severe lesions, necrotic laryngitis calf. **(page 224)**

24. Necrotic laryngitis, calf. **(page 225)**

25. Contact ulcers, larynx, calf. **(page 225)**

26. Contact ulcers, vocal folds, calf. **(page 226)**

27. Foreign body, plant awn, larynx, calf. **(page 226)**

28. Acute IBR, trachea, calf. **(page 227)**

29. Acute IBR, trachea, calf. Note extensive mucosal congestion and haemorrhage, and a few tiny pustules. **(page 227)**

30. Diphtheritic tracheitis, IBR, calf. **(page 228)**

31. Mucosal erosions, necrotic material within tracheal lumen, IBR, calf. **(page 228)**

32. Lungworm, Dictyocaulus, sheep, showing raised obstructed areas filled with mucus. Sheep. **(page 229)**

33. Opened airway from figure 32 showing worms in large airways. **(page 229)**

34. Lung collapse and bronchogenic abscesses. **(page 230)**

35. Chronic bronchitis with extensive scarring and bronchiectasis, ox. **(page 230)**

36. Bronchiectasis with accumulated exudates in sacculated airways, fixed perfused lung specimen. **(page 231)**

37. Acute pneumonia with necrotising bronchiolitis, Haemophilus somnus. **(page 231)**

38. Section of lung from Figure 37 showing acute purulent bronchiolitis and pneumonia. **(page 232)**

39. Foetal atelectasis. In this lung, there is also severe oedema. **(page 232)**

40. Localised alveolar emphysema with small subpleural bulla, secondary to bronchitis, ox. **(page 233)**

41. Severe interstitial emphysema, atypical interstitial pneumonia (AIP) ox. **(page 233)**

42. Lung section illustrating interstitial emphysema, AIP. **(page 234)**

43. Severe pulmonary oedema secondary to cardiac insufficiency, white muscle disease. **(page 234)**

44. Hypoplastic and malformed lungs from lambs. **(page 235)**

45. Bronchopulmonary dysplasia. In this example the lung is fleshy and solid, but in other cases they are often cystic. **(page 235)**

46. Acute pneumonic pasteurellosis, 6 hrs post experimental infection (Mannheimia haemolytica) calf. **(page 236)**

47. Acute bronchopneumonia, Mannheimia haemolytica.**(page 236)**

48. Red hepatisation, bronchopneumonia, Mannheimia haemolytica. **(page 237)**

49. Chronic bronchopneumonia with bronchogenic abscesses, steer. **(page 237)**

50. Lung collapse and severe bronchiolitis, H. somnus. **(page 238)**

51. Lung collapse and severe acute bronchiolitis, H. somnus. **(page 238)**

52. Necrotising bronchiolitis, and pneumonia, H. somnus. **(page 239)**

53. Acute bronchopneumonia, H. somnus. **(page 239)**

54. Acute bronchopneumonia, multiple sections to illustrate bronchiolar pattern. H. somnus. **(page 240)**

55. Histology of necrotising bronchiolitis, H. somnus. **(page 240)**

56. End stage of chronic bronchopneumonia. Multiple abscesses in cranioventral lung fields, sheep. **(page 241)**

57. Granulomatous bronchopneumonia, tuberculosis, ox. **(page 241)**

58. Granulomatous pneumonia, tuberculosis, ox. **(page 242)**

59. Caseating granulomas, with mineral fleck, tuberculosis, lung, ox. **(page 242)**

60. Chronic granulomatous pneumonia with extensive scarring, tuberculosis, lung, ox. **(page 243)**

61. Necro-haemorrhagic focus, liver fluke, ox. **(page 243)**

62. Acute infarcts, Shipping fever, calf. **(page 244)**

63. Histology illustrating pulmonary sequestra, fibrinous pneumonia, shipping fever, steer. **(page 244)**

64. Typical appearance of fibrinous pneumonia, lung section. **(page 245)**

65. Visceral larval migrans, sheep lung. **(page 245)**

66. Typical stance for severely dyspnoeic animal, AIP. **(page 246)**

67. Interstitial emphysema and acute pneumonia, AIP. **(page 246)**

92. Acute aspiration pneumonia. **(page 259)**

93. Acute necrohaemorrhagic pneumonia following accidental drenching. **(page 259)**

94. Early gangrenous pneumonia. **(page 260)**

95. Gangrenous pneumonia and pleuritis. **(page 260)**

96. Gangrenous pneumonia with rupture and cavitation of necrotic lung. **(page 261)**

97. Foetal pneumonia and multifocal hepatic necrosis, campylobacter, aborted lamb. **(page 261)**

98. Foetal pneumonia and fibrinous pleuritis, septicaemia. **(page 262)**

99- 100 Hydatid cysts, lungs and liver. **(pages262 and 263)**

Chapter 1

Alimentary Tract

Keith Thompson

Introduction and general comments

Diseases of the alimentary tract are common in ruminants, often resulting in either death or significant loss in productivity. In many cases, an accurate diagnosis will require postmortem examination of one or more recently dead or sacrificed animals. The alimentary tract should be given special attention in cases where diarrhoea and/or illthrift are characteristic features of the clinical syndrome, although a range of other presenting signs, including sudden death, may be associated with gastrointestinal diseases. Gross lesions are sometimes sufficiently specific to allow a definitive diagnosis, but even an experienced pathologist will often require ancillary tests. The challenge for practitioners is in knowing when to make a diagnosis on gross lesions alone, and how to make cost-effective use of laboratory services.

Examination of the lower alimentary tract, because of its accessibility on opening the abdominal cavity, is a routine part of most postmortem examinations, but the upper alimentary tract is often neglected. Lesions of diagnostic significance may be present in the oral cavity or oesophagus and could be overlooked if these regions are not checked.

At the risk of stating the obvious, it is important that practitioners performing postmortem examinations are aware of the normal structures and species variations in the different regions of the alimentary tract, as well as the range of artefactual changes that may accompany autolysis. Furthermore, the predilection of some diseases for certain regions of the alimentary tract, and other organ systems, must be recognised if appropriate samples are to be collected for microscopic or microbiological examination. These topics will be considered below in the relevant sections.

Autolysis proceeds rapidly in the lower alimentary tract because of its mixed bacterial flora and the presence of lytic, digestive enzymes. Subtle changes at the gross and microscopic level can soon become masked by autolysis. In general, the chance of making an accurate diagnosis of enteric disease is much greater if the necropsy is performed within a few hours of death. If the problem is occurring on a herd or flock basis then the best option may be to convince the farmer to sacrifice one or two animals for immediate examination rather than waste time and money on those that have been dead for 12-24 hours.

Special care must be taken when collecting samples for submission to a laboratory. The mucosa throughout much of the alimentary tract is readily damaged by rough handling and if histopathology is required then

it is important to select areas that have not been handled excessively. Ideally, the lumen should be opened to allow rapid penetration of fixative. Since infectious diseases are often regional, several segments of bowel should be submitted, even if the laboratory does not choose to examine them all. It makes sense to collect specimens for microbiology during the early stages of the necropsy in order to minimise the risk of contamination. Some laboratories prefer to receive swabs in culture media while other may be content with tied-off loops of bowel. In cases where worm counts are required, the abomasum and intestines should be opened into a tray or bucket to avoid loss of contents. Any specimens submitted to a laboratory should be accompanied by a description of the clinical syndrome and gross findings.

The intent of this paper is to review the gross pathology of selected diseases of the alimentary tract of ruminants, emphasising differential diagnoses for common lesions. Due to time constraints the list is not complete and the emphasis is on diseases of significance to Australia and New Zealand. For convenience, the diseases and lesions will be considered on a regional basis with brief, general comments at the start of each section. Although there are several important exotic diseases characterised by lesions in the alimentary tract, these will be discussed in a separate presentation at this seminar.

Oral cavity, Oesophagus and Forestomachs

General considerations

The oral cavity should be opened routinely to expose the hard palate, tongue, teeth and pharynx. In young animals the mandibular symphyses can be easily separated with a knife but in adults this will require the use of a saw or large bone-cutters. The mandibles can usually be disarticulated and the tongue reflected by cutting along either side, then through the hyoid apparatus. The oesophagus should be opened along its entire length after removal of the pluck, as lesions of diagnostic significance may be concentrated at one end or the other. When opening the forestomachs, make note of the nature of the contents and, if plant poisoning is a possibility, collect any leaf fragments for later identification. The green-stained mucosa of the rumen normally detaches readily within a few hours of death. Failure to do so suggests the possibility of chemical rumenitis or healed lesions of mycotic or bacterial rumenitis. The mucosa is best viewed after it is washed with running water.

Congenital and inherited anomalies

Congenital diseases such as brachygnathia inferior and cleft palate occur in all species, sometimes in association with other defects (or together). **Cleft palate** is more common in calves than in lambs and is probably inherited in some cases. The challenge is not in making the diagnosis, as the lesion is obvious, but in knowing what advice to give the client. A

genetic aetiology has been reported in the Charolais and Hereford breeds and should be suspected when several affected calves have been born to a particular sire in a season, or over several seasons. Most cases occur sporadically and the aetiology is never determined. Any exposure to potential teratogens would have occurred early in pregnancy and is unlikely to have been noticed.

Brachygnathia inferior (micrognathia) is also more common in calves than in lambs and may be inherited as an autosomal recessive trait. The defect may also be linked to other genetic abnormalities, including osteopetrosis in calves and osteogenesis imperfecta in lambs. Examination of the bones may therefore be warranted in affected animals.

Extensive loss of epithelium from the hard palate and tongue occurs in newborn Angus calves with **familial acantholysis** and Suffolk lambs with **epidermolysis bullosa**. Both disorders are inherited as autosomal recessive traits and are also characterised by loss of skin over pressure points and shedding of hooves. The oral lesions are no doubt related to detachment of the defective epithelium during sucking.

Tooth problems

The importance of abnormalities in **molar teeth** as a cause of ill thrift in sheep (and cattle) is probably underestimated. Such abnormalities include impaction of food in deep tooth sockets, loosening and/or loss of teeth, and recession of gums. In some cases, the maxilla or mandible is swollen due to chronic osteomyelitis. In a recent survey of ill thrift in sheep on a large property in New Zealand, lesions involving molar teeth were considered to be the primary cause of weight loss in several cases. In cattle, infection of the mandible or maxilla by *Actinomyces bovis,* an obligate parasite of the oral cavity, may lead to massive enlargement of the bone, (so-called **"lumpy jaw"**). The organism presumably gains access to the underlying bone by lymphatic drainage from ulcerative lesions in the oral mucosa or by tracking down tooth sockets.

Pitting, yellow/brown discolouration and irregular wear of incisor teeth is a characteristic feature of **fluorine toxicity** in cattle. Only those teeth exposed to excess fluorine during enamel formation are affected. Consequently, some incisors may be normal while others are severely affected, but the lesions are always symmetrical. Uniform red/brown pigmentation of all teeth occurs in cattle with **erythropoietic porphyria**, a rare inherited disease of certain breeds. Pigmentation of teeth does not occur in the erythropoietic protoporphyria of Limousin cattle. The molar teeth of ruminants are normally covered by a dark black/brown layer of tartar due to impregnation of mineral salts with chlorophyll and porphyrin pigments of dietary origin. This should not be misinterpreted as a lesion.

Enamel hypoplasia characterised by patchy absence of enamel and discolouration of the exposed dentine, in newborn calves is associated with intrauterine infection by bovine viral diarrhoea (BVD) virus.

Lesions caused by infectious agents

Bovine papular stomatitis, caused by a parapoxvirus, is a common disease of young calves characterised by the formation of papular to shallow erosive lesions on the muzzle, nares, gums, hard palate, ventral and lateral surfaces of the tongue, and occasionally in the oesophagus. The lesions are typically circular and often have a raised, pale margin. The disease is not clinically significant and the lesions heal rapidly, but several waves of new lesions may appear over a period of a few months.

Infection of sheep and goats with a closely related parapoxvirus results in **contagious ecthyma** (orf, scabby mouth). Although the lesions typically occur around the lips, face and feet, they may also extend into the oral cavity, involving the tongue, gums, dental pad and hard palate. Oral involvement is more common in goats than in sheep. The lesions are more proliferative than those of bovine papular stomatitis, and are more likely to be clinically significant, especially in suckling animals. Oral lesions are less likely to develop a scabby surface than those on the lips or skin and usually appear as raised, red coalescing areas on the tongue or around molar teeth. On rare occasions, similar lesions are found in the forestomachs of sheep, goats and deer. Deer may also develop lesions associated with parapoxvirus infection on their antler velvet.

Parapoxvirus infections in cattle, sheep or goats can usually be based on gross lesions, but histopathology may be useful in equivocal cases. Laboratory demonstration of typical parapoxviral particles using electron microscopy can also allow rapid confirmation.

Papillomatosis induced by bovine papillomavirus are very common on the skin of young cattle and occasionally occur in the oesophagus and/or forestomachs. The lesions may appear as smooth-surfaced nodules or consist of multiple closely packed fronds of squamous epithelium.

Mucosal disease, caused by superinfection of immunotolerant, seronegative cattle (persistently infected with non-cytopathic BVD virus) with a cytopathic strain of **BVD virus**, typically causes extensive erosive lesions throughout the oral cavity, oesophagus and forestomachs. Erosive lesions may also be present on the muzzle and nares. The severity and distribution of lesions vary markedly, depending on the stage of the disease at which the animal dies or is killed. In the acute stage, multiple, irregular-shaped erosions with a red base are usually present on the hard palate and tongue. Papillae on the buccal mucosa may be blunt and hyperaemic. Oesophageal erosions are typically linear, and may extend throughout the entire length but are more common in the proximal third. Fragments of necrotic epithelium are sometimes loosely adherent to oesophageal erosions. Plaque-like lesions or erosions are often present in the reticulorumen. Holes in omasal leaves may represent chronic lesions of mucosal disease. Mucosal surfaces heal rapidly and the oral or oesophageal lesions in animals that survive the acute stage of mucosal disease but die a week or so later are much less impressive. In such cases, the margin of the erosions will be slightly elevated due to

proliferating epithelial cells and the base will be pink or white rather than red due to the presence of a thin layer of new epithelium.

Lesions of mucosal disease may also be detected in the lower alimentary tract. In particular, there may be multiple, discrete, dark red ulcers on abomasal rugae. The small intestinal mucosa is often normal grossly but haemorrhage and/or necrosis of Peyer's patches may be present in acute cases. Peyer's patches may be visible from the serosal surface as dark red, elongated foci and fibrinonecrotic exudate may be adherent to the overlying mucosa. In chronic cases, the Peyer's patches may be either indistinct or even sunken below the adjacent mucosa. Colonic lesions of mucosal disease vary from fibrinohaemorrhagic inflammation in acute cases to multifocal cystic change in some chronic cases. The cysts represent markedly dilated glands that have herniated into necrotic submucosal lymphoid follicles and become filled with mucus.

BVD virus attacks rapidly dividing cells, including epithelial cells in the base of intestinal crypts and lymphoid cells in germinal centres. The most characteristic microscopic lesions of mucosal disease are therefore in the small and large intestine and in lymphoid tissues. Immunoperoxidase staining of sections of intestine for BVD antigen is now commonly used by veterinary pathologists to support a histological diagnosis.

BVD infection in immunocompetent cattle exposed to the virus for the first time results in a milder, non-fatal clinical syndrome characterised by lethargy, anorexia, oculonasal discharge and diarrhoea. Shallow erosions may be present in the oral cavity.

The severe gross lesions of mucosal disease are indistinguishable from those of **rinderpest**. This highly infectious disease is exotic to Australia and New Zealand and will be discussed in a separate paper.

The principal differential diagnosis for mucosal disease in countries without rinderpest is **malignant catarrhal fever (MCF)**. Similar lesions may be present on the tongue, hard palate and oesophagus, but are usually deeper and more haemorrhagic in MCF due to the underlying vasculitis. Haemorrhagic and/or ulcerative lesions may also be present in the abomasum, small intestine and colon. Lesions in other tissues may assist in differentiating MCF from mucosal disease at the time of necropsy. In MCF, the kidneys often contain multiple small (2-4 mm) yellow/grey foci caused by interstitial aggregates of lymphocytes. Similar nodules may be present in the mucosa of the urinary bladder. Other common gross lesions in MCF include enlargement of lymph nodes throughout the body and keratoconjunctivitis with marked corneal opacity.

In peracute cases of MCF in cattle and deer the gross lesions may be mild or non-existent. In chronic cases, a characteristic gross lesion is the presence of prominent arcuate arteries in the kidneys. These vessels are clearly apparent on cut surface of the kidney due to marked thickening and inflammation of their muscular walls.

MCF can be readily differentiated from mucosal disease by demonstrating the typical vascular lesions histologically. Although the vasculitis may be found in a wide range of tissues, preferred sites for examination by pathologists include the brain, kidney, urinary bladder, liver, small intestine, lung and lymph nodes.

In cattle and deer with severe **photosensitisation**, for example in sporidesmin toxicity, there may be extensive ulceration of the muzzle and undersurface of the tongue. The tongue lesions are due to exposure to sunlight during persistent licking of the irritated muzzle.

Oesophageal lesions similar to those of BVD and MCF may occur in **acorn** or **oak bud toxicity**, probably secondary to uraemia. Diseases associated with reflux of abomasal contents into the oesophagus or forestomachs also cause ulceration since the squamous mucosa lining these regions of the alimentary tract is not protected by a layer of mucus.

Actinobacillosis (wooden tongue) caused by *Actinobacillus lignieresii* infection, is a relatively common infection of the oral cavity in cattle. The organism presumably gains access to soft tissues following mucosal trauma and initiates a chronic, pyogranulomatous inflammatory response. When the tongue is affected it becomes extremely firm and may have multiple, yellow/tan nodules on cut surface or protruding through ulcers in the overlying mucosa. Lesions may also develop in other soft tissues of the head and neck, including the lips and pharynx, and are occasionally found in the wall of the forestomachs. The infection often extends to regional lymph nodes and may resemble those of tuberculosis grossly. Affected tissues become markedly swollen and firm and involvement of the pharynx or associated lymph nodes may result in dysphagia or severe dyspnoea. The diagnosis is best confirmed by histopathology, as the microscopic changes are classical.

Oral necrobacillosis (necrotic stomatitis) is a severe, necrotising disease caused by invasion of soft tissues by *Fusobacterium necrophorum*, usually following traumatic or viral disruption of the mucosal barrier. Pharyngeal infection in calves is well known as **calf diphtheria**. Grossly, the lesions are characterised by locally extensive areas of ulceration covered by a thick layer of grey/green or yellow material consisting of necrotic tissue and inflammatory exudate. Death may occur rapidly due to asphyxiation. Similar oral lesions caused by either *Fusobacterium necrophorum* or other bacteria are sometimes associated with **drenching gun injuries** in sheep, goats and deer. In some cases the lesion extends deep into surrounding tissues causing extensive cellulitis, massive swelling and death due to either toxaemia or asphyxiation. *Fusobacterium necrophorum* occasionally causes necrotising lesions in the forestomachs of cattle usually as a sequel to ruminal acidosis.

Mycotic rumenitis and **omasitis** caused by opportunistic zygomycetes (e.g. species of *Rhizopus, Mucor, Absidia)* may also follow ruminal acidosis, particularly in cattle and deer, but sometimes occur in animals

without a history of grain feeding. The lesions are typically multiple, discrete, dark red, transmural infarcts, reflecting fungal invasion of submucosal blood vessels and the associated thrombosis. Similar lesions are rarely seen in calves in association with **adenoviral infection**, which also causes vascular damage and thrombosis.

Parasites

Sarcocystis gigantea causes grossly visible, ovoid white nodules up to 1cm in length in the oesophagus of sheep. In spite of the abundance of such nodules in some sheep, they incite little or no host reaction and are not clinically significant. Other species of *Sarcocystis* commonly produce microscopic cysts in the striated muscles of the tongue and oesophagus of sheep.

Adult stages of the fluke ***Paramphistomum*** are found in the rumen of sheep, goats and cattle. These small, pale red, droplet-shaped parasites are not much larger than ruminal papillae and do not cause any problem in the rumen. Immature stages inhabit the duodenum and heavy infestations may cause severe enteritis.

Chemical rumenitis

Ruminal acidosis secondary to carbohydrate overload is an important and relatively common disease of cattle, sheep, goats and deer. Some animals die acutely of metabolic acidosis while others survive the acute stage but develop secondary lesions, such as mycotic or fusobacterial rumenitis or hepatic abscessation. Ingestion of excess carbohydrate in the form of grain, root crop or fruit, leads to a marked change in the rumen micro flora and increased production of lactic acid. The pH of ruminal fluid may fall from a normal level of between 5.5 and 7.5 to as low as 4.0 to 4.5. Most normal ruminal microorganisms die once the pH falls below 5.0. Body fluid is attracted into the rumen due to the increased osmotic pressure created by the accumulating lactic acid. This results in severe dehydration and circulatory collapse. Concurrent absorption of lactic acid into the systemic circulation may lead to metabolic acidosis.

The gross lesions in animals that die of acute ruminal acidosis are not specific and must be interpreted in conjunction with an appropriate history. The carcass is dehydrated and dark due to haemoconcentration. The rumen content typically resembles thin porridge, may have a fermentative odour and its pH is usually less than 5.0, although the pH starts to rise within an hour of death. The absence or death of protozoa in the rumen content of a freshly dead animal is supportive. The ruminal and omasal mucosa may show patchy or diffuse reddening on removal of the green-stained cornified layer. Since characteristic microscopic changes are present in the ruminal epithelium, histopathology is the best means of confirming the diagnosis.

Rumenitis may also be associated with the ingestion of certain **toxic plants**, including rhododendron and oleander. In such cases, history of access to the plant (or prunings) is important, as is the demonstration of leaf fragments in the rumen contents.

Miscellaneous

Bloat (ruminal tympany) is a common cause of sudden death in cattle and may be either primary or secondary. It occurs only rarely in goats, sheep and deer. The primary form is the most common and is due to excessive formation of foam in the rumen of animals on pastures containing high concentrations of legumes or in feedlot cattle fed predominantly on grain-based rations. Affected animals are typically found dead. Secondary bloat is usually chronic and intermittent, and occurs when there is a physical or functional defect in eructation of ruminal gas.

Gross lesions in a cow that has died of bloat are not specific and may be confused with clostridial diseases accompanied by acute death and rapid autolysis, or with anthrax. The abdomen is usually so distended that the animal rolls partly onto its back with its legs in the air. Blood may be exuding from body orifices and the eyes and tongue may be protruding. The blood is dark and poorly clotted due to anoxia and there is usually oedema, congestion and haemorrhage in the subcutaneous tissues, musculature and lymph nodes of the head and neck. Blood clots are often present in paranasal and frontal sinuses of the skull. In general, the anterior regions of the carcass are congested due to pressure on the thoracic cavity impaired venous return. This is reflected in some cases by the so-called "bloat line" in the oesophagus, characterised by congestion of the oesophagus anterior to, and blanching caudal to, the thoracic inlet. The lungs are compressed and subpleural, epicardial and endocardial ecchymoses are common (but non-specific). Abdominal viscera, particularly the liver, are usually pale due to ischaemia, as are the muscles of the hind limb. In primary bloat, the rumen is filled with frothy ingesta, but the foam disappears gradually after death and may be gone if the necropsy is delayed for 12 hours. Laboratory tests are of little value in confirming a diagnosis of bloat, other than to rule out differentials.

Traumatic reticuloperitonitis following ingestion of a nail or short length of wire is well recognised in cattle. There is a tendency for sharp metallic foreign bodies that have lodged in the reticulum to perforate the reticular wall in an anteroventral direction. The object may be walled off at that location by a granulomatous inflammatory response, but some objects progress further, penetrating the diaphragm and causing traumatic pericarditis. The accompanying infection results in a severe, fibrinopurulent pericarditis and epicarditis. In such cases, the pericardium may be massively thickened and the pericardial sac filled with purulent exudate. The reticulum will be firmly adherent to the diaphragm. An extensive search may be required in order to find the offending nail or piece of wire.

Newborn ruminants fed on rations high in concentrates and with inadequate roughage have shortened, club-shaped villi, which tend to clump together and have a thickened, parakeratotic epithelium. The syndrome is referred to as **ruminal parakeratosis**. Affected calves often have large hairballs in their rumen.

Abomasum

General considerations

Examination of the abomasum and its contents is an important part of any postmortem examination in ruminants, particularly in cases where gastrointestinal parasitism is suspected. Collect the contents into a bucket or tray in case a worm count is required and rinse the mucosa gently in running water. The mucosal surface should be smooth, glistening and pale pink. If the content is dark red or brown/black, search carefully for the presence of ulcers. Abomasal folds should be thin and lie flat against the mucosa.

Most diseases involving the abomasum will also induce lesions in other parts of the alimentary tract or in other organ systems.

Abomasitis

Inflammation of the abomasum can be caused by several infectious or non-infectious agents, only some of which are discussed in this paper.

Diffuse, intense, reddening of the abomasal mucosa is a feature of **salmonellosis** in sheep caused by either *S. hindmarsh* or *S. typhimurium* infection. Multiple shallow ulcers may also be present. Histopathology and culture of abomasal or intestinal contents should allow confirmation of the diagnosis. Similar gross lesions also occur in some cattle with **MCF**, and in ruminants that have ingested caustic chemicals, such as **arsenic**.

Braxy, caused by *Clostridium septicum* is an acute bacterial abomasitis characterised by marked oedema, hyperaemia and necrosis of the abomasal mucosa. Although typically a sporadic disease of young lambs, a similar syndrome is reported occasionally in calves and goat kids. In this disease the abomasal lesions may be either diffuse or focal. The folds in affected areas are thickened, oedematous and reddened, and may contain dry, yellow foci of necrosis. The lesions usually extend deep into the submucosa or musculature and may be visible from the serosal surface. Diagnosis is confirmed by histopathology and demonstration of *Cl. septicum* in typical lesions by either immunochemistry or fluorescence technology.

Shallow abomasal erosions and moderate reddening of the mucosa may be present in cattle with mucosal disease but, as discussed above, more remarkable lesions are likely to be present elsewhere in the alimentary tract.

Mycotic abomasitis is occasionally seen in calves and is most likely secondary to mucosal damage caused by other agents (usually bacterial or viral). The lesions are typically discrete, dark red foci (infarcts), 1-2 cm in diameter, and may be transmural.

Abomasal parasitism

The most important parasites of the abomasum in cattle, sheep and goats are *Ostertagia spp* and *Haemonchus spp* either on their own or in combination. *Ostertagia spp* are small, brown, thread-like nematodes up to 1.5 cm in length and are difficult to see grossly unless present in large numbers. *Haemonchus spp* are larger (2-2.5 cm in length) and the females have characteristic red and white striped (barber's pole) appearance.

Ostertagiasis (caused by *O. ostertagi*) is one of the most important production-limiting diseases of young cattle. In cattle that die of the disease, the carcass is dehydrated and wasted. The abomasal mucosa is often thickened due to oedema and to the presence of multiple small (1-2mm) nodules, which in severe cases are confluent. The pH of the abomasal contents may be increased above 4.5 due to extensive replacement of parietal cells by proliferating mucus cells. Worm counts on abomasal contents are not always high and digestion of the mucosa to release pre-emergent stages may be required in order to achieve an accurate count. In sheep and goats, *Ostertagia (Teladorsagia) circumcincta* produces similar mucosal nodules to those caused by *O. ostertagi* in cattle, but they are seldom as numerous or as significant clinically. Concurrent infestation with *Trichostrongylus axei* and/or *T. colubriformis* (the latter in the small intestine) is common and the combined effect may result in illthrift or death.

Haemonchosis is an important cause of blood-loss anaemia and sudden death in sheep and goats, usually following summer rainfall. The entire carcass is very pale and there may be oedema in the submandibular region or elsewhere due to severe hypoproteinaemia. In heavy infestations, the parasites can be readily detected in the abomasal contents, sometimes forming tangles masses between mucosal folds. A total worm count will add support to a diagnosis but is often not necessary.

Miscellaneous

Abomasal bloat occurs sporadically in calves, lambs and goat kids, usually after engorgement on milk replacer. Bacterial fermentation of the milk results in excessive gas production, marked abomasal distention and death, presumably due to asphyxia. At necropsy, the abomasum is usually distended with gas and milk and may show patchy mucosal reddening. In some cases, the abomasum ruptures after death due to continued gas production, spilling its contents into the abdominal cavity. The absence of peritonitis or of haemorrhage along the margins of the rupture indicates that the rupture has occurred post mortem.

Abomasal volvulus is much less common that intestinal volvulus (see later) but may occur in young milk-fed ruminants. As in abomasal bloat, affected animals are usually found dead with a distended abdomen, but in this case the distention is due to a gas-filled, markedly congested

abomasum. The twist can easily be detected at the time of necropsy. Laboratory tests are neither required nor useful.

Abomasal ulceration is common in cattle, including calves and adult dairy cows, and is considered to be linked to stressful events such as weaning and parturition. No doubt many abomasal ulcers go unnoticed, but some will perforate and cause septic peritonitis while others will result in exsanguination. Abomasal ulceration should always be considered a likely option in an adult dairy cow with blood loss anaemia, particularly if there is evidence of melaena. The ulcers are usually multiple and may have a red/brown base, indicating that they are active. In such cases, the abomasal content may be dark brown or have a "coffee ground" appearance due to the action of gastric acid on haemoglobin. Previous ulceration may be indicated by a scalloped margin to rugae. Ulceration often accompanies infiltration of the abomasal mucosa with neoplastic lymphocytes in cattle with enzootic bovine leucosis.

Multiple 1-2 mm, dark brown **microhaemorrhages** are sometimes found at necropsy on the abomasal mucosa of young calves, lambs or kids that die acutely. These appear to represent the earliest stage of stress-related abomasal ulceration perhaps due to gastric hyperacidity. Although the foci may be so numerous as to result in significant discolouration of abomasal or intestinal contents, the cause of death is likely to be found elsewhere.

The abomasum is a predilection site for infiltration with neoplastic lymphocytes in adult cattle with **enzootic bovine leucosis**. The submucosa is massively thickened with homogenous, pale cream tissue and the overlying mucosa inevitably contains several variably sized ulcers. Other predilection sites for neoplastic involvement in this disease are the heart and uterus. The tumour may also infiltrate a range of other tissues, including lymph nodes, liver, kidneys and muscle, but the abomasum is always involved in this form of lymphosarcoma. In contrast, the abomasum is not a predilection site in cattle with sporadic forms of lymphosarcoma.

Small Intestine and Colon

General considerations

Autolysis proceeds most rapidly in this part of the alimentary tract because of its mixed microbial content and the presence of digestive enzymes. As a result, diseases producing subtle enteric lesions may be difficult or impossible to diagnose unless the postmortem examination is performed, and samples collected for laboratory testing, within the first few hours of death. This should not however be used as an excuse for not performing a necropsy or taking specimens for histopathology in an animal that has been dead for a longer period as diagnostic lesions may still be present histologically if not grossly.

Because of the regional nature of many enteric diseases, it is important to open (and sample) several segments of both small intestine and colon. If a worm count is likely to be required then the contents should be collected as each segment is opened. Make sure that the gut wall is handled gently during this process or the delicate mucosa will be rendered useless for histopathology. Also pay attention to mesenteric lymph nodes as they will often be involved in animals with infectious or neoplastic diseases of the lower alimentary tract.

As with the abomasum, the mucosa of the small intestine and colon is normally smooth and glistening. Adherent material that cannot be easily removed by gentle scraping is likely to be abnormal, perhaps indicating mucosal necrosis or fibrinous exudate. The nature and volume of the contents varies markedly both in normal and diseased animals but may provide useful information (see below). Similarly, the colour and thickness of the gut wall may provide valuable information and should be noted in descriptions accompanying specimens submitted to a laboratory for histopathology. But they can also be misleading. Patchy or diffuse reddening of the small intestine may indicate inflammation or volvulus, but it may also reflect splanchnic pooling in an animal with terminal circulatory collapse, rather than a primary disease of the alimentary tract. Thickening of the gut wall is a feature of certain diseases, such as Johne's disease, but in freshly dead animals contraction of smooth muscle in the outer coat can produce a thickened, corrugated appearance to the jejunum closely resembling the gross change associated with Johne's disease.

Absence of gross lesions in the small intestine or colon does not exclude the possibility of significant enteric disease. In some cases the lesions will only be apparent histologically.

Congenital anomalies

Segmental aplasia or **atresia** of the ileum or colon is relatively common in newborn calves, lambs and kids. A genetic aetiology has been suggested, but not proven, in certain cattle breeds (e.g. Holstein, Jersey, Swedish Highland). An association has been made between rectal palpation for pregnancy diagnosis prior to 42 days gestation and the occurrence of atresia coli in calves, possibly linked to pressure on the amnionic vesicle. In sheep, occasional "mini-outbreaks" on individual properties have led to suggestions of a genetic aetiology, but there appears to be no convincing data to support this. Affected animals are normal at birth, but do not pass faeces and develop gradual abdominal enlargement over the first few days of life. Some animals survive for a week or more, but death is inevitable. The gross lesions at necropsy are classical and no laboratory support is required to confirm the diagnosis. The bowel anterior to the atretic segment is markedly dilated and filled with ingesta and gas. The distal portion is considerably smaller and is empty.

Atresia ani is the most common congenital defect of the lower alimentary tract. Clinical signs resemble those of ileal or colonic atresia but at necropsy, both small and large intestines are distended. The absence of a perforate anus makes the diagnosis obvious and a necropsy is usually not required, but the defect is sometimes associated with other anomalies of the spinal column or urogenital tract, including rectovaginal fistula.

Lesions caused by infectious agents

Infectious enteritis is a common and important cause of diarrhoea and death in neonatal ruminants and may involve ***Escherichia coli*, rotavirus, coronavirus and *Cryptosporidia sp*** alone or in combination. In all of these infections, the gross lesions are usually unremarkable and non-specific. In addition to faecal soiling of the perineum, the eyes are sunken due to dehydration. The small intestines may show mild, patchy reddening or may be distended with gas, the gas formation presumably due to bacterial fermentation of poorly digested or unabsorbed milk. The contents are often watery and yellow/white. An aetiological diagnosis is best achieved by a combination of histopathology and microbiology. The presence of cryptosporidia, and sometimes *E. coli*, can be confirmed histologically, but intestinal contents should be tested (by ELISA) for the presence of rotavirus and cultured for enteropathogenic types of *E. coli*. The histological lesions of coronavirus infection in calves are more specific but confirmation would require culture of the virus.

Age is a useful factor when considering the likely aetiology of neonatal diarrhoea. *E. coli* is unlikely to be a problem in calves, lambs or kids older than 1 week of age, rotavirus infections usually within the first 2 weeks of life, while coronaviral and cryptosporidial infections typically occur between 1 and 4 weeks of age.

Salmonellosis is an important cause of enteritis in cattle and sheep but is rare in goats and deer. *S. typhimurium* is the most common cause in **cattle**, particularly calves, but *S. dublin* is responsible for some cases both in adult cattle and calves. Salmonellosis in calves seldom occurs less than a week of age and is more common from 3 weeks to 6 months. In the acute septicaemic form, which usually occurs in younger calves, there are few gross lesions other than engorgement of intestinal blood vessels and, in some cases, subserosal petechial haemorrhages. The lesions of acute enteritis in older calves and adult cattle are more characteristic. Segments of the jejunum, ileum and colon may be fluid filled, reddened and thick walled. The mucosal surface is often markedly inflamed and may be partly covered by a loosely adherent layer of fibrinous or fibrinohaemorrhagic exudate. A cast of fibrinohaemorrhagic exudate may be present in the lumen of severely affected regions, typically in the ileum. Mesenteric lymph nodes are enlarged and oedematous. The diagnosis is best confirmed by a combination of histopathology and culture.

In **sheep**, salmonellosis tends to be a disease of adults rather than lambs, and is usually stress-related (e.g. overcrowding, transport). In New Zealand it occurs most often in the summer, often in outbreak form, and may be caused by either *S. typhimurium* or *S. hindmarsh*. Affected sheep are usually found dead with evidence of recent khaki-coloured diarrhoea. Grossly, there is an acute haemorrhagic abomasitis and enteritis.

Yersiniosis has long been recognised as a cause of haemorrhagic enteritis and death in young farmed **deer**, but has now become a significant entity in cattle, goats and sheep in Australia and New Zealand. In Australia, *Y. pseudotuberculosis* infection in **cattle** is reported in adults on river flat properties following winter flooding or persistent rain, whereas in New Zealand it occurs in yearlings during autumn or winter. The disease in **sheep** and **goats** is usually caused by *Y. enterocolitica* and also occurs in young animals entering their first winter. The gross lesions of yersiniosis in deer are typically much more remarkable than those in other ruminants. The small intestine may be diffusely reddened and the contents haemorrhagic. In cattle, goats and sheep, the intestinal reddening is only mild. The contents are usually watery, but there is seldom any evidence of either haemorrhage or of fibrinous exudate attached to the mucosa. The diagnosis is best confirmed histologically as the microscopic lesions are virtually pathognomonic. Culture of the organism from intestinal contents provides additional support, but *Yersinia spp* can also be cultured from the faeces of clinically normal animals.

Enteric listeriosis has been recognised with increased frequency in sheep in New Zealand over the last 5 years, possibly due to increased reliance on baleage or silage (sometimes of poor quality) as winter feed. Affected animals usually develop diarrhoea and depression prior to death, or may just be found dead. Gross lesions include marked, patchy reddening of the alimentary tract, including the abomasum and caecum, and could be confused with salmonellosis or toxic enteritis (e.g. following ingestion of fertiliser). Histologically there is an acute suppurative and/or ulcerative abomasitis, enteritis, colitis and typhlitis. Confirmation requires culture of the organism from intestinal contents as the gross and microscopic lesions are not specific.

Johne's disease caused by *Mycobacterium avium paratuberclosis* is a chronic wasting disease of ruminants and has received more publicity in recent years than any other enteric disease. In most species, it seldom occurs in animals less than 2 years of age and is considered a disease of adults, but in deer it typically occurs in the first year of life. In many animals with advanced Johne's disease, the gross lesions are sufficiently characteristic to allow a definitive diagnosis, at least in the hands of an experienced pathologist. But because of the significance of a positive diagnosis, it is dangerous to rely on gross lesions alone. Similar changes may occur in some other disease syndromes and lesions are sometimes detected histologically in animals with equivocal or inapparent gross changes.

Animals that die of Johne's disease, or are euthanased in the advanced stages, are emaciated and usually have minimal body fat reserves. Some animals also have oedema in the submandibular region, intestinal serosa and mesenteric lymph nodes. The most characteristic lesion is diffuse thickening of the wall of the intestine, particularly the ileum and distal jejunum, but sometimes extending into the proximal colon. Affected areas of bowel appear enlarged and flabby. The mucosal surface is often corrugated and may be pale tan. Similar corrugation of the small intestine, particularly the jejunum, occurs in freshly dead animals due to contraction of smooth muscle in the wall. Serosal lymphatics are sometimes prominent and contain small, nodular thickenings corresponding to foci of granulomatous lymphangitis. Although this lesion is sometimes considered to be pathognomonic for Johne's disease, it occurs occasionally in association with gastrointestinal parasitism in goats and sheep due to granulomatous lymphangitis surrounding degenerate nematode larvae.

In deer, the lesions are spread more uniformly throughout the small intestine. Mesenteric lymph nodes are usually enlarged, oedematous and on cut surface the cortex is often expanded with large, contiguous pale cream nodules. In deer, goats and occasionally sheep, the mesenteric lymph nodes may contain foci of caseation and mineralisation, similar to the lesions of tuberculosis.

Unless the gross lesions of Johne's disease are unequivocal, samples of ileum, ileocaecal valve and mesenteric lymph node should be submitted for histopathology. Alternatively, scrapings of ileal mucosa stained by an acid-fast method (ZN or Kinyoun's) may allow confirmation of the gross diagnosis.

As mentioned earlier in this paper, intestinal lesions are often present in cattle with **BVD** and cattle and deer with **MCF**. Haemorrhagic or necrotising lesions in the small intestine and colon also occur sporadically in cattle and deer in association with **adenovirus** infections.

Parasites

Coccidiosis occurs in intensively reared calves, lambs and kids, often causing clinical disease and sometimes death. In **calves**, the disease may occur anywhere between 1 month and 1 year of age, depending on the time and magnitude of exposure to infectious oocysts. Clinical signs include diarrhoea, dysentery, tenesmus and dehydration. In severe, acute cases, affected calves may die before oocysts have had a chance to appear in the faeces and diagnosis is best achieved by postmortem examination. Gross lesions are most marked in the large intestine and consist of a fibrinohaemorrhagic typhlocolitis, sometimes extending as far as the rectum. The terminal ileum may also be involved. The mucosa of the bowel may be oedematous, reddened or contain multiple petechial haemorrhages and may be partly covered by a diphtheritic membrane. A "tiger-stripe" pattern created by exaggerated, congested longitudinal or transverse mucosal folds is sometimes present, perhaps reflecting the tenesmus.

The gross lesions of coccidiosis in **lambs** and **kids** differ from those in calves and tend to be less haemorrhagic. Some species of *Eimeria* induce discrete yellow/white nodules (0.5-1.5 mm diameter) in the mucosa of the small intestine. These consist of hyperplastic enteric epithelial cells containing various stages of coccidia and are often detected incidentally during postmortem examination of kids and lambs. In animals that have died of coccidiosis the nodules are often abundant and may be virtually contiguous. Not all *Eimeria spp* in lambs and kids induce nodule formation. Others may infect epithelial cells in the colon and between nodules in the small intestine and their significance may be underestimated grossly. The mucosa may contain petechiae but is seldom as reddened or the intestinal contents as haemorrhagic as it is in heavily infected calves.

A diagnosis of coccidiosis can be supported by the demonstration of large numbers of protozoal stages in mucosal scrapings or tissue sections, but attributing significance to a coccidial burden is often difficult.

Nematode infestations of the small and large intestine are extremely important in grazing ruminants, but the gross changes are seldom specific. *Trichostrongylus spp, Nematodirus spp* and *Cooperia spp* reside in the proximal third to half of the small intestine but are too small to be easily seen grossly in the gut contents. In heavy infestations, the content is watery and there may be oedema of the mesentery and mesenteric lymph nodes. Diagnosis should be based on a combination of drenching history, clinical signs, faecal egg counts in live animals and total worm counts in animals that have died or been sacrificed. *Oesophagostomum columbianum* infestation in sheep is characterised by the formation of large nodules (0.5-1.0 cm diameter), with a caseous or mineralised centre, in the submucosa of the small and large intestine. The nodules are caused by invasion of the mucosa by larval stages. Adult worms reside in the lumen of the colon where they damage the mucosa and induce catarrhal inflammation. *O. venulosum* also infects sheep but is much less pathogenic and does not form nodules. In calves, *O. radiatum* is more pathogenic than *O. venulosum* and causes lesions similar to those of *O. columbianum* in sheep.

Acute duodenitis may occur in cattle, sheep and goats following the ingestion of herbage contaminated with massive numbers of **Paramphistomum** metacercariae. Immature paramphistomes invade the duodenal mucosa and may be detected grossly and/or histologically in large numbers in animals that die of intestinal paramphistomosis. As mentioned above, adult stages of the fluke are found in the forestomachs where they do not cause significant damage.

The **tapeworm** *Moniezia expansa* is a common incidental finding in the small intestine of lambs and kids. Heavy tapeworm burdens have been incriminated as a cause of diarrhoea and illthrift in lambs but such claims are not supported by convincing evidence. *Cysticercus tenuicollis*, the cystic form of the canine tapeworm *Taenia hydatigena* is found incidentally in the peritoneal cavity of sheep. While not clinically significant, the presence of these cysts indicates that the farmer has

been feeding raw offal to his dogs. This creates the risk of infecting his sheep with *Cysticercus ovis*, which has important implications for meat quality.

Miscellaneous

Mesenteric torsion is a relatively common cause of acute death in young ruminants, but can also occur in adults. Affected animals are usually found dead with a markedly distended abdomen. On opening the abdominal cavity, the dark red, gas-filled loops of bowel bulge from the incision. In most cases the diagnosis can be readily confirmed by palpation of the root of the mesentery and demonstration of a twist. It is important to check the mesenteric root before the bowel is removed, otherwise the twist may no longer be apparent. In some cases the lesion involves only a short section of small or large intestine, while in others the entire small intestine and/or colon may be involved. Animals that survive for a few days before dying of torsion usually have an acute fibrinous peritonitis due to leakage of toxins or bacteria through the devitalised wall of the twisted bowel. A syndrome referred to as "red gut" is recognised in sheep and occasionally calves grazing lucerne and other lush, leguminous pastures. Although the gross lesions are consistent with mesenteric torsion, a twist about the mesenteric root is not always apparent at necropsy and the pathogenesis may be more complex, at least in some cases. Histopathology is of little value in confirming a diagnosis of mesenteric torsion.

It is debateable whether **enterotoxaemia** should be included amongst diseases of the alimentary tract as the gross and microscopic lesions occur elsewhere. The disease is well recognised as a cause of sudden death in lambs and occasionally adult sheep. It also occurs in calves and kids but its importance in these species is probably over-rated. Excessive production of epsilon toxin by *Clostridium perfringens* type D in the small intestine is the basis of the disease. If sufficient epsilon toxin is absorbed, and if there is insufficient protection by anti-epsilon antibodies, widespread endothelial damage occurs. The lungs are typically congested and oedematous and there is usually an excess of clear fluid containing fibrin in the pericardial sac. The enteric changes are unremarkable even though some animals show profuse, terminal diarrhoea. Some loops of small intestine may be distended with gas and contain a modest amount of creamy "mayonnaise" content. The "pulpy kidneys" commonly associated with enterotoxaemia are not always present and can be misleading even when they are. Glycosuria is also an unreliable diagnostic criterion as it may also be present in other CNS diseases of sheep, including polioencephalomalacia and listeriosis. Confirmation of a diagnosis of enterotoxaemia is best achieved by histological examination of the brain. Endothelial cells in the brain are particularly susceptible to epsilon toxin and small blood vessels in some areas become surrounded by lakes of protein-rich fluid.

Intestinal carcinoma is a relatively common tumour of adult sheep in New Zealand, causing a chronic wasting condition resembling Johne's disease clinically. It also occurs in other countries but the prevalence is much lower. The gross lesions are sufficiently characteristic to allow a definitive diagnosis in most cases. In the advanced stages, multiple firm, white plaques varying from a few millimetres to several centimetres in diameter are present on the serosal surface of the jejunum or occasionally the ileum. A polypoid projection into the gut lumen is often present and is likely to be the site of origin of the tumour. In some cases, a scirrhous band at the site of origin causes partial obstruction of the jejunum. The tumour metastasises to mesenteric lymph nodes and by coelomic spread to the serosal surfaces of other abdominal viscera. Distended lymphatics caused by blockage of lymphatic drainage may be confused with the lymphangitis associated with Johne's disease in some cases, but the lesions in intestinal carcinoma generally involve the jejunum rather than the ileum. The diagnosis can easily be confirmed by histopathology.

Lymphosarcoma of the intestine occurs occasionally in sheep and may be confused with intestinal carcinoma. In lymphosarcoma, the involved segment of bowel (perhaps up to 10 cm) is uniformly thickened and pale cream due to infiltration of the mucosa and submucosa with tumour cells. The corresponding mesenteric lymph node is also likely to be enlarged and uniformly pale cream.

Mesothelioma of the peritoneal cavity is rare but a congenital form of the tumour is reported in cattle. Multiple, firm, red or yellow nodules or plaques, varying from a few millimetres to several centimetres in size are scattered throughout the peritoneal cavity.

Abdominal fat necrosis is an unusual but not uncommon disorder of adult cattle, particularly Channel Island breeds. The pathogenesis is not known but a dietary origin is suspected. Extensive areas of necrotic omental or retroperitoneal fat may surround intestinal loops or other viscera, sometimes causing obstruction of the intestine or ureters. Necrotic fat in the pelvic canal may cause dystocia. The necrotic fat is firm, dry and may be surrounded by a zone of hyperaemia.

Chapter 2

Skeletal System

Keith Thompson

Introduction and general comments

The skeleton probably receives less attention than all other organ systems during postmortem examination, even by experienced pathologists. Most organs are examined as part of the routine necropsy technique, but examination of the skeleton is more often confined to those occasions where the clinical history clearly indicates a skeletal problem. As a result, many skeletal disorders are likely to be missed. Furthermore, lack of familiarity with the normal appearance of skeletal structures commonly leads to misinterpretation in cases where a skeletal disease is suspected and a detailed examination of the skeleton is performed.

Complete examination of the skeleton at necropsy is both impractical and unnecessary but the standard procedure should include assessment of the shape, flexibility and breaking strength of readily accessible bones, such as ribs, cranium and key limb bones. Ideally, one or two representative long bones should be sectioned longitudinally to reveal the growth plates, the thickness of the cortex, and the amount and density of trabecular bone in metaphyseal and epiphyseal regions. If the clinical history suggests the possibility of a skeletal disorder, a more detailed assessment is required. Antemortem or postmortem radiographs may provide valuable information on the extent and severity of bone proliferation, lysis or demineralisation, but is an insensitive indicator of diffuse bone loss, as occurs in osteoporosis.

The manifestations of generalised skeletal diseases vary between bones and even within bones of the same animal. For example, lesions associated with metabolic bone diseases, such as rickets and fibrous osteodystrophy, will be most marked at sites of rapid bone formation. The growth plates of the distal radius, proximal humerus, distal femur and proximal tibia should therefore be targeted for gross and histological examination. Costochondral junctions of the largest ribs are also useful sites to examine in such cases. In osteoporosis, the depletion of trabecular bone is more rapid than that of cortical bone, presumably due to the greater surface area available for resorption in trabecular bone tissue.

This paper presents an overview of skeletal diseases of ruminants, with an emphasis on aetiology, pathogenesis and gross lesions.

Skeletal dysplasias

A diverse range of inherited disorders of bone and cartilage formation, referred to as skeletal dysplasias, has been reported in human beings and domestic animals. Only a small number of these have been described in any detail in ruminants.

Chondrodysplasias

Since most of the skeleton develops by endochondral ossification, where bone replaces a crude cartilage model, any abnormality in cartilage development can have a substantial effect on the skeleton. Most, but not all chondrodysplasias are characterised by disproportionate dwarfism, and the effect is usually generalised.

In **cattle**, the most severe form of chondrodysplasia is the lethal **bulldog type**, which is best known in the Dexter breed but also occurs in Holsteins and occasionally in the Charolais and Jersey breeds. Dexter cattle are considered short-legged derivatives of the Kerry breed, originating from Ireland, and are gaining in popularity in many countries because of the desirability of small, easily managed cattle for "lifestyle" farms. Some short-legged Dexters are heterozygous for an incompletely dominant gene which, when homozygous, gives rise to a bulldog calf. Bulldog calves may be carried to full term but are usually aborted before the seventh month of gestation and may not be detected by the owner. The skeletal abnormalities are severe and relatively consistent. As well as being much smaller than normal for the stage of pregnancy, they have extremely short limbs, which are usually rotated, a domed head with retruded muzzle and protruding mandible, and a large ventral abdominal hernia. The tongue is of normal size so protrudes markedly. The shortened limb bones consist of mushroom-shaped, cartilaginous epiphyses separated by a short, central segment of diaphyseal bone. Holstein bulldog calves are similar to those of the Dexter breed, but in Holsteins, the defect is characterised by autosomal recessive inheritance rather than incomplete dominance. The defective gene coding for chondrodysplasia in Dexter cattle has recently been identified and a test for carriers is now commercially available.

Brachycephalic ("snorter") type dwarfism was common in the Hereford breed during the late 1940's and early 1950's, but also occurred in other beef breeds, especially the Angus. Although inherited as an autosomal recessive trait, the defect appears to be partially expressed in heterozygotes, which are slightly smaller and more compact than normal. Selection for this phenotype most likely facilitated the spread of the chondrodysplasia gene in these traditional beef breeds and accounted for the high gene frequency. With a change in emphasis towards a larger frame score in beef cattle, and the introduction of programs to eliminate the defective gene, snorter dwarfism is now rare.

Snorter dwarfism is a much milder form of chondrodysplasia than the bulldog type. Affected calves have a short, broad head with bulging forehead, retruded upper jaw and a slightly protruding mandible. The vertebral column is shortened and the ventral borders of individual vertebrae are flattened, a useful diagnostic feature visible radiographically in young calves. Chronic ruminal tympany is a feature of snorter dwarfs, possibly as a result of reduced intra-abdominal space and impaired eructation. There is premature closure of basicranial synchondroses leading to compression of the cerebellum and shortening of the brain stem. The distal limb bones are proportionately shorter than proximal bones, the metacarpi showing the greatest degree of shortening. Interestingly, the width of long bones from brachycephalic dwarfs is comparable to, or greater than that of normal calves. The ratio of total metacarpal length to diaphyseal diameter is therefore a useful diagnostic indicator of this form of dwarfism. In snorter dwarfs the ratio is usually 4.0 or less, but in normal animals it is greater than 4.5.

In **sheep**, the most common form of chondrodysplasia is **spider lamb syndrome**, a semi-lethal condition of Suffolk and Hampshire sheep. Spider lambs were first recognised in North America in the late 1970's and the defect has since been introduced to Australia and New Zealand with imported Suffolk genetics. The trait is characterised by autosomal recessive inheritance with complete penetrance, but with variation in expressivity between individuals. The high prevalence of spider lamb syndrome in North America is probably due to selection for long-legged animals heterozygous for the "spider" gene.

Lambs with spider syndrome may be aborted or stillborn, but most are born alive showing skeletal deformities of varying severity. Some appear clinically normal at birth but develop typical signs of the disease within their first month of life, including disproportionately long limbs and neck, shallow body, scoliosis and/or kyphosis, sternal deformity, and valgus deformity of the forelimbs below the carpus, creating a "knock-kneed" appearance. Hind limb deformities may also be present, but are less severe than those involving the forelimbs. Facial deformities, including "Roman nose", deviated nasal septum and shortening of the maxillae are common, but not consistent. The deformities of the limbs and spinal column become progressively more severe with age. Diagnosis is best confirmed by demonstrating characteristic radiographic changes in the elbow, sternum and shoulder. Multiple, irregular islands of ossification are present consistently at these sites and there is malalignment and displacement of sternebrae.

Other gross lesions that may be detected at necropsy include: elongation of occipital condyles in a craniocaudal direction and dorsal deviation of the sternum between the second and sixth sternebrae. The caudal sternebrae often fail to fuse across the midline. Cervical and thoracic vertebral bodies contain excessive quantities of cartilage with disorganized arrangement, often accompanied by abnormalities in shape and symmetry. The olecranon and distal scapula also contain an excess of cartilage surrounding the multiple, irregular-shaped islands of

ossification. Severe degenerative arthropathy, particularly involving the atlanto-occipital, elbow and carpal joints, is present in lambs older than 3 months.

A point mutation in ovine FGFR3 (a receptor for fibroblast growth factor) has been identified as the underlying defect in spider lamb syndrome. The gene encoding this receptor has largely been cloned and sequenced, and an accurate test for detecting heterozygous individuals is now available.

A chondrodysplasia characterized by disproportionate dwarfism and varus deformity of the forelimbs has recently been recognised in **Texel sheep** in New Zealand. The syndrome appears to be inherited as an autosomal recessive trait, but with variable expression. Affected lambs appear normal at birth, but by 2-4 weeks of age show evidence of reduced growth rate, shortened neck and legs, varus forelimb deformities and a wide-based stance. Severely affected lambs show progressive reluctance to walk, respiratory difficulty following exercise, and often die within the first 4 months of life. In such cases, the articular cartilage on major weight-bearing surfaces of the hip and shoulder joints may be completely eroded, exposing the subchondral bone. The trachea is flaccid, sometimes kinked, and tracheal rings are partially flattened. The biochemical defect has yet to be characterised but presumably involves the synthesis of either type II collagen (the major type of collagen in cartilage) or glycosaminoglycans.

Osteogenesis imperfecta

This disease is characterised clinically by joint laxity and excessive bone fragility due to a genetic defect in type I collagen. Several forms of varying in severity are recognised in human beings, where it is one of the most common inherited disorders of connective tissue. Most reports in animals are in calves and lambs and appear analogous to the most severe form of the disease in humans. There is convincing evidence to support an autosomal dominant mode of inheritance, even though the sire and dam of affected animals are clinically normal. The disease results from new mutations in gonadal germ cell lines and may therefore occur in "outbreak" form, depending on the degree of gonadal mosaicism and the number of offspring sired.

In **cattle**, the disease has occurred in Australia, USA and Denmark in the offspring of three clinically normal, unrelated **Holstein-Friesian** bulls, and in **Charolais** calves in Denmark. The manifestations of the disease in each report in calves have been similar, but minor variations exist, suggesting that different mutations may be involved. Affected calves are usually born alive and are of normal size, but most are unable to stand due to marked hypermobility of the joints and, in some cases, the presence of limb fractures. Some affected Holstein-Friesian calves are able to stand and can walk with difficulty, but have a characteristic crouched stance with pasterns almost touching the ground. As in some forms of the human disease, calves with osteogenesis imperfecta have

small, translucent pink-gray teeth, which are barely erupted at birth and may fracture in calves that survive for a few weeks. In some calves the sclerae are distinctly blue, but this is more evident during postmortem examination following enucleation of the eye. Skin fragility is not a feature of the disease in calves although bone fragility has been reported in Belgian calves with dermatosparaxis.

The main findings during postmortem examination of calves with osteogenesis imperfecta relate to the skeleton. The bones are essentially normal in shape, but are extremely brittle and can usually be broken with little effort. Acute fractures are common in the mandibles and major limb bones; the latter probably occurring during attempts to stand. Severely affected calves may have multiple, well-developed calluses on their ribs, indicating intrauterine fractures. Tendons are thinner than normal and discolored pink.

In **sheep**, severe forms of osteogenesis imperfecta have occurred in two flocks in New Zealand and one in the United Kingdom. In both New Zealand reports, one of which involved the **Romney** breed, affected lambs died either during parturition or soon after. The Romney lambs had a domed head with brachygnathia inferior, dark blue sclerae, fragile, pink teeth and marked joint laxity. A feature of the disease in Romneys, which involved about 50 lambs, was the presence of marked skin fragility. In affected lambs, the bones could be easily bent or cut with a knife and were often abnormally shaped with thickened diaphyseal regions. Most lambs had recent fractures surrounded by hemorrhage and older (*in utero*) fractures with poorly formed calluses, especially involving the ribs.

Type I collagen is the predominant collagen type in bone, dentine, ligaments, tendons and in the ocular sclera, thus accounting for the characteristic distribution of lesions.

Osteopetrosis

Osteopetrosis (marble bone disease) is a group of rare disorders occurring in humans and animals, characterised by defective osteoclastic bone resorption and the accumulation of primary spongiosa in marrow cavities.

In **cattle**, osteopetrosis is best studied in the **Angus** breed, where it is inherited as an autosomal recessive trait. Affected calves are small, premature (250-275 days of gestation) and usually stillborn. Clinically, they show brachygnathia inferior, impacted molar teeth and protruding tongue. The long bones are shorter than normal and easily fractured. Radiographically, the medullary cavities are dense, without clear differentiation between the cortex and medulla. Vertebrae are shortened, frontal and parietal bones are thick, and the bones of the cranial base are thick and dense. On cut surface, the metaphyses and diaphyses of long bones, are filled with dense, unresorbed cones of primary spongiosa extending from the metaphysis to the center of the

diaphysis. In spite of their increased density, the bones are more fragile than normal and fractures are sometimes detected at necropsy, but the fragility is much less marked than in osteogenesis imperfecta.

Osteopetrosis also occurs in the **Hereford** and **Simmental** breeds, but in affected Herefords the frontal bones are markedly thickened and filled with cystic spaces. The domed forehead of these calves could be misinterpreted as hydrocephalus unless the skull is sectioned.

Osteochondrosis

Osteochondrosis is most common and important as a disease of pigs, horses and large breeds of dog, but it also occurs in cattle, sheep and farmed deer. Young, fast growing animals are most susceptible to osteochondrosis, especially breeds selected for rapid growth. It is characterized by multifocal abnormalities in endochondral ossification involving articular-epiphyseal cartilage complexes (the immature cartilage covering the ends of growing long bones) and growth plates. Other synonyms for the disease are **osteochondrosis dissecans** and **osteochondritis dissecans**. Such differences in terminology are due, at least in part, to the variation in lesions when examined at different stages. Severe degenerative joint disease is a common sequel to osteochondrosis and is one of the most common causes of lameness in domestic animals.

The aetiology and pathogenesis of osteochondrosis are poorly understood and have been the subject of considerable recent debate. The aetiology is multifactorial, but most likely involves the effect of trauma or biomechanical factors on cartilage that has been weakened by nutritional or hormonal imbalances, vascular disruption, or genetic factors. Whatever the cause, the initial lesion in the articular-epiphyseal cartilage complex of each species where detailed studies have been performed are remarkably similar, suggesting a common pathogenesis, most likely involving ischemic damage to the growing cartilage.

Although there are only occasional reports of osteochondrosis in **cattle**, the disease is likely to be much more common in this species than is currently recognised. Due to financial constraints and difficulties in detailed radiologic examination, many lame cattle are sent for slaughter without definitive diagnosis. In a survey of middle-aged bulls slaughtered for non-medical reasons, lesions of osteochondrosis were detected in the stifle joint of 3 of 25 animals in the absence of clinical lameness. Degenerative joint disease was detected in the stifle of 14 of the 25 bulls and although these lesions were too advanced to accurately determine their origin, the fact that the lesions identified as osteochondrosis, and those of degenerative joint disease both had a predilection for the lateral trochlear ridge, suggested that at least some cases of degenerative joint disease in this population of bulls were secondary to osteochondrosis. Other predilection sites for osteochondrosis in cattle are the humeral head, distal radius, elbow joint, and the tibial tarsal and occipital condyles.

Early gross lesions of osteochondrosis appear as thickened, white or cream foci of articular cartilage, which are sharply demarcated from adjacent normal areas of cartilage. In more advanced lesions the affected cartilage usually shows evidence of separation and underrunning, and there may be nodules of cartilage reflecting attempts at repair. In other cases, underrun segments of articular cartilage may be detached completely, leaving a deep ulcer with exposure of subchondral bone.

In farmed red **deer** and wapiti x red deer hybrids in New Zealand, a strong association is recognized between osteochondrosis and copper deficiency. On some farms, more than 30% of the fawns are affected. Lameness may be noticed as early as 1 month of age, but more commonly, the problem is not noticed until weaning at around 4 months-of-age. Epiphysiolysis of the femoral head is a common manifestation of the disease and may be bilateral. Animals with this lesion are severely lame and may adopt a "bunny-hopping" gait or "cow-hocked" stance. Other predilection sites are the carpal, hock, and stifle joints. The lesions are usually bilateral. Affected deer invariably have low serum and/or liver copper concentrations and the disease can be prevented by copper supplementation of pregnant hinds.

Osteochondrosis appears to be rare in **sheep**, but has been reported as a cause of lameness in young, rapidly growing, Suffolk ram lambs. It is likely that the incidence of osteochondrosis in sheep will increase with continued selection for rapid growth. Valgus and varus limb deformities are common in ram lambs in feedlots and test stations in the USA and also occur in other countries. Grossly, some affected rams have thickening of the distal radial physis, similar to the growth plate lesions of osteochondrosis in other species, but joint changes are absent. Vascular and growth plate lesions mimicking osteochondrosis can be produced experimentally in lambs by procedures that increase weight bearing. Epiphysiolysis of the distal radial growth plate, associated with deformity of the forelimbs, is reported in 3-month-old lambs, supporting the concept that the physeal lesions of osteochondrosis may be one cause of angular limb deformity in sheep.

Localised skeletal dysplasias

Syndactyly, a defect characterized by partial or complete fusion of functional digits, occurs in several breeds of cattle, including Holstein-Friesian, Angus, Chianina, Hereford and Simmental. Inheritance is autosomal recessive with incomplete penetrance and variable expression. The disorder became widespread in the Holstein-Friesian breed following extensive use of a heterozygous bull by artificial breeding, but is rare in other breeds. In Holstein-Friesians, the disorder seldom affects all 4 digits. The right forelimb is most frequently affected, followed by the left forelimb then the right hindlimb. In contrast, the defect in Angus cattle usually affects all 4 digits. The lesions of syndactyly may vary from complete horizontal fusion of paired phalanges to fusion of only one or

none of the phalanges, but fusion of interdigital soft tissues. Vertical fusion of phalanges is reported in some affected Angus cattle. **Polydactyly,** an increase in the number of digits, is an inherited trait in various bovine breeds but the inheritance pattern is poorly understood. In most cases, it is the medial digit (digit 2) that is duplicated and although all 4 feet may be affected, the anomaly is more frequently confined to the forelimbs. A polygenic mode of inheritance requiring a dominant gene at one locus and two recessive genes at another is postulated in Simmental cattle.

Hemimelia refers to the partial absence of one or more limbs and occurs as a recessively inherited lethal defect in Galloway calves. Affected calves have bilateral agenesis of the tibial bones and patellae. Other bones of the hind limbs are apparently normal, highlighting the localized nature of the defect. A similar syndrome characterized by tibial hemimelia, meningocele, retained testicles and abdominal hernia is reported in Shorthorn calves and is also believed to be transmitted as an autosomal recessive trait

Brachygnathia inferior, shortening of the mandibles, and **brachygnathia superior**, shortening of the maxillae, may occur alone or in combination with other skeletal defects. Brachygnathia inferior is commonly encountered in otherwise normal domestic animals and, while not life-threatening, is an undesirable characteristic. Genetic and teratogenic aetiologies have been suggested and both are likely to occur. Brachygnathia superior occurs in association with degenerative joint disease as a lethal genetic defect in Angus calves. In addition to brachygnathia superior, affected calves have other skull changes similar to those of brachycephalic dogs and degenerative changes are present in articular cartilage throughout the body.

Porphyria

Red-brown discoloration of the teeth and bones, caused by a recessively inherited defect in porphyrin metabolism (**congenital erythropoietic porphyria**), is reported in several breeds of cattle, including Hereford, Holstein, Ayrshire, Shorthorn, and Jamaica Red and Black. A deficiency of uroporphyrin III cosynthetase leads to the accumulation of uroporphyrin I and coproporphyrin I in blood, bone and a variety of other tissues. The urine may also be red-brown or turn red on exposure to sunlight. The action of sunlight on porphyrins accumulated in the skin results in photodynamic dermatitis. The teeth, bones and urine of affected animals show bright cherry-red fluorescence on exposure to ultraviolet light in a darkened room. Congenital erythropoietic protoporphyria in Limousin cattle, caused by a deficiency of the mitochondrial enzyme ferrochelatase, is associated with photosensitivity but no discoloration of the bones or teeth.

Acquired porphyria with pink discoloration of bones was recognized at slaughter in approximately 300 of 390 *crossbred lambs in Australia.* Similar "outbreaks" have also occurred in lambs and young deer in New

Zealand. The discoloration was most prominent in the cortex of long bones and fluoresced on exposure to ultraviolet light, but teeth were not affected. On cut surface of long bones in a sample of affected lambs and deer, the pink discoloration was confined to areas of bone that had formed in the weeks prior to death, in particular the outer cortex. This reflects the fact that porphyrins are only deposited at sites of active mineralisation. In congenital porphyria, the constant availability of porphyrins during dental and skeletal mineralisation results in diffuse discoloration of all mineralised tissues. The extraction of coproporphyrin and protoporphyrin from the bones of lambs in the Australian outbreak suggested an enzyme block towards the end of the heme synthetic pathway, most likely induced by a toxin. Although lead toxicity can induce porphyrin accumulation, no lead was detected in affected lambs. Toxicity caused by some chlorinated hydrocarbons can also result in impaired heme synthesis and the detection of 1,2,4-trichlorobenzene in fat samples supported this possibility in the lambs. This compound is a major metabolite of lindane, an organochlorine insecticide that was widely used in parts of Australia and New Zealand before being banned. The occurrence of acquired porphyria in grazing animals may therefore reflect environmental contamination due to leakage from chemical dumpsites.

Acquired abnormalities in skeletal development

It is important to recognise that skeletal abnormalities do not always have a genetic basis. Many teratogenic agents have been shown to mimic genetic diseases of the skeleton and other organ systems, and unless there is clear evidence that the problem is inherited, or it resembles an established genetic disorder, any temptation to attribute a genetic aetiology should be resisted. Bone growth and maturation is a complex process, requiring an interaction between genetic factors, local and systemic hormones, dietary nutrients and mechanical forces. Anything that interferes with the synthesis of proteoglycans or collagen by chondroblasts or osteoblasts, the differentiation of precursor cells, or the resorption of bone by osteoclasts can result in a skeletal abnormality. The expression of an abnormality depends on many factors, including the phase of skeletal development that is altered, the severity of the defect, the age of the animal at the time of the insult, and how long it persists. As a result, the range of possible skeletal defects is huge, and a single aetiology may vary considerably in its manifestations. An accurate aetiological diagnosis is not always possible in an animal with a skeletal defect, particularly since the inciting cause is often no longer present at the time of examination.

Manganese deficiency

Manganese is essential for the activation of xylosyltransferase, the first enzyme in the biosynthetic pathway of sulfated glycosaminoglycans. A deficiency of manganese causes decreased production and increased

degradation of cartilage glycosaminoglycans and therefore potentially affects all bones that develop by endochondral ossification.
Manganese deficiency has been incriminated as the cause of skeletal deformities in newborn calves and other farmed livestock. The deficiency does not appear to affect adult animals but calves born to cows fed on manganese-deficient rations during pregnancy may show varying degrees of skeletal deformity. The abnormalities include shortening and twisting of limbs, enlarged, mushroom-shaped epiphyses and reduced breaking strength. Tracheal rings may be thickened and collapsed in severe cases.

Copper deficiency

Copper deficiency has been incriminated as a cause of **osteoporosis** and, in some species, **osteochondrosis**, but full appreciation of the role of this trace mineral in skeletal development is lacking. As a component of the enzyme lysyl oxidase, copper is required for cross-linkage of collagen molecules. This is an important step in strengthening the matrix elements of bone tissue, cartilage, and other connective tissues that rely on collagen for support. It is not surprising therefore that increased fragility of bone, and possibly cartilage, is a feature of copper deficiency. Studies in dogs and swine have demonstrated reduced osteoblastic activity in animals with copper deficiency, leading to narrow cortices of long bones and reduced deposition of bone on persistent spicules of mineralised cartilage in the primary spongiosa. These metaphyseal changes resemble those of vitamin C deficiency, which is not surprising since both deficiencies interfere with collagen synthesis and cross-linkage.

In calves (but not lambs), copper deficiency has been associated with grossly visible focal thickenings in rapidly growing growth plates, but the mechanism for this lesion is not clear. It is possible that the stress of weight bearing causes microfractures of fragile trabeculae in the primary spongiosa with local disruption of the metaphyseal blood supply and impaired invasion of the mineralized cartilage. These growth plate lesions bear a strong resemblance, grossly and histologically, to those of rickets and osteochondrosis. Differentiation from rickets may be further complicated by the possibility of spontaneous long-bone fractures in copper-deficient animals due to osteoporosis and increased bone fragility.

Copper deficiency may be either primary, due to inadequate dietary copper, or secondary to increased dietary levels of copper antagonists, such as molybdenum, zinc and iron.

Fluorosis

Fluorine is an essential trace element but, when present in chronic excess, is capable of inducing characteristic dental and/or bony changes. All species are susceptible but because of the manner in which chronic poisoning occurs, fluorosis is most common in herbivores, cattle being more susceptible than sheep.

The characteristic changes of severe fluorosis occur in teeth and bones and are accompanied by shifting lameness, loss of production and a variety of non-specific signs of debility. The mildest gross evidence of dental fluorosis is the presence of small foci with a dry, chalky appearance compared to the normal glistening surface of enamel. In more severe cases, all the enamel in affected teeth may be chalky, opaque and show various degrees of yellow, dark brown or black discoloration, which is virtually pathognomonic for fluorosis. Affected teeth show accelerated wear and may develop chip fractures. In chronic cases, they may be worn to the gum line. The pigment is present in the enamel layer and possibly in the dentin, and may reflect oxidation of the organic matrices of the teeth. Unlike the pigment of food stains and tartar, it is not limited to the surface and cannot be removed by scraping.

The dental lesions develop only if intoxication occurs while teeth are in the developmental stages and enamel is forming. Ameloblasts and odontoblasts are extremely sensitive to fluorine, which causes them to produce a matrix that mineralises abnormally and is reduced in quality and quantity.

The bone lesions of fluorine toxicity are generalized but not uniform and, in severe cases, are characterized grossly by the formation of periosteal hyperostoses.

Lead toxicity

Lead toxicity is better known as a cause of CNS lesions, but it may also cause bone lesions. The characteristic lesion is a band of sclerosis, referred to as a **"lead line"**, visible radiographically and grossly in the metaphyses of developing bones. This is a relatively early morphological lesion in children with lead poisoning, and also occurs in animals. The sclerosis is due to persistence of mineralised cartilage trabeculae in the metaphysis because of impaired osteoclastic resorption. The metaphyseal sclerosis associated with lead toxicity radiographically and grossly resembles that seen in association with some cases of intrauterine bovine viral diarrhea virus infection, which also interferes with osteoclast function or number.

Plant toxicities

Many plant species are known, or suspected, to cause skeletal abnormalities, either by inducing a teratogenic effect on the developing foetus, or influencing skeletal remodeling in young growing animals. Those with a teratogenic action typically exert their influence early in pregnancy and require ingestion by the dam during a specific stage of foetal development. The classic example is ***Veratrum californicum***, which causes **cyclopia** in the progeny of ewes that consume the plant on day 14 of gestation.

A syndrome referred to as **crooked-calf disease** occurs when pregnant cows ingest certain **wild lupins**, including *Lupinus caudatus, L. sericeus*

and *L. formosus*, especially between days 40 and 80 of gestation. Malformation of the limbs, notably the forelimbs, is the most common alteration, but the axial skeleton may also be involved. The limb abnormalities consist of flexion contracture and arthrogryposis associated with disordered growth of joints, in addition to shortening and variable rotation of the bones. Torticollis, and either scoliosis or kyphosis are common, involvement of the thoracic spine being associated with costal deformities. Possible abnormalities in the skull include cleft palate and brachygnathia superior. Affected calves are usually born alive and may survive, depending on the nature and severity of their malformations, but growth is retarded and the malformations persist, often becoming more severe with age.

Various plant toxicities (and other aetiologies), have been incriminated in a limb deformity syndrome of lambs referred to as "**bentleg**". In Australia, the syndrome has been associated with ingestion of *Trachymene ochracea* (white parsnip), *T. cyanantha* and *T. glaucifolia* (wild parsnip) by ewes, which preferentially graze the inflorescence of *Trachymene sp.* The toxic principle is unknown, but the deformity may be either be congenital, due to exposure of lambs *in utero*, or may develop during postnatal growth, probably following exposure of lambs through the milk. Gross deformities are usually most prominent in the forelimbs, and include outward bowing, flexion and lateral rotation of the carpal joints and medial or lateral rotation of the fetlocks. Similar syndromes are described in New Zealand (where it is called "**bowie**") and South Africa, but plant toxicities are not suspected. In both of these conditions, calcium deficiency and osteoporotic bone disease play a major role in the weakening and deformity that develop.

Metabolic bone diseases

Metabolic bone diseases, also referred to as **osteodystrophies**, are the result of disturbed bone growth, modeling or remodeling due to either nutritional or hormonal imbalances. The manifestations are generally most severe in young animals where the skeleton is undergoing rapid turnover, but lesions also occur in adults due to an effect on the quality or quantity of bone formed during remodeling. In addition to variations with age, there are variations between species in the manifestations of dietary mineral imbalances.

Metabolic bone diseases are traditionally classified as **rickets**, **osteomalacia**, **fibrous osteodystrophy** or **osteoporosis**. Although these are distinct morphological entities with characteristic pathogenesis and lesions, they can occur in combination in the same individual. This may create confusion diagnostically. Furthermore, their aetiology can vary between species. For example, calcium deficiency in sheep is likely to result in osteoporosis, but in a rapidly growing pig, fibrous osteodystrophy is a more likely result. Also, each of these disorders can be caused by more than one dietary or endocrine imbalance.

Since bone matrix is composed largely of calcium and phosphate ions in the form of hydroxyapatite crystals, any dietary or physiological factors affecting the metabolism of calcium and/or phosphorus can interfere with the formation of bone tissue and cause an osteodystrophy.

Osteoporosis

Osteoporosis is easily the most common of the metabolic bone diseases, both in man and animals. Rather than being a specific disease, it is a lesion characterised by a reduction in the quantity of bone, the quality of which is normal. In effect, osteoporosis represents an imbalance between bone formation and resorption in favour of the latter, resulting in bone that is structurally normal but with reduced breaking strength.

Many mild cases of osteoporosis in animals remain undetected, even at post mortem examination, as the shape of individual bones is not altered and unless there have been pathological fractures, lameness is not likely to have been observed clinically. The occurrence of a bone fracture without evidence of excessive trauma may be the first indication that an animal is suffering from osteoporosis. In farmed livestock, there may be an unusually high incidence of fractures in the herd or flock, suggesting increased bone fragility.

Most cases of osteoporosis in farm livestock are **nutritional** in origin and may be due to deficiency of a specific nutrient, such as calcium, phosphorus or copper, or to **starvation**, where there is restricted intake of an otherwise balanced ration. Starvation is relatively common in grazing animals in areas prone to drought or due to overstocking in seasons when pasture growth is below expectations. Poor quality milk replacers fed to young calves or other young animals may also result in starvation due to inadequate digestibility and absorption of nutrients. In starved animals, the mechanism of osteoporosis is complex, but the lack of dietary protein and energy most likely contribute, either directly or indirectly. The effects of starvation on the skeleton are greater in young growing animals than in adults. **Growth arrest lines** may be evident in the metaphysis, reflecting intermittent periods of premature physeal closure followed by reactivation of growth. **Serous atrophy of medullary adipose tissue** is a common feature of starvation-induced osteoporosis in animals.

Calcium deficiency, in the presence of adequate dietary levels of phosphorus and vitamin D, causes osteoporosis experimentally in mature and immature animals, but rarely if ever occurs as a natural disease. Unless the deficiency is extremely severe, physeal growth and mineralisation of cartilage are normal. Rickets is not a feature of uncomplicated calcium deficiency because calcium resorption from bone ensures that this mineral is not a limiting factor at sites of mineralisation.

Phosphorus deficiency produces osteomalacia in adults and rickets in growing animals, both under natural and experimental conditions. However, under some circumstances it causes osteoporosis. The reasons

for this are not clear, but it may be related to the anorexia that often accompanies phosphorus deficiency, the age and growth rate of the animals, and the severity and duration of phosphorus deficiency.

Osteoporosis is recognised as a feature of naturally occurring and experimental **copper deficiency** in lambs and calves. As a component of the enzyme lysyl oxidase, copper is required for the cross-linkage of collagen and elastin. Deficiency of this enzyme is probably responsible for the reduced osteoblastic activity observed in swine and dogs with copper deficiency, while the impaired cross linkage of collagen in bone matrix most likely accounts for the increased bone fragility in copper-deficient animals when compared to animals with osteoporosis of other causes. As mentioned above, copper deficiency may also predispose to osteochondrosis (in some species) and induce physeal lesions resembling those of rickets.

Osteoporosis is often present in animals with severe **gastrointestinal parasitism.** Although malabsorption is likely to be a factor, the mechanism may be more complex and probably involves the generation of pro-inflammatory cytokines such as interleukin-1 and interleukin-6, both of which induce bone resorption and inhibit its formation. There is also evidence that some nematodes, e.g *Trichostrongylus colubriformis,* may induce phosphorus deficiency. In another study, osteoporosis in lambs with subclinical *Ostertagia circumcincta* infestation was linked to reduced availability of protein and energy for bone matrix production. Increased production of endogenous corticosteroids may also be involved. The importance of parasite-induced osteoporosis in grazing animals is unknown but it is undoubtedly much more common than is recognised and may be responsible for some of the unexplained cases of spontaneous bone fractures encountered in cattle and sheep.

The gross lesions of osteoporosis are generally most marked in bones, or areas of bones, consisting predominantly of cancellous bone. This is presumably because cancellous bone has a greater surface area to volume ratio than cortical bone and is resorbed more rapidly. Vertebral bodies in particular are affected early in the disease in human patients and animals with osteoporosis and may contain pathological fractures. Flat bones of the skull, scapula, ilium and the ribs may also be severely affected and the breaking strength of the ribs, as assessed during necropsy, may be noticeably reduced. Cancellous bone in the metaphyses and epiphyses of long bones may be reduced in amount and more porous than normal. Trabeculae that are most concerned with transmission of weight-bearing stress are relatively spared and may become more prominent. In advanced stages of osteoporosis, the medullary cavities of long bones are enlarged and the cortices extremely thin.

Rickets and Osteomalacia

It is convenient to consider these two diseases together as they have a similar aetiology and pathogenesis, differing only in the age at which they occur. **Rickets** is a disease of the developing skeleton in young animals and is accompanied by abnormal endochondral ossification at physes, in addition to defective bone formation. **Osteomalacia** occurs only in adults and although there are no lesions associated with growth cartilages, the bone changes are the same as those that occur in rickets. Both diseases occur in all ruminant species, including wildlife, but there are differences between species in the circumstances under which they occur, and in the most likely cause.

The pathogenesis of both rickets and osteomalacia involves **defective mineralisation**. In young animals with rickets, this includes cartilage matrix at sites of endochondral ossification, as well as newly formed osteoid. In adults, where skeletal growth by endochondral ossification is no longer occurring, the defective mineralisation affects only the osteoid formed during skeletal remodeling.

Anything that interferes with the mineralisation of cartilage or bone matrix may cause rickets or osteomalacia, but most cases in animals result from dietary deficiencies of either vitamin D or phosphorus. Calcium deficiency on its own causes either osteoporosis or fibrous osteodystrophy, but not rickets.

Vitamin D deficiency may occur in grazing animals where the combination of relatively high latitudes and temperate climates allow them to be pastured for much of the year. Such conditions occur in parts of the United Kingdom, South America, New Zealand and southern Australia. Photobiosynthesis is a more important source of vitamin D than diet in grazing animals, but may be inadequate during the winter months in some regions. When the winter sun is at an angle of less than 30 degrees to the horizontal, the short-wavelength ultraviolet rays required for the activation of 7-dehydrocholesterol in the skin are reflected into the atmosphere and dermal synthesis of previtamin D_3 is impaired. Mature grass and sun-cured hay are relatively good alternative sources of vitamin D_2, but the levels present in immature pasture are likely to be inadequate. This may be further compounded by the anti-vitamin D activity of carotenes present in lush pasture and green cereal crops. The extra demands of pregnancy and lactation during winter and early spring may also contribute significantly to the development of clinical osteomalacia. It is likely that many grazing animals are vitamin D deficient for a period during the winter, but clinical rickets or osteomalacia are only likely to develop if the deficiency is marked or persists for longer than usual. Problems may also occur if vitamin D deficiency is combined with deficiencies of other essential nutrients, such as phosphorus or copper.

Sheep appear to be more susceptible to vitamin D deficiency than **cattle**, possibly because a dense fleece covers much of their skin. The concentration of vitamin D in blood increases following shearing. **Alpacas** and **llamas** may be even more susceptible to vitamin D deficiency than sheep. Rickets has been diagnosed in young camelids in New Zealand, South Australia and northern regions of the United States of America. The disease occurs during winter months and is accompanied by low blood concentrations of both 25-hydroxyvitamin D and phosphorus. In the New Zealand report, lambs grazing the same pasture had normal serum phosphorus concentrations and the phosphorus content of the pasture was normal. The natural environment for alpacas and llamas is at high altitude near the equator, where solar irradiation is intense. Their dense fibre and pigmented skin may have evolved as a protective mechanism to prevent excessive solar irradiation reaching the skin. This could prove to be a disadvantage in animals moved to lower altitudes, especially at latitudes with limited solar irradiation during the winter.

Rickets and osteomalacia due to **phosphorus deficiency** are uncommon, but do occur in animals grazing pastures low in phosphorus. There are many areas of the world, including South America, South Africa, northern Australia and New Zealand, where soil phosphorus levels are very low and successful livestock production requires application of phosphorus either to the soil or the animals. **Cattle** appear to be more susceptible than **sheep** to phosphorus deficiency. Rickets has also been diagnosed in farmed red **deer** grazing phosphorus deficient pastures in New Zealand.

Signs of phosphorus deficiency develop slowly, especially in the mature skeleton, and many animals with subclinical osteomalacia no doubt remain undiagnosed. Clinical disease is most likely to occur in cows where the deficiency is exacerbated by the extra demands of pregnancy or lactation. Such animals lose condition, develop transient, shifting lameness and show an increased susceptibility to fractures. They may crave phosphorus-rich materials, and osteophagia and pica are characteristic signs of the deficiency. Hypophosphatemia develops early but also returns to normal rapidly if the animals are supplemented. Serum calcium concentrations are usually normal or increased. The presence of normal serum phosphorus concentration in an animal with osteodystrophy does not therefore exclude phosphorus deficiency as the cause.

Animals with rickets are generally stiff or lame, and in severe cases are reluctant to stand. The limbs, especially the forelimbs, may be bowed. Swelling of the carpals and other joints, due to enlarged ends of long bones, may lead to an initial suspicion of arthritis.

Gross lesions of rickets are most prominent at sites of rapid growth, including metaphyseal and epiphyseal regions of long bones and costochondral junctions of the large middle ribs. Enlargement of costochondral junctions is a classic feature and is referred to as the

"rachitic rosary". In rickets, the metaphysis of the rib is often wider than the cartilaginous portion and on sagittal section, the chondro-osseous junction is irregular, with tongues of unresorbed cartilage extending into the metaphysis. The normal architecture of the metaphysis is replaced by a mixture of disorganised trabeculae, irregular tongues and islands of cartilage, fibrous tissue and sometimes haemorrhage. Similar changes may be evident in sagittal sections of long bones, especially at sites of most rapid growth, such as distal radius, proximal humerus, distal femur and both ends of the tibia. Irregular thickening of physes at one or more of these sites is the hallmark of rickets. Metacarpal and metatarsal physes are also likely to show gross changes. The severity of lesions between different physes may vary considerably, even within the same animal. This emphasizes the importance of examining sagittal sections of several bones during postmortem examination. The enlargement of the ends of long bones is due partly to flaring of the metaphysis and partly to compression caused by weight bearing on metaphyseal bone of reduced strength. Also, there is accumulation of poorly mineralised osteoid, which is not removed efficiently by osteoclasts.

Pathological fractures may be present in the limbs, ribs or vertebrae in severe cases. When the deficiency is relatively recent but severe, a distinct zone where abnormal bone formation commenced may be present in the metaphysis. This reflects a change from adequate to inadequate dietary phosphorus or vitamin D and may of value in relating the disease to a particular change in diet or environment.

The lesions of **osteomalacia** are similar to those of rickets but since they occur in adult animals, growth plates are not involved. Pathological fractures are common in advanced cases. In affected cattle, fractures are most common on the ribs, pelvis, and long bones.

Fibrous osteodystrophy

Fibrous osteodystrophy is caused by persistent elevation of parathyroid hormone concentrations and in herbivores is almost invariably due to an imbalance in dietary levels of phosphorus and calcium. Nutritional secondary hyperparathyroidism may be associated with either low dietary calcium or excess dietary phosphorus and its effects are most marked in young, growing animals.

Severe fibrous osteodystrophy is relatively common in **goats** fed rations high in concentrates, but there are no convincing reports of the disease in either **sheep** or **cattle**, suggesting species variation in susceptibility. In goats, fibro-osseous enlargement of the mandibles and maxillae is a characteristic clinical feature. Respiratory distress may be present due to encroachment by swollen maxillary bones on the nasal cavity. The relative severity of lesions in bones of the skull in goats and certain other species may be related to the mechanical stimulus associated with chewing. The bones of the limbs are also affected in goats with fibrous osteodystrophy and may be markedly bowed.

Inflammatory diseases of bones and joints

Bacterial infections of bones are very common in young ruminants, particularly following neonatal bacteraemia or septicaemia in animals with inadequate passive immunity. Since the route of infection is usually haematogenous, most are centred on the medullary cavity and are referred to as **osteomyelitis**. Bacterial osteomyelitis is most likely far more common than is diagnosed. Affected animals often die of septicaemia before the bone lesions become evident and the skeleton is generally not closely examined at necropsy unless clinical signs have suggested a skeletal disorder.

During bacteraemia or septicaemia, bacteria can become localised in many organs and at many sites. In bones, there is a strong predilection for sites of active endochondral ossification within the **metaphyses** and **epiphyses** of long bones and **vertebral bodies**. This reflects the unique nature of the vascular architecture at the physis, and at the equivalent site in expanding epiphyses. Capillaries invading the mineralised cartilage make sharp loops before opening into wider sinusoidal vessels that communicate with the medullary veins. The capillaries are fenestrated, thus permitting ready escape of bacteria into the bone marrow. Localisation of bacteria in the vessels of cartilage canals is also common in haematogenous infections of young animals. As the skeleton matures, the vascular morphology at chondro-osseous junctions alters to make it less suitable for bacterial localisation and there is probably only a narrow window during which bacteria are able to establish in bones. If the infection is not controlled by host defences or antibiotic therapy, the likely sequelae are localised bone destruction and/or **sequestration**. Large sequestrae are not resorbed and become walled off by an **involucrum**, but interfere with healing and harbour bacteria. The clinical manifestations of osteomyelitis may not develop until several months later when the bone lesion becomes extensive enough to cause pain, disfigurement of the bone, or perhaps result in a pathological fracture.

Vertebral osteomyelitis is a relatively common manifestation of bacterial osteomyelitis in young ruminants. Following localisation in the epiphysis or metaphysis of a vertebral body, or adjacent to a growth plate in a developing vertebral arch, the infection causes progressive destruction and weakening of the affected vertebral bone. As in long bones, sequestration and abscessation may occur. The most common sequela is pathological fracture and collapse of affected vertebrae with dorsal displacement of pus and necrotic bone fragments into the spinal canal. Such an event is accompanied by the sudden onset of neurological signs (e.g. hind limb paralysis) caused by compression of the spinal cord.

Mandibular osteomyelitis ("lumpy jaw") caused by *Actinomyces bovis* is well known in **cattle**, and occurs occasionally in other ruminants. *A bovis* is probably an obligate parasite of the oropharyngeal mucosa in a number of animal species, and most infections involve the buccal tissues. The organism is not particularly virulent, and in most, perhaps all cases,

the surface tissues must be injured by some other agent or by a foreign body for invasion to occur. *A bovis* may invade bone directly though the periosteum, but osteomyelitis usually develops from periodontitis, presumably via lymphatics, which drain into the mandibular bone. Once in the bone, *A bovis* causes a chronic, pyogranulomatous inflammatory reaction. Suppurative tracts permeate the medullary spaces leading to multiple foci of bone resorption and proliferation. Large sequestra do not develop, even when the cortex is invaded, probably because of the slow, progressive nature of the disease. Fistulae often extend into the overlying soft tissue and may discharge through the skin or mucous membranes. Periosteal proliferation is excessive and the bone may become enormously enlarged, the normal architecture of the mandible being destroyed. On cut surface, the affected mandible has a "honeycomb" appearance with reactive bone surrounding pockets of inflammatory tissue. The pus often contains many 1-2 mm diameter, soft, light yellow granules referred to as **"sulfur granules"**. These consist of an internal mass of tangled, gram-positive filaments mixed with some bacillary and coccoid forms, and a periphery consisting of closely packed, club-shaped, gram-negative bodies.

Localisation of bacteria infection in the highly vascular synovial membrane of joints during bacteraemia is very common, resulting in **polyarthritis**. The arthritis is more readily apparent clinically than osteomyelitis, but most animals that develop arthritis in the neonatal period will also have multiple foci of osteomyelitis. The prognosis is therefore poor unless affected animals can be treated with appropriate antibiotics very early in the disease process.

Acutely inflamed joints are swollen, hot and painful. Fibrin clots may be floating free within the joint fluid, attached to the synovial membrane or lodged within recesses of the joint. Sheets of yellow fibrin sometimes cover the synovial membrane, which is often oedematous and hyperaemic or studded with petechiae. Synovial villi, which are barely noticeable in normal joints, may become prominent due to the oedema and hyperaemia. The synovial fluid is increased in volume and may be either slightly turbid and mucinous or thin and cloudy, the latter implying septic inflammation. Complete resolution of septic arthritis is possible if the infection is eliminated spontaneously or by antibiotic therapy before erosion of cartilage occurs, but if the inflammatory process persists, the joint and adjacent structures will be severely altered. Cartilage degeneration occurs mainly at sites of weight bearing or at the articular margins, the latter in association with pannus formation. Erosion of the degenerate cartilage may allow infection to enter the subchondral bone, resulting in purulent osteomyelitis with extensive underrunning and separation of the articular cartilage. In such cases, it may be difficult to determine whether the arthritis preceded the osteomyelitis or *vice versa*, or whether the infectious agent gained access to both sites independently. Granulation tissue originating in the subchondral bone may grow out over the degenerate articular surface and predispose to ankylosis.

The suppurative process may extend from the joint to involve adjacent tendon sheaths and outwards from the synovial membrane of the articular capsule to produce cellulitis in periarticular tissues. The articular region is then greatly enlarged and the proliferation of fibrous tissue in response to inflammation, or during the healing process, results in permanent joint stiffness. In some cases, localisation of the cellulitis into a periarticular abscess may be followed by fistulation to the skin.

A range of opportunistic bacteria may be involved in neonatal osteomyelitis and polyarthritis in ruminants including: *Streptococcus spp, Escherichia coli, Arcanobacterium pyogenes, Staphylococcus aureus* and *Salmonella spp.* Other organisms, such as *Erysipelothrix rhusiopathiae, Mycoplasma spp* and *Chlamydia spp* have a strong predilection for the synovium and cause polyarthritis in the absence of osteomyelitis in lambs or kids and infection with such organisms is usually not related to neonatal septicaemia.

Degenerative diseases of joints

Degenerative joint disease is relatively common in **cattle** and is an important cause of wastage of stud bulls and bulls in artificial breeding centres. The **hip**, **stifle** and **hock** joints are most frequently involved. Although an inherited aetiology is suspected in the Friesian and Jersey breeds it is likely that most cases are secondary to poor conformation, traumatic damage to ligaments during fighting or mounting, or as a sequel to osteochondrosis. Osteochondrosis is probably most important in young, fast-growing bulls of large beef breeds that have been fed on concentrate rations in preparation for shows or sales.

By the time an affected joint is examined at slaughter, the lesion is usually too advanced to determine its cause. In chronic cases the cartilage may be completely eroded from weight-bearing surfaces, exposing eburnated subchondral bone, and any surviving cartilage is usually yellow and fibrillated. Exostoses may surround the articular surface and, in severe cases, there may be ossification of joint capsules and tendon sheaths. If the degenerative joint disease is secondary to trauma it is likely to involve a single joint while multiple joint involvement is a feature of osteochondrosis. It is a good idea to open several joints as healed lesions of osteochondrosis may still be apparent, even in joints that did not appear to be clinically affected.

Spondylosis (spondylosis deformans, ankylosing spondylosis) is a degenerative disease of the vertebral column characterised by the formation of osteophytes at the ventral and lateral margins of vertebral bodies adjacent to intervertebral spaces. The osteophytes may appear as spurs growing towards the adjacent vertebral body or as complete bony bridges with fusion of vertebrae.

Spondylosis is common in **bulls** kept in artificial breeding centres where it is presumably related to repeated traumatic damage to intervertebral

disks during semen collection. Lesions are found in almost any animal past middle age. Osteophytes develop mainly on the posterior end of thoracic vertebrae and the anterior end of lumbar vertebrae, and their incidence and size tends to decrease in either direction from the thoracolumbar junction. Although is a common incidental finding in breeding bulls, the disease is sometimes associated with mild or severe clinical signs. Affected bulls may show posterior weakness and ataxia, or even paralysis, after dismounting from service. They may continue to be mildly ataxic or recover, only to be affected again later. The onset of signs is usually associated with fracture of the vertebral bodies and of the ankylosing new bone, which is dense, but tends to be brittle. There is little displacement of the fractured ends in most cases and trauma to the spinal cord is usually mild. Paralysis is usually secondary to either haemorrhage or repeated trauma.

Tumours of bones and joints

Primary and secondary tumours of the skeleton are rare in ruminants and there are few reports in the literature. Chondromas and chondrosarcomas are occasionally found on flat bones (e.g. sternocostal complex, scapula, ilium) of aged ewes at slaughter. Most pathologists have seen isolated cases of tumours such as osteoma, osteosarcoma and fibrosarcoma involving the bones of ruminants, but there are too few cases to establish reliable information on their prevalence or behaviour.

The juvenile form of sporadic **lymphosarcoma** commonly involves the bones of calves. Large pale tan or yellow infarcts, associated with tumour cell infiltration, contrast sharply with the normal red, haematopoietic marrow on sectioning of long bones. Multiple bones are usually involved and the tumour also involves other tissues, including lymph nodes, liver, and kidney.

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Chapter 3

Macroscopic Pathology of the Lymphoreticular System of Ruminants

Philip W. Ladds

In common with the circulatory and nervous systems, the lymphoreticular system (LRS) consists of central, and less conspicuous but equally important peripheral components which are present to a greater or lesser degree, in almost all organs throughout the body of normal animals. Also, tissues of the LRS can arise *de novo,* as and when required, at sites of chronic inflammation. It is important to always be aware of this ubiquitous presence of the LRS because diagnosis of diseases primarily affecting it, such as lymphosarcoma, are often made, or at least suspected when changes are seen first in other, non-lymphoid, organs.

Essentially, the LRS consists of an intimate association of lymphocytes with reticular cells and fibres - the so-called macrophage phagocytic system whose primary role is to recognise, trap and process antigens and "present" them to lymphoid elements so that immune reactions may proceed.

The major, central, components of the LRS are the thymus, spleen and haemolymph nodes, the lymph nodes, and the tonsils.

Thymus

Age-associated changes

In normal animals thymus weight is maximal in the very young or up to puberty, after which there is progressive involution. Studies in cattle have confirmed that in contrast to other LRS tissues, thymus weight-bodyweight ratio decreased progressively from birth (Figure 1). Irrespective of the degree of involution, however, some remnant of the thymus always remains – although this author's experience is that it may not always be possible to find! In age-associated atrophy of the thymus, functional tissue is replaced largely by fatty tissue although cysts filled with serous fluid may also develop.

Haemorrhages

The thymus, perhaps because of its pale colour, is frequently recognised as a conspicuous site of haemorrhages – especially petechiae and ecchymoses. The causes of such haemorrhages are varied and include septicaemia (eg leptospirosis, listeriosis) or toxaemia (enterotoxaemia, cyanobacterial poisoning).

Developmental disturbances

There are early reports of accessory thymus tissue, associated with the thyroid gland in both cattle and sheep. Also, a more recent report describes large (4 cm diameter) bilaterally symmetrical masses of accessory thymus located at the angles of the mandible in a Nubian kid goat; herd history suggested the condition was heritable

Small thymus

Although there appears to be no report of thymic aplasia or hypoplasia associated with clinically apparent immune deficiency in cattle or small ruminants, profound thymic atrophy has been described in one breed of cattle in association with disturbed zinc metabolism.

Much more important is the striking atrophy of the thymus that may occur in response to "stress". Acute infection, severe injury, X-irradiation or a large dose of cortisone can all cause the thymus to shrink to half its size or less within a day or so – hence the erroneous interpretation, early in this century, of status *thymo lymphaticus* in children who died suddenly - without prior illness. The normal, large, thymus in these children was mistaken as a lesion; there had simply not been sufficient time for thymus involution to occur. Probably in disease of varied cause, rapid thymic involution reflects both a stress response (presumably cortisone mediated) as well as direct destruction of LRS components by eg toxins of infectious agents, particularly viruses.

Large thymus

Obvious enlargement of the thymus is probably most often due to neoplasia (see below). Quite significant thymic enlargement may occur in cattle after castration. Endocrine influences would seem to be involved; it is recognised that the thymus and therefore cell-mediated immunity, are influenced during development and in adult life by endocrine hormones.

Thymic hyperplasia is a diagnosis that mostly requires histopathological examination as there may be proliferation of particular elements such as follicles without any increase in overall size of the thymus. Repeated vaccination of calves, however may induce hyperplasia such that the thymus may fill the anterior mediastinum and extend up the neck.

Thymitis

Whereas swelling is an expected change in most organs in acute inflammation, for the reasons given above, thymic inflammation is probably more often associated with atrophy. Such is the case in epizootic abortion in calves, in which there is involution in spite of concurrent cellular infiltration.

Neoplasia

In contrast to the spleen or lymph nodes, the thymus contains epithelial elements; so-called thymoma is a tumour derived from such epithelium. Thymic tumours composed only of epithelium are however quite rare so in most such tumours lymphoid proliferation predominates. In general, these lymphoid tumours of the anterior mediastinum and thoracic inlet of bovine yearlings are aggressive whereas those in sheep and goats are encapsulated masses that because of their large size may cause clinical signs but do not metastasise.

Thymic lymphoma in cattle is not associated with bovine leukaemia virus infection. Swelling at the base of the neck may be massive, and the tumours, which may weigh in excess of 20 kg, can extend from the base of the heart to the rami of the mandible. There is invasion of tumour tissue into adjacent structures.

Lymphoid and lympho-epithelial lymphomas in sheep and goats are usually incidental "space-occupying" lesions found at necropsy or slaughter. They form well-encapsulated irregular masses up to ~15 cm in diameter that on section may resemble normal thymus but with prominent fibrous septae.

Spleen

Involution

As with other lymphoid organs, splenic involution occurs with advanced age such that the spleen of an old animal is firm, and is seen histologically to be composed largely of connective tissue rather than lymphoid elements. In one study in cattle for example, the spleen-bodyweight ratio (obtained by weights measured after animals had been "bled out" in an abattoir), decreased from a maximum of 38 ($x10^{-4}$) at approximately 5 month-of-age to 18 ($x10^{-4}$) in animals older than 7 years (*Figure 1*).

Atrophy of the spleen may also occur with starvation or as a consequence of protracted wasting disease. Rapid involution of the spleen may occur in fulminating disease such as bovine virus diarrhoea. Changes in overall size of the spleen in disease will reflect concurrent circulatory events and an increase or decrease in LRS parenchyma. In rinderpest, for example, there is early splenomegaly but microscopically there is marked breakdown of lymphocytes – so-called lympholysis.

Developmental disturbances

A variety of such disturbances occur rarely in ruminants. These include complete absence (aplasia), hypoplasia, duplication (in association with other defects), and accessory spleens. There is a recent report of accessory (supernumerary) spleen in an otherwise normal mature goat;

both spleens were of similar weight and were supplied independently by separate splenic vessels at the hilus.

Pigmentation

Haemosiderosis of the spleen, which results from the excessive breakdown of erythrocytes, is likely to be observed in areas where piroplasmoses are endemic. For haemosiderosis to be apparent grossly, however, very large amounts need to be present. Affected spleens are slightly enlarged, firm in consistency, and dark brown on the cut surface.

Enlarged spleen (splenomegaly), and splenitis

Essentially the spleen may be enlarged because of one or more changes, perhaps occurring simultaneously – increased blood, hyperplasia of the macrophage phagocytic system, inflammatory oedema and cell infiltration, and lymphoid hyperplasia. Although histology is needed to clarify the type of change, careful gross examination may provide some indication.

The most common cause of severe congestion of the spleen at necropsy, is when barbiturate drugs are used for euthanasia. Distension of the spleen with blood also occurs as acute hyperaemia in acute systemic infections and some acute bacterial intoxications such as in clostridial enterotoxaemia.

Of particular interest in ruminants, however, is the acute hyperaemic swelling of the spleen that occurs in anthrax, in which the reaction is almost solely vascular. Grossly the capsule is tense and encloses excessive soft pulp of tarry consistency and dark colour. Note however that this change can to some extent be caused by post mortem autolysis, so case history and caution in interpreting findings, are needed. The appearance in acute babesiosis is similar to anthrax, and in endemic areas, is largely diagnostic. In less acute conditions there is hyperplastic splenomegaly, manifested grossly as the cut surface of the enlarged spleen exuding less blood but having a more "meaty" consistency.

Such change is a feature of salmonellosis in calves, in which histology confirms that there is diffuse hyperplasia and hypertrophy of reticular elements. An enlarged spleen, "meaty" as a result of hyperplastic changes, may also be seen in bovine malignant catarrh (malignant catarrhal fever), and is particularly striking (almost to the point of resembling neoplasia) in Jembrana Disease – a lentivirus infection of Bali cattle.

Nodular hyperplasia

This condition is seen occasionally in old bulls, and was also the subject of a specific report in New Zealand where it was observed in 0.8% of aged ewes from one source. Grossly, shape of the spleen was irregular and nodular, shown microscopically to be due a mix of localised

hyperplasia of reticular elements, congestion, haemorrhage and thrombosis.

Neoplasia

Although uncommon in ruminants, no doubt because they are slaughtered before reaching "cancer age", haemangioma-haemangiosarcoma may occur and may metastasise to the liver. Lymphosarcoma may cause diffuse splenic enlargement with total weight in cattle being 50 kg or more. In one review of bovine lymphomas, the spleen was involved in 30% of cases. Rupture and haemorrhage are likely complications.

As in other species, and presumably because of the peculiar vascularity of the spleen, it is, in ruminants, an uncommon site for secondary neoplasms. Superficial (capsular), implants of squamous cell carcinoma and other neoplasms, are however, observed.

Haemolymph (haemal) nodes

These nodes which are often intimately associated with lymph nodes, are typically found only in ruminants and rats. Although there is debate about communications between lymph and blood vessels in these nodes, there are probably no such connections.

Haemolymph nodes have germinal centres and because they filter blood, one expects their function and pathology to parallel that of the spleen. Marked enlargement of these nodes occurred in experimantal *Trypanosoma vivax* infection in sheep and goats. Haemangiosarcoma in haemal lymph nodes of sheep has also been observed.

Lymph nodes

The normal node:

There is considerable variation in the size, colour and shape of lymph nodes in apparently normal animals and such variation is, to a large extent, unexplained. Because of this, one has to recognise a "range of normality", particularly if nodal changes are generalised throughout the body. In interpreting more localised changes, however, comparison of the node in question with its opposite, contra-lateral node, is especially useful.

Some variation in nodal morphology can be related to "non-disease" factors such as age, anatomical location and physiological state. The nodes of foetuses and neonates are pale and lack the irregular capsular contours of nodes in older calves, indicative of follicular development.

Dark pigmentation of the deeper, medullary regions is a feature of bovine nodes. With increasing age the amount of pigment (probably the "wear

and tear" pigment, lipofuscin) increases in all nodes but is most pronounced in the mesenterics, probably because of material draining directly from the gut.

Deposition of a striking orange carotenoid pigment is sometimes observed in the lumbar nodes of cattle and is presumed to originate from the corpora lutea of the ovary (cows) or gut. Dark brown to black melanin pigment in nodes is mostly secondary to melanomas located in their drainage area, but may be congenital. In the case of melanoma, histology of the node is necessary to distinguish simple pigment drainage from metastasis.

Pale, lipid accumulations are not uncommon in the mammary nodes of lactating animals, and their firm nature may cause confusion with infectious granulomas. In very fat animals there may be considerable encroachment of fat into the hilar region of nodes.

General reactions of lymph nodes:
Regional lymph nodes may respond to a wide variety of stimuli so that ultimately they are quite different from their contra-lateral node or other nodes in the same animal. Clinically, and on macroscopic examination the most obvious change is increased size, but changes in shape, consistency and colour may also be observed. Perhaps unfortunately, microscopic examination is needed to ascertain precisely which nodal component has proliferated. In this regard it needs to be stressed that lymph nodes are physically rather "fragile" so that if histology is to be done, the node must be handled gently (not squeezed or tugged!) and slices for fixation in formalin should be obtain using a very sharp knife, or scalpel.

In very general terms, enlargement associated with a uniformly pale colour and soft consistency is likely indicate lymphoid hyperplasia or neoplasia, whereas an enlarged node that on cutting is seen to be oedematous and have a discoloured, perhaps mottled surface, is more likely to be acutely inflamed. Also, quite extensive sclerosis with hardening of the node is a common feature of chronic change both in inflammation and neoplasia, sometimes even leading to the formation of bone, so-called osseous metaplasia.

Non-infectious, non-neoplastic changes:
Whereas the spleen has the role of filtering the blood, the lymph nodes act as filters for extravascular fluid. Non-infectious, non-neoplastic morphological changes in nodes primarily involve this filtering function.

Lipid drained from a site of injury to a regional node may appear as distinct firm foci that are pale, or yellow if discoloured by bilirubin from haemorrhage in the same area.

Emphysema, with the presence of distinct bubbles, is occasionally seen in the mediastinal nodes of cattle with interstitial pulmonary emphysema.

Although the normally pale colour of nodes facilitates the recognition of haemorrhage, additional information and histology are needed to decide whether erythrocytes (mostly in nodal sinuses) represent actual haemorrhage within the node or simply drainage from an injured area. Studies on bruising in cattle indicate that many, perhaps most erythrocytes drained to a regional node continue through the afferent lymphatics to re-enter the blood. Therefore erythrocytes that remain in a lymph node would appear to have been defective as a consequence of eg toxaemia or inflammation. Erythrocytes retained in this way are converted by macrophages in the node to the pigment haemosiderin, and this process (haemosiderosis) is detected grossly by the colour of the node, and especially its medulla, changing from red to rusty brown.

Another pigment which may result in a striking green colour of eg the parotid lymph node of calves is an exogenous one used for ear marking. Similar changes occur in nodes draining tattooed areas in humans.

Local or generalised non-inflammatory oedema of nodes that are enlarged and on cutting have a moist appearance and perhaps increased fibrosis, is occasionally observed. Impaired drainage from the node, possibly due to damaged afferent lymphatics, would seem to be the cause.

Lymphadenitis:

As explained above under 'general reactions', microscopy is needed to determine the cause of nodal enlargement but such enlargement seen grossly to be associated with suppuration, oedema and increased "redness" due to active hyperaemia will suggest *acute lymphadenitis*. This is especially so if similar changes are observed in any primary lesion within the drainage area. It is important to note that acute inflammation of the parenchyma of the larger nodes in cattle (and presumably small ruminants) may not be uniform; this is because afferent lymphatics to different parts of the node originate from different body regions. The superficial cervical (prescapular) node for example, is considered to be a composite of at least four nodes, each draining separate, large areas.

As discussed in relation to the spleen, changes in acute inflammation will be a combination of fluid and cellular accumulation (to dilute and remove the irritant) and purely immunological events – both of which can occur with great rapidity such that inflamed nodes can treble in size in several days. Rarely, however, the gross appearance my be suggestive of a particular pathogen. Acute lymphadenitis in anthrax is diffuse, exudative and haemorrhagic. Similar changes are observed in both lymph node and peri-nodal tissue in infection with *Clostridium septicum* but frequent gas bubbles are an additional finding.

In *sub-acute lymphadenitis* continued nodal enlargement is most likely to represent a balance between inflammation per se and immunological responses; the gross appearance of these lesions is unlikely to be suggestive of any particular pathogen.

With subsequent development of lesions however, and progression to *chronic lymphadenitis*, observed changes are more likely to be of value in diagnosis. Essentially the lesion may localise to form an abscess – with varying degrees of capsular fibrosis and inspissation of necrotic debris (such as in caseous lymphadenitis in sheep and goats), or a granulomatous response will result. Fortunately, the microscopic, and sometimes the gross appearance of the so-called "infectious granulomas" are sufficiently characteristic to permit precise diagnosis – except in old, largely resolved lesions.

Included among the causes of infectious granulomas are microorganisms such as *Rhodococcus equi, Propionibacterium* sp., *Nocardia-Streptomyces,* to so-called "club-forming" granulomatous organisms (*notably Actinobacillus lignieresi), Mycobacteria* spp., *Brucella* spp., fungi and algae, and parasites ranging from protozoa through helminths to pentastomes. These specific infections will be illustrated.

More difficult to diagnose and categorise than those diseases mentioned above is the response of lymph nodes to several viral pathogens in cattle. In Malignant Catarrhal Fever, and even more so in Jembrana Disease, the nodal response to infection is essentially enlargement with a massive proliferation of lymphoid cells, which in many respects resembles neoplasia.

Neoplasia:

Once again, lymph node changes in neoplasia are usually detected as enlargement. If gross examination of the enlarged node reveals that the shape, colour and consistency of the node are more or less normal, the immediate problem is to decide whether the change is neoplasia, and in particular lymphoma, or reactive hyperplasia. Knowledge of any associated lesion in the drainage area of the node, or elsewhere in the body, will usually help resolve this question..

Typically, however, neoplastic proliferations in a lymph node will appear as nodules which distort its shape from normal, which bulge on cutting and tend to compress adjacent lymphoid tissue, and have a consistency and colour which is different from normal node. This appearance of course may vary considerably depending on the age and degree of malignancy of the lesion, and concurrent inflammation, necrosis and haemorrhage. Particularly in the absence of any primary lesion, it may be impossible on gross examination to distinguish between a neoplasm and a granuloma.

Neoplasia in lymph nodes may be primary but is more often secondary, reflecting the importance of nodes as filters of lymph from their drainage areas.

Lymphoma is a general term applied to any *primary neoplastic disorder* of lymphoid tissue; the terms lymphosarcoma and malignant lymphoma are used to describe those tumours which are clearly malignant. It may

be impossible on gross examination, and often very difficult histologically to differentiate these tumours from reactive hyperplasia.

The presence and type of *secondary tumours* in lymph nodes are somewhat easier to diagnose. This is because a less diffuse and more nodular appearance of lesions with a consistency and perhaps colour contrasting with normal node can be expected. Even though most farm livestock are slaughtered before reaching "cancer age", an impressive variety of tumours forming metastases in lymph nodes is described. These include melanomas, squamous cell carcinoma (SCC) and adenocarcinoma (especially of uterine origin), neurofibroma, and heart-base tumours. Especially because the keratinised masses (epithelial "pearls") in metastatic SCC may induce a foreign body type granulomatous response, they may, even histologically, be mistaken for granulomas of infectious origin, so history, and knowledge of the primary lesion are important.

Age-associated changes in bovine lymphoid system

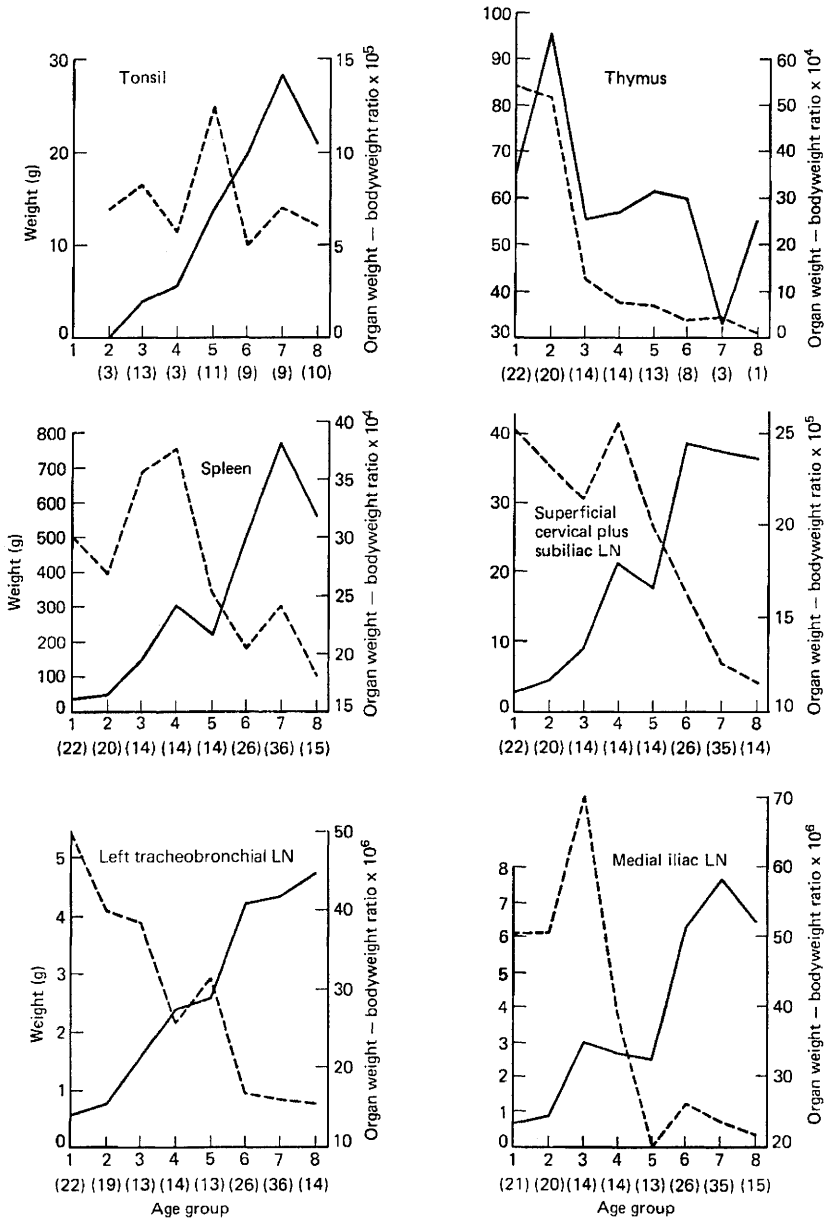


FIG 1: Changes in organ weights (————), and organ weight-bodyweight ratios (— — — —) in relation to age. Approximate ages were groups 1 and 2 — 'young' and 'mature' fetuses, respectively; groups 3, 4 and 5 — calves newborn to one month, four to six months, and seven to nine months, respectively, and groups 6, 7 and 8 — heifers or cows nine months to three years, four to six years and seven to nine years, respectively. Figures in brackets indicate number of animals within each age group

Chapter 4

Cardiovascular and Haemopoietic Systems

Roger W Cook

HEART

Introduction

The purpose of gross examination of the cardiovascular system at necropsy is to detect lesions and interpret their significance.

A relatively minor but critically located lesion may cause a marked, possibly fatal, disturbance in cardiovascular function. Some fatal diseases (eg acute phalaris toxicosis and hypomagnesaemia) produce functional cardiac effects only and therefore no detectible lesions. On the other hand, a major structural abnormality (eg an extensive area of cardiac fibrosis) may be an incidental necropsy finding.

Some gross cardiovascular lesions may be sufficiently distinctive to suggest a specific disease (eg focal mural haemorrhage at the base of the pulmonary artery in bluetongue in sheep; a necrotising myocarditis in blackleg in cattle).

History, clinical findings, and evidence at necropsy of **cardiac compensation** (eg cardiac hypertrophy or dilation) or **congestive heart failure** (eg ventral oedema, hepatic congestion and enlargement, or fluid accumulation in body cavities) can assist interpretation of cardiovascular lesions found at necropsy.

A working knowledge of **cardiovascular structure and function** is an important basis for identifying and interpreting gross **pathological patterns of cardiovascular disease**.

Cardiovascular Responses to Maintain Cardiac Output

The role of the cardiovascular system is to maintain an adequate circulation of blood to meet the metabolic (nutritional, oxygen and excretory) needs of body tissues.

The heart (a rate-variable, one-way pump) drives the system.

There are three determinants of heart function, **rate and rhythm**, **haemodynamics**, and **contractility** *(see **Table 1**)*, and they mediate:

- **Disturbances** of heart function in cardiac disease.
- **Compensatory responses** of the heart to demands on cardiac output in both normal and diseased hearts *(see **Tables 1** and **2**)*.

The normal heart has the capacity (cardiac reserve) to increase its output up to five-fold, as seen, for example, during physical exertion.

Compensatory responses can maintain an adequate cardiac output and circulation of blood for some time in animals with severe cardiac disease and compromised cardiac function.

Determinants of Heart Function	Disturbances	Compensatory Responses in Normal and Diseased Hearts
1. Rate and Rhythm (ability to depolarise regularly but variably).	**Arrhythmias** (disturbed impulse formation or conduction) may be: • **Intrinsic.** • **Secondary to myocardial damage** (necrosis, fibrosis, or infiltration by inflammatory or neoplastic cells).	• Increased heart rate
2. Haemodynamics (ability to maintain efficient, one-way blood flow). *Haemodynamics involve:* • *Heart chamber **pressures.*** • *Heart chamber **volumes.***	**Haemodynamic disturbances**, affecting one or both ventricles, include: • **Systolic (pressure) overload** (eg outflow stenoses and hypertension). • **Diastolic (volume) overload** (eg valvular insufficiencies). • **Diastolic (volume) underload** (eg constrictive pericarditis).	• Hypertrophy. • Hyperplasia.

3. Contractility
(ability to contract with vigour).
	Contractility deficits (myocardial failure) may be:
	• **Intrinsic** (eg cardiomyopathies).
	• **Secondary to myocardial damage.**
		• Increased contractile force:
		  • From sympathetic stimulation.
		  • In stretched myofibres in cardiac dilation.

Table 1. Determinants of heart function.

Cardiovascular Responses to Maintain Adequate Cardiac Output	Outcomes
1. Systemic Responses • **Increase in peripheral resistance.** • **Redistribution of blood flow to vital organs.** • **Venular constriction.** • **Increase in blood volume** *(modulated by sodium and water retention, a renal response to hypovolaemia, and by sodium retention due to renin / angiotensin / aldosterone activation).*	**Systemic responses** enhance venous return to the heart. ***Circulatory filling pressure*** *is the "tightness" with which the circulation is filled with blood (it depends on peripheral resistance, venous tone, vascular compliance and blood volume) and is central to the events that follow the onset of heart failure.* ***Venous return*** *is proportional to* ***circulatory filling pressure*** *minus* ***atrial pressure. Cardiac output*** *is directly proportional to* ***atrial pressure****.* *As the heart fails, renal compensation increases circulatory filling pressure to enhance venous return and restore cardiac output, but at the price of an increase in atrial pressure.*
2. Intrinsic Cardiac Responses • **Increase in heart rate**	**Increase in heart rate** (from sympathetic stimulation) increases cardiac output per minute. Stroke volume is maintained by more rapid filling and emptying of ventricles.
• **Cardiac dilation** *Dilation is a compensatory response that can increase cardiac output, as stretching of myofibres increases the contractile force (Frank-Starling phenomenon) and increased stroke volume results. However stretching beyond certain limits results in decreased contractile force.* **Cardiac dilation** results from: • **Diastolic (volume) overload** (eg in heart shunts; atrioventricular and semilunar valvular insufficiencies).	**Cardiac dilation** is indicated by: • Rounded (globose) cardiac profile. • Enlarged ventricular lumen(s) (with or without change in wall thickness). • Changes in size of atrioventricular rings (AVR) (normal ratio of circumference LAVR / RAVR is 0.8 - 0.9). *Dilation occurs terminally in many cardiac diseases.* *In both* ***cardiac dilation*** *and* ***eccentric hypertrophy*** *the heart tends to be globose and the ventricular wall is usually thin, especially relative to the overall chamber dimensions. The papillary muscles may be attenuated.*
• **Cardiac hypertrophy (concentric or eccentric)** *Hypertrophy is an important long-term compensatory response to sustained changes in pressure or volume loads.* **Concentric hypertrophy** results from: • **Systolic (pressure) overload** (eg in aortic stenosis; pulmonic stenosis; pulmonary hypertension). • **Diastolic (volume) underload** (eg in constrictive pericarditis; hydropericardium; restrictive cardiomyopathies). **Eccentric hypertrophy** results from: • **Diastolic (volume) overload** (eg in cardiovascular shunts; atrioventricular and semilunar valvular insufficiencies).	**Cardiac hypertrophy** is indicated by: • Increased heart mass (normally 0.5 - 1.0 % of body weight). • Concentrically or eccentrically thickened ventricular walls *(in normal animals, the left ventricular wall is thicker than the right, except in neonates where they are of similar thickness).* • *Hypertrophy of the right side broadens the base of the heart.* • *Hypertrophy of the left side increases heart length.* • *Bilateral hypertrophy produces a globose heart.* In **concentric hypertrophy**: • Ventricular mass is increased **without** increase in end-diastolic volume (ventricular lumen volume may be **decreased**). • Affected ventricular wall is thicker than normal as are papillary muscles, muscle ridges (*trabeculae carneae*) and moderator bands, especially the large band in right ventricle. In **eccentric hypertrophy**: • Ventricular mass is increased **with** increase in end-diastolic volume. • Affected ventricular wall is **not** thicker and may be thinner.

Table 2. Cardiovascular responses to maintain adequate cardiac output.

Circulatory Failure

There are **three syndromes of cardiovascular circulatory failure** that should be considered at necropsy *(see **Table 3**).* History and clinical findings assist in this assessment.

Circulatory Failure Syndromes	Pathological Outcomes
1. Acute Heart Failure (cardiac syncope). *Causes include:* • *Reflex vagal inhibition.* • *Tachycardia or fibrillation.* • *Conduction failure.* • *Terminal congestive heart failure.*	Outcome of acute heart failure is: • No detectible lesion (except in terminal congestive heart failure).
2. Congestive Heart Failure. *Congestive heart failure develops when the compensatory cardiovascular responses to sustained **arrhythmias, pressure or volume overloads**, or **myocardial damage** can no longer maintain an adequate cardiac output from a diseased heart to meet the metabolic needs of body tissues.*	Pathophysiological features of congestive heart failure are: • **Accumulation of fluid** (due to retention of sodium and water). • **Tissue and organ ischaemia.** *The compensatory response of increased blood volume is initially beneficial as it enhances venous return and cardiac output, but it also results in an **increase in capillary hydrostatic pressure,** which tends to promote **interstitial oedema** ("waterlogging").*
• **Left-sided failure** results in increased hydrostatic pressure in the pulmonary venous system (and decreased forward blood flow to peripheral tissues). *Causes include:* • *Disease of mitral or aortic valves.* • *Several congenital heart diseases.* • *Contractility loss from myocardial necrosis, myocarditis, or cardiomyopathy.*	Outcomes of left-sided failure are: • **Pulmonary congestion and oedema** (with white frothy fluid in airways). • **Hydrothorax** (possible).
• **Right-sided failure** results in increased hydrostatic pressure in the systemic and portal venous systems (and decreased forward blood flow to lungs and left ventricle). *Causes include:* • *Pulmonary hypertension.* • *Disease of tricuspid and pulmonary valves.* • *Contractility loss from myocarditis, myocardial necrosis or cardiomyopathy.*	Outcomes of right-sided failure in ruminants are: • **Ventral oedema.** • **Hepatic congestion and enlargement** ("nutmeg liver", congestive hepatic nodularity). • **Fluid accumulation in body cavities** (ascites, hydrothorax and hydropericardium). *Sodium and water retention and resulting increase in blood volume are more severe in right-sided than in left-sided failure.*
3. Peripheral Circulatory Failure *Causes include:* • *Reduced circulatory blood volume due to acute blood loss, shock, or splanchnic venous pooling.*	Outcomes of peripheral circulatory failure include: • Evidence of blood loss. • Congestion of viscera.

Table 3. Cardiovascular circulatory failure. Their pathological outcomes are summarised.

Dissection of the Heart

An essential part of any necropsy is a systematic examination of the heart, including:

- **Pericardium.**
- **Endocardium (mural and valvular).**
- **Myocardium.**
- **Large vessels.**

Always follow the same procedure for dissection and examination of the heart, to optimise detection of **gross lesions** as well as **changes in size**, **shape** and **position** of the heart, its components and associated thoracic structures. There are several ways to open a heart:

- **Inflow-Outflow Method**: The heart is opened by incisions A and B on the right side and incisions C and D on the left *(see **Appendix 1. Dissection and Gross Examination of the Heart**)*.

  This common method allows good access to all chambers, preserves atrioventricular valves and moderator bands, and allows easy measurement of atrioventricular valve rings.

  *Measurements of body weight, circumference of atrioventricular valves and weights of whole heart, right ventricular free wall, combined left ventricular free wall plus interventricular septum, and combined atria allow assessment of **heart to body weight ratios** and degree of chamber dilation (see **Appendix 1**).*

- **Ventricular Slice Method**: The heart is preferably fixed first, and then sliced transversely, perpendicularly to the septum from apex to base at 1-cm intervals.

  This 'breadloaf" method is used to determine ventricular mass, extent of ventricular lesions (eg necrosis, fibrosis), chamber dimensions and wall-to-lumen relationships.

- **Four Chamber Method**: The heart is preferably fixed first, and then bisected longitudinally perpendicularly to the septum from base to apex to reveal all walls and chambers.

  This method is used to compare thickness of the ventricular septum and free walls.

For **histological examination:**

- Collect and formalin-fix 5mm-wide sections from myocardial lesions or a minimum of five standard sites (sites 1. 2, 4, 6 and 9) *(see **Appendix 2. Standard Sites for Histological Examination of the Heart**)*.
- With special cases or small animals, **fix the whole opened heart** before collecting samples from lesions and standard sites.

Postmortem Changes in the Heart

Rigor mortis of the myocardium occurs earlier than in skeletal muscle, and produces contracted rigid ventricular walls in a freshly dead animal (within an hour of death). The left ventricle is affected first. As blood clots relatively slowly in the unopened carcass, rigor usually expresses blood completely from the left ventricle and incompletely from the right. Clotted blood in the left ventricle suggests incomplete rigor due to myocardial degeneration. Postmortem blood clots in the atria, right ventricle and large vessels at the base of the heart are dark red ("current jelly"). As sedimentation of red cells is slow in ruminants, so-called "chicken-fat" clots do not occur except in severely anaemic animals.

As rigor passes (after 12 to 24 hours) and **autolysis** proceeds, the appearance of the heart changes. Unclotted or haemolysed blood may flow back into the ventricles. Postmortem leakage and haemolysis of erythrocytes can cause dark-red, haemoglobin staining of pericardial fluid and endocardium, and should not be mistaken for antemortem haemorrhage. The autolysed myocardium is inelastic and pale grey, with a partially-cooked appearance.

Congenital Developmental Abnormalities of Heart and Large Vessels

The embryological development of the heart and large vessels is complex and consequently anomalies can occur. The most severe defects result in death *in utero* and the mildest remain subclinical throughout life. It is only animals with anomalies of intermediate severity that, after surviving the circulatory changes from foetal to neonatal life, develop signs of cardiac disease.

Most congenital cardiac anomalies in ruminants appear to be spontaneous diseases of low incidence. In other species, and particularly in dogs, some anomalies are genetically determined. They can be produced experimentally by various chemicals and drugs, physical agents (x-radiation and hypoxia), and nutrient deficiencies and excesses.

Necropsy of any foetus or neonate, with or without signs of cardiac failure, should include systematic examination of the heart for the most common cardiac anomalies *(see **Appendix 1**)*. Always examine the heart and large vessels *in situ*, and do **not** separate them from the lungs until after the locations and connections of the large vessels at the base of the heart have been evaluated.

Congenital cardiac anomalies can be broadly classified as:

- **Anomalies from failure of closure of foetal cardiovascular shunts.**
- **Anomalies from failure of normal valvular development.**
- **Anomalies from malpositioning of large vessels.**
- **Other cardiac anomalies.**

Anomalies from failure of closure of foetal cardiovascular shunts

A **patent ductus arteriosus** may be an anatomical finding in neonatal ruminants, but is rarely functional. *In utero*, blood is shunted from pulmonary artery to aorta, bypassing the lungs. *If it persists after birth, there is a shunt from the left to right ventricle and pulmonary hypertension results.*

A congenital **atrial septal defect** may result from a **true septal defect** or from **failure of closure of the foramen ovale** (in the unborn foetus this is a right-to-left interatrial septal shunt; it may still be anatomically-patent but functionally-closed in neonates and occasionally in adults due to the higher pressure in the left ventricle). *Left-to-right interatrial shunt produces right ventricular dilation and hypertrophy, relative pulmonary stenosis and bilateral atrial dilation.*

A **ventricular septal defect** is one of the commonest seen in ruminants, and usually is located in the dorsal membranous septum (rather than the ventral muscular septum), or in the subpulmonary septum. It may be hereditary in Hereford and Limousin breeds. *In utero* there is no flow across the defect as pressures in both ventricles are the same. *After birth there is a left-to-right shunt, which produces bilateral ventricular hypertrophy (more eccentric in left ventricle).* Always check for concurrent defects, such as **dextropositioning of the aorta**, which will straddle the ventricular septal defect.

The **tetralogy of Fallot** is a relatively common complex cardiac anomaly comprising three primary defects of high ventricular septal defect, pulmonic stenosis and dextropositioning of the aorta and a fourth, secondary defect, compensatory hypertrophy of the left ventricle. **Eisenmenger's complex** is similar to tetralogy of Fallot, with pulmonary hypertension but without a pulmonary stenosis.

Anomalies from failure of normal valvular development

Pulmonic stenosis (subvalvular, valvular or supravalvular)) causes post-stenotic dilation and thinning of the wall of the pulmonary trunk and concentric right ventricular hypertrophy. It is usually reported in dogs, but occurs in other domestic animals.

Subaortic and aortic stenosis (most commonly the former) causes post-stenotic dilation of the aorta, and concentric right ventricular hypertrophy and frequently multifocal myocardial necrosis. It occurs frequently in Danish pigs and dogs.

Congenital haematomas (haematocysts) are common, blood-filled cysts lined by endothelium frequently seen on the margins of the atrioventricular valves of young ruminants. They measure up to 10 mm in diameter and usually regress after several months. They occasionally enlarge and persist up to a year with serous fluid content replacing blood.

Anomalies from malpositioning of large vessels.

Transposition of the aortic and pulmonary trunks is a severe cardiac anomaly that occurs in calves and involves **dextropositioning of the aorta** so that it receives blood from the right ventricle. It occurs in four types: **overriding aorta** (aorta straddles a defective septum); **partial transposition** (both aorta and pulmonary artery leave the right ventricle); with **overriding pulmonary artery** (pulmonary artery straddles a defective septum, and the aorta leaves the right ventricle) and **complete transposition** (aorta leaves the right ventricle, and the pulmonary artery leaves the left).

Persistence of right aortic arch in calves results in the aortic trunk ascending on the right rather than on the left side of the trachea and oesophagus (because the right fourth aortic arch persists instead of the left, as is normal, to form the ascending trunk of the aorta). The ductus arteriosus (ligamentum arteriosum) passes from the aorta to the pulmonary artery from right to left over the oesophagus, compressing it against the trachea. This eventually leads to obstruction and proximal dilation of the oesophagus (mega-oesophagus).

Other cardiac anomalies.

Ectopia cordis is congenital displacement of the heart (cervical, sternal, or abdominal) and is usually reported in calves. It is not strictly a malformation of the heart but of adjacent structures.

Ventricular hypoplasia, aortic hypoplasia, aortic coarctation (aorta constricted at the site of entry of the ductus arteriosus), **persistent truncus arteriosus** (common aortic trunk: one vessel arises from the heart base and the aorta and pulmonary artery arise from it), **abnormal origin of carotid arteries** (arise from pulmonary artery instead of the aorta), **cor triloculare biatriatum** (complete absence of interventricular septum, resulting in three heart chambers: two atria and one ventricle) and **endocardial fibroelastosis** are also reported.

In a 14-year Kansas study of calves with cardiac defects, 36 calves had 78 congenital cardiac defects: ectopia cordia cervicalis (10 defects), common aortic trunk (3), dextraposed aorta (8), duplicated major trunks (1), hypoplastic aorta (2), interventricular septal defect (11), interatrial septal defect (2), left ventricular hypoplasia (10), patent ductus arteriosis (5), patent foramen ovale (5), right ventricular hypoplasia (10), cor triloculare biatriatum (1), endocardial fibroelastosis with calcification (3) and valvular haematomas (7). All septal defects were high in location and ranged from 5 to 35 mm in diameter.

Reference:

Gopak T, Leopold H W and Dennis S M (1986) Congenital cardiac defects in calves. *Am J Vet Res* 47: 1120-1121.

Cardiac Haemorrhages

Haemorrhages may be localised in the epicardium, endocardium or myocardium.

Epicardial and **endocardial haemorrhages** are common, non-specific, terminal lesions in ruminants. They are seen particularly in animals that have died acutely (eg from bloat, infectious diseases, blue-green algal toxicosis) and reflect terminal anoxia. They range from petechial to ecchymotic to suffusive, and may be extensive. They occur in **bluetongue** in sheep, in addition to the distinctive **focal, mural haemorrhage at the base of the pulmonary artery** (and aorta).

Ecchymotic endocardial haemorrhages particularly in the **left ventricle** are seen in **clostridial enterotoxaemia** in lambs and calves.

Epicardial and **endocardial haemorrhages** are consistent gross lesions in ruminants poisoned by cardiac glycosides in plants such as *Bryophyllum* tubiflorum (mother of millions) and its *B daigremontianum* hybrid, *Nerium oleander* (oleander) and *Homeria* spp (cape tulips).

Pericardial Diseases

Noninflammatory lesions of the pericardium

After death, there may be some transudation of red (haemolysed) fluid into the pericardial sac.

Hydropericardium is the accumulation of clear, colourless to light yellow, watery fluid in the pericardial sac. In chronic cases there is fibrous or fibrovascular villous thickening and opacity of the pericardial and epicardial surfaces; vessel rupture within villous areas can cause blood-staining of the fluid. *In those diseases causing generalised oedema, there may be concurrent ascites, hydrothorax and pulmonary oedema.*

High-protein pericardial oedema fluid (**exudate**, which forms fibrin clots, particularly on exposure to air), results from:

- **Increased vascular permeability** in acute systemic diseases (eg clostridial toxaemias, and heartwater (*Cowdria ruminantium*).

Low-protein pericardial oedema fluid (**transudate** which does not clot) results from:

- **Decreased capillary osmotic pressure** due to **hypoproteinaemia** (eg. illthrift and undernutrition, severe anaemia as in haemonchosis and fascioliasis, and protein-losing enteropathy or nephropathy).
- **Increased hydrostatic pressure** in **congestive heart failure**.

- **Obstruction to lymphatic drainage**, (eg by pericardial, and other thoracic granulomatous lesions or neoplasms, including mesothelioma and lymphoma).

When hydropericardium develops rapidly, cardiac tamponade (compression) compromises cardiac filling, especially of the atria, as the pericardium cannot stretch quickly. When it develops slowly, the pericardium can stretch to accommodate a large volume of fluid without tamponade.

Haemopericardium is the accumulation of pure blood (clotted blood indicates a true haemocardium) in the pericardial sac. Death is usually sudden due to cardiac tamponade. The source of haemorrhage is usually rupture or puncture of the heart or a major vessel.

Serous atrophy of pericardial fat occurs in cachectic animals. The fat is grey and gelatinous and may contain small white foci of fat necrosis.

Pericarditis

Fibrinous pericarditis results usually from systemic (haematogenous) infection, and less frequently from local spread of infection from adjacent thoracic organs (lungs and pleura). Extending from the base of the heart, fibrinous exudate is grey to yellow (neutrophils), to red (blood) and covers epicardial and pericardial surfaces, which when peeled apart have a characteristic "bread and butter" appearance. Fluid is not prominent. Organisation of the exudate can produce patchy or diffuse adhesion between these surfaces. Causes include sporadic bovine encephalomyelitis, pasteurellosis, blackleg, clostridial haemoglobinuria, contagious bovine pleuropneumonia, and neonatal coliform (umbilical) infections. *Heart function may be minimally affected.*

Suppurative pericarditis, invariably of pyogenic bacterial cause, occurs mainly in cattle with a foreign body perforating from the reticulum. The pericardial surfaces are thickened by a shaggy mass of fibrous tissue enclosing a yellow to grey, foul-smelling, fibrinopurulent exudate. *Animals may survive for weeks to months before dying of congestive heart failure (usually right-sided) and septicaemia.*

Constrictive pericarditis occurs as an end stage of a chronic pericarditis where organization results in formation of extensive fibrous adhesions, which may obliterate the pericardial sac and constrict the heart. *Compensatory ventricular hypertrophy with reduced heart chamber volumes (concentric hypertrophy) and congestive heart failure may follow.*

Strong, localised, fibrous adhesions within the pericardial sac at necropsy are usually longstanding, incidental findings.

Endocardial Diseases

Noninflammatory lesions of the endocardium

Endocardial mineralisation and **fibrosis** may occur alone or concurrently in the atria and left ventricle in chronically dilated hearts, and in a variety of chronic debilitating diseases (eg Johnes disease in cattle). A severe form involving also the aorta has been seen in India in climatically-stressed Australian Corriedale sheep (Jackson, 1987).

Focal endocardial fibrosis (**"jet lesions"**) result from abnormal jets of blood or turbulence associated with congenital or acquired valvular disorders.

Endocarditis

Vegetative valvular endocarditis is usually caused by bacterial infections. Lesions first develop on the free margin of the valves at the line of closure, and then extend onto the valves and into myocardium. One or more heart valves have friable grey masses of fibrinonecrotic material colonised by bacteria (or occasionally fungi) and covered by a thin blood clot. Embolic fragments (either bland or septic) may be found in the vessels of other organs (eg causing pulmonary thrombosis or abscessation). In cattle, *A. pyogenes* is the usual cause (a primary infection source such as an hepatic abscess, metritis or mastitis may be found) and enteric *Streptococcus* spp. have also been isolated. Neonatal umbilical and post-marking bacterial infections can be the cause in lambs and calves.

Mural endocarditis is usually an extension from a valvular lesion.

Acute ulcerative mural endocarditis can accompany the haemorrhagic, necrotising myocarditis of *Clostridium chauvoei* infection (blackleg) in ruminants.

Myocardial Diseases

Myocardial degeneration

Myocardial degeneration occurs in a variety of systemic diseases, including infections, toxaemias and severe anaemia. Gross changes may be minimal and difficult to distinguish from autolysis. **Hyaline degeneration** may produce gross, dull-grey discolouration, friability, and, on cut section, a homogeneous appearance of the myocardium. **Fatty degeneration** (fatty change) produces uneven patchy yellow discolouration of the myocardium or more diffuse change, with the heart flabby and paler than normal. **Atrophy** of the heart in chronic wasting diseases and malnutrition may be associated with gross brown discolouration (brown atrophy) due to lipofuscin accumulation in myocytes.

Myocardial necrosis and mineralisation

Myocardial necrosis in ruminants occurs in acute infections, nutritional deficiencies, chemical and plant toxicoses, ischaemia (infarction) and physical injuries. It produces focal, multifocal and diffuse gross changes of discolouration, pallor or reddening, often accompanied by prominent chalky-white areas of **mineralisation**. The left ventricular subepicardial myocardium and papillary muscles are the most common sites for ischaemic degeneration, necrosis and mineralisation, as these areas develop the greatest intramural tension during systole. A necrotic area is difficult to detect during the first day after injury, but by 2 to 4 days it is more sharply defined as inflammatory cells infiltrate it. The necrotic myocytes are replaced over the next 6 weeks by fibrous tissue, which is initially dark-red to tan (fibrovascular) and later white and opaque. Myocardial necrosis is followed by **replacement fibrosis,** as myocardium does not regenerate (except possibly in neonates), in contrast to skeletal muscle, which does regenerate.

Nutritional myopathy (selenium/vitamin E-responsive disease) in young ruminants can cause cardiac lesions of necrosis with mineralisation or so-called **cardiac "white muscle disease"**. In lambs this syndrome is usually congenital, with involvement mainly of the **right** ventricle. In calves the syndrome is usually delayed in clinical onset until several weeks after birth (so-called delayed white muscle disease) with cardiac lesions mainly in the **left** ventricle. Skeletal muscle lesions are also present, but may be detectible only microscopically. *The predilection for the right ventricle in congenital disease in lambs may reflect right ventricular workload in utero, and for the left ventricle in calves may reflect left ventricular relative workload after birth.*

Cardiomyopathy and woolly haircoat syndrome (**CWH**) in **Poll Hereford** calves in Australia, is an autosomal recessive congenital disease caused by a presumed defect of desmosomal intercellular junctions. Affected calves have a distinctive woolly haircoat and gross **congenital** cardiac lesions of fibrosis and / or necrosis and mineralisation in the ventricular myocardium. Gross lesions are often prominent in the **right** ventricular free wall; the epicardial surface may be irregularly depressed by extensive dark-red areas of fibrovascular (granulation) tissue extending 3 mm into the myocardium. Death usually occurs within two months of birth and may be sudden (from ventricular fibrillation) or follow a period of congestive heart failure. Necrosis and mineralisation of the **left** ventricle, identical to that described for nutritional myopathy, have been seen in CWH calves dying several weeks after birth. Affected calves are not selenium-deficient and do not have skeletal muscle lesions. If the woolly haircoat is overlooked, CWH may be misdiagnosed as nutritional myopathy.

Falling disease in Western Australia occurs in **copper-deficient** dairy cattle that collapse and die suddenly, with pale, flabby hearts, generalised venous congestion, and microscopic lesions of myocardial fibrosis.

Toxic agents and **plants** that cause **myocardial necrosis** (frequently detectible only microscopically) in ruminants include:

- Sodium fluoroacetate (1080) in baits used to control rabbits can accidentally poison ruminants. Plants that accumulate fluoroacetate in Australia include *Gastrolobium* spp, *Oxylobium* spp, and *Acacia georginae. In sodium fluoroacetate toxicosis in ruminants there are usually minimal gross lesions of myocardial pallor and mottling. There are microscopic lesions of myocardial necrosis.*
- Ionophores (monensin, lasalocid, salinomycin, narasin).
- Gossypol (in cottonseed products), which is cardiotoxic to preruminant calves, and also in goats but not orally to sheep.
- *Persea americana* (avocado) leaves, which are cardiotoxic to sheep and goats *They also cause a sterile mastitis and agalactia in goats and horses.*
- *Cassia occidentalis* (coffee senna), which also affects skeletal muscle.
- *Ixiolaena brevicompta* (flat billy button), which primarily affects skeletal muscle.
- *Lantana camara,* which causes myocardial necrosis in sheep.
- Cardiac glycosides in plants. ***Epicardial*** *and* ***endocardial haemorrhages*** *are consistent gross lesions.*

Myocarditis

Gross lesions of myocarditis may appear as areas of reddening (congestion), focal to diffuse pallor or discolouration, with or without evidence of suppuration or abscessation. In **chronic myocarditis** there may be **reactive** or **replacement fibrosis**.

Suppurative myocarditis can result from septicaemia (eg *Listeria monocytogenes*) or secondary spread from other suppurative foci (eg *A. pyogenes, Corynebacterium pseudotuberculosis*).

Haemorrhagic necrotising myocarditis is a feature of *Clostridium chauvoei* infection.

Necrotic myocarditis due to *Fusobacterium necrophorum* can be from secondary spread from necrobacillosis in other tissues.

Acute myocardial necrosis with a **lymphocytic myocarditis** is a feature of **foot and mouth disease** in neonatal ruminants and pigs. Lesions are seen as irregular opaque grey streaks in the ventricular myocardium ("tiger heart").

Eosinophilic myocarditis in cattle, with or without accompanying skeletal muscle lesions, produces poorly-circumscribed, yellow-green foci within the myocardium. The cause is unknown, but the lesions may be associated with degenerating *Sarcocystis* spp.

Granulomatous eosinophilic myocarditis, severe enough to be detectible grossly as extensive, confluent, off-white areas in the ventricular myocardium, is present in some cases of **woolly-pod** and **popany vetch** (*Vicia villosa* ssp *dasycarpa* and *V benghalensis*) **toxicosis.** This disease syndrome of pruritic dermatitis, diarrhoea, illthrift and death usually affects Friesian and Angus cattle. It causes a generalised granulomatous, eosinophilic inflammation, particularly involving the renal cortex, skin, myocardium, adrenal glands, lymph nodes and liver.

Cysticercus bovis and ***Cysticercus ovis*** in cattle and sheep respectively are the intermediate metacestode stages of the human tapeworm *Taenia saginata* and dog tapeworm *Taenia ovis*. They may be seen as an intact small vesicle (viable form) or as a degenerate fibrotic focus up to 1cm in diameter within the myocardium. **Hydatid cysts** of *Echinococcus granulosus* occur infrequently in the myocardium.

Reference:
Harper PAW, Cook RW, Gill PA, Fraser GC, Badcoe LM, Power JM Vetch toxicosis in cattle grazing *Vicia villosa* spp. *dasycarpa* and *V. benghalensis*. *Aust Vet J* 1993;70:140-144.

Cardiomyopathies

Cardiomyopathies are primary diseases of the heart that are of idiopathic cause. Morphological and clinical classifications such as hypertrophic cardiomyopathy, dilated (congestive) cardiomyopathy, and restrictive cardiomyopathy, are currently applied. However, many are inherited diseases that will eventually be classified on a molecular genetic basis.

A number of cardiomyopathies have been reported in cattle.

Cardiomyopathy of adult Friesian-Holsteins in Australia, Canada, Japan and Britain, and in Simmental-Red Holstein crossbreds in Switzerland results in right-sided heart failure including ventral oedema, hepatomegaly, pericardial effusion, and ascites associated with bilateral ventricular dilation. There are microscopic lesions of myofibre atrophy and vacuolar hypertrophy with interstitial and replacement fibrosis and myofibre necrosis. Autosomal recessive transmission is probable.

Cardiomyopathy and woolly haircoat syndrome (CWH) in Poll Hereford calves in Australia *(see above). Cases of a* ***cardiomyopathy with bilateral ventricular dilation*** *have been observed in calves from a horned Hereford herd in Australia (Cook RW, unpublished).*

Cardiomyopathy in Japanese Black calves causes death suddenly or after a short period of dyspnoea, usually at less than 30 days of age. The necropsy findings are of left and right-sided congestive heart failure, with left ventricular dilation and extensive myocardial degeneration, necrosis and fibrosis of the left ventricle and less frequently the right. An autosomal recessive mode of transmission is suspected.

Bovine generalised glycogenosis type II (**Pompe's disease**) is not a primary cardiomyopathy. Most affected animals have a generalised muscle weakness. Some have eccentric cardiac hypertrophy and signs of left-sided heart failure.

References:
Bradley R, Jefferies AR, Jackson PGG, Wijeratne WVS. Cardiomyopathy in adult Holstein Friesian cattle in Britain. *J Comp Path* 1991;104:101-112.
Morrow CJ, McOrist S. Cardiomyopathy associated with curly hair coat in Poll Hereford calves in Australia. *Vet Rec* 1985;117:312-313.
Storie GJ, Gibson JA, Taylor JD Cardiomyopathy and woolly haircoat syndrome of Hereford cattle. *Aust Vet J* 1991;68:119.
Watanabe S, Akita T, Itakura C, Goto M. Evidence for a new lethal gene causing cardiomyopathy in Japanese black calves. *J Heredit* 1979;70:255-258.
Whittington RJ, Cook RW. Cardiomyopathy and woolly haircoat syndrome of Poll Hereford cattle: electrocardiographic findings in affected and unaffected calves. *Aust Vet J* 1988;65:341-344.

Conduction System Diseases

The conduction system of the heart comprises the sinoatrial node, internodal atrial pathways, atrioventricular node, atrioventricular trunk (bundle of His), right and left crura (right and left bundle branches), and cardiac conducting fibres (Purkinje fibres). An awareness of the general location of the major components of this system during dissection of the heart at necropsy allows them to be included in samples collected for histological examination *(see **Appendix 2**)*.

In ruminants, most dysrhythmias (that can cause intermittent collapse and sometimes sudden death) are not due to primary lesions within the conduction system, but secondary to myocardial degeneration and necrosis, inflammation or neoplasia.

Neoplasms

Primary neoplasms of the heart are rare.

In **sheep**, in a United Kingdom series of 891 tumours, 22 were from the cardiovascular system. Cardiac tumours were **rhabdomyoma** (1), **neurofibroma** (1), **fibromas** (3). The remaining 17 tumours were **haemangiomas** of liver (4), spleen (9), subcutis (3), and intestine (1).

In **cattle**, **bovine leucosis** can cause nodular or diffuse lesions in the heart. **Bovine neurofibromas** may involve cardiac nerves, and form single or nodular masses on the epicardial surface or in the myocardium. **Mesotheliomas** arising from the pericardial, pleural, and peritoneal serosa produce multiple, small, firm nodules or villous projections from these surfaces; lymphatic obstruction and fluid effusion can follow.

Reference:
Head K. Tumours in sheep. In Practice: J Vet Postgrad Clin Study 1990;12:68-80.

VASCULAR SYSTEM

Introduction

The vascular system comprises **arteries**, **microcirculation** (arterioles, capillaries and venules), **veins** and **lymphatics**.

Pathogenesis of Vascular Lesions

Gross vessel-associated lesions result from:

- **Vessel wall damage and increased permeability** (causing oedema, haemorrhage).
- **Vessel obstruction** (causing congestion, oedema, ischaemia / infarction).
- **Coagulopathy and thrombocytopathy** (causing haemorrhage).

Vessel Wall Damage and Increased Vessel Permeability

Petechial haemorrhage and **oedema**, with **ischaemia** in some tissues, follow generalised damage to small vessels. Haemorrhage (often massive) is the hallmark of damage to large vessels. Generalised petechiation reflects anoxic capillary damage in acute septicaemic or toxaemic disease.

Altered capillary permeability appears to be the basis of the mild lesions of **bovine ephemeral fever** (oedema of lymph nodes, polyserositis) and the more severe lesions of **heartwater** (pulmonary oedema, hydrothorax and hydropericardium*). Heartwater, a tick-borne rickettsial disease (Cowdria ruminantium), does not occur in Australia.*

Viral-induced endothelial damage within the microcirculation produces microthrombosis and increased permeability with associated ischaemic necrosis, oedema and haemorrhage in many tissues in **orbiviral infections**. These include **bluetongue** of sheep, **epizootic haemorrhagic disease** (EHD) of deer and **Ibaraki disease** of cattle (the last is caused by an EHD 2 virus). In **bluetongue** in sheep, **focal haemorrhage within the tunica media at the base of the pulmonary artery** (also of the base the aorta, and in the endocardium and epicardium of the heart) is a distinctive finding. *In bluetongue in cattle overseas, only 5% of infected animals show signs of disease (fever, lameness, and erosive muzzle and oral lesions). In Australia, infection by bluetongue and EHD viruses occur in cattle but clinical disease has not been reported.*

Generalised necrotising arteritis and arteriolitis are associated with a range of gross lesions in **bovine malignant catarrh**, including lymphadenopathy, exudative dermatitis, erosive stomatitis and gastroenteritis, keratoconjunctivitis, erosive, possibly pseudomembranous, rhinitis and tracheitis, renal infarcts (or foci up to 4

mm of nonsuppurative interstitial nephritis), white foci of nonsuppurative periportal hepatitis. and oedema and scattered petechiae within leptomeninges.

Generalised vasculitis in *Chlamydophila psittaci* infections causes gross lesions of fibrinous polyserositis in **sporadic bovine encephalomyelitis** of cattle, and polyarthritis and conjunctivitis in sheep (both species have more generalised microscopic lesions including meningoencephalomyelitis).

Although there is microscopic submucosal arteritis in the lower alimentary tract in **mucosal disease** (caused by **bovine pestivirus**), the gross alimentary tract lesions are attributable to the direct necrotising effect of pestivirus on epithelium in the upper alimentary and on aggregated lymphoid tissue (eg Peyer's patches) in the intestines.

Massive haemorrhage (often fatal) following rupture of large vessels is rare but can follow trauma. Fatal pulmonary haemorrhage can result from pulmonary arterial wall erosion and rupture following pulmonary thromboembolism from **thrombosis of the caudal vena cava**.

Vessel Obstruction

Congestion, **oedema**, **ischaemia** and **infarction** (**necrosis**) can follow vessel obstruction. When infective agents cause a generalised vasculitis, microvascular obstruction can occur (in addition to vessel damage and increase in permeability). **Arteriole thrombosis** in salmonellosis can cause digit necrosis.

Gangrene of the extremities follows sustained vasoconstriction of arterioles and endothelial damage caused by alkaloids in *Claviceps purpurea*, the ergot of rye and other grain crops and grasses. Tall fescue grass, which causes an identical condition, harbours endophytic fungi that can produce ergot alkaloids *in vitro*.

Constriction of the muscular pulmonary venules produces **post-capillary pulmonary hypertension** and right-sided heart failure with right ventricular dilation (but never hypertrophy), ventral oedema and hydrothorax in cattle with **St George disease**, caused by the ingestion of *Pimelea* spp. There is also a severe haemodilution anaemia and diarrhoea. A daphnane ester, simplexin, isolated from *P. simplex* produces most of the signs of the disease. Pathogenesis of the associated **hepatic peliosis**, which causes the liver to be enlarged and blue-black, is uncertain.

Hypoxia-induced vasoconstriction in **high altitude disease of cattle** produces **pre-capillary pulmonary hypertension**, with medial hypertrophy of pulmonary arteries and arterioles, and right-sided heart failure with right ventricular hypertrophy, ventral oedema and ascites.

Venous stasis in the hind limbs of "downer cows" can lead to thrombosis and venous infarction with necrosis of medial thigh muscles.

Thrombosis of the caudal vena cava caused by localised phlebitis associated with hepatic abscessation, can produce pulmonary thromboembolism and arteritis, pulmonary abscessation (organisms isolated include *Fusobacterium necrophorum* and *A pyogenes*) and fatal pulmonary haemorrhage. Massive septic embolism can follow erosion of the posterior vena cava by an hepatic abscess.

Omphalophlebitis in newborn calves can produce disseminated bacterial infection and hepatic thrombophlebitis.

Arterial medial calcification is a sporadic finding in aged and often debilitated cattle and sheep. Overseas, it occurs, with mineralisation of other tissues, in cattle grazing plants containing 1,25 dihydroxycholecalciferol or a related compound.

Granulomatous serosal lymphangitis in **Johnes disease** of ruminants may be severe enough to produce a characteristic gross **"cording" of lymphatics** in the serosa of the intestines and mesentery.

Coagulopathy and Thrombocytopathy

Haemorrhagic diathesis is the hallmark of:

- Coagulation system defects.
- Reduced platelet numbers or function.

Most cases of haemorrhagic diathesis in sheep are associated with hepatic injury. In **blue-green algal toxicosis** caused by *Microcystis aeruginosa*, blood clots slowly and poorly in the opened carcass. As well as hepatic liver damage, there is generalised petechial and ecchymotic haemorrhage (involving subcutaneous tissue, skeletal muscle fascia, serosal surfaces and particularly the intestinal mucosa) within 24 hours of algal consumption.

Accidental **warfarin** consumption or ingestion of **dicoumarol** (dicoumarin or dihydroxycoumarin) in mouldy sweet clover hay causes haemorrhages, including large subcutaneous haematomas most commonly in cattle, and less so in sheep. *Wikstroemia indica* (tiebush) contains diydroxycoumarin compounds and causes diarrhoea and possible dysentery in cattle and deer; widespread haemorrhages are present in deer at necropsy.

Factor VIII deficiency has been reported in horned Hereford cattle; 5% of male calves died within a day of marking in affected herds.

Pancytopaenic disease in cattle following ingestion of bracken (*Pteridium* spp) and rock fern (*Cheilanthes seiberi*) causes generalised haemorrhages ranging from petechiae to large extravasations of blood (due to thrombocytopaenia). Red or yellow bacterial infarcts can occur in liver, heart and kidney, and, in calves, in the oral mucosa. The bone marrow is pink and soft.

In **disseminated intravascular coagulation**, the activation of the coagulation system to produce generalised microthrombosis within arterioles and capillaries can sufficiently deplete coagulation factors to cause a haemorrhagic diathesis (consumptive coagulopathy). The microthrombotic obstruction of arterioles and capillaries is thought to contribute to the lesion of bilateral haemorrhagic renal cortical necrosis in septicaemic or endotoxaemic post partum cows, and to lesions of haemorrhagic adrenal necrosis, microangiopathic haemolytic anaemia and gangrene of the extremities in septicaemic calves. *Unfortunately, microthrombi are not readily seen at microscopic examination as fibrinolysis continues after death and most thrombi can be lysed within three hours of death.*

Pulmonary Oedema

Oedematous lungs are wet, heavy and do not collapse. However, sections placed in formalin solutions will float. The lungs are frequently congested. The interlobular septa are distended with fluid, which may be clear, or pink from haemorrhage. Fluid oozes from the cut lung surface and the airways may contain foam. Fluid accumulates in the interstitium and lymphatics of the compliant hilar areas of the lung before alveoli are flooded. ***Hydrothorax*** *can accompany pulmonary oedema.*

High-protein pulmonary oedema (permeability oedema with **exudate**) results from:

- **Increased vascular permeability** caused by damage to alveolar capillary endothelium or alveolar type 1 epithelial cells. Causes include bacteria (in peracute pneumonias), pneumotropic viruses, clostridial exotoxins, ingested or inhaled toxins such as 3-methyl indol (produced in the rumen from L-tryptophan in pasture to cause so-called atypical interstitial pneumonia), endotoxic shock, disseminated intravascular coagulation, and anaphylaxis.

Low-protein pulmonary oedema (haemodynamic oedema with **transudate**) results from:

- **Decreased capillary osmotic pressure** due to **hypoproteinaemia** (eg illthrift and undernutrition, severe anaemia, and protein-losing enteropathy or nephropathy).
- **Increased pulmonary capillary hydrostatic pressure** in **left-sided heart failure** (cardiogenic oedema) and systemic vasoconstriction following acute brain damage (neurogenic oedema).
- **Obstruction of lymphatic drainage** (usually by neoplastic invasion of pulmonary lymphatic vessels).

Hydrothorax

Hydrothorax is the accumulation of clear, colourless to light yellow, watery fluid in the thoracic cavity. Causes are the same as those involved in oedema of the pericardium and lungs and include:

- **Increased vascular permeability** (eg clostridial toxaemias),
- **Decreased capillary osmotic pressure** due to **hypoproteinaemia** (eg illthrift and undernutrition, severe anaemia, and protein-losing enteropathy or nephropathy).
- **Increased hydrostatic pressure** in **right-sided heart failure** (including **cor pulmonale** associated with pulmonary hypertension, as in pre-capillary pulmonary hypertension in bovine brisket disease and post-capillary pulmonary hypertension in St George disease, and left-sided congestive heart failure).
- **Obstruction of lymphatic drainage** (eg by thoracic granulomatous lesions or neoplasms including mesothelioma and lymphoma).

In chronic hydrothorax there is fibrosis and reactive hyperplasia of the pleura.

HAEMOPOIETIC SYSTEM

The haemopoietic system comprises **blood** and **blood-forming tissues**, and **lymphoreticular tissues and organs**.

It includes **bone marrow**, **spleen**, **haemolymph nodes**, **thymus**, **lymph nodes**, and **mucosa-associated lymphoid tissue (MALT)**, the last including large discrete lymphoid aggregations forming the **tonsils** and intestinal **Peyer's patches**.

This presentation focuses on the gross lesions of **diseases of blood**, and particularly those affecting red blood cells.

*See **Chapter 3. Lymphoreticular System**, for information on the immunological arm of the haemopoietic system.*

BLOOD

Introduction

Changes in the cellular and plasma components of blood are best assessed by examining a peripheral blood sample from the live animal. It is useful to routinely collect an EDTA, lithium heparin and clotted blood sample when a live animal is presented for necropsy.

Signs of blood disorder include:

- anaemia
- generalised oedema (hypoproteinaemia).
- haemorrhagic diathesis
- splenomegaly
- haemoglobinuria / icterus

At necropsy, if a haemopoietic disorder is suspected, make impression smears from haemopoietic marrow (femur) for Wright / Giemsa staining. Air-dry and pack these smears **before** you open containers of formalin solution. Then collect and formalin-fix marrow samples for histological examination.

For suspected bovine babesiosis, make impression smears of kidney, brain, liver and heart. Brain smears from the cerebral cortex of animals dying of *B. bovis* infection commonly have capillaries choked with sludged erythrocytes, many of which are parasitised. This phenomenon does not occur in *B. bigemina* infection.

Anaemia

The carcass is pale and the blood watery. The heart is pale and flabby, and there may be pulmonary oedema, hydrothorax and hydropericardium. In severe anaemias there may be a fine, reticulated mottling of the liver due to periacinar degeneration.

The spleen is small in haemorrhagic anaemias, and enlarged in haemolytic anaemias.

Haemorrhagic anaemia

In **acute haemorrhagic anaemias**, the site of extensive haemorrhage sufficient to cause anaemia with acute circulatory failure is usually obvious, whether blood loss is internal or external.

Parasitic causes in cattle and sheep include internal parasites (including *Fasciola hepatica*, *Haemonchus* spp, hookworms and coccidia) and massive infestations by external parasites (ticks, sucking lice).

Other causes in cattle include pulmonary haemorrhage following pulmonary thromboembolism from the posterior vena cava, abomasal haemorrhage (sometimes associated with a bovine leucosis lesion), bladder haemorrhage in enzootic haematuria, renal haemorrhage in pyelonephritis, ruptured middle uterine artery from uterine prolapse, castration of calves with Factor VIII deficiency, cardiac tamponade from coronary artery or cardiac ventricle rupture (traumatic pericarditis), haemorrhagic diathesis in mouldy sweet clover toxicosis, and gastrointestinal and generalised haemorrhage due to bracken (*Pteridium* spp) toxicosis.

In **chronic haemorrhagic anaemias**, with blood loss from the body, **there is also oedema due to hypoproteinaemia**. Causes are those of chronic haemorrhage into the gastrointestinal tract (abomasal ulceration, internal parasites (including, *F. hepatica, Haemonchus* spp, hookworms, *Oesophagostomum radiatum* in calves, and coccidia), into the urinary tract (enzootic haematuria, pyelonephritis), or through the skin (bloodsucking external parasites: ticks and sucking lice).

Haemolytic anaemia

Haemolytic anaemias are characterised by:

- **Icterus**, which may obscure (and also be accentuated by) the pallor of the anaemic carcass.
- **Splenomegaly**.
- **Haemoglobinuria**, when haemolysis is **acute** and **intravascular** (eg in bovine babesiosis and *L. pomona* infections). The kidneys are brown to black.

  *Haemoblobinuria does **not** occur in diseases where haemolysis is **extravascular** (eg bovine anaplasmosis and ovine eperythrozoonosis).*

Causes of haemolytic anaemia include babesiosis, anaplasmosis and theileriosis (particularly in splenectomised cattle), eperythrozoonosis, bacillary haemoglobinuria, leptospirosis (*L. pomona*, not *L. hardjo*), postparturient haemoglobinuria, poisoning by *Brassica* spp. (eg canola, kale, chou moellier), onions and copper, ingestion of cold water, and isoerythrolysis in calves (where dams vaccinated against babesiosis / anaplasmosis). ***Heinz body formation*** *in erythrocytes, due to denaturation of haemoglobin, is a feature of haemolyic anaemias caused by Brassica spp and onions, and is involved to some degree in postparturient haemoglobinuria in cattle and chronic copper toxicosis in sheep.*

Chronic copper toxicosis is the most common cause of haemolytic anaemia in sheep in certain parts of Australia. It is associated with accumulation of copper in livers damaged by pyrrolizidine alkaloids in plants, and release of stored copper to produce the acute haemolytic episode in which up to 60% of circulating erythrocytes may be lysed. There is sufficient haemoglobin in the urinary system to produce brown to black kidneys and gross haemoglobinuria. The liver is swollen and yellow, and the spleen is enlarged and soft.

Calves accumulate excessive levels of liver copper if their diets (eg milk replacer) contains in excess of 30 mg copper per kg DM. Haemolytic episodes occur in these calves, but these may be overshadowed by a clinical syndrome of hepatic failure with marked icterus resulting from **progressive hepatic fibrosis** associated with the copper accumulation.

Eperythrozoon ovis is the usual cause of infectious haemolytic anaemia in sheep in Australia. It is widespread and can cause severe anaemia in lambs and weaners but not in adult sheep. There is barely discernible, mild icterus but **no** haemoglobinuria. Fatal cases have flabby hearts, excessive pericardial fluid, brown liver and kidneys, and an enlarged soft spleen with white pulp hyperplasia.

Congenital erythropoietic porphyria in Holstein and Shorthorn cattle causes a mild to moderate haemolytic anaemia associated with the more dramatic signs of photosensitization and **porphyrin pigmentation of teeth**, **bones** and **urine**, all of which fluoresce red under UV light. ***Erythropoietic protoporphyria*** *in Limousin and Limousin-cross cattle causes only photosensitization (without anaemia or discolouration of teeth and bones).*

Haemolytic anaemia of Murray Grey calves is a chronic progressive, fatal, genetic, presumed autosomal recessive disorder. Signs are first detected between two weeks and two months of age and include retarded growth, poor exercise tolerance, progressive weakness, marked icterus and death. There is a **regenerative anaemia**. At necropsy there is anaemia, icterus and splenomegaly, the heart may be flaccid and globose (due to anaemia), the liver has a very enlarged dark-green right (dorsal) lobe and often an atrophic tan fibrotic left (ventral) lobe, the kidneys are enlarged and dark green-brown, urine is brown, and bone marrow is red and gelatinous.

Anaemia of defective haemoglobin formation

The depression anaemias of chronic disease (eg. neoplastic, inflammatory and uraemic) are listed in this category, as iron may be rate limiting for erythropoiesis in these disorders. Iron deficiency probably causes the usually subclinical anaemia of calves on solely milk diets.

In the absence of parasitism, anaemia without icterus in adult sheep is most likely of nutritional origin; frank malnutrition will produce anaemia probably due to deficiency of protein or iron.

Copper and cobalt deficiencies are inconsistently associated with anaemia in ruminants

Anaemia of deficient cell production

In bracken toxicosis in cattle, **pancytopaenia** results in a peripheral neutropaenia, haemorrhagic anaemia (from gastrointestinal and generalised haemorrhage due to thrombocytopaenia) that is **non-regenerative** (due to bone marrow depression of erythropoiesis). Rock fern and trichlorethylene extracted soya bean meal cause similar disease syndromes. In St George disease (*Pimelea* spp. toxicosis) in cattle there is a severe **non-regenerative, haemodilutional anaemia** caused by progressive expansion of plasma volume.

Toxic Anoxias (Nitrate and Cyanide Toxicoses)

Nitrate toxicosis results when the normal conversion of nitrate via nitrite to ammonia by ruminal microorganisms is inadequate and **nitrite** is absorbed and causes methaemoglobinaemia (nitrite oxidises the ferrous iron of haemoglobin to ferric iron to form methaemoglobin, which is incapable of transporting oxygen). Plants containing >1.5% DM nitrate are potentially toxic. Cattle are more susceptible than sheep. The blood is dark with a brownish colour ("chocolate") and clots poorly. There is cyanosis of mucous membranes and light brown discolouration of tissues. There are petechial or ecchymotic serosal haemorrhages, and the pericardial sac contains an excess of blood-stained fluid.

Cyanide (hydrocyanic or prussic acid) toxicosis results when cyanogenic glycosides in ingested plants are metabolised by ruminal microorganisms to release hydrocyanic acid. The cyanide ion produces a cellular hypoxia (cytotoxic anoxia) by forming a stable complex with cytochrome oxidase which can then not function in electron transport (oxyhaemoglobin is unable to release oxygen for electron transport). Death is rapid, with signs of anoxia. The blood is bright red and often clots slowly or not at all. The mucous membranes are pink and appear well oxygenated. There may be an odour of bitter almonds in fresh rumen contents.

References

Bishop SP. Necropsy Techniques for the Heart and Great Vessels. In: Fox PR, Sisson D, Moisse NS, editors. *Textbook of Canine and Feline Cardiology. Principles and Clinical Practice* 2nd edn. WB Saunders Co, Philadelphia, 1999:845-849.

Jackson ARB. The cardiovascular, haemopoietic and respiratory systems of the sheep. *Proceedings No 97 "Through the Naked Eye". Gross Pathology of Domestic Animals* Post Graduate Committee in Veterinary Science. May 1987:507-509.

Jackson PGG, Slater J. Cardiovascular disease in cattle. *In Practice: J Vet Postgrad Clin Study* 1997:19:472-483.

King JM, Roth L, Dodd DC, Newson ME. *The Necropsy Book* Charles Louis Davis DVM Foundation (cldavisdvm@ameritech.net). 38-40; 189-217.

King JM, Dodd DC, Newson ME. *Gross Necropsy Technique for Animals* 1979:9-10. *Originally published as: Necropsy of the horse. Modern Vet Practice, Dec 1978:697-699, Jan 1979:29-32, Feb 1979:109-112.*

Robinson WF. The Cardiovascular System. In: Robinson WF, Huxtable CRR, editors. *Clinicopathologic Principles for Veterinary Medicine* Cambridge University Press, Cambridge 1988:122-162.

Robinson WF, Maxie MG. The Cardiovascular System. In: Jubb KVF, Kennedy PC, Palmer N, editors. *Pathology of Domestic Animals Volume 3.* 4th edn. Academic Press Inc, San Diego, California, 1993:1-100.

Winter H. *Postmortem Examination of Ruminants*, University of Queensland Press 1966:46-56.

Van Vleet JF, Ferrans VJ. Myocardial disease of animals. *Am J Pathol* 1986:124: 95-178.

Van Vleet JF, Ferrans VJ. Pathology of the Cardiovascular System. In: McGavin MD, Carlton WW, Zachary JF, editors. *Thomson's Special Veterinary Pathology* 3rd edn. Mosby, St Louis, 2001:197-233.

Appendix 1. Dissection and Gross Examination of the Heart

General
A systematic examination of the heart (including **pericardium, endocardium (mural and valvular), myocardium** and **large vessels**) is an essential part of any necropsy. Always follow the same procedure to optimise detection of **gross lesions** as well as **changes in size, shape** and **position** of the heart, its components and associated thoracic structures.
• **Weigh the animal at the start of the necropsy.** *The following relates to the examination of the heart.*
• Examine heart and lungs *in situ* for changes in size, shape or position. eg ectopia cordis (cervical, sternal, or abdominal).
• Examine pericardium (normally smooth, shining and transparent). Open pericardial sac. Note amount and type of fluid.
• Remove heart and lungs from thoracic cavity with trachea, oesophagus and tongue attached.
• Examine trachea and lungs.
• Do **not** separate heart from lungs unless there are special reasons for doing so. If separation is required, **examine large vessels at base of heart before cutting them 1 to 3 cm from their cardiac origin.**
• Examine epicardial surface of heart and large vessels at base of heart.
• **Dissect and examine the heart (Inflow-Outflow Method)**: The attached diagrams illustrate opening of heart chambers by four incisions, **Incisions A** and **B** on the right side and **Incisions C** and **D** on the left. Blood flow is followed from right atrium (RA) to right ventricle (RV) to pulmonary artery and lungs. Then from left atrium (LA) to left ventricle (LV) and aorta.

Heart Measurements at Necropsy
Circumference of atrioventricular valve rings • After opening and completing the examination of the heart by the Inflow-Outflow Method, use a flexible ruler or string to measure the circumference of the opened atrioventricular valve rings. *The circumference of the left atrioventricular ring (LAVR) is compared with that of the right (RAVR) and expressed as a ratio (LAVR / RAVR). Deviation from the normal ratio of 0.8 to 0.9 indicates AV ring dilation.*
Weights of heart components • Dissect the heart free of extraneous tissue attached to its base, and weigh it (HW). • Separate the right ventricular free wall (RV) from the right atrium at the right coronary groove (it has already been separated from the interventricular septum during Inflow-Outflow Method dissection), and weigh it. • Dissect the rest of the combined atria (A) from the remaining ventricular mass at the left coronary groove. Weigh the combined left ventricle plus interventricular septum (LV + S). Weigh the combined atria (A). *The total heart weight, right ventricular free wall weight, and combined left ventricle plus septum weight are then compared with total body weight of the animal and expressed as a ratio.* *The right ventricular free wall weight and combined left ventricle plus septum weight are compared with total heart weight and expressed as a ratio.* *The combined left ventricle plus septum weight is compared with right ventricular free wall weight and expressed as a ratio.*
Thickness of interventricular septum and ventricular free walls Avoiding *trabeculae carneae*, papillary muscles and supraventricular crest, measure thickness of: • Interventricular septum at its thickest point, one third to half way from aortic valve to apex of left ventricle. • Left ventricular free wall between the papillary muscles. • Right ventricular free wall near the ring of the right AV (tricuspid) valve.

Body Weight, Heart Weight and AV Ring Ratios Assessed at Necropsy
(Indicative values for young cattle)

BW (kg) HW (g) A (g)	HW / BW (g / kg)	RV / BW (g / kg)	LV+S / BW (g / kg)	RV / HW (g / g)	LV+S /HW (g / g)	LV +S / RV (g / g)	LAVR / RAVR
	5 - 12	1.0 – 3.0	4.0 - 7.0	0.18 - 0.25	0.55 - 0.75	2.20 – 4.20	0.8 - 0.9

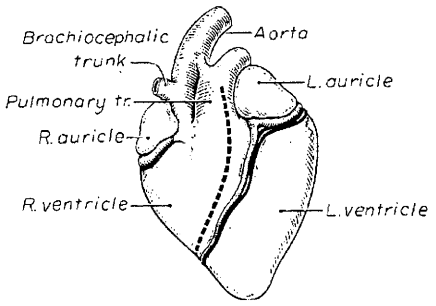
A = atria (combined); BW = body weight; HW = total heart weight; LV + S = left ventricle plus septum; RV = right ventricular free wall; LAVR = left atrioventricular ring circumference; RAVR = left atrioventricular ring circumference.

Appendix 1. Dissection and Gross Examination of the Heart (continued)

Dissection of Heart *(See attached diagrams)*	**Heart Structures Examined** *Congenital abnormalities detected.*
"Starting position": Hold the heart in the left hand with the right side of the heart on the left and the left side on the right, with the apex pointing towards you. The left longitudinal sulcus is uppermost. For orientation, return the heart in this "starting position" before making each of the following four incisions.	• *Transposition of large vessels (often associated with other cardiac anomalies, eg ventricular septal defect).*
Incision A: Cranial border of right ventricle (RV) dorsoventrally from pulmonary trunk to apex of RV, along interventricular septum parallel to left longitudinal sulcus (with knife or scissors).	• Semilunar valves of pulmonary trunk. • *Patent ductus arteriosus* • *Ventricular septal defect*
Incision B: Caudal border of right ventricle (RV) ventrodorsally from apex of RV along interventricular septum to right atrium (RA) and last part of the caudal vena cava (with knife or scissors). ***Atrial Incision B (optional): Right atrium (RA), 1 cm above and parallel to coronary groove*** *from caudal vena cava forward into right auricle (with scissors). Avoid the cranial vena cava to preserve for histological examination the sinoatrial node, which lies along the junction (sulcus terminalis) between the cranial vena cava and right atrium.*	• Remove blood clots from lumen; distinguish between postmortem clots and antemortem thrombi. • Right atrioventricular (tricuspid) valve. • Openings of cranial vena cava and caudal vena cava. • Fossa ovalis (foramen ovale in neonates may be probe-patent but functionally closed). • Coronary sinus. • *Patent foramen ovale.*
Atrial Incision C (optional): Left atrium (LA), 1 cm above and parallel to coronary groove *from pulmonary vein opening forward to left auricle (with scissors).* **Incision C: Centre of left atrium (LA) and left ventricle (LV)**, dorsoventrally through parietal cusp of left atrioventricular valve, between cranial and caudal papillary muscles in the left ventricular free wall (with knife).	• Left atrioventricular (mitral) valve. • Openings of pulmonary veins. • Foramen ovale remnant. • *Congenital haematomas of A/V valve margin; common in neonates, but do not persist.*
Continue with heart held as for Incision C. **Incision D: Under centre of septal cusp of left atrioventricular valve**, ventrodorsally through septal cusp, left atrium and along aortic trunk (with knife or scissors).	• Semilunar valves of aortic trunk. • Openings of right and left coronary arteries. • Opening of brachiocephalic trunk. • Measure circumference of right atrioventricular ring (RAVR) and left atrioventricular (LAVR). *Normal LAVR / RAVR = 0.8.-.0.9).* • *Subaortic stenosis, aortic hypoplasia.*

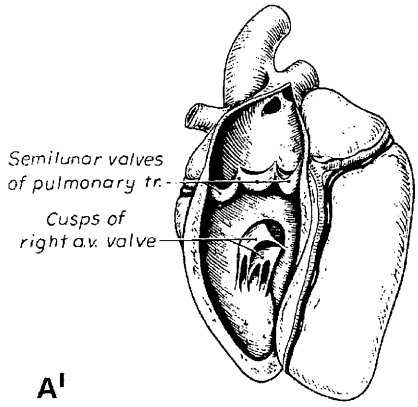
Incision variations *(See Appendix 2)*	
Incision C (v): Caudal border of left ventricle (LV) dorsoventally from last part of the pulmonary vein and left atrium (LA) to apex of LV along interventricular septum (with knife or scissors).	• As for **Incision C** above.
Incision D (v): Cranial border of right ventricle (RV) ventrodorsally from apex of LV, along interventricular septum, parallel to left longitudinal sulcus, **under** septal cusp of left atrioventricular valve **and along aortic trunk** (with knife or scissors).	• As for **Incision D** above.

Appendix 1. Dissection and Gross Examination of the Heart (continued)



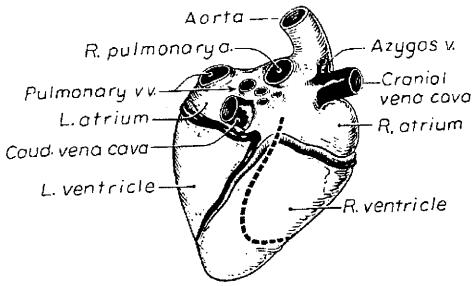
A

To open right ventricle, hold heart in left hand with left side of heart towards you. Make incision, starting at pulmonary trunk, into right ventricle, close to interventricular septum.



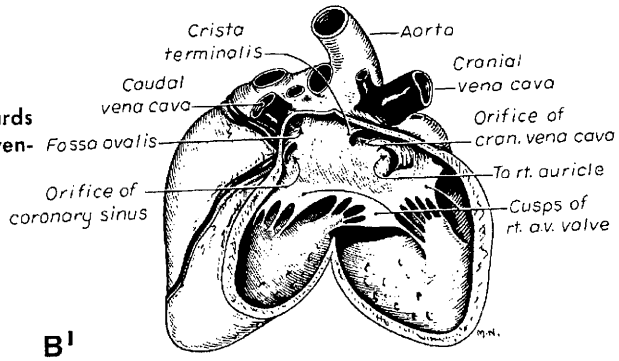
A'

Open pulmonary trunk past bifurcation. Check semilunar valves.



B

Turn heart over with its right side towards you. Continue incision, following interventricular septum, into right atrium.

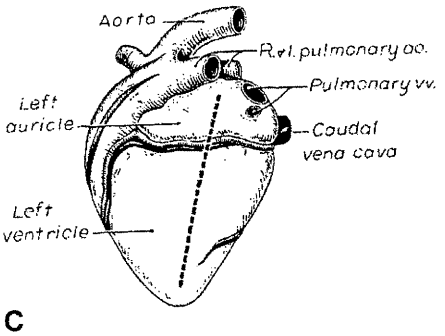


B'

Open right ventricle and atrium.
Check right atrioventricular valve, orifices of cranial vena cava, caudal vena cava, fossa ovalis and coronary sinus.

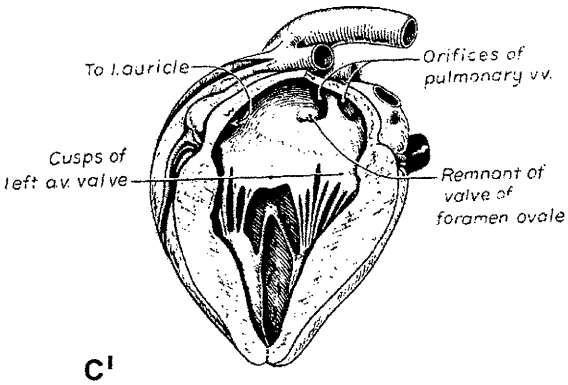
Diagrams are reprinted from King JM, Dodd DC, Newson ME. *Gross Necropsy Technique for Animals* 1979: pages 9-10, with permission from JM King.

Appendix 1. Dissection and Gross Examination of the Heart (continued)



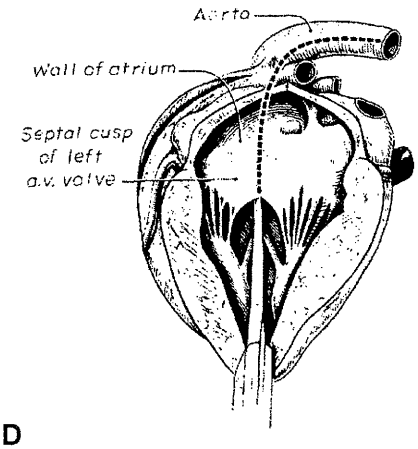
C

Open left atrium and ventricle with straight incision.
Incise through parietal cusp of left atrioventricular valve.



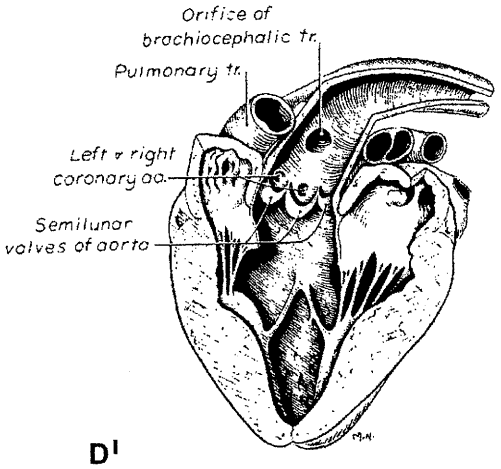
C'

Check left atrioventricular valve and openings to pulmonary veins.



D

To open aorta, insert knife under septal cusp of left atrioventricular valve.
Incise through wall of atrium, out and down aorta.



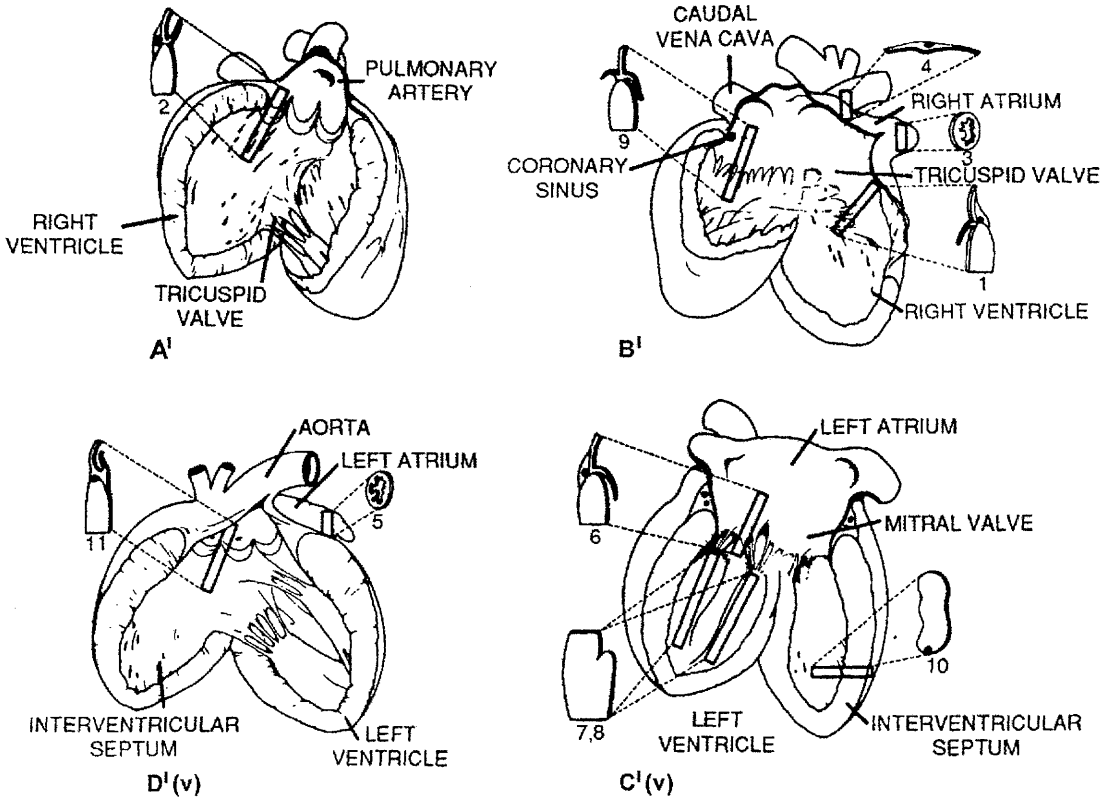
D'

Check semilunar valves of aorta, orifices of right and left coronary arteries, orifice of brachiocephalic trunk.
Make multiple inspection slices through organ.

Open abdominal aorta and its major branches (mesenterics, iliacs, etc.).

Diagrams are reprinted from King JM, Dodd DC, Newson ME. *Gross Necropsy Technique for Animals* 1979: pages 9-10, with permission from JM King.

Appendix 2. Standard Sites for Histological Examination of the Heart



A¹	Right ventricle and pulmonary outflow tract.	**B¹**	Right ventricle and right atrium.
D¹(v)	Left ventricle and aortic outflow tract.	**C¹(v)**	Left ventricle and left atrium.

Standard sites for histological examination of heart	
1*	Right ventricular free wall, parietal cusp of right atrioventricular (tricuspid) valve and right atrium.
2*	Right ventricular outflow tract, including pulmonic semilunar valve and pulmonary artery.
3	Right auricular appendage.
4*	Right atrium and cranial vena cava at sulcus terminalis to include sinoatrial node.
5	Left auricular appendage.
6*	Left ventricular free wall, parietal cusp of left atrioventricular (mitral) valve and left atrium.
7	Cranial papillary muscle of left ventricular free wall.
8	Caudal papillary muscle of left ventricular free wall.
9*	Interventricular septum base (including atrioventricular node), septal cusps of left and right atrioventricular valves, and interatrial septum.
10	Interventricular septum near apex of left ventricle, including terminal branches of left coronary artery.
11	Left ventricular outflow tract, including aortic semilunar valve and aorta.
***Sites sampled for modified histological study of myocardium.**	

Diagrams are reprinted from *Textbook of Canine and Feline Cardiology. Principles and Clinical Practice.* 2nd edn. (Fox PR, Sisson D, Moisse NS, editors), Bishop SP. *Necropsy techniques for the heart and great vessels.* page 846, Copyright 1999, with permission from Elsevier Science.

Chapter 5

Ruminant Liver Disease

Roger Kelly

Introduction

The liver remains comparatively inaccessible to the clinician, despite advances in ultrasonography and contrast radiography, and this is particularly true in large animals, in which only the longest arms can palpate a small portion of the liver during rectal examination. This inaccessibility, coupled with the fact that clinical signs of liver failure often take the form of disorders of skin, blood or nervous system, explains why liver disease is often overlooked by veterinary clinicians, or mistaken for disease of some other system.

What Should a Field Veterinarian Know About Liver Form and Function?

The liver is a large brown organ whose **FORM** (**size**, **shape** and **color**) is relatively constant for a given species. If clinicians are to recognize liver disease during field necropsy examinations, they must be confident about the gross features of normal liver. Likewise, knowledge of the range of **FUNCTIONS** carried out by the liver will reduce the chance of misdiagnosing significant liver disease.

Size: "Normal" liver mass is in fact the outcome of a balance between several factors. It has long been known that removal of more than half the liver mass by surgery or disease will result in vigorous regenerative attempts to replace the missing tissue. Regeneration will cease when the balance between these factors has been re-established, so there must be finely-tuned feed-back loops which regulate total liver mass.

The first of these factors is the animal's state of **nutrition**: severely malnourished animals of all species will have small livers, since the above-mentioned reserve capacity of the liver means that a considerable proportion of the functional hepatocyte cytoplasm can be catabolised as an emergency source of nutrition during severe starvation or debilitating illness. The second important factor is the presence in the portal venous blood of normal concentrations of **hepatotrophic factors** from the gut and pancreas. Some of these factors are absorbed nutrients from the gut, so some of the above-mentioned atrophy of starvation falls into this category, but there are in addition some humoral factors such as insulin and other hormones which help maintain normal liver mass. If their concentration in incoming blood falls (as happens in porto-systemic shunting), then the liver will undergo atrophy. Thirdly, normal liver produces **chalones,** and these substances keep mitotic activity of

hepatocytes in check. So if part of the liver is lost, circulating chalone levels decrease and this has the effect of stimulating hepatocellular proliferation. Fourthly, liver size may be uniformly increased by certain diffuse pathological processes which do not cause increase in hepatocyte **numbers.** The most common of these is **fatty liver,** but there are other diffusely distributed conditions such as generalised **hepatitis**, **diffuse neoplasia** and **amyloidosis**.

Shape: The most common cause of distortion of the liver is uneven deposition of scar tissue, or fibrosis. This can be due to a wide variety of infectious, parasitic and toxic insults, and when it is severe, results in compression of hepatocytes and restriction of blood flow to them. This has the effect of diverting blood and hence hepatotrophic factors away from the affected parenchyma, which in turn results in atrophy of this part of the liver, so the distortion is accentuated. When much liver has been lost in this way, circulating chalone concentrations diminish to the point where surviving hepatocytes are stimulated to proliferate. Because of the constriction by scar tissue and the uneven blood supply, uniform proliferation of hepatocytes is impossible, so the phenomena of nodular regeneration and lobar hypertrophy are seen.

Colour: Liver parenchyma in most species is normally a deep reddish-brown colour; this is due to the presence in the hepatocytes of high concentrations of oxidative enzymes such as cytochrome oxidase. These enzymes are also responsible for the brown colour of the renal cortex. Normal concentrations of cytochrome oxidase can only be maintained if the hepatocytes are healthy and have access to an adequate blood supply. Thus **pallor** of the liver is a very common observation in livers damaged by a wide variety of insults. Generalized pallor of the liver can also be caused by dilution of the enzymes by large amounts of **fat** in the cells, or by severe infiltration of the liver by inflammatory or malignant cells, which contain few oxidative enzymes. Note the considerable overlap between causes of diffuse liver **enlargement** and liver **pallor**.

The liver carries out a huge number of **FUNCTIONS** that may be broadly classed as: **synthetic** and **secretory** (*eg* production of glucose, bile acids and albumin and many other soluble macromolecules), **transformations** (*eg* oxidation, hydrolysis and conjugation of dangerous endogenous and exogenous compounds), and **excretory** (*eg* elimination of bile pigments, phylloerythrin, etc). What is critical to an understanding and rational management of liver disease is that the liver possesses a large **reserve** of live function. The most often-quoted example of this is the fact that 70% of the organ can be removed without causing liver failure (see below).

What Must a Field Veterinarian Know About Failure of Liver Function?

Clinical signs may follow failure of any of the above liver functions. Unfortunately, these clinical signs will be very varied and may not be immediately referable to the liver by the casual observer. For example, failure of the liver to convert ammonia to urea (for excretion by the kidneys) will result in **nervous signs** due to the toxic effects of ammonia on the brain. These nervous signs may be exacerbated by the failure of the liver to remove other neurotoxic substances from the portal blood following their formation in and absorption from the lower bowel. These substances, secondary and tertiary amines and the like, are produced by bacterial action in normal animals and are removed from the portal blood by one passage through the normal liver. This prevents them from reaching the brain, where they may act as false neurotransmitters and cause a variety of nervous signs ranging from depression and somnolence to mania and generalised convulsions.

Failure of the liver to excrete/secrete bile pigments, bile acids and bile salts is called **cholestasis**. **Intrahepatic cholestasis** is the term used when the failure is at the hepatocellular level (failure of bilirubin conjugation, non-specific hepatocyte degeneration/death, etc). It produces the clinical phenomenon known as **icterus** (**jaundice**), which is yellowish discoloration of tissues by bile pigments. The intensity of this discoloration is dependent on two factors: firstly the *severity* of the cholestasis (quantitatively, how much bile pigment is being retained), and secondly, the *duration* of the cholestasis. It takes several days at least for tissues levels of bile pigments to equilibrate with those of the plasma. This may explain why an animal that has been suffering moderately severe cholestasis may be much more yellow than an animal which died after a short episode of complete liver failure.

Icterus can of course also be caused by **obstruction** of the extra-hepatic biliary vessels, and by the overproduction of bile pigments caused by **severe haemolysis**. Obstruction can be detected by palpation and expression of the biliary apparatus (provided you remember to do it before removing the liver!), while haemolytic disease is recognized by the presence of haemoglobin-stained kidneys and urine (in the case of intravascular haemolysis), or by significant splenomegaly in extravascular (sequestration) haemolysis. The gallbladder bile in both types of haemolysis should be deep greenish-black with excess bile pigment and will be thick, dark and even granular in texture. In animals suffering from intra-hepatic cholestasis, insufficient bile pigment reaches the biliary tract, so gallbladder bile is abnormally pale, and photosensitivity is more likely.

Failure of a damaged liver to remove phylloerythrin from the portal blood has particular significance for herbivores. This compound is produced in the digestive tract as a breakdown product of chlorophyll. It is photodynamic, which means that it is changed into very reactive chemicals by the action of visible light. So, after it has had time to

accumulate in pale, sparsely-haired skin which is exposed to sunlight, it will cause vascular and epidermal damage known as **secondary photosensitisation**. Since phylloerythrin excretion involves the same pathways as bile pigment excretion, **icterus** (jaundice) is a common (but not necessary) accompaniment of secondary photosensitivity. Because jaundice may be very mild in photosensitised animals, it is possible to mistakenly exclude liver damage from a diagnostic list because an animal with eczema of exposed skin has no clinical jaundice. Such animals, however, will always have some elevation of plasma bilirubin and/or bile acids, so these parameters must always be measured in such cases. If they are within normal limits, then consideration may be given to the possibility of **primary photosensitivity**, in which some component of the diet is directly photodynamic and for which there is no effective hepatic detoxification/excretion mechanism (hypericin intoxication, for example). Primary photosensitivity may also be caused by the accumulation of substances such as porphyrins due to inherited errors of metabolism (porphyria).

In animals suffering from haemolytic jaundice there will usually be no photosensitisation, since phylloerythrin is still being excreted, while photosensitivity is expected in the other causes of cholestasis.

If liver damage is sudden and severe, an early clinical sign may be **haemorrhage**. In acute necrotizing liver damage, a large proportion of the animal's blood volume is suddenly exposed to several m^2 of damaged parenchyma and sinusoidal endothelium. This will trigger the usual thrombotic cascade, which will in turn initiate compensatory **fibrinolysis**. The end result of this sequence will be rapid consumption of clotting factors which will be all the more profound because most of these are synthesized in the liver in the first place, and a severely damaged liver will not be able to produce them at the normal rate. Thus hemorrhagic diathesis will occur terminally in such animals, and be reflected at necropsy by widespread ecchymotic and petechial haemorrhages that may distract the observer from changes in the liver itself, which macroscopically may well be less spectacular.

Liver failure may be manifested by **hypoproteinaemic oedema**, due to failure of synthesis of albumin and other plasma proteins by the liver. This will result in oedema of dependent loose skin (submandibular and brisket). Hypoproteinaemic oedema, however, can also be caused by haemorrhage such as that caused by severe internal parasitism, and since oedema can also be induced by vascular permeability changes and by circulatory failure, oedema is just as likely to distract the clinician from a diagnosis of liver failure.

It is most important is to remember the huge **functional reserve** of the liver, which means that, once liver failure is clinically apparent, a huge proportion of liver must have been damaged or destroyed. This must always lead to a grave prognosis. Sometimes a favourable outcome may be hoped for when only one function is impaired, such as excretion of bile in toxic cholestasis, since the other important functions of the liver are still working, and removal from the toxin may allow the organ to recover.

Responses of The Liver to the Various Classes of Liver Insult

There are four fundamental disease processes which may affect the liver as well as any other tissue. These are:

- **developmental (congenital etc) abnormalities**,
- **inflammation (acute, subacute and chronic)**, and
- **degenerative disease (includes toxic insult and necrosis)**,
- **proliferative/neoplastic disorders**.

It is usual for one more of the above basic disease processes to be combined with any of the others. Thus there is nearly always some **degeneration** (including necrosis) associated with **inflammation**, but it is helpful, when confronted with a confusing combination of gross changes in any organ, to at least try to identify the primary process and eliminate the least likely processes.

Sometimes it is difficult to separate true disease from physiological response; for example, the proliferation that takes place in a tissue as a result of increased demand, such as removal of part of the organ, may be regarded as beneficial and hence physiological.
Applying each of these basic disease processes to the liver, the following comments may be made.

Developmental abnormalities

Developmental abnormalities of the liver have little or no clinical significance, unless they are the rare ones that result in failure of bile secretion (*e.g.*, biliary atresia). In this sense the liver differs from organs like brain, heart and eye, in which developmental anomalies often have catastrophic effects. The liver has no specialized substructure, so (unlike brain or heart) a few isolated malformations may not impair function at all, since any part of the liver can take over the function of a damaged portion.

Inflammation

The processes of inflammation are essentially the same in liver as they are in other tissues. As far as **cause** is concerned, the most common stimulus is the lodgment in the liver of bacteria (or their spores) that have passed through the lining of the alimentary tract. This an extremely common event: probably the best example is the formation of liver abscesses as a result of bacteria getting into the portal vein blood as a result of rumenitis in ruminants on high grain diets. Bacterial infection is discussed further in a later section.

Inflammatory lesions in the liver may be **focal** or **diffuse**. In either case there will be increase in liver size (focally or overall) in the acute and the subacute stages: later with chronic inflammation (scarring) there may be shrinkage.

Degeneration

Degeneration of the liver is of more importance since it includes **toxic** and **metabolic** diseases, which are of more clinical significance in ruminants. As mentioned above, degenerate liver usually becomes paler, unless the problem is **congestion** (see below), in which case of course it is dark red, especially in the early stages. The palest liver is produced by severe **fatty change**; this may be due to toxicity or to endogenous metabolic disorder. Severe fatty liver is always enlarged; this is one of the few examples where an organ becomes swollen as a result of metabolic or degenerative disease.

When a large proportion of the liver is damaged by degenerative disease, the special feature of the liver, its regenerative potential, comes into play if the animal survives long enough. This produces irregular, often nodular swellings separated by fibrous tissue; the former can sometimes lead the observer to suspect neoplasia (see below)

Neoplasia

Neoplasia of the liver in ruminants in relatively rare; as in other species it can arise in the liver itself (from hepatocytes or from biliary tract) or metastasise to the organ from elsewhere. Metastatic disease most commonly originates from primaries in the gut, since the effluent blood from the entire alimentary tract must pass through the liver. It should be remembered that primary neoplasms may be much smaller than their metastases; this applies particularly to secondaries in the liver, which seems to permit their more rapid growth.

Mention has been made above of the fact that a scarred, shrunken liver may develop nodular swellings in its attempts to regenerate. These nodules can mimic certain forms of neoplasia. This confusion can be resolved by determining whether the liver mass overall is greater or less than normal: a nodular scarred liver will always be smaller overall than a normal liver (no matter how big the regenerative nodules), while neoplastic tissue added to liver will increase its size.

Gross Evidence of Disordered Liver Circulation

Because the liver is such a large organ and contains such a large volume of sinusoidal blood channels, it is peculiarly prone to respond to changes in blood volume and pressure. In fact the liver is a more important short-term regulator of blood volume than is the spleen.

The liver responds in a rather predictable way to **chronic congestion**, whether this be due to **right-sided heart failure**, or to **compression of the posterior vena cava**. Blood flow through the liver slows dramatically as the hepatic venous pressure rises relative to the arterial and portal vein pressures. In this semi-stagnant situation, the

hepatocytes and sinusoids that are furthest from the incoming blood undergo atrophy and dilatation, respectively, while surviving hepatocytes closer to the portal triads accumulate fat and lose cytochromes (see above) and become pale. The effect of the resulting contrast in colours is that the cut surface of the liver assumes a characteristic reticulated pattern that has been likened to the cut surface of a nutmeg. However, this so-called "**nutmeg liver**" pattern (also known as **acinar pattern**) is not pathognomonic for chronic liver congestion unless it is obviously more pronounced in the subcapsular parenchyma than in the deeper parts of the organ. A more uniform nutmeg pattern can be seen in livers that have been acutely damaged by hepatotoxins (see below). Chronically congested livers usually have a slightly thickened, slightly irregular pale gray capsule, sometimes with fresh or organizing fibrin adherent to it, and there is usually a great excess of watery clear abdominal fluid (**ascites**). As soon as these features are noticed at necropsy, great care should be taken in examining the heart, since congestive heart failure is by far the most common cause of passive congestion of the liver. However, sometimes in cattle a large hepatic abscess or a tumour may cause passive congestion by compressing the posterior vena cava as it passes through the dorsal part of the liver.

Sometimes at necropsy of young animals which have been chronically unthrifty (sometimes showing nervous signs as well), the liver will be very noticeably smaller than normal. If at the same time it is normal in colour, consistency, shape and texture, then there is the possibility of a congenital porto-systemic venous shunt. These are more commonly associated with companion animals but they have been found in cattle. The liver is uniformly small because it has been perfused with lower than normal concentrations of hepatotrophic factors. If the possibility of a porto-systemic shunt is not recognized early in the necropsy, the shunt will probably be destroyed in the subsequent dissection and the diagnosis will not be able to be confirmed.

Biochemical Assessment of Liver Function and Damage

The significance of changes in circulating levels of bilirubin and bile salts has been discussed above.

There are several intracellular enzymes that are only found in significant concentrations in hepatocytes of the various domestic species, therefore when their levels in plasma are elevated, there is a likelihood of significant active liver disease. Unfortunately, different enzymes are "liver-specific" in this manner in different species. Alanine aminotransferase (ALT) for example, while widely used as an indicator of liver damage in carnivores, is essentially useless for this purpose in ruminants, whose hepatocytes are poorly furnished with it. Arginase and sorbitol dehrydrogenase are more useful liver-specific enzymes in ruminants, but their assay is a bit more complicated and expensive.

Gamma glutamyl transferase (GGT) is concentrated in canalicular and bile duct membranes; also in renal tubular epithelium. GGT levels in plasma are usually elevated in ruminants suffering from cholestatic liver disease, and such disease should be strongly suspected when there is concomitant elevation of plasma bile acids or bilirubin.

Clearance of injected exogenous chemicals (usually dyes such as bromsulphthalein and indocyanine green) can give accurate assessment of liver function, but these procedures are rarely appropriate for clinical practice because of their expense and time needed.

How about the use of liver biopsy?

Liver biopsy of ruminants is a relatively simple procedure. The equipment is simple *(see Fig.1)* and can be made from stainless steel rod and tube by local workshops. Appropriate anaesthesia is easily achieved by using paravertebral local anaesthethic injection behind ribs 10-13, with xylazine sedation as necessary. A cruciform stab incision through the skin will facilitate insertion of the trochar-cannula combination. While in the animal, the trochar must be kept within the cannula at all times to lessen the chance of pneumothorax occurring. Rapid removal of the cannula-retracted trochar combination will provide sufficient negative pressure to keep the liver core within the cannular lumen. Retrieval of good cores will be facilitated by sharpening the cannula before use, and remembering to twist the cannula when advancing it into the liver. Livers that are diffusely fibrotic or scarred may yield hardly any liver tissue, but in these cases, experienced operators will recognize the altered texture of the liver, and at least a diagnosis of liver fibrosis will be indicated.

The advantage of a 7mm core liver biopsy is that it provides enough tissue for good histological assessment, as well as enough for biochemical analysis (Cu, etc)

Insights Into Some Specific Liver Diseases of Ruminants

Acute hepatotoxicities

There are widely differing sources of hepatotoxins which are acutely fatal for ruminants. These range from the cyanobacteria (blue-green algae) through numerous genera of higher plants, to the larvae of certain insects, and these will be covered elsewhere in this course.

While these substances range in chemical formulae from atractylosides to toxic octapeptides, the clinical signs and pathology of these intoxications are remarkably similar; almost stereotyped. Attention should be drawn to the mysterious condition known as "acute bovine liver disease" in the southern Australian states: it occurs unpredictably and in outbreak form in both dairy and beef cattle, and sheep seem not to be affected. Rough Dog's tail grass (*Cynosurus echinatus*) has been loosely implicated:

charges have been laid but there have been no convictions to date. This condition is interesting for the pathologists because it is one of the rare acute hepatopathies in which periportal tissue is preferentially destroyed, and, while regeneration of destroyed liver cells can occur in survivors, cholestasis is more severe and prolonged than it is after other acute hepatoxicities in which periacinar tissue is targeted.

Clinical signs rarely include jaundice or photosensitivity because of the acuteness of the disease, although these signs may develop later in surviving affected animals. The most severely affected animals are either found dead, or show an unpredictable range of clinical **neurological signs** such as generalized convulsions, aggression, tremor and stupor; these signs may be exhibited alternately and unpredictably in the one affected animal. If a blood sample is drawn from such a case, the bleeding and coagulation times should be carefully measured, since **clotting factors** are usually exhausted in these cases (see above). Recovery is most unusual in a ruminant showing bleeding disorder and nervous signs due to acute liver damage: the animal is usually dead by the time serum enzymology has been performed. This one condition in which liver biopsy as described above, while likely to give a diagnosis, will probably shorten the animal's life, since fatal haemorrhage is likely due to the bleeding disorder. But one can argue that the animal would very likely have died, anyway.

So the clinical signs are fairly non-specific. Clinical chemical results will include spectacular elevations in levels of liver-specific enzymes such as arginase and sorbitol dehydrogenase, but these results will probably come too late for clinical diagnosis, so it is most important for the field veterinarian to be able to recognize the **macroscopic** features of acute hepatotoxicity **at necropsy** in the field. The carcass is unlikely to be jaundiced (see above), nor will there be severe photodynamic dermatitis. The carcass overall will often be in good nutritional condition because the animals which ingest most toxin will often be the dominant members of the herd. There will usually be petechial and ecchymotic haemorrhages on serosal surfaces (especially the epicardium). There will be slight excess of peritoneal fluid; yellow, clear and with some free fibrin in it. The liver itself may be relatively normal in gross appearance, although a distinct **acinar pattern** will nearly always be evident on cut surfaces. Often it is swollen and dark red due to the blood trapped in the corrupted sinusoids. The gall bladder wall will usually be somewhat oedematous.

Only rarely will the gross inspection be diagnostic; the liver damage should always be confirmed by the submission of liver samples for histopathological examination. Brain should be similarly examined, especially in cases that showed nervous signs before death. Liver failure in ruminants often leaves characteristic histological changes in white matter tracts, which can be helpful in cases where the liver has autolysed. The rumen may contain recognizable fragments of the culprit ingesta, but this is rare because rumenal fermentation makes botanical recognition extremely difficult, even for experts.

If acute hepatotoxicity is suspected on the basis of the above case features, then immediate efforts should be made to deny surviving stock access to the suspected source.

Not much can be done to treat affected animals, other than supportive provision of shade, shelter and fluids.

Chronic hepatotoxicities

Once again, the range of chemicals capable of causing chronic liver damage in ruminants is large, but the range of clinical features shown by affected animals is relatively small. The most helpful of these is **photosensitivity**, or photodynamic dermatitis (see above). If the death rate is low but photosensitivity appears suddenly in 20% or more of the flock, then cholestatic liver disease is very likely, the rare exceptions being the ingestion of plants such as ***Hypericum perforatum*** (containing a **primary photosensitiser**; see above) or the even rarer cases of **congenital porphyria**.

Chronic non-fatal hepatotoxicity

Liver disease that is primarily cholestatic will not necessarily be rapidly fatal, since the other vital liver functions may be relatively unimpaired. The classic example of this is poisoning by Lantana camara. It is possible to treat affected animals with activated charcoal and fluids to remove the toxin (lantadene A) from the alimentary tract, but it is expensive. The reason for the success is that these livers are not fibrotic, so the organ can recover.

Similarly, poisoning by steroidal sapogenins may not be fatal unless neglected cases die from the secondary effects of severe photosensitivity (blindness, thirst, starvation, etc). These cholestatic compounds have been shown to be potent cholestatic agents, causing primary inhibition of bile salt excretion and as a consequence of that, phylloerythrin retention. Antemortem diagnosis may be made on liver biopsy if the liver contains the characteristic sapogenin crystals associated with cholangitis, but it is important to remember that, in may cases, clinical photosensitivity precedes the crystal-associated cholangiopathy. Careful appraisal of grazing history, aided if possible by total plasma bile acid determination, may be needed to make a provisional diagnosis.

At necropsy the liver looks surprisingly normal. Gallbladder bile should be collected for examination for the characteristic rhomboidal crystals of sapogenin, which can be provisionally identified microscopically.

It is now emerging that steroidal sapogenins can be elaborated by a wide variety of plants, some of them valuable pasture species such lucerne, in grasses in the genera Panicum, Brachiaria and Pangola, and in weeds like Tribulus terrestris. Because the conditions that favour such accumulation are poorly understood, outbreaks of hepatogenous photosensitivity in animal grazing these plants tend to be unpredictable.

Sporodesmin toxicity ("facial eczema"), on the other hand, can be predicted with a little more accuracy, since the botanical substrate and weather conditions predisposing to the overgrowth of Pithomyces chartarum are rather better understood.

Since the biliary tract, rather than the hepatocyte, is the principal target for sporodesmin, it is usual for affected animals to show signs of cholestasis (photosensitivity) without other signs of liver failure, as for sapogenin and Lantana poisoning. Unlike the latter conditions, at necropsy one expects to see macroscopic oedema/fibrosis of the biliary tract. Since chronic cholangitis eventually causes left lobe atrophy in the livers of ruminants, a sheep or bovine liver in which the right lobe is enlarged while the left is pale, thin, tough and small should always signal the possibility of chronic sporodesmin poisoning or chronic liver fluke damage (or both).

Chronic fatal hepatotoxicities

Pyrrolizidine alkaloid (PA) poisoning:

Cattle are much more susceptible to these alkaloids than are sheep: in Australia Echium plantagineum is known as "Paterson's Curse" by cattle graziers, whereas sheep owners call it "Salvation Jane", because it can sustain sheep in times of nutritional stress. The age of exposed animals is also critical to the outcome. The genera Senecio, Heliotropium and Crotolaria are more widely recognized throughout the world as the most important sources of this class of toxin.

By the time affected animals show specific clinical disease, they are running out of reserve total liver function, so clinical signs may include nervous signs as well as photosensitivity. But the syndrome may be only a vague and non-specific problem of depression, ill-thrift and wasting. When such cases die or are killed for necropsy, the liver may be quite unspectacular (no marked scarring or nodularity). It will, however, be small, its capsule thick and grey and the cut surface tougher than normal and mottled and greenish-yellow. The atrophy is due to a combination of malnutrition and the antimitotic effect of the toxin. Because of the atrophy and diffuse fibrosis, there will usually be portal hypertension due to impedance of portal vein flow. This will produce sometimes spectacularly severe ascites, and oedema of mesenteries and bowel wall. Lower bowel oedema is thought to be responsible for diarrhoea, and tenesmus (sometimes leading to rectal prolapse) which may be part of the clinical syndrome.

The histopathology of affected livers is fairly characteristic, so this condition may sometimes be diagnosed by liver biopsy if necropsy is not an option. However, it should be noted that the pathology of aflatoxin poisoning (see below) can be essentially identical to that produced by pyrrolizidine alkaloids

A major advance in diagnosis of PA poisoning has been the ability to detect bound pyrroles in liver and blood for at least several weeks after exposure has ceased (provided you can find a lab which is prepared to do the test in this era of economic "reform").

(see below for association between PA and chronic copper poisoning in sheep)

Phomopsin poisoning:

This mycotoxin is traditionally associated with mouldy lupin stubble, but other substrates may be the source. The clinical syndrome and gross pathology can almost completely overlap that of PA poisoning, but fortunately there are usually characteristic histological changes (bizarre mitoses) in the liver which promote the use of liver biopsy for diagnosis in live animals (see below for association between phomopsin and chronic copper poisoning in sheep).

Aflatoxin poisoning.

This mycotoxicosis produces fairly non-specific changes in the liver which to a large extent overlap those produced by PAs. The range of clinical signs is pretty well indistinguishable in all these chronic fatal hepatotoxicities. In more acute cases of aflatoxicosis it is possible to detect the toxin in the liver for quite a few days after exposure, but the techniques involved are sophisticated and expensive (GCMS). Aflatoxicosis is traditionally associated with mouldy peanuts, but it must be borne in mind that substrates as diverse as citrus pulp and milk replacer have been implicated as sources of the mycotoxin for cattle.

Chronic copper poisoning:

Sheep are much more susceptible than cattle to this intoxication (in contrast to PA poisoning), and there are marked differences in breed susceptibility. The pathogenesis involves slow asymptomatic accumulation of copper in hepatocytes, followed by an acute haemolytic crisis as the copper-loaded liver self-destructs and releases enough copper into the plasma to destroy erythrocytes. The crisis as far as the liver is concerned occurs when the death rate of copper-loaded hepatocytes exceeds their replacement by mitosis: until then, the new hepatocytes manage to take up the copper spilling from dying hepatocytes. Understandably, exposure to the anti-mitotic effects of pyrrolizidine alkaloids or phomopsin (lupinosis) will bring forward the crisis. So, although the disease is a chronic intoxication, it usually presents as an acute syndrome or as sudden death.

Because death is due to a combination of liver failure and severe haemolytic disease, the classic gross findings at necropsy are severe jaundice combined with the presence of reddish-brown urine in the bladder. The kidneys will be deeply stained throughout with haemoglobin. The most revealing feature of the liver grossly is the presence in the gall bladder of dark, concentrated bile. Photosensitisation does not have time to develop.

The above findings in members of a flock of British breed sheep would justify a provisional diagnosis of chronic copper poisoning and institution of control measures while awaiting laboratory confirmation of the diagnosis, since cohort animals must be at risk. Samples for diagnosis must include whole kidney, since only after the haemolytic crisis do kidney copper levels rise, whereas clinically healthy sheep in the same flock may have higher liver copper concentrations because they have not yet begun to tip the copper out into the blood.

What about diagnosing significant liver fluke infestations these days?

Diagnostic enzyme-linked immunosorbent assay (ELISA) techniques have been developed to detect antibodies against *Fasciola hepatica* in serum of sheep and cattle. These tests have improved in specificity and sensitivity, to the point that they should become a useful tool for determining the fluke status of herds and for control of the disease.

Determining the significance of liver damage by fluke at necropsy is difficult, particularly in cattle. Many a prime beast has come to slaughter with a frightful-looking fluky liver. The organ may be dramatically distorted with the left lobe reduced to a fibrotic leaf-like appendage and the right hugely hypertrophied in compensation, and bile ducts thick, tough and partly calcified. Yet this animal passed ante-mortem inspection and its carcass makes profitable product. Severely fluky sheep, on the other hand, are more likely to be unthrifty and anaemic.

Echinococcosis (hydatids)

A recent abattoir survey of bovine offal in Queensland revealed that hydatid lesions were the most common cause of downgrades and condemnation of livers. Since these hydatids were without exception sterile and degenerate, they pose no health risks to man or pet, yet the loss borne by the industry is considerable. Control seems unlikely as foxes seem to be involved, yet not much work seems to be done on the problem. The gross pathology in the liver can mimic cancer and tuberculosis and actinobacillosis, which causes diagnostic confusion.

Bacterial liver disease

It seems that bacteria are perpetually gaining access to the portal blood from the gut. This is understandable, given the masses of organisms separated from intestinal capillaries by only a few cells, most of which are dedicated to absorbing stuff and some of which are actively involved in sampling particulate antigens from the bowel lumen (M-cells of the Peyers patches).

So bacteria often attack the liver and liver abscess has been mentioned above. The most dramatic examples are the clostridial infections black disease (necrotic hepatitis) and bacillary haemoglobinuria. The spores of *Clostridium novyi* or *C. haemolyticum* are filtered out of the sinusoidal blood in the liver and presumably remain in Kupffer cells until activated by liver damage. The resulting focus of necrotic liver has a yellow crumbly appearance that may easily be missed: the most telling feature is the intense red line that marks the edge of the lesion. The necrotic foci can be remarkably small and easy to miss unless the liver is sliced diligently: I once missed one hiding under the gall bladder. If the triggering agent was fasciolosis, then of course that pathology may confuse things.

The filtering role of the sinusoidal macrophages suggests that the liver will always be a good site for sampling in cases of suspected generalised bacterial infection. Well, yes; but remember that post-mortem invaders have been looking forward to the time when they can race up the portal vein from the gut and revel in the riches of the liver, so appropriate caution must be applied to interpreting results of bacterial culture of the liver, particularly when the post-mortem interval is more than a couple of hours.

Fatty liver

The commonest abnormal finding in ruminant liver is pallor of greater or lesser severity caused by triglyceride (fat) accumulation in hepatocytes. The causes of fatty liver range from poor circulation and severe metabolic upset (*e.g.* ketosis) to physiological increase in lipid processing which is seen in heavily-lactating dairy cows or heavily pregnant cattle and sheep. In these latter circumstances, fatty liver is really physiological, rather than a pathological manifestation of true clinical disease. Unfortunately for the field or abattoir veterinarian, it is often difficult to differentiate confidently between the physiological and pathological states.

The most spectacular cases of fatty liver in ruminants are seen in **ketosis**, whether this be primary or secondary. But any condition that stops a fat ruminant from eating will lead to increase in net triglyceride in the liver, since it is much easier to get mobilized body fat into the liver than it is to export it as lipoprotein. So some degree of fatty liver will be seen in any animal whose liver function is compromised, since only mild disorder will turn the liver into a bottleneck as far as fat metabolism is concerned. It follows, therefore, that fatty liver is a common and usually non-specific finding at necropsy, particularly in high-producing adult females.

Ovine white liver disease is often a disease of younger sheep, which seem to require more cobalt/vitamin B_{12} than do older animals. The cause of this condition has been controversial because some outbreaks have been associated with sudden change in feed, and it was thought that some nutritional/toxic factor might be involved as well. That may be the case sometimes, but the condition seems to have been reliably reproduced experimentally by simple induction of cobalt deficiency. The livers are pale and fatty, and in chronic cases become quite firm as delicate fibrosis is initiated. This can be helpful in gross diagnosis, since fatty liver is usually more friable than normal.

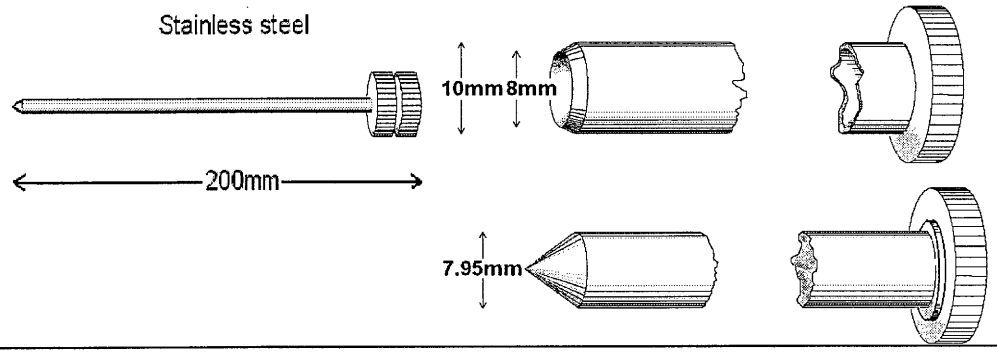


Fig.1 Specifications for trochar and cannula for liver biopsy of cattle and sheep

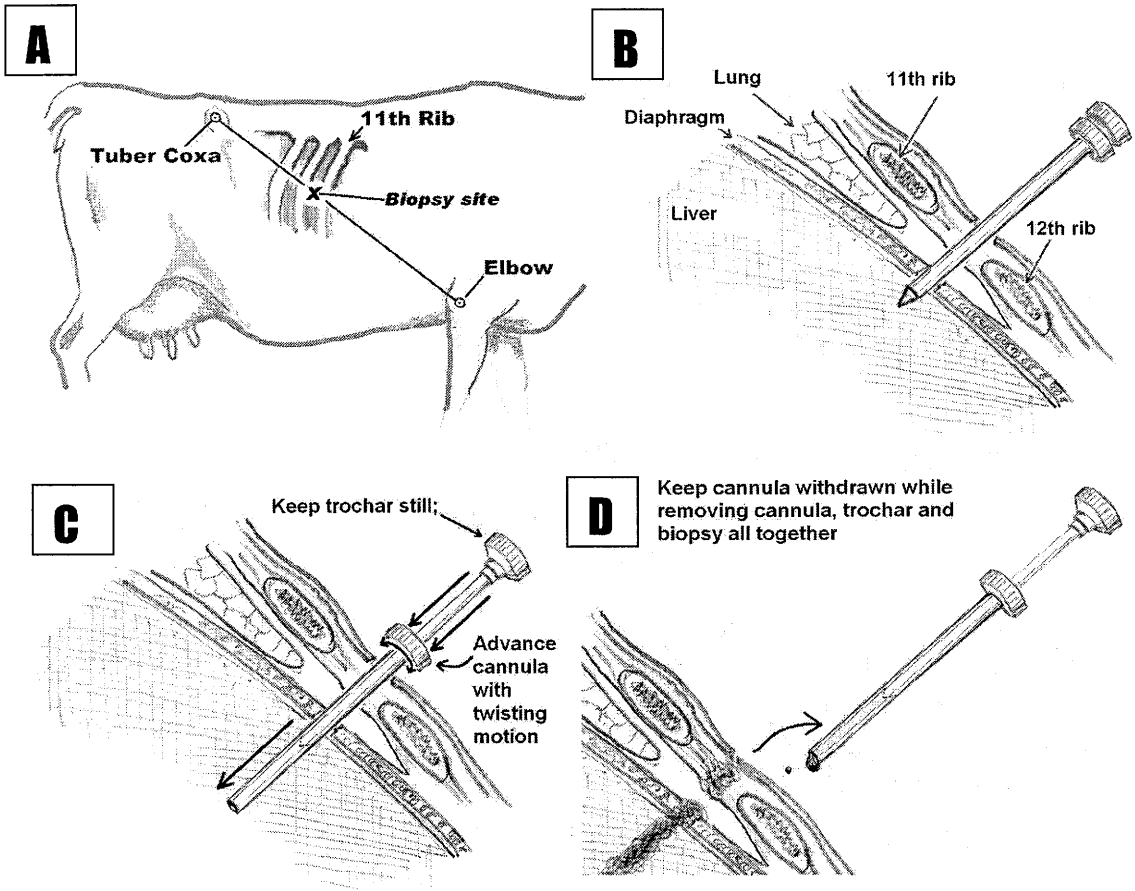


Fig.2 Liver biopsy technique for ruminants

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Chapter 6

Macroscopic Pathology of the Reproductive Tract of Domestic Ruminants

Philip W. Ladds

Detailed examination of the genitalia is often overlooked in routine necropsy procedures; the ovaries or testes normally receive little attention in comparison with "vital" organs such as liver, kidney or brain. This is no doubt because changes in these vital organs are more likely to tell why an animal sickened and died – the usual reason for necropsy being performed. Thus even experienced pathologists may not be certain of what is normal, and may have difficulty in assessing pathological changes in genitalia.

It also needs to be noted that changes associated with aging tend to be more pronounced in the genitalia than in other organs, and in the female, knowledge of morphological changes associated with pregnancy and the ovarian cycle is essential before interpretation of pathological change can be attempted.

NECROPSY TECHNIQUE

Before dissection commences it is of course important to conduct an external examination, which in so far the reproductive organs are involved, might reveal such disorders as hermaphroditism, vulvitis in the female, or cryptorchidism in the male.

Removal of Genitalia

Satisfactory examination of the pelvic organs can be achieved only after removal of a portion of the bony pelvis.

Most necropsy procedures involve placing the animal on its side, disarticulation of the uppermost hip joint, reflection of both legs and the skin on one side, removal of the abdominal and thoracic walls, and examination *in situ*. Then follows removal of the thoracic viscera, and all abdominal viscera other than the genito-urinary organs.

After completion of these steps, removal of part of the bony pelvis can be achieved by cutting (with saw or garden pruning shears) along the symphysis pubis and through the shaft of the ilium on the uppermost side. A knife is then used to cut adjacent fibrous and muscular tissue, and a complete segment of the bony pelvis is removed.

Before cutting along the symphysis pubis in the male, it is necessary to carefully dissect free the fibrous attachments of the root of the penis to the ischium. If care is taken, the penis can then be freed from its ischial attachments and dissected proximally to include the prepuce.

Because of their intimate association, it is frequently desirable to examine and remove the entire genital and urinary systems, including the kidneys, simultaneously – and more or less intact. This is best accomplished by dissecting the kidneys and ureters free by cutting attachments on their *lateral* aspects. In the female, in order to achieve complete removal of the ovaries and related structures, the ovarian ligaments should also be cut at their lateral extremities, as close to the body wall as possible. Likewise in the male, the urogenital organs can be removed by cutting the vas deferens near the internal inguinal rings.

In small ruminants it is possible to hold the kidneys, ovaries or accessory sex glands and attached ductal structures in one hand and use the other hand to dissect free the remaining intra-pelvic structures. Inclusion of a generous amount of contiguous adipose and fibrous tissue with the urogenital organs will ensure complete removal. These organs are lifted through the opening made on the ventro-lateral aspect of the pelvis. Removal is then completed by incising the skin around the anus and vulva or prepuce, in the female or male, respectively. A small portion of rectum is removed with the genitalia, so tying this off to avoid faecal contamination, may sometimes be advisable.

Although veterinarians are encouraged to include genital examination as part of their routine necropsy procedure, for the assessment of reproductive disorders in farm animals, genitalia are frequently collected after slaughter at an abattoir, rather than at necropsy. Important in this regard is realisation that the genital organs *per se* are of little commercial value so can normally be obtained gratis. In abattoirs it is customary for the genitalia to be removed from the carcass along with other viscera. Prior discussion with the slaughterman will result in more suitable specimens; little extra effort is required to achieve removal of the entire genital tract.

When it is decided to collect male genitalia after slaughter in an abattoir, it is convenient to obtain the accessory sex glands, urinary bladder and urethra collectively, by dissecting these organs free from the rectum after the animal has been eviscerated. Care should be taken not to miss the small bulbourethral (Cowper's) glands, which (in the bull) are located posteriorly, associated with the bulbocavernosus muscle; they are more conspicuous in the ram and buck. The remainder of the genitalia can then be readily obtained by taking the root of the penis plus the scrotum and its contents and dissecting these free by cutting forward to the anterior aspect of the prepuce.

Gross Examination of Genitalia

Female

The urinary organs should first be examined, and the occurrence of conditions that might involve both the genital and urinary systems (eg congenital malformations, endometritis-pyelonephritis) should be noted.

The *ovaries* should next be exposed, and particular attention should be paid to whether any cysts that may be present are located in the ovary or in the paraovarian tissues. Adhesions between these tissues or between genital and extra-genital organs should also be noted.

Ovarian size, weight, surface characteristics, colour and internal appearance after sagittal midline sectioning can all be used to ascertain the presence of congenital defects (eg ovarian hypoplasia), ovarian activity or inactivity, inflammation, intra-ovarian cysts and neoplasia.

Patency of the *oviducts* can then be checked by carefully inserting a blunted hypodermic needle (with syringe containing saline attached) in the ovarian extremity of the oviduct. Insertion of the needle into the minute opening (the abdominal ostium) is facilitated by stretching the delicate ovarian and oviduct membranes over one forefinger, with the funnel-shaped dilation of the oviduct lumen (infundibulum) uppermost. Gentle pressure on the syringe will force saline into the oviduct, which becomes visibly dilated as the saline progresses downward. Small incisions into the tips of the uterine horns permit examination of the entry of saline from the oviducts. Size of the needle will depend on the species; an 18 - SWG needle is suitable for the cow. For fixation the oviduct is dissected away from the mesosalpinx, wrapped around a small piece of cardboard and placed in Bouin's fixative (saturated aqueous picric acid 75 ml, formalin 25 ml and acetic acid glacial 5 ml.).

The remaining genitalia should initially be palpated and examined externally for the presence of congenital defects such as segmental aplasia (in which a distinct segment is absent) or incomplete fusion (especially caudally) of the tubular organs. Using blunt pointed Mayo scissors, both uterine horns, the uterine body, cervix, vagina and vulva are then opened on the dorsal aspect. Patency of the cervix should be recorded.

Attention should first be directed toward the uterine contents, particularly any foetal or embryonic remnants that may be present. Such remnants may easily be overlooked if present in a large volume of exudate.

The colour, viscosity, volume and odour of any intra-uterine exudate should be noted. The underlying endometrium is then examined for the presence of inflammation and/or hyperplastic and cystic changes.

In the cervix, vagina and vulva, the colour, viscosity and volume of mucus should again be noted and a search made to detect vesicles,

pustules, erosions or ulcerations of epithelium, and neoplasms. Other abnormalities that may be observed after opening the genitalia in this location include cystic Gartner's ducts (cattle), imperforate hymen, fusion defects as previously indicated and incomplete separation of the vagina and rectum, resulting in a form of cloaca.

Male

Dissection of the male genitalia involves three areas: the external genitalia, the testes and epididymides, and the accessory sex glands. Examination of the *external genitalia* should commence with the scrotal skin. Lesions here that may impair fertility include dermatitis and varicose dilation of scrotal veins.

The skin of the prepuce, especially the preputial orifice, should be examined, and the penis should then be extruded to permit examination. Conditions to be noted in this location include preputial eversion or prolapse, persistent penile frenulum, congenital short penis, duplicated penis (diphallia), hypospadias, phimosis or paraphimosis, inflammation, traumatic lesions, and neoplasms such as papillomatosis.

In the bull the sigmoid flexure should be palpated to detect the presence of haematomas, and the retractor penis muscle should be examined in its mid-portion for evidence of degeneration and calcification.

When indicated, the penis should be opened by cutting along the urethra; predilection sites for urinary obstruction are the sigmoid flexure, and the vermiform penile appendage in the ram.

On removal of the *testes* and *epididymides* from the scrotum, the attached spermatic cords should be examined, and the presence and type of any tunic adhesions (fibrinous or fibrous) should be noted. After checking the completeness and continuity of the epididymides and attached vas deferens (to detect segmental aplasia), the epididymides are then separated from the testes; it is advisable to weigh and measure these organs.

The testes are next dissected by a longitudinal (mid-sagittal) cut to expose the mediastinum, and the testicular parenchyma then examined to detect the presence of calcified foci (occasional small foci are of no significance), fibrosis, orchitis and neoplasms.

Testicular "halves" are then cut transversely with a sharp knife, making slices no more than 1 cm in thickness.

The epididymides are examined for the presence of cysts, and the size, location and content of these should be recorded. Sperm granulomas and larger foci of epididymitis will be detected at this time, especially in the ram. Occlusion and dilation of more proximal epidydimal ducts result from these conditions. On gross examination it is to be remembered that

accumulated sperm resemble purulent exudate and that microscopic examination of a smear of the exudate will quickly clarify its composition.

The *accessory sex glands* (asg) comprise the seminal vesicles, prostate, bulbourethral (Cowper's) glands and the ampullae (dilations of the proximal extremities of the vas deferens). Among the domestic species there is considerable variability in the morphology and pathological involvement of these glands. In domestic ruminants the seminal vesicles are most often affected.

After examination of the urinary bladder, a cut in the neck of the bladder on its dorsal aspect is extended along the urethra to the root of the penis.

The asg should be examined for the presence of congenital defects and should be palpated to detect cysts, foci of inflammation, fibrosis, hyperplasia or neoplasia. Any adhesions to adjacent structures should be noted.

After collection of specimens for microbiological examination, all glands are opened by multiple incisions. The type of exudate present in each gland should be recorded.

It is often convenient to collect samples of spermatozoa at this time. In the bull, spermatozoa for morphological examination can usually be obtained by incising the ampullae with a sharp scalpel and aspirating the contents into a Pasteur pipette. This sample can be washed into saline or formal saline or used to prepare fresh smears. As compared with the clinical collection of semen, spermatozoa obtained at necropsy in this way can be identified with either the right or the left gonad; such identification may be helpful in evaluating other findings in the testis or epididymis on a particular side.

Specimen collection and processing

Female

Samples obtained at necropsy for microbiological study are best acquired before actual dissection of the genitalia is commenced.

The surface of the uterus is seared with a heated spatula, and a sterile Pasteur pipette or disposable sterile needle and syringe used to aspirate any contained exudate. A drop of the aspirate may be placed on a glass slide, coverslipped and examined directly (eg for trichomoniasis in cattle), or smears may be prepared for fixation, Gram-staining and bacteriological identification.

Exercising care to avoid or minimise contamination, the remaining aspirate should then be transferred to a sterile screw-topped container, and dispatched for culture and other laboratory examinations (eg dark-ground study).

Specimens for histopathological study should be placed in fixative as soon as possible. Bouin's fluid [is] preferable to formalin for fixation of genital tissues. Tissues to be fixed should be cut to a thickness of less than 1 cm, and the ratio of tissue to fixative should be about 1 to 20. These tissues must be removed from the fixative after 24 to 48 hours and stored in 10 per cent formalin.

Male

For microbiological sampling of the preputial cavity, the penis is held with rat-tooth forceps and drawn from the prepuce. The moist preputial and penile epithelia are then gently scraped with a sterile scalpel blade. Preputial contents so obtained may be placed directly into tissue culture medium for virological studies (eg to detect bovine herpesvirus 1 infection (IBR) in cattle), incubated in special media for the detection of trichomoniasis (in cattle) or used for bacterial (eg *Campylobacter* sp.) isolation. Samples for microbiological examination from lesions in the remaining genitalia are collected using sterile procedures as previously described for the uterus.

For satisfactory histopathological evaluation of the testis and epididymis, fixation within a short time after collection is necessary. As for the female genitalia, Bouin's fluid is again the preferred fixative. It is best to fix thin transverse slices of testicular tissue (previously discussed) taken from three locations - the dorsal pole in the area of attachment of the epididymal head, the central region and near the ventral pole. If a sharp knife is used, it is possible to cut slices less than 1 cm that include both the tunica albuginea laterally and the mediastinum centrally. After the epididymis has been grossly examined and cut by multiple sections, it is best fixed *in toto*. Representative portions of the remaining genitalia and tissue from any lesions that maybe present are fixed as indicated.

GENITAL LESIONS IN CATTLE

Essentially because genital pathology has been most studied and is best documented in cattle, lesions in cattle are considered first and in most detail; sheep and goats are then considered on a comparative basis.

Female genitalia

Ovary

Rare anomalies of the ovary include agenesis, and vascular hamartomas – which increase in size with time, and resemble neoplasms.

Ovarian hypoplasia is an important condition in cattle and may occur in a herd at the same time as testicular hypoplasia in bulls. In one breed (Swedish Highland cattle), ovarian hypoplasia was shown to be a genetic

defect conditioned by an autosomal recessive gene. In other populations prevalence rates are in the order of 1-2% although prevalences of 7 to 19% were recorded in particular beef herds in northern Queensland. The condition is usually bilateral but varies in severity and symmetry. Differentiation of less severe "partial" hypoplastic ovaries from ovaries in anoestric cattle is important. Whereas hypoplastic ovaries have characteristic grooves running longitudinally on the surface, anoestric ovaries are smooth, rounder and larger. Also in ovarian hypoplasia there is accompanying hypoplasia of remaining genitalia. Severe generalised hypoplasia of the genitalia is a feature of freemartins (genetic females born co-twins to males), many of which have seminal vesicles.

Haemorrhage in the ovary may be intra-follicular and of unknown cause in calves or in atretic follicles in cows. Extensive haemorrhage, of up to several litres and even progressing to death, may be the result of manual enucleation of corpora lutea – especially in cows that are pregnant or have pyometra.

Cysts in and around the bovine ovary are important but are of varied origin and significance.

Paraovarian cysts are located adjacent to the ovary and arise from either mesonephric or paramesonephric tubules or ducts. They may be up to several centimetres in diameter. Histological examination is sometimes necessary to distinguish these from true ovarian cysts.

Cystic rete tubules arise from the rete ovarii, a structure of mesonephric origin that is composed of groups of anastomosing tubules in the medulla of the ovary.

True ovarian cysts may be defined clinically, as follicular structures of at least 2.5 cm in diameter that persist for at least 10 days in the absence of a corpus luteum. The incidence on ovarian cysts in dairy cattle is reported to be from 6 to 19%. Therefore cystic ovarian disease is a serious cause of reproductive failure even though 40 to 80 % of cows with ovarian cysts re-establish ovarian cycles following treatment with products high in luteinising hormone (LH) activity. Ovarian cysts may be classified as follicular cysts or luteal cysts. Probably the pathogenesis of both follicular and luteal cysts is similar – ie failure of hypophyseal release of adequate LH.

Follicular cysts (cystic Graafian follicles) are more common than luteal cysts. They may be single or multiple on one or both ovaries. They are larger and have thicker walls than normal follicles and are under more tension. Luteal cysts are usually solitary on one ovary and are generally thicker-walled than follicular cysts. Their yellow-orange luteal mass is smooth and rounded and a layer of fibrous tissue lines their central cavity.

Note that both the follicular and luteal cysts lack an ovulatory papilla and this latter feature can be used to distinguish luteal cysts from cystic corpora lutea in which the ovulation papilla distorts the outline of the cyst. Cystic corpora lutea can only be considered pathogenic if they do not produce adequate progesterone for normal cyclic events.

If ovarian cysts persist, changes develop in the remaining genitalia. These include cystic endometrial hyperplasia (see below), the accumulation of mucus (mucometra), cystic distension of Gartner's ducts (vestigial remnants of male ducts in the vaginal wall) and Bartholin's glands, and oedema of the vagina and vulva.

Neoplasms of the ovary may arise from surface coelomic epithelium, gonadal stroma, or the germ cells. Review of 104 bovine ovarian tumours revealed that 66 were granuloma cell or other stromal tumours. Therefore most ovarian tumours in cattle are of gonadal stromal type; they are unilateral and there is a tendency for the tumour to occur in the daughters of affected dams. Also, removal of the affected ovary may result in development of a tumour in the remaining ovary. The most common associated clinical sign is nymphomania, but anoestrus or normal cycling may occur.

Gonadal stromal tumours may be quite large (eg 15 – 20 cm in diameter), are smooth externally, and on section are composed of cystic and solid areas, which are white to yellow depending their lipid content. These tumours are rarely malignant.

Epithelial tumours constituted 17 of the 104 tumours in the above study and included cystadenomas, which when small, might be confused with cystic ovaries. Germ cell tumours including dysgerminoma and teratoma are rare in cattle but are recorded.

Ovaritis (oophoritis), with lesions of sufficient severity to be recognised grossly are rare in cattle but abscessation may be a consequence of enucleation of the corpus luteum in cows with pyometra. Necrotising ovaritis has been observed in heifers infected 11 – 15 days previously with the virus of infectious bovine rhinotracheitis (IBR); the occurrence of such lesions in spontaneous infection does not appear to be reported.

Uterine (Fallopian) tubes

Hydrosalpinx (distension of the uterine tube by fluid) is not infrequent in cattle, and (depending on case history) caution may be needed in ascertaining whether or not such lesions resulted from speying, "webbing" (oviduct removal), or other manipulation of the ovary or oviduct. Hydrosalpinx may also be secondary to salpingitis. In hydrosalpinx the uterine tube is distended up to a diameter of 1.5 cm with clear watery fluid – which can be seen through the thin stretched wall.

Macroscopic evidence of inflammation of the uterine tubes (**salpingitis**), or their distension with pus (**pyosalpinx**) is rare in cattle, the latter being most likely to accompany similar changes in the uterus.

Uterus, Cervix, Vagina and Vulva

Excluding intersexuality (see freemartins, above)-, in which enormous variation in the extent of genital development may be seen, there are two important congenital defects of the so-called tubular genitalia

(including uterine tubes) of the cow; these are segmental aplasia, and anomalies of fusion.

In **segmental aplasia of the paramesonephric (Mullerian) ducts** a distinct segment is absent so there is an accumulation and inspissation of genital secretion from above this point. On rectal examination this secretion, forming a mass of 10 or more cm in diameter, may be interpreted as a neoplasm or perhaps a retained foetus. Segmental aplasia may take various forms ranging from rudimentary development of the cranial vagina, cervix or uterus to degrees of hypoplasia or aplasia of a uterine horn. Where only one horn is involved the cow can conceive in the opposite horn. Imperforate hymen is one of the simplest forms of aplasia. In general, the more serious defects of the paramesonephric duct differentiation involve its anterior part, and the less serious are caudal.

Necropsy examination in these cases will reveal the firm doughy intra-luminal accumulations of brown mucoid material and the absence of pus and foetal remnants.

Segmental aplasia is especially common in white Shorthorn cattle ('white heifer disease') but probably occurs occasionally in all breeds.

Anomalies of fusion usually affect the cervix where, once again, a number of structural defects can occur. These include such variations as double uterine body and cervices (uterus didelphys) or double cervices in a single body. Such abnormalities may cause little trouble with fertility as such but may give rise to problems at parturition.

Endometrial hyperplasia with or without cysts is a sign of excessive stimulation by endogenous (cystic ovaries – see above) or exogenous (plant) oestrogens. Macroscopically, cysts may reach 5 cm in diameter and be associated with an excessive amount of mucoid fluid in the uterus. Cases complicated by endometritis become more purulent.

Although not as important as in ewes, endometrial hyperplasia has been observed in cows grazing oestrogenic (subterranean) clover and has been related to infertility.

Most uterine inflammations are confined to the mucosa or endometrium (**endometritis**) and it is important to note that there are no gross lesions in mild forms of endometritis such as those caused by post coital infection with pyogenic organisms of low pathogenicity, *Campylobacter fetus* or *Tritrichomas foetus.* Low-grade catarrhal endometritis with minor epithelial damage has been associated with a variety of bacteria such as pyogenic cocci, *Escherichia coli* and some *Corynebacterium* spp.

Severe endometritis is most likely to follow calving and veterinarians in bovine practice will readily anticipate the macroscopic changes. The uterus is flabby and enlarged by much chocolate-coloured lochia that is slightly tenacious. The content progressively becomes a dirty greyish

yellow because of a mixing of inflammatory exudate and placental detritus. Removal of this exudate reveals that the underlying endometrium is congested, swollen and mottled as a result of foetal haemorrhage and tattered intercotyledonary areas. In cases where foetal maceration has occurred, fragments of bone may be present in the exudate. Suppurative, ulcerative endometritis associated with Bovine Hepesvirus-4 in post-parturient dairy cows has recently been described as a herd problem. In these cases ulcerated endometrial epithelium was replaced by fibrino-necrotic suppurative "mats" and there was pyometra from which *Arcanobacterium pyogenes, Escherichia coli,* and rarely *Clostridium perfringens* and *Streptococcus* sp., were isolated.

Although uncommon, spread of inflammation from the endometrium to deeper layers (**metritis, uterine abscess**) may occur and be seen as "paintbrush" haemorrhages beneath the serosa of the un-dissected uterus. Partial resolution of such lesions may result in the formation of well-encapsulated abscesses 1 to 3 cm in diameter. Larger abscesses (eg up to 15 cm in diameter), especially in the dorsal uterine wall, are more likely to be post surgical.

Pyometra (uterus filled with pus) may result from acute suppurative nephritis or persistent low-grade infections with organisms such as *T. foetus*. Other organisms involved are haemolytic streptococci, coliforms, *Arcanobacterium pyogenes*, and *Pseudomonas aeruginosa.*

In the cow pyometra is also associated with corpus luteal activity in the ovary, but in contrast to the bitch it is the uterine disease that causes the corpus luteum to persist.

In bovine pyometra the amount of pus varies from a few ml to several litres. The cervix has no seal so a small amount of pus escapes into the vagina. Pyosalpinx and perimetritis may co-exist.

Inflammation of the vagina (**vaginitis**) and vulva (**vulvitis**) are not uncommon in cattle. Numerous pale small papular eruptions on the vulva (but not vagina) are seen in non-pregnant animals and the condition is referred to as granular venereal disease. Microscopically the papules are seen to be lymphoid accumulations . This change, which also occurs on the penis and prepuce of the bull, is in response to mild irritation and is not specific for any particular infectious agent.

Larger and more discrete ulcers (2 – 3 mm diameter) of both vulval and vaginal epithelium are characteristic of infectious pustular vulvo-vaginitis; these lesions are transient and again resemble those seen in the bull (see below) in response to infection with the same herpesvirus. This herpesvirus (or a subtype of it) also causes infectious bovine rhinotracheitis (IBR) but as a rule nasal and vaginal infections behave epidemiologically as distinct diseases.

With the exception of vulval fibropapilloma, **neoplasms of the tubular genitalia** of cattle are quite rare. Smooth muscle tumours (leiomyomas)

are seen occasionally as discrete and very firm round swellings up to 10 or more cm in diameter. They are pale, and bulge on cutting.

Endometrial carcinomas are sometimes seen in old (usually dairy) cows and differ from leiomyomas in that tumour growth is quite infiltrative and sclerosing – causing irregular nodular thickening of the uterine wall. Metastases in the regional (medial iliac) lymph nodes are likely.

The tubular genitalia of cattle are probably a more common site for lymphosarcoma than is the case in other domestic species; both diffuse and nodular infiltration occurs.

Studies in the USA have revealed that **retrovaginal constriction** in Jersey Cattle, a condition, which would more accurately be referred to as anovestibular stenosis, is a congenital defect regulated by an autosomal recessive gene. The condition does not directly involve Mullerian duct structures. Non-elastic fibrous bands of tissue at the ano-rectal junction and within the vestibular muscularis are seen in affected cows, which are prone to dystocia.

Male genitalia

Pathological examination of culled bulls is a particularly valuable and cost-effective method of investigating infertility problems in extensively run beef herds, where effective examination of live bulls is extremely difficult, if not impossible.

External genitalia:

The external genitalia comprise the penis, prepuce and scrotum. These organs can suffer pathological conditions that may be congenital (present at birth) or acquired.

Malformations:

Normally epithelial separation and rupture of the frenulum occurs at puberty. Failure to rupture results in temporary or permanent adherence. When present, **persistent penile frenulum** is composed of loose collagenous tissue, some elastic fibres, small blood vessels and epithelium.

Although persistent frenulum is a "trifling anatomical abnormality" – readily corrected by surgery, it has been suggested that the defect is heritable. **Frenular remnants**, observed as flaps and tags of tissue along the raphes of adult bulls, represent lesser degrees of the same defect but are of no pathological significance.

Other malformations which may occur, include: **short penis**, possibly associated with shortening of the retractor penis muscle; **abnormal insertion of the retractor penis muscle**, with stretching of the skin anterior to the testis during erection; **duplication of the penis** (total or partial); **hypospadias**, where the urethra opens under the penis or on the perineum; and so-called "**blood fistula**" in which haemorrhage occurs during erection, from a congenital vascular defect at the penile

tip. Deviation of the penis, an important condition considered to have a congenital or hereditary basis is essentially a clinical entity, and is difficult to study at necropsy.

Preputial eversion and prolapse:

The term **eversion** is used to describe a condition in which the preputial epithelium protrudes temporarily from the preputial orifice. It has been demonstrated that polled but not horned bulls evert their prepuces, and that this may be due to the well developed retractor muscles of the prepuce in horned bulls, as opposed to polled bulls.

While eversion per se is not associated with an increased incidence of preputial abscess, it is suggested that exposure of the preputial lining during eversion may predispose to damage by trauma, myiasis, frostbite and irreversible preputial prolapse.

It is generally agreed that **preputial prolapse** occurs as a result of eversion with subsequent injury, inflammation (posthitis) and oedema which prevents retraction of the prepuce. Bulls with a long and pendulous sheath are especially affected but polled *Bos taurus* beef bulls are also susceptible. Prolapse may be associated with fracture of the penis. Other associated lesions are fibrosis, gangrenous inflammation of the sheath and infection of the prolapsed tissue with staphylococcus, streptococcus, *A. pyogenes* and *E. coli.*

Phimosis and paraphimosis:

Inability to protrude the penis (**phimosis**) may be congenital but is mostly acquired. It may follow severe inflammation of the penis and the prepuce, haematoma, neoplasia or bruising, necrosis and fibrosis of the prepuce with prolapse.

Paraphimosis (inability to withdraw the penis into the prepuce) results in strangulation of the protruded portion of the penis; neoplasms, penile haematomas, and withdrawal of preputial hairs into the prepuce have been incriminated in the cause.

Penile haematoma:

Rupture of the tough fibrous wall of the penis with resultant haemorrhage and haematoma formation, usually occurs as a longitudinal tear on the dorsal surface of the penis at a point just anterior to the scrotum and adjacent to the attachment of the retractor penis muscle. Rupture at this point is not related to the thickness of the wall of the penis but rather to the fact that greatest tension occurs in this location. In one study, however, it was found that rupture in the penile wall was not necessarily involved; haematomas in 9 of 15 bulls examined apparently resulted from injury to blood vessels outside the wall. Abscesses may form in old haematomas but in uncomplicated cases natural healing occurs with varying degrees of residual scarring restricting movement of the penis.

Balanitis and posthitis:

These inflammations of the penile and preputial epithelium usually occur simultaneously, so-called balanoposthitis.

A muco-purulent preputial discharge is the characteristic clinical picture of balanoposthitis due to infectious pustular vulvovaginitis (IPV). Because lesions of IPV are widespread and involve more of the penis than the tip or "glans", the term "penoposthitis" has been suggested as a better description than balanoposthitis. In the acute stage 2 – 3 days post-infection (PI) numerous 2 mm grey-white opaque pustules are present; these pustules may form confluent and flat lesions , on the borders of which, separate pustules are to be seen.

The pustules, which exist for 1 –2 days only, then become indistinct, their surface sloughs and ulcers or erosions remain – especially in the area of the glans. Healing commences 5 – 6 days PI following sloughing. The basic lesion of IPV in bulls is focal necrosis of the lining of the penis and prepuce.

In addition to this typical form, there occurs in repeated IPV infections, a diffuse balanoposthitis with little suppuration and without the formation of typical pustules; pustular lesions are fact rarely seen in chronically infected bulls.

Infections of the penis and prepuce with *C. fetus* and *T. foetus* produce non-specific gross alterations. In the absence of any characteristic lesions the diagnosis of both vibriosis and trichomoniasis must depend on laboratory examination of preputial washings (or scrapings) collected from the live animal or from the genitalia after slaughter.

Tuberculous balanoposthitis is characterised by the presence of typical tubercles. Lesions are seen (1 – 2 mm), brown red nodules in the epithelium and subcutis, forming rounded projections on the surface of the glans.

Other organisms incriminated in the cause of balanoposthitis include mycoplasmas and various fungi, but there are no specific gross lesions.

An ulcerative posthitis of unknown aetiology has been observed in range bulls in South America and Australia; lesions were mostly at the preputial orifice and up to 2.5 cm in diameter. In the South American outbreaks, the lesions were sometimes more extensive, and *Corynebacterium renale* was often isolated. Lesions seem to occur especially in animals on a high plane of nutrition, and pathogenesis may be similar to the condition in sheep – in which however, wethers rather than rams are mostly affected.

Neoplasms:

Fibropapillomas (or papillomas) occur singly or multiply on the glans penis. They are most common in young bulls (1 – 2 years) and may not be noticed until after service, when haemorrhage occurs. Mostly they are up to 3 or 4 in number and up to several cm in diameter. Tumours are pink or grey-white, and on section they are composed primarily of fibrous tissue with an epithelial covering of variable thickness.

The malignant epithelial tumour of the penis and prepuce is the squamous cell carcinoma. Though common in other species (stallions) this tumour is extremely rare in the genitalia of male ruminants.

Miscellaneous conditions:

These include strangulation of the penis due to the drawing in of preputial hairs, extensive necrosis and calcification of the retractor penis muscle in old bulls, fracture of the penis, epidermoid cysts of the prepuce, pediculosis (lice infestation) of the prepuce and scrotum, varicose dilation of scrotal veins and frostbite.

Testis and Epididymis

Post mortem alterations can occur relatively quickly in the testis and epididymis; they are apparent after a few hours at room temperature and after 7 – 8 hours in the refrigerator. After 21 hours at room temperature or after 30 hours refrigeration, material is no longer suitable for assessment, especially in regard to differentiation of mild testicular hypoplasia from degeneration.

Testicular hypoplasia:

Testicular hypoplasia was recognised as a genetically determined defect in Swedish Highland cattle (see ovarian hypoplasia - above). In other countries it occurs sporadically at a low incidence. A high occurrence of "small testes", has however been observed in *Bos indicus* bulls but caution is needed in such cases to differentiate true hypoplasia from delayed testicular maturation in these bulls. Hypoplasia, by definition, means "defective or incomplete development". In the bull, one or both testes may be abnormally small, and in the absence of satisfactory history (eg previous clinical examination) it is difficult, even histologically, to distinguish between a hypoplastic testis and one which is small as a result of degeneration. Testes in cryptorchidism, especially those retained in the abdomen, are severely hypoplastic.

Hypoplasia is usually unilateral, generally affecting the left testis. The affected testis may be as small as ½ - 1/3 normal size and it is freely movable in the scrotum. Consistency of the hypoplastic testis varies; probably it usually approaches the normal more than with degeneration where a small hard testis ultimately results from progressive fibrosis. Hypoplastic testis do bulge on cutting.

Other Malformations:

With the exception of congenital cysts, other malformations are rare and include aplasia of the epididymis and or vas deferens (see segmental aplasia – accessory sex glands) and supernumerary testes.

Congenital retention cysts of the epididymis are not uncommon. They are regarded as blind remnants of mesonephric tubules and although they usually cause no harm, sperm accumulation within cysts (spermatocele) with subsequent extravasation and tuberculoid reaction, may occur however, and compromise fertility.

Testicular degeneration (atrophy):

As with most tissues, the testis can respond in only a limited number of ways to a wide variety of insults. It has been shown that the primary spermatocyte is the seminiferous cell most susceptible to insult of varying

type, while the B-spermatogonium and the Sertoli cells are the most resistant.

Degeneration may occur locally or involve the whole testis. Although the damaged testis may at first swell as a result of oedema, it soon becomes smaller than normal. While the organ is initially soft and flabby (does not bulge on cutting), there is subsequent hardening due to fibrosis, often associated with calcification. The relative size of the epididymis is sometimes useful in differentiating testicular hypoplasia from degeneration. This is because atrophy of the testis exceeds that of the epididymis. Therefore a high epididymal–testis ratio is likely to indicate atrophy rather than hypoplasia.

Causes of testicular degeneration are many and varied; they include localised or systemic diseases, after lameness with decubitis, trauma, after mange, poisoning with molybdenum, arsenic or chlornaphthalene, malnutrition or avitaminosis A, hormonal disturbances, high atmospheric temperatures, neoplasia, vascular lesions, obstructive lesions of the epididymis, inguinal hernia, auto-immunity, obesity and intensive overfeeding. In one recent report, testicular degeneration in young bulls was due to impaired thermoregulation of the testes associated with scrotal oedema that occurred as a result of infection with *Eperythrozoon* sp. infection.

Degenerative changes, fortunately, are usually reversible, and regeneration is possible so long as the spermatogonia and Sertoli cells remain.

Orchitis:

Orchitis (inflammation of the testis) is an uncommon lesion in the bull. Mostly it arises by spread via the bloodstream but extension of inflammation from neighbouring organs (eg testicular tunics), or via the genito-urinary tract is possible. The picture and progress of orchitis obviously varies from case to case; a useful classification however is that of intra-tubular, interstitial, and necrotising orchitis.

Macroscopically in intra-tubular orchitis numerous sub-miliary to miliary, eventually confluent, white to yellow foci are seen on cutting the testis.

In interstitial orchitis, the macroscopic appearance is predominantly one of increased scar tissue and the affected testis is harder and smaller than normal.

Necrotising orchitis is characteristic of brucellosis but may result from other infections. The affected testis undergoes complete or partial necrosis. On sectioning, necrotic areas are dry, yellow, often laminated and only slightly calcified.

In association with the above forms of orchitis we may find abscessation, periorchitis (inflammation of the adjacent tissues), and fistulation through the scrotum.

It is difficult and frequently impossible to relate observed pathological changes to specific causal agents or even to the type of agent. This is especially so in chronic orchitis. To complicate the picture still further the so-called "tuberculoid reaction" to spermatozoa which escape from the

duct system (see below) confounds even the diagnosis of specific infections.

Viral orchitis in the bull appears to be uncommon although further work is needed to clarify. IPV virus has been isolated from the testis but its appearance there is probably transitory.

Bacterial orchitis due to Diplo-, Strepto- or Staphylococcus, *A. pyogenes, Mycobacterium tuberculosis* and *Actinomyces bovis* as well as *Brucella abortus* have been described. Other infectious causes of orchitis are *Nocardia farcinica*, Mycoplasmas and Chlamydia.

Non-infectious causes of orchitis include trauma, and allergic responses to spermatozoa (so-called immune orchitis) and possibly other allergens.

Epididymitis:

Epididymitis occurs more frequently than orchitis but may be associated with it or with inflammation of the accessory sex glands. In contrast to orchitis, epididymitis is considered to arise chiefly by spread of infection in the genito-urinary passages.

Macroscopic findings in epididymitis vary; in acute cases there is enlargement with oedema. Abscessation may follow. One has to be careful not to confuse accumulated spermatozoa with pus, since they resemble each other in consistency and colour. Fibrosis, periorchitis with extensive adhesions, and inflammation of the spermatic cord are common sequels to epididymitis. In the bull the causal organisms of epididymitis are those listed for orchitis; additionally Pseudomonas or *E. coli* may be involved.

Tuberculoid reaction (sperm granuloma):

Fatty substances similar to those found in the tubercle bacillus, are contained in spermatozoa. The sperm head especially is resistant to disintegration and its presence in extra-ductal locations in the testis or epididymis elicits a pronounced chronic inflammatory or "granulomatous" reaction. Such granulomas may be indistinguishable from tuberculous lesions.

Neoplasms of the testis:

Primary testicular neoplasms of the bovine testis are rare and are not associated with obvious hormonal changes. Interstitial (Leydig) cell tumours are regarded as the most frequent but we have observed more Sertoli cell tumours. Teratoma (mixed congenital tumour) in the testis of a calf, has been described.

Miscellaneous conditions of the testis and epididymis:

These include partial black pigmentation (melanosis) of the epididymis, spontaneous torsion of the testis in the process of normal descent, thrombosis of testicular arteries, and paradidymis – a structure in the anterior part of the spermatic cord composed of isolated tubules which did not develop normally.

Accessory Sex Glands (asg)

Segmental aplasia (partial absence) of the mesonephric duct: The mesonephric (Wolffian) duct in the male foetus is responsible for the ultimate development of the epididymis, vas deferens, ampulla and seminal vesicle. These structures secrete fluids that are necessary for the storage and transport of sperm. Aplasia or hypoplasia of the mesonephric duct may affect all or any of the structures derived from it. The defect mostly involves the right side, and is rarely bilateral.

Varying degrees of fusion of mesonephric duct derivatives may be associated with segmental aplasia, but in mature bulls caution is needed in distinguishing congenital fusion from old inflammatory lesions., Also, cysts may result from fusion of the mesonephric ducts; in these cases soft fluctuating masses up to ~7 cm in diameter may be found just anterior to the body of the prostate gland.

When segmental aplasia is unilateral, or when only the seminal vesicles are involved, the bull is probably fertile. However, as there is strong evidence that the condition is heritable, affected animals should not be used for breeding purposes.

Other malformations:

These include cysts, aplasia, hypoplasia and fusion of the bulbourethral glands, prostatic "appendage", and melanosis in various locations.

Cysts and concretions:

The lumen of the seminal vesicles may be altered to form cystic dilations of varying size. Cysts may be congenital or acquired and may be generalised or in individual lobules. Similar cysts are observed in the ampullae, bulbourethral glands and prostate.

Concretions in the seminal vesicles may fill the described cysts. They are usually friable, rough externally and may have a laminated appearance on sectioning. They are composed of organic components, spermatozoa, phosphates and carbonates, and are attributed to precipitation of retained secretions or to chronic inflammation.

Seminal vesiculitis:

Of the asg, the seminal vesicles appear to be most commonly involved. Probably they are more often infected than even the testis or epididymis.

Seminal vesiculitis may be classified as being chronic interstitial or predominantly degenerative. In the former type there is a marked increase in size of the gland, excess fibrosis and loss of lobulation; cystic cavities lined by a whitish smooth membrane are frequent. In the predominantly degenerative type, increase in gland size is slight or absent, and increase in consistency is minimal. Complications of seminal vesiculitis include pronounced abscessation with involvement of surrounding tissues, adhesions, and fistula formation into the rectum or urinary bladder.

Infectious agents incriminated in the cause of seminal vesiculitis include IPV virus, Chlamydia, *Mycoplasma bovigenitalium, A. pyogenes, C. renale*, Streptococcus, Staphylococcus, *E. coli*, Proteus, *Pseudomonas*

aeruginosa, Brucella. abortus, M. tuberculosis, M. paratuberculosis, Actinobacillus actinoides, Nocardia-like organisms, and *Aspergillus fumigatus.* There is a report of isolation *of T. foetus* from the (inflamed) seminal vesicles.

In chronic seminal vesiculitis, bacteriological investigations are almost always negative. Autoimmune phenomena against spermatozoa may be implicated.

As with orchitis it is difficult to relate the type of lesion to a specific aetiological agent and the above classification reflects the duration of inflammation rather than the cause. Nevertheless described lesions in seminal vesiculitis attributed to viruses, *A. actinoides* and *M. bovigenitalium* were of the predominantly degenerative type.

Suppurative lesions suggest the presence of bacteria (especially *A. pyogenes*) and in specific inflammations such as tuberculosis, the usual characteristic changes will be observed. Possibly bacterial involvement is secondary in many cases.

Ampullitis, prostatitis and bulbourethral adenitis:

These may occur with seminal vesiculitis and the causal agents are similar. The bulbourethral glands are the least often affected.

Ampullitis usually causes a slight increase in diameter of the gland, with increased turgidity due to oedema. Induration and excess connective tissue around the gland may occur. Purulent ampullitis seems not to have been described. Studies on allergic epididymo-orchitis indicated the ampulla as a prediction site for such inflammation.

GENITAL LESIONS IN SHEEP AND GOATS

Female genitalia

Ovine

In general, pathological conditions of the reproductive tract of the ewe parallel those of the cow. Other important conditions in the ewe, however, include cystic endometrial hyperplasia in response to ingested plant oestrogens (clover disease), and vulvitis – associated with posthitis in wethers and occasionally rams.

Clover disease:

In ewes grazing subterranean clover (*Trifolium subterraneum*), lambing percentages may be decreased by as much as 20%. In affected flocks the disease is characterised by a high occurrence of difficult births, cystic hyperplasia of both cervix and endometrium, inactive ovaries, and hydrometra. Endometritis also occurs, presumably from functional damage to the cervix allowing passage of bacteria into the uterus. Although oestrogens are the cause of disease, prolonged exposure of ewes to these pastures results in masculinisation of the external

genitalia. There is partial fusion of the lips of the vulva, and hypertrophy of the clitoris.

Vulvitis:

In ewes, ulcerative lesions similar to the external ulcers of wethers appear ("scabby ulcers"), and sometimes ulceration extends into the vagina. These ulcers do not seem to interfere with conception or parturition but they are a factor in maintaining the disease in a flock and do predispose to fly-strike. As in wethers, a high protein diet and an organism resembling *Corynebacterium renale* are causally involved.

Spontaneous, partial or total *vaginal rupture in pregnant ewes*, has recently been described. The lesion always consisted of a tear in the dorso-lateral aspect of the vagina with a partial or total perforation of the wall close to the cervix. Most cases occurred one week before expected lambing. Circulatory disturbance resulting from uterine torsion was considered to be the underlying cause.

Caprine

Although genital disease in the doe is, in general, comparable to the ewe, several conditions warrant special mention.

Intersexuality:

This condition is an important cause of infertility in the doe and buck. In both cases the intersex state is related to hornlessness. If either parent is horned the offspring will almost never be an intersex. Affected animals are genetically female but abnormalities present include ovotestes, hypoplastic abdominal testes, and enlarged clitoris (visible externally) or obvious penis - sometimes with hypospadias.

Hydrometra and pseudopregnancy:

Hydrometra is also a significant cause of infertility and abdominal distension in the doe. The uterus is thin-walled and contains up to several litres of clear serous fluid. The cause is apparently unknown.

Pseudopregnancy occurs rather frequently in the doe. Although the cause is unclear, hormonal imbalances and early foetal resorbtion maybe involved – uterine fluid continuing to accumulate thereafter. Pseudopregnancy terminates in the doe voiding much cloudy fluid ('cloudburst'), which sometimes may represent spontaneous correction of hydrometra.

Herpesvirus vulvitis:

As in the buck (see below) the morbidity of this condition may be quite high. Characteristic are initial discrete erosions, pustules then ulcers up to several mm in diameter on the vulval and vaginal epithelia , and an associated erythema with a yellow to grey vaginal discharge. These lesions heal spontaneously, usually within two weeks.

Male genitalia

Ovine

Ulcerative posthitis occurs in wethers particularly, probably because of their tendency to urinate within their sheath. Urine rich in urea facilitates the growth of *Corynebacterium renale* in animals on a high protein diet. Hormonal factors may also be involved.

In early lesions there is focal necrosis on bare epithelium near the preputial orifice. This expands to involve the whole orifice, which may become stenosed, and infection will extend into the preputial cavity.

Fully developed lesions are those of extensive internal ulceration of the prepuce, hence the common name "sheath rot", with much accumulation of urine and pus and ulceration of the penis.

Bacterial epididymitis is of particular importance in sheep as compared with other domestic species. The cause is *Brucella ovis* or other so-called gram-negative pleomorphic organisms (GNPO) such as *Actinobacillus seminis* and *Histophilus ovis*.

There are important differences in pathogenesis depending on age of rams, and the causal organism. Whereas infection with *Br. ovis* mostly infects the epididymis of mature rams via a haematogenous route, infection with the GNPO ascends from the prepuce - especially in young rams, in which hormonal changes associated with puberty are important.

Macroscopic lesions may not always develop, but if present these are similar, irrespective of which of the above organisms is involved. Lesions, which may be uni- or bilateral and overwhelmingly involve the tail of the epididymis, are those of marked enlargement; there is no associated orchitis. The affected epididymis is firm to hard and often irregularly nodular as a consequence of spermatic granuloma formation and fibrosis. Associated tunic adhesions are common.

Varicoceles occur in 1-2% of rams and present clinically as nodular swellings above the testis.

The cause of varicocele is unknown. Early events are likewise unclear as most varicoceles in rams are thrombosed when seen. Once established, varicoceles seem to quickly increase in size - possibly due to a compounding effect of inadequacy of valves and the dependent position of the testis. Some degree of testicular atrophy is associated with large varicoceles.

Most varicoceles are located high in the pampiniform plexus near the inguinal ring and some distance from the testis. Dimensions of 10 - 40 cm are common and such varicoceles are composed mostly of laminated thrombi. Associated changes are testicular mineralisation, oedema of the epididymal head, and sometimes thrombosis of testicular vessels.

Bulbourethral gland hyperplasia in wethers (but not rams) results from their grazing certain clovers (*Trifolium* spp.) which have estrogenic activity. The development of cysts in these lesions may cause enormous

enlargement that gives swelling in the perineal region and sometimes urethral obstruction and death.

Caprine

Herpesvirus balanitis, which as in the bull (but not the ram) causes discrete ulcers, may lead in the buck to extensive necrosis of both penis and prepuce. Lesions vary from discrete 2-4 mm diameter ulcers on preputial epithelium to severe necrosis and suppuration and secondary bacterial infection of prepuce and penis, and phimosis. Stress associated with herding and transport of bucks, is a likely explanation for the severity of lesions.

A further interesting species difference occurs in relation to brucellosis. Whereas *Brucella ovis* infection in the ram typically causes a slowly progressive epididymitis, *Br. abortus* and *Brucella melitensis*, in the bull and buck, respectively, causes are more rapidly progressive inflammatory process that targets the testes.

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Chapter 7

Foetal and Neonatal Diseases

Roger W Cook

Introduction

This presentation focuses on diseases of pregnancy and congenital neonatal diseases of ruminants.

Normal Ruminant Conceptus

The **conceptus** is the whole product of conception, comprising the embryo or foetus plus foetal membranes.

The **placenta** is the structure of intimate contact between maternal and foetal tissue during gestation. It facilitates exchange of nutrients, oxygen, carbon dioxide and foetal waste products and produces various enzymes, cytokines and hormones necessary for implantation and maintenance of pregnancy.

The placenta has a **maternal endometrial part**, and a **foetal part** that may be:
1) Chorionic, non-vascularised (only transitional),
2) Choriovitelline (yolk sac placenta),
3) Chorioamnionic, or
4) **Chorioallantoic** (the predominant type in domestic animals).

In ruminants, the **maternal caruncles** (40 to 100 oval prominences on the endometrial surface) interdigitate with the **foetal cotyledons** (circular tufts of villi projecting from the chorionic surface of the chorioallantois) to form the **placentomes**, which are the units of placentation. The placentomes are the areas of closest proximity of the maternal and foetal circulations as the vessels of the foetal membranes are an extension of the embryonal or foetal circulation. Placentation in cattle is epitheliochorial, and in sheep is syndesmochorial due to the loss of endometrial epithelium within the placentomes. At birth separation is complete (ie the placenta is non-deciduate).

In cattle, the caruncles are dome-shaped and the villi of the foetal cotyledons project into them from the periphery.

In sheep and goats, the caruncles are cup-shaped and the cotyledonary villi project outwards from the centre of the caruncular cup. In sheep, haemorrhage within the placental arcade is a normal finding (ie from the tips of maternal caruncular septa between the bases of the chorionic villi).

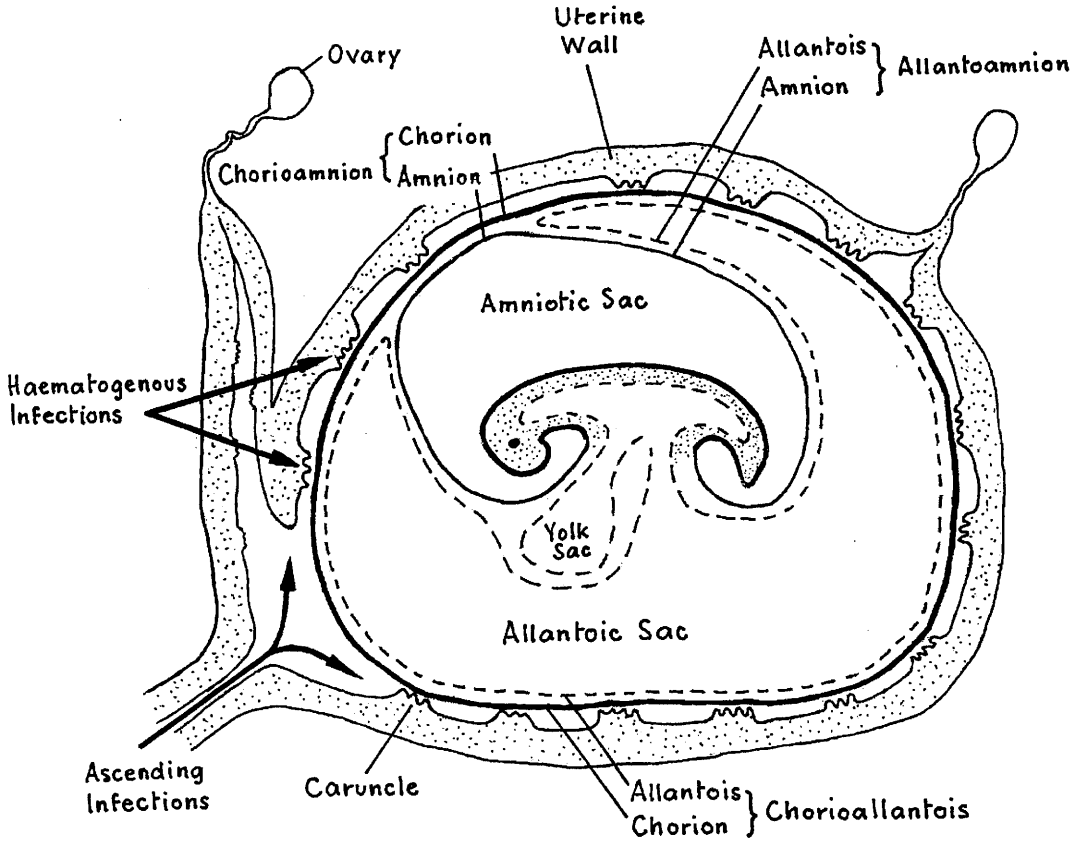

Figure 1. Diagram representing the relationships of the ruminant foetus, its membranes and the uterine wall, and routes of haematogenous and ascending infection.

At gross examination, two sets of foetal membranes can be identified surrounding the foetus *(see **Figure 1**)* and these contain a network of foetal blood vessels:

- The **chorioallantois** is the outer foetal membrane that results from fusion of the chorion and allantois. Its inner surface lines the allantoic sac, which in cattle contains up to 15 litres of watery allantoic fluid (hypertonic foetal urine received through the urachus). Its outer, chorionic surface comprises the cotyledons and the villus-free intercotyledonary areas. *In ruminants, the whole chorioallantois is usually referred to as the "placenta" although strictly speaking, placentation is limited to the maternal and foetal components of the cotyledonary placentomes.* The **chorioamnion** is that part of the outer foetal membrane formed by fusion of the chorion and amnion.
- The **allantoamnion** is a thin, translucent membrane resulting from fusion of the allantois and amnion. It envelops the amniotic sac, which contains the foetus and, in cattle, up to eight litres of amniotic fluid, a mucinous secretion consisting mainly of foetal saliva.

Routes of Infection of the Conceptus

Infectious agents can reach the conceptus via:

- **Maternal circulation to the uterus** (this occurs with most infections in ruminants),
- **Ascending uterine infection from the vagina through the cervix** (eg by *Campylobacter fetus venerealis*; also by pestivirus and *Ureaplasma diversum* contaminating semen or embryo transfer fluids), or
- **Infection within the ovum** (eg by transovarial transmission of viruses).

Once any part of the chorionic surface of the foetal membranes is exposed to an infectious agent, it has the potential to spread to the foetus and the rest of the chorioallantois by:

- **Foetal blood circulation**, and
- **Direct extension through foetal membranes and their contained fluids.**

These two routes of infection within the conceptus are intimately associated and can therefore occur concurrently. Chorioallantoitis ("placentitis") increases the risk of a pathogen invading of the conceptus.

Amniotic fluid, which bathes the foetus and is swallowed and aspirated *in utero*, can be a primary route of foetal infection, or be a medium for secondary proliferation of the pathogen following primary foetal infection via blood circulation. Lesions can develop in foetal skin, conjunctiva, lungs and stomach.

There is always the potential for rapid dissemination of an infectious agent within the conceptus via blood and foetal fluids. *Experimental inoculation of Listeria ivanovii into the amniotic sac of sheep results in infection of the foetus and dissemination of organisms to the chorionic surface of the placenta within 24 hours, via foetal blood circulation and direct invasion. Ascending human uterine infection by vaginal bacteria can result in amniotic fluid infection across intact foetal membranes and preterm delivery (in most cases without demonstrable foetal infection).*

Regardless of the route(s) of foetal infection, the essential sites for isolation of pathogens from cases of abortion are foetal stomach fluid and lung *(see **Appendix 1. Necropsy procedure for conceptus and neonate**)*.

Reference:
Goldenberg RL, Hauth JC, Andrews WW. Intrauterine infection and preterm delivery. *N Engl J Med* 2000;342:1500-1507.

Pathogenesis of Conceptus Damage

The outcome of an infectious or toxic insult on the conceptus depends on:

- **Cytotoxicity of the infectious or toxic agent**
- **Age-dependant susceptibility of conceptus,** involving:
    - **Stage of development of immune and inflammatory responses.**
    - **Stage of differentiation or maturation of tissues and organs.**

Pathological responses of the ruminant foetus to various viral infections (eg pestivirus, Akabane virus, and vaccine strains of bluetongue virus) illustrate the above principles. The gestational age at the time of infection affects the **pathological pattern of disease**:

- In early gestation, before the foetus develops inflammatory or immune cells, foetal lesions are directly attributable to the cytotoxic effect of the agent on susceptible foetal cells. *Also, foetuses that survive **pestivirus** infection at this early gestational age may be immunotolerant and remain persistently infected by pestivirus after birth.*
- Following infection at a later stage of gestation, inflammatory and specific immune responses are elicited but are initially ineffective and contribute to the severity and pattern of the pathological changes.
- When infection occurs in late gestation, the foetal responses may neutralise the infection before tissue injury occurs.

Teratogenic effects of viruses and toxins are generally most marked in early to mid gestation during differentiation of organs and tissues:

- Cells of the external granular layer of the foetal bovine cerebellum are susceptible during their period of most rapid multiplication (at 107 to 150 days of gestation) to virus–induced necrosis (eg by pestivirus or bovine parvovirus), and **cerebellar hypoplasia** is the outcome.
- Foetal bovine cerebral hemispheres growing rapidly at 70 to 100 days of gestation are susceptible to lysis induced by Akabane virus, and **hydranencephaly** results.

Pathological Responses of the Conceptus to Infection

Once an infectious agent breaches the placental barrier and spreads within the conceptus via foetal blood circulation or direct extension, the outcome can be:

- **Foetal survival, with no placental or foetal lesions**, with or without foetal antibody response, or
- **Foetal death, with minimal placental or foetal lesions** (eg in leptospirosis), or
- **Foetal death** (or possible survival), **with lesions in one or more of**:
    - **Chorioallantois** (including cotyledons and intercotyledonary areas).
    - **Allantoamnion.**
    - **Foetus.**

*The type and extent of gross and microscopic lesions that develop in these three parts of the conceptus depend on **virulence of the agent** and **immunocompetence of the conceptus.***

*Examination of the aborted conceptus (see **Appendix 1**) aims to detect the **pathological pattern of disease** in different organs and any **distinctive lesions** for diagnosis (see **Appendices 2** and **3**).*

Chorioallantoitis (**"placentitis"**) involving cotyledonary and / or intercotyledonary areas is present to some degree in most cases of infectious abortion. The cut surface of cotyledons and caruncles may show evidence of infarction or suppuration.

Allantoamnionitis (**amnionitis**), usually with a concurrent chorioallantoitis, is a gross feature of *Ureaplasma diversum* and mycotic abortion in cattle, and can occur in *B ovis* infection in sheep.

Chronic chorioallantoitis and / or **allantoamnionitis** (**amnionitis**) **without** (or with only minimal) **foetal lesions**, despite spread of infection to the foetus. characterise(s) some bacterial and mycotic abortions. *Some of the agents that produce these **chronic lesions within foetal membranes** may multiply within the conceptus for long periods before abortion occurs (eg U diversum in amniotic fluid for 117 days; B ovis and Aspergillus fumigatus in the chorioallantois for 60 to 90 days and 25 days respectively).* Offspring born alive or aborted from cases with chronic lesions in foetal membranes (eg *T gondii* and *B ovis* in sheep) may be small for gestational age.

Foetal bronchopneumonia (usually a microscopic lesion only) is a feature of many bacterial and mycotic but not of protozoal or viral abortions. There may be minimal gross changes in foetal lungs, with or without fibrinous polyserositis (eg *Campylobacter* spp, *Y pseudotuberculosis*). In some cases, however, the lungs are swollen, firm

on palpation, and dark red, often with confluent, off-white foci of infiltration by inflammatory cells in a bronchiolar distribution *(eg Br abortus; A pyogenes*). *Inhalation of meconium-contaminated amniotic fluid may produce a microscopic giant cell alveolitis.*

Multifocal foetal hepatic necrosis may be seen grossly in abortions caused by various **bacteria** (eg *C fetus fetus*, *Listeria* spp, *Y pseudotuberculosis, Fusobacterium* spp, *and Flexispira rappini* in sheep) and by some **viruses** (eg bovine herpesvirus 1 and Rift Valley fever virus).

Hepatic enlargement, with **nodularity**, **mottling** and **ascites** indicates *in-utero,* right-sided, congestive heart failure.

Myocardial changes seen grossly include **mottling** and **discolouration** (due to myocarditis, myonecrosis, mineralisation or fibrosis), **fibrinous epicarditis**, and **congenital cardiac defects** (associated possibly with compensatory **cardiac dilation** or **hypertrophy**).

Teratogenic effects of viral infections include arthrogryposis and hydranencephaly (Akabane virus) and cerebellar hypoplasia (pestivirus).

Embryonic and Foetal Death, Abortion and Stillbirth

Zygote or early embryonic death is followed by **resorption** or **expulsion**. The incidence is high (15 to 30%) in all animal species. Causes include zygote chromosomal abnormalities (numerical or structural, with the latter caused by viruses, drugs and radiation), transport problems within uterine tubes, and attachment or implantation problems due to diseases of the blastocyst or endometrium. The dead, early embryo disintegrates and is resorbed or expelled, with a return to oestrus usually after a prolonged interoestral period.

Abortion is the expulsion of a live or dead foetus at any stage of gestation. **Stillbirth** is the expulsion of a dead foetus at term (ie within the period of expected viability). **Premature birth** is the birth of a viable foetus before expected parturition.

Foetal death may result in **abortion**, **stillbirth** or retention with **mummification** (requires absence of uterine bacterial infection) or **maceration** and **emphysema** (require uterine bacterial infection).

Non-specific autolytic changes are seen in the **foetus and foetal membranes** that have been retained *in utero* for 24 hours or longer after foetal death. Most obvious are **dark-red, haemoglobin-stained body fluids and tissues** from haemolysis of erythrocytes leaked from capillaries after death. **Bloody subcutaneous and perirenal oedema**, and **bloody fluid accumulated in body cavities** are also present. As autolysis advances, the tissues of the foetus develop a green-brown,

partially-cooked appearance, and solid visceral organs (especially kidneys, spleen and liver) and brain become soft, with the lungs and myocardium the last affected. The autolysing chorioallantois ("placenta") is oedematous and discoloured, initially dark-red and then progressively green-brown or tan. The cotyledons may be soft or pasty. Autolysis may mask antemortem lesions.

Meconium staining of the foetal skin and amnion follows *in-utero* defaecation (due to foetal diarrhoea, anoxia or stress) into the amniotic sac. The foetal skin and amnion have a prominent, yellow-stained appearance, and the amnion may be infarcted.

Non-inflammatory Changes in the Conceptus

Adventitial placentation in cattle is a response to inadequate development of placentomes when there are too few caruncles. This may be congenital or due to loss of caruncles following endometritis. Compensatory increase in size, with fusion of conventional placentomes is the first response. This is followed by formation of adventitial placental areas by simple villous interdigitation, initially adjacent to placentomes. It can extend along the floor of the uterus to involve much of the intercotyledonary areas; in such cases, pregnancy may not be maintained or **hydrallantois** may develop.

Amniotic plaques are foci of squamous metaplasia up 4 mm in diameter. They are frequently keratinised, and are a normal incidental finding on the internal surface of the amnion at the umbilical stump, particularly in cattle. They can infold to form spherical structures filled with keratinised material.

Placental mineralisation is a physiological process in ruminants. In **cattle**, it is visible between 60 and 120 days of gestation as milky, non-gritty foci and streaks along small vessels in the chorioallantois. In **sheep**, non-inflammatory **calcification of cotyledonary villi** is common and may involve a few or many cotyledons, which have several to many elongated white gritty structures amongst otherwise normal foetal villi. *These calcified villi may be mistaken for the cotyledonary lesions of ovine toxoplasmosis.*

Avascular chorion or "necrotic tips" are normal, white to brown, wrinkled, avascular and avillous structures at the ends of ruminant chorioallantoic membranes.

Amorphus globosus comprises a round, hard cystic structure next to the umbilical cord and considered to be an incomplete twin or "teratoma".

Hippomanes are amorphous rubbery masses that are frequently found in allantoic fluid of the horse but have been reported in cattle and pigs. They are allantoic calculi that result from deposition of material from

allantoic fluid on a central nidus of desquamated epithelial debris from the lining of the allantoic cavity.

Hydramnios in cattle and sheep is usually associated with foetal, musculoskeletal malformation particularly of the head, possibly affecting the foetal drinking reflex.

Hydrallantois in cattle results in a marked increase in allantoic fluid to up to 170 litres. Adventitial placentation and twin pregnancies predispose. Outcomes are abortion and dystocia associated with small dead calves with anasarca and ascites.

Prolonged Gestation

Foetal anomalies that disrupt the hypothalamic-pituitary-adrenal axis (an intact foetal axis appears necessary for initiation of parturition) can result in prolonged gestation. Sporadic cases occur in grossly deformed bovine foetuses with severe brain anomalies.

Akabane disease in sheep and cattle can prolong gestation. In sheep outbreaks in Israel (1971) and Japan (1975), gestation was prolonged (to 180 days) in association with severe foetal hydranencephaly, hydrocephalus and arthrogryposis (and a high incidence of abortion); in Australia, gestation was only marginally prolonged in sheep outbreaks (1974, 1976), in which micrencephaly was the most common foetal defect.

Two autosomal recessive defects in cattle, including one associated with adrenal hypoplasia in Holsteins and Ayrshires and one associated with cyclopean head anomalies or absence of the pituitary gland in Guernseys and Jerseys, prolong gestation.

Veratrum californicum ingestion by ewes on day 14 of gestation results in cyclopean giant lambs with displaced pituitaries, and prolonged gestation.

Salsola tuberculatisformis (a drought-resistant African shrub) ingestion by ewes during the last 50 days of gestation results in lambs with hypoplastic pituitaries and adrenals, and prolonged gestation.

Viral Causes of Foetal and Congenital Disease

Bovine pestivirus and Border disease virus infections

The outcome of *in-utero* infection of ruminants by pestivirus depends on the stage of gestation.

In **cattle**, exposure of the conceptus to **bovine pestivirus** at:

- 0 to 30 days of gestation causes either **embryonic death** or no infection.

- 30 to 100 days of gestation causes **abortion**, mummification, premature birth, stillbirth, **stunted, full-term calf** (due to **in-utero growth retardation**), normal but **immunotolerant, persistently-infected**, full-term, live calf and some **congenital malformation** (cerebellar hypoplasia and hydranencephaly).
- 100 to 180 days of gestation causes **congenital malformation** (cerebellar hypoplasia, hydranencephaly, micrencephaly, microphthalmia, chorioretinopathy, cataracts, hypotrichosis and rarely arthrogryposis).
- 180 days of gestation causes seroconversion only.

In **sheep** and **goats**, exposure of the conceptus to **Border disease virus** at:

- 30 to 55 days of gestation causes **abortion**, mummification, or normal but **immunotolerant, persistently-infected**, full-term, live lamb / kid.
- 55 to 70 days of gestation causes **hairy shaker** (with hairy fleece and hypomyelinogenesis), **immunotolerant, persistently-infected,** full-term, live lamb / kid, and **congenital abnormalities** (**HE, porencephaly, cerebral dysgenesis**).
- 70 to 90 days of gestation causes variable changes and seroconversion.
- 90 days of gestation causes seroconversion only.

Reference:
Taylor LF, Rodwell BJ. Outbreak of foetal infection with bovine pestivirus in a central Queensland beef herd. *Aust Vet J* 2001;79:682-685.

Akabane virus and other Bunyaviridae (Aino, Cache Valley and Rift Valley fever virus) infections

Akabane virus, a member of the Bunyaviridae, causes congenital malformations (Akabane disease) that depend on the stage of *in-utero* infection of the foetus.

Cattle are most commonly affected by Akabane disease. *In-utero* exposure to Akabane virus at:

- 76 to 104 days of gestation causes **hydranencephaly** (**HE**), usually with a **normal-sized cerebellum**.
- 104 to 173 days of gestation causes **arthrogryposis** (**AG**), after degeneration of lower motor neurons.
- > 173 days of gestation causes seroconversion only or **encephalomyelitis** in the newborn calf (or less frequently abortion or stillbirth).

Sheep and **goats** have a similar but not identical spectrum of congenital malformations associated with Akabane disease. *These **malformations often develop concurrently (rather than sequentially** as in cattle above) due to the shorter gestation and susceptibility periods in small ruminants.* Exposure of the conceptus at:

- 30 to 50 days of gestation causes **micrencephaly, porencephaly, AG, HE, scoliosis and kyphosis.**

Aino virus is reported to produce similar **congenital malformations** in ruminants as Akabane virus, but also **cerebellar hypoplasia** and **unilateral porencephaly**, which are not usual features of Akabane disease.

Cache Valley virus causes **AG** and **HE** in sheep in the USA, with foetal disease resulting from infections in a similar gestational age range as for Akabane virus. The main outcomes of foetal infections at 27 to 35 days of gestation are **foetal death** with **resorption** or **mummification**, and at 36 to 45 days are **AG** and **HE.**

Rift Valley fever virus, another member of the Bunyaviridae, is exotic to Australia but should be considered as a differential diagnosis of **abortions affecting multiple ruminant species** (cattle, sheep and goats) associated with outbreaks of **sickness** and **deaths** particularly in young animals, with necropsy findings of **hepatic necrosis** and generalised ecchymotic haemorrhages. Rift Valley fever is a zoonosis.

Reference:
Kirkland PD, Barry RD, Harper PAW, Zelski RZ. The development of Akabane virus-induced congenital abnormalities in cattle. *Vet Rec* 1988;122:582-586.

Orbivirus (Bluetongue, Epizootic Haemorrhagic Disease and Palyam virus) infections

Eight of 27 known serotypes of bluetongue virus occur in Australia, with infection occurring mainly in cattle, which do not develop clinical disease. Although all serotypes are potentially pathogenic for sheep and goats, clinical bluetongue in these species has not yet been reported in the main Australian sheep-raising areas.

Although **bluetongue virus** can cause foetal disease and congenital malformation (including **hydranencephaly** but not arthrogryposis) in ruminants (see **Appendices 1** and **2**), it is believed that only vaccine and not wild type viruses induce them, ie they are an artifact of laboratory manipulation.

Other members of the Orbivirus genus, including **six of eight known serotypes of epizootic haemorrhagic disease** (**EHD**) **virus**, and also **Palyam viruses**, cause subclinical infection in Australian cattle. One of these, a Palyam virus (**D'Aguilar virus**) is occasionally associated with **abortion**, **foetal mummification** and **congenital malformation** (**cerebellar hypoplasia** is reported).

In Japan, an EHD 2 virus (**Ibaraki virus**) causes outbreaks of severe disease in cattle with up to 10% mortality, and reported **abortion** and **congenital malformations**. Also in Japan, a Palyam virus (**Chuzan** or **Kasba virus**) causes **hydranencephaly** and **cerebellar hypoplasia** in cattle.

Bovine herpesvirus infections

Bovine herpesvirus 1 (**BHV 1**) causes infectious bovine rhinotracheitis and infectious pustular vulvovaginitis in Australia and New Zealand but not foetal infection with abortion.

Overseas, where **foetotropic strains of BHV 1** occur, abortions follow three to six weeks after clinical illness or IBR vaccination of non-immune pregnant animals, usually in the last trimester. Once the virus invades the foetus, death is rapid, but expulsion is delayed for at least for one to five days and the foetus and membranes are invariably markedly autolysed. **Abortion, mummification, stillbirth** and **birth of weak calves** are the outcomes. Gross lesion are usually absent or obscured by autolysis, but if present consist of multiple 1 to 3 mm diameter, off-white foci of necrosis in liver and less frequently lung and spleen. In live, affected newborn calves as well as **multifocal hepatic necrosis** there can be **necrosis and ulceration of the upper alimentary tract**, particularly in **forestomachs** where accumulated necrotic material on the mucosal surface resembles curdled milk.

Bovine parvovirus infections

In the USA, **bovine parvovirus** is described as a cause of diarrhoea in calves and of abortion and birth of weak calves. Infections in the first trimester cause **repeat breeding**, **early embryonic mortality** and **abortion**; in the second trimester **cerebellar hypoplasia**; and in the third trimester seroconversion only. Microscopically there are intranuclear inclusions in the cerebellar external granular layer cells, hepatocytes, adrenal cortical cells and intestinal cryptal epithelium.

Bacterial and Mycotic Causes of Foetal Disease

Many organisms of relatively low virulence and ubiquitous in the environment (eg *E coli*, *Bacillus* spp and fungi) can cause sporadic cases of abortion after invading the gravid uterus and conceptus. However, when isolated from the foetus and / or foetal membranes they should to be regarded as likely postmortem contaminants unless they are associated with lesions such as foetal bronchopneumonia or placentitis (often detectible only at histological examination).

The following infections of the ruminant conceptus have **pathological patterns of disease** that are an aid to differential diagnosis.

Brucellosis

Brucella abortus is now eradicated from cattle in Australia. The main lesion is a chronic placentitis with oedema, fibrosis and wrinkling of the intercotyledonary chorioallantois, which is covered by a custard-like exudate. Changes are most marked adjacent to cotyledons, all or portions of which are necrotic. The foetus is autolysed and oedematous

and may have gross evidence of foetal pneumonia (firm, red lungs, with fibrin strands on the pleural surfaces).

Brucella ovis is mainly a cause of epididymitis in rams, but can cause placental infection in late pregnancy resulting in abortion (the non-pregnant uterus is not susceptible to infection). As with *Br abortus*, *Br ovis* localises in the chorionic epithelium and produces a severe, chronic placentitis (vasculitis is a feature), with gross oedematous thickening, wrinkling and mineralisation of the intercotyledonary chorioallantois, and necrosis of cotyledons. The aborted foetus may be autolysed or mummified, but most are alive at the start of parturition (and may survive) and show no gross lesions other than calcified plaques on the hooves and the accessory digits (in about 50% of cases from grossly-diseased placentas).

Campylobacteriosis

Campylobacter fetus venerealis is a venereal infection transmitted by coitus, and causes infertility and abortion in cattle. *C fetus fetus* and *C jejuni* are intestinal organisms that are transmitted orally with bacteraemic spread to the pregnant uterus in sheep and cattle, causing abortion. *C lari* (also known as *C laridis*), which is common in seagulls and infrequently causes human enteric disease, is reported as causing ovine abortion in New Zealand.

In cattle, both *C fetus* subspecies can cause abortion from four months gestation onwards, with expulsion of the foetus and foetal membranes that may be fresh or show signs of *in-utero* autolysis. There is clear or bloodstained fluid within the subcutis, thorax and abdomen and the liver may be enlarged. Fibrinous polyserositis (sheets of fibrin covering the serosal surface of the lungs, liver and intestines) is a distinctive finding in some cases. Rarely there are multiple small necrotic foci in the liver. The gross placental changes resemble those of brucellosis but are milder. There may be intercotyledonary oedema and cotyledonary necrosis.

In sheep, *C fetus fetus* and *C lari* cause abortion outbreaks in late pregnancy to full term, with considerable variation in gross lesions. Gross changes are as for cattle. However, with *C fetus fetus* there is an additional distinctive liver lesion in a third of affected foetuses: multiple (few or many) circular, tan, necrotic areas 5 to 20 mm in diameter, often with a raised outer border to give a target appearance.

A microscopic foetal bronchopneumonia is present and the distinctive organisms can be demonstrated in and isolated from foetal stomach fluid.

Reference:
Van Donkersgoed J, Janzen ED, Chirino-Trejo M et al. *Campylobacter jejuni* abortions in two beef cattle herds in Saskatchewan. *Can Vet J* 1990;31:373-377.

Flexispira rappini infections

Reported in the USA as a cause in sheep of sporadic cases of abortion, mummification and birth of weak lambs, *F rappini*, an anaerobic flagellated organism, can produce gross placental and hepatic lesions

identical to those of *C fetus fetus,* including the distinctive circumscribed hepatic foci.

Reference:

Kirkbride CA, Gates CE, Collins JE. Abortion in sheep caused by a nonclassified, anaerobic, flagellated bacterium. *Am J Vet Res* 1986;47:259-262.

Fusobacterium spp infections

In New Zealand, a *Fusobacterium*-like organism causes abortion in sheep associated with similar gross and microscopic placental and foetal lesions to those of *C fetus fetus* and *F rappini.* The organism is demonstrable in Gram-stained smears of foetal stomach contents.

References:

Clark G, Gill JM A review of sheep abortions in Otago and Southland *VETscript* December 2002;:18-19.

Smart JA, Gill JM. Fusobacterium-like abortions – an overview. Proceedings of 29th Seminar, Society Sheep *and Cattle Veterinarians NZVA* 1999:35-38

Listeriosis

Listeria monocytogenes and *L ivanovii* cause sporadic abortions and occasionally small outbreaks of abortion in sheep and cattle, often associated with feeding silage. In early third trimester infections, there is rapid invasion of the placenta and foetus with foetal death and abortion within five days; minor gross lesions are masked by autolysis. In near term infections, abnormal parturition with dystocia and severe metritis can occur, and placental and foetal lesions are less likely to be obscured by autolysis.

Grossly there are multiple, circular, yellowish necrotic foci 1 to 3 mm in diameter in the liver (and occasionally in lungs). There is a microscopic foetal bronchopneumonia.

The gross placental changes are severe and include extensive thickening and necrosis of the intercotyledonary chorioallantois with adherent necrotic exudate and necrosis of cotyledons.

References:

Ladds PW, Dennis SM, Cooper RF. Sequential studies of experimentally induced ovine listerial abortion: Clinical and bacteriological examinations. *Am J Vet Res* 1974;35:155-160.

Ladds PW, Dennis SM. Sequential studies of experimentally induced ovine listerial abortion: Pathological changes. *Am J Vet Res* 1974;35:161-170.

Gill PA, Boulton JG, Fraser GC, Stevenson AE, Reddacliff LA (1997). Bovine abortion caused by *Listeria ivanovii. Aust Vet J* **75**:214.

Leptospirosis

Abortion in cattle is caused worldwide by *Leptospira interrogans* serovar *pomona (L pomona),* and in Northern Ireland by *L interrogans* serovar genotype *hardjo-prajitno (L hardjo-prajitno). L borgpetersenii* serovar genotype *hardjo-bovis (L hardjo-bovis),* which causes milk drop syndrome in Australia, is not associated with abortion in cattle. During systemic infection of the dam, *Leptospira* spp may localise in the placenta and in some animals produce foetal disease followed by abortion of an autolysed foetus.

The placenta may be grossly oedematous. Despite the presence of leptospires in the chorionic epithelium and in foetal tissues, inflammation is modest (there is occasionally microscopic, non-suppurative foetal nephritis and meningitis).

Mycoplasmosis

***Mycoplasma* sp bovine group 7** causes outbreaks of polyarthritis in calves, which may be associated with outbreaks of mastitis and abortion. Gross changes reported in aborted foetuses are excessive straw-coloured, turbid fluid in body cavities and hip joints. Microscopically there is a suppurative bronchopneumonia with an interstitial myocarditis and epicarditis. *Isolates from foetal stomach fluid, liver and lung appear as beta-haemolytic colonies after five days incubation, a period longer than that routinely used for bacteriological cultures (48 hours), so the diagnosis may be missed.*

Most post-natal-cases of polyarthritis are clinically affected between two to three weeks of age, a finding consistent with infection from consumption of milk contaminated with *Mycoplasma* sp bovine group 7.

Reference:
Hum S, Kessell A, Djordjevic S, Rheinberger et al. Mastitis, polyarthritis and abortion caused by *Mycoplasma* species bovine group 7 in dairy cattle. *Aust Vet J* 2000;78:744-750.

Ureaplasma diversum infections

***Ureaplasma diversum* (formerly T mycoplasma)** is frequently found in the nasal cavity, vagina and prepuce of cattle, and virulent strains can cause granular vulvitis, embryonic deaths, abortion and birth of weak calves. Abortion is in the last trimester, with retention of foetal membranes. Reports are mainly from North America, but in New Zealand vulvitis and an outbreak of abortion in embryo-transfer recipients associated with *U diversum* have been reported.

Gross lesions are a chronic thickening of the amnion, with yellow, firm tissue running through white oedematous areas and multiple confluent red plaques, and hyperaemia of the chorioallantois, with intercotyledonary oedema. Microscopic changes are a chronic non-suppurative amnionitis and lymphocytic bronchointerstitial pneumonia. Isolation of *U diversum* from placenta, or foetus is necessary for diagnosis.

References:
Johnstone AC Voges H. Ureaplasma diversum as a cause of abortion in embryo-transfer recipient cattle in New Zealand *Proc Annual Meeting Aust Soc Vet Pathol* Brisbane, May, 1997.

Thornton R, Wake H. *Ureaplasma* in New Zealand dairy cattle *Surveillance* 1997;24(3):15-16.

Arcanobacterium (formerly *Actinomyces*) pyogenes infections

The pyogenic organism *A pyogenes* is a common mucosal contaminant of tonsils and vagina and can localise in the placenta following a transient bacteraemia, causing sporadic cases of abortion in cattle and, less frequently, in sheep. Gross lesions are a suppurative placentitis (autolysed chorioallantois, with yellow to brown exudate covering swollen cotyledons), and in the foetus, a haemorrhagic tracheal cast and dark-red, swollen lungs containing multiple, off-white, suppurative foci with a bronchiolar distribution. Some cases with modest inflammation have massive microscopic *A pyogenes* colonisation of placenta and foetal skin and lung.

Bacillus spp infections

Bacillus spp cause abortion in cattle and sheep worldwide. *Bacillus licheniformis* abortion in cattle is reported mainly from Europe, but also from Australia and the USA. Gross lesions are a necrotising chorioallantoitis (yellow discolouration, thickening and oedema of cotyledons and intercotyledonary areas), with or without gross evidence of foetal bronchopneumonia, fibrinous polyserositis and mediastinal, bronchial and hepatic lymphadenopathy. Microscopically there is necrotising chorioallantoitis and suppurative bronchopneumonia.

References:
Agerholm JS, Jensen NE, Dantzer HE et al. Experimental infection of pregnant cows with *Bacillus licheniformis* bacteria. *Vet Pathol* 1999;36:191-201.

Mason RW, Munday BL. Abortion in Sheep and Cattle associated with *Bacillus* spp. *Aust Vet J* 1968;44:297-298.

Mitchell G, Barton MG. Bovine abortion associated with *Bacillus licheniformis*. *Aust Vet J* 1986;63:160-161.

Salmonellosis

Salmonella spp abortion in ruminants can occur within a week of signs of systemic disease in the dam, or without such prior clinical signs. Sickness and death of the dam may occur after abortion occurs. Serotypes involved include *S* Typhimurium, *S* Dublin and *S* Brandenburg (abortion outbreaks caused by *S* Brandenburg in New Zealand sheep were first detected in 1997 and reached a peak incidence in 2001; it also caused bovine abortions). *Salmonella* spp infect the placentome, where they proliferate causing necrosis, mineralisation and suppuration within the foetal chorionic villi (with relative sparing of the maternal caruncular septa) and abortion, often with placental retention.

Grossly the chorioallantois is oedematous with a diffusely grey to red surface, and the cotyledons are tan to red and covered by a yellow exudate.

The aborted foetus is autolysed. There may or may not be detectible *Salmonella* spp invasion of the foetus, and when it occurs it produces only microscopic lesions (bronchopneumonia and multifocal hepatitic necrosis).

Sheep foetuses from *Salmonella* Brandenburg abortions in New Zealand had haemorrhagic subcutaneous oedema and autolysed viscera; the skin of older foetuses with wool, had a "cooked" appearance. *(G Clark, pers comm 2003).*

Yersiniosis

Yersinia pseudotuberculosis is an intestinal inhabitant of sheep, cattle and goats, and following transient bacteraemia colonises the maternal caruncle before spreading to the chorioallantois and foetus. Grossly the cotyledons are red or tan and thickened, and the adjacent intercotyledonary areas may be thickened. The foetus is aborted fresh, with excessive amber-coloured thoracic and abdominal foetal fluid, and multiple pale tan foci 1 to 10 mm in the liver and possibly in the kidneys.

Microscopically there is a non-suppurative myocarditis and pneumonia and lymphoplasmacytic colitis.

References:

Hannam DAR. Bovine abortion associated with *Yersinia pseudotuberculosis. Vet Rec* 1993;133:372.

Jerrett IV, Slee KJ. Bovine abortion associated with *Yersinia pseudotuberculosis* infection. *Vet Pathol* 1989;26:181-183.

Haemophilus somnus infections

Haemophilus somnus, usually a cause of respiratory and CNS disease, can cause abortion in cattle following bacteraemic spread to produce histological lesions of an acute nonsuppurative cotyledonary placentitis associated with severe fibrinoid necrosis and thrombosis of large and small chorionic arteries. The foetus becomes infected, dies rapidly, is aborted after undergoing marked autolysis, and shows few lesions other than a microscopic fibrinous bronchopneumonia.

Chlamydiosis

Chlamydophila abortus (formerly *Chlamydia psittaci* immunotype 1) causes enzootic abortion of sheep overseas, but is not reported as causing abortion in sheep, goats or cattle in Australia. Other strains of *C psittaci* may cause sporadic cases of abortion in ruminants.

Gross placental lesions are similar to those in brucellosis; there is a chorioallantoitis (with vasculitis). The foetus is usually fresh and without gross lesions. Microscopic changes include multifocal necrosis of liver and spleen, alveolitis and mild meningoencephalitis.

References:

Cox HU, Hoyt PG, Poston RP et al. Isolation of an avian serovar of *Chlamydia psittaci* from a case of bovine abortion. *J Vet Diagn Invest* 1998;10:280-282.

Holliman A, Daniel RG, Parr JG et al. Chlamydiosis and abortion in a dairy herd. *Vet Rec* 1994;134:500-502.

Coxiella burnetii infections (Q fever)

Coxiella burnetii is a widespread persistent intracellular infection of dairy cattle, goats and sheep. In Australia, it is rarely diagnosed as a cause of abortion. *C burnetii* is shed at parturition and in milk. Infection in people and animals is from inhalation of contaminated dust or fluid, or in animals from ingestion of massively contaminated pasture.

Gross lesions are confined to the placenta. There is a thickened, leathery chorioallantois with confluent areas of mineralisation and copious off-white exudate, most obvious in the intercotyledonary areas.

Microscopically there is colonisation by organisms, necrosis and neutrophilic infiltration of chorionic villi of cotyledons and of chorionic epithelium of the intercotyledonary areas. Within the underlying chorionic stroma there is a lymphoplasmacytosis (without the vasculitis of chlamydiosis).

Mycotic infections

Mycotic abortions in cattle are late-term, usually sporadic and caused by *Aspergillus* spp, *Absidia* spp, *Mucor* spp, *Rhizopus* spp and *Mortierella wolfii*. The placental lesions develop first within the placentomes (indicating haematogenous infection) which are enlarged and necrotic, and spread to the intercotyledonary chorioallantois which becomes leathery and ulcerated. The foetus is infected (fungal hyphae are demonstrable in foetal stomach) but is usually free of gross lesions. Some foetuses have a few or many ringworm-like, skin lesions and occasional necrotic foci in liver, lung, brain, and amnion.

M wolfii infection appears to be more acute and is often causes a fatal pneumonia in the dam following abortion.

Protozoal Causes of Foetal Disease

Babesiosis

Transplacental transmission of *Babesia* spp in cattle appears most likely to occur close to parturition, as most reports describe clinical disease in calves within a few days of birth. It is a rare cause of abortion. Gross lesions of *Babesia bovis* infection in an 8-month aborted foetus were anaemia ("thin, watery blood"), generalised icterus and a swollen, orange-coloured liver. Microscopically there was a concentration of parasitised erythrocytes in brain capillaries, hepatic canalicular cholestasis and Kupffer cell haemosiderosis, focal renal cortical haemorrhage, and depletion of erythrocytes from the splenic red pulp.

Reference:

Trueman KF, McLennan MW. Bovine abortion due to *Babesia bovis* infection. *Aust Vet J* 1987;64:63.

Neosporosis

Neospora caninum causes abortion in cattle during the second and third trimester. It can also cause ascending paralysis in neonatal calves.

Apart from non-specific autolytic changes in the foetus and foetal membranes, there are no gross lesions. Distinctive microscopic lesions of granulomatous myocarditis and necrogranulomatous encephalomyelitis are diagnostic. There is also microscopic necrosis of cotyledonary chorionic villi. As in toxoplasmosis in sheep and goats, the intercotyledonary chorioallantois is normal.

Toxoplasmosis

Toxoplasma gondii causes embryonic death, mummification, abortion, stillbirth and neonatal death in sheep and goats, with expulsion of most infected foetuses late in gestation.

Gross lesions are seen in about half of the placentas and are confined to the cotyledons. These are firm and usually contain distinctive multiple, white or pale-yellow, soft, 1 to 2 mm foci along the villi, with similar lesions in almost all cotyledons. The intercotyledonary chorioallantois is normal. The foetus tends to be undersized, but has no distinctive gross changes. Microscopically there is a necrogranulomatous encephalomyelitis and small to large necrotic areas within white matter of the forebrain (these latter areas may sometimes be detectible grossly).

Sarcocystosis

Sarcocystis spp are uncommon causes of abortion, stillbirth, and neonatal deaths in cattle, goats, and sheep. The different ruminant species are infected by ingestion of oocysts from the definitive hosts, and systemic spread results in an acute necrotising endometritis followed by abortion. There is autolysis but no other gross lesions of the foetus and foetal membranes.

Microscopic lesions of necrosis, with cysts containing zoites with a predilection for endothelium, may be confined to the endometrium and caruncles or also be disseminated through soft tissues of the foetus in association with a nonsuppurative meningoencephalomyelitis.

Trichomoniasis

Tritrichomonas foetus is a flagellated protozoal organism that spreads venereally in cattle and causes transient vaginitis and chronic cervicitis and endometritis that result in repeat breeding, abortion during the first half of pregnancy, and pyometra.

The chorioallantois has only mild gross changes of slight thickening, with small amounts of white or yellowish flocculent exudate, and cotyledonary haemorrhage with minimal necrosis. In the foetus there are no gross lesions but there is a microscopic bronchopneumonia. Trichomonads are detectible in the placenta, lungs and stomach contents.

Reference:
Rhyan JC, Stackhouse LL, Quinn WJ. Fetal and placental lesions in bovine abortion due to Tritrichomonas foetus. *Vet Pathol* 1988;25:350-355.

Congenital Developmental Abnormalities of Plant-associated Toxic Cause

Toxic, nutritional, genetic and other undefined diseases can cause reproductive failure, and some produce foetal disease resulting in abortion or congenital disease, including developmental malformation.

Arthrogryposis is reported in calves and lambs born to dams grazing ***Sorghum* spp.**

"Bentleg" (**"bowie"**) of lambs is characterised by lateral curvature of the long bones of the forelegs and other deformities of limbs. It occurs as a congenital deformity in lambs born to ewes grazing **wild parsnips** (***Trachymene ochracea***, ***T cyanantha*** and ***T glaucifolia***) during pregnancy and is reported in western Queensland and north-western New South Wales.

Overseas, the following plants have been associated with abortion or congenital disease:

- ***Veratrum californicum*** ingested by ewes on day 14 of gestation can cause **cyclopia** and **prolonged gestation** and, at other gestational ages, embryonic mortality and other anomalies in lambs (eg at 29 days, **shortening of metacarpals, metatarsals, tibiae** and sometimes **radii**). Ingestion by pregnant cows between 12 and 30 days of gestation can produce cleft palate, brachgnathia, hypermobility of hock joints, syndactylia, decreased length and diameter of all bones or shortening of metacarpals and metatarsals only, and reduction in number of coccygeal vertebrae; ingestion between 30 and 36 days produces shortening of metacarpals and metatarsals.

- ***Astragalus* spp** and ***Oxytropis* spp** (**locoweeds**) cause **abortions** and **bony abnormalities** (**brachgnathia, contractures or overextension of joints, limb rotations** and **osteoporosis**) in lambs.

- ***Lupinus* spp** (**lupins**) ingested by cows from days 40 to 70 of gestation cause **abnormalities of the limbs and axial skeleton** in calves (**crooked calves**).

- ***Nicotiana glauca*** (**wild tree tobacco**) ingested by cows from days 45 and 75 of gestation produces **arthrogryposis** and **spinal deformities** in calves. It also causes congenital **abnormalities of the limbs and axial skeleton** in lambs and kids.

- ***Pinus ponderosa*** and other ***Pinus* spp** cause **abortion** or **birth of weak calves** two to 20 days after ingestion of pine needles.

Congenital Developmental Abnormalities of Nutritional Cause

Selenium / vitamin E-responsive disease can cause **congenital cardiac lesions** of **nutritional myopathy** (**cardiac "white muscle disease"**) in **lambs**, with gross, chalky-white lesions of necrosis and mineralisation in the **right ventricle**. In **calves, cardiac lesions of nutritional myopathy** are rarely congenital, and are usually **delayed** in onset until several weeks of age, with lesions mainly involving the **left** ventricle. In Australia, many cases of suspected bovine congenital cardiac "white muscle disease" have proved to be the inherited **cardiomyopathy and woolly haircoat syndrome** (**CWH**) in **Poll Hereford** calves. *In Saskachewan, aborted bovine foetuses with cardiac dilation and hypertrophy, a nodular liver, ascites and often microscopic myocardial necrosis and mineralisation had a lower mean concentration of selenium in liver (but not kidney) than aborted foetuses without these lesions; the latter group had a lower mean liver selenium concentration than non-aborted foetuses.*

Iodine deficiency can cause **goitre,** with either cystic or solid enlargement of thyroids.

Copper deficiency can cause **congenital swayback** in sheep, with liquefactive necrosis of cerebrocortical white matter, resulting in cavitation and occasionally hydranencephaly. This condition is rare in Australasia.

Manganese deficiency in dams during pregnancy is reported to produce **congenital limb deformities** including reduced length and breaking strength of humeri, enlarged joints and twisted legs in calves, lambs and kids.

Reference:

Orr JF, Blakley BR. Investigation of the selenium status of aborted calves with cardiac failure and myocardial necrosis. *J Vet Diagn Invest* 1997;9:172-179.

Congenital Developmental Abnormalities of Genetic or Familial Cause

Chondrodysplasia in Dexter cattle, a type of disproportionate dwarfism, has an incompletely dominant, simple Mendelian mode of inheritance (the causative gene, which is required for normal cartilage development, has recently been identified). The heterozygotes are usually short-legged animals. The homozygotes, cases of **congenital lethal achondroplasia** (Dexter bulldogs), are usually aborted before the seventh month of gestation. Characteristics of these bulldog calves are disproportionate dwarfism, a short vertebral column, marked micromelia, a relatively large head with retruded muzzle, cleft palate, protruding tongue, and a large abdominal hernia. Lungs are ventrally multilobulated (presumably due to the ribs restricting lung development *in utero*) and represent those non-skeletal organs, including tongue and abdominal viscera, whose growth is not primarily affected by the growth retardation of the disease.

Cardiomyopathy and woolly haircoat syndrome (**CWH**) in **Poll Hereford** calves is an autosomal recessive congenital disease caused by a presumed defect of desmosomal intercellular junctions. Affected calves have a distinctive woolly haircoat and gross congenital cardiac lesions of fibrosis, necrosis and mineralisation in the ventricular myocardium. Death usually occurs within two months of birth and may be sudden or follow a period of congestive heart failure.

Other genetic or familial congenital diseases of **cattle** include **cerebellar hypoplasia, arthrogryposis and cleft palate in Charolais, proportionate and other types of disproportionate (chondrodysplastic) dwarfism, osteogenesis imperfecta, epitheliogenesis imperfecta,** and **polymicroglia.**

Genetic or familial congenital diseases of **sheep** and **goats** comprise an extensive list including **arthrogryposis, micrencephaly, congenital cystic kidney / bile ducts / pancreas, anasarca, spina bifida, skin fragility, photosensitisation** and **goitre.**

References:

Harper PAW, Latter MR, Nicholas FW, Cook RW, Gill PA. Chondrodysplasia in Australian Dexter cattle. *Aust Vet J* 1998;76:199-202.

Morrow CJ, McOrist S. Cardiomyopathy associated with curly hair coat in Poll Hereford calves in Australia. *Vet Rec* 1985;117:312-313.

Whittington RJ, Cook RW. Cardiomyopathy and woolly haircoat syndrome of Poll Hereford cattle: electrocardiographic findings in affected and unaffected calves *Aust Vet J* 1988;65:341-344.

Congenital Developmental Abnormalities of Unknown Cause

Acorn calf syndrome occurs periodically in outbreak form or sporadically in the Riverina area of New South Wales. It affects all cattle breeds over a large area. Full term calves are born with shortened limb bones. Associated tendons and muscles seem unaffected and there is resulting hypermobility of joints. Most calves make a good recovery to normal bone growth if they are able to suck or are hand-reared. Some survivors have permanent bowing of limbs.

Hydrops foetalis is rare condition in ruminants. It has been reported in Australia in proportionate dwarf calves in pregnancies with multiple foetuses, and in lambs.

Congenital biliary atresia and icterus in lambs and calves was reported in outbreak form in 1964 and 1988 on two adjoining properties in the southern tablelands of New South Wales. During early pregnancy affected ewes and cows had grazed the exposed silt foreshores of Burrenjuck Dam and a toxic insult to the foetus at this time was suspected.

Sporadic defects in any organ system represent *in-utero* arrest in development and are often combined with defects in other organs (ie **multiple congenital defects**).

For example, the following is a selection of gross **congenital CNS defects** that may be accompanied by defects in other organs:

- **Cerebral defects** include holoprosencephaly (cyclopia is its most severe form), arhinencephaly, agenesis of corpus callosum, anencephaly, exencephaly, hydranencephaly, hydrocephalus, meningoencephalocoele, micrencephaly and polymicroglia.
- **Cerebellar and brain stem defects** include Arnold-Chiari malformation (caudal displacement of cerebellar vermis and elongated medulla and fourth ventricle through foramen magnum, caudal displacement of occipital poles of the cerebral hemispheres, hydrocephalus, spina bifida and meningomyelocoele), Dandy Walker syndrome (hydrocephalus, aplasia or hypoplasia of cerebellar vermis, and cystic enlargement of fourth ventricle), and cerebellar aplasia, hypoplasia or degeneration.
- **Spinal cord defects** include spina bifida, spinal aplasia (amyelia), and spinal dysraphism.

References:

Harper PAW, Latter MR, Wilkins JF. Hydrops foetalis in dwarf calves associated with twinning. *Aust Vet J* 1995;72:236-237.

Harper PAW, Plant JW, Unger DR. Congenital biliary atresia and jaundice in lambs and calves. *Aust Vet J* 1990;67:18-22.

Neonatal Diseases

Dystocia and / or **prolonged birth** with anterior presentation produces moderate to marked, clear or blood-stained **localised oedema,** involving the head and tongue, and sometimes extending down the neck and to the extremities of the forelimbs. There may be extensive bruising of muscles over the thorax, and abdominal haemorrhage from liver rupture.

Trauma and / or anoxia within the central nervous system during birth can cause **meningeal congestion** and **haemorrhage.** It has been suggested that such lesions in neonatal animals are manifestations of injury that may lead to death during or immediately after birth, and that less severe injury may impair physical and behavioural activity and prejudice the survival of the neonate (Haughey 1973, 1975). These lesions are reported in lambs, calves (and foals).

In the **cranium**:

- **Subdural haemorrhages** (small to large clots in the space between the dura mater and leptomeninges).
- **Leptomeningeal haemorrhages** (**blood-stained cerebrospinal fluid** in the subarachnoid spaces over the cerebral sulci, **haemorrhages anywhere over the brain surface**, or large perivascular **extravasations along the course of the main leptomeningeal vessels**).
- **Leptomeningeal congestion** (marked engorgement of subarachnoid veins and capillaries).

In the **spinal canal**:

- **Epidural haemorrhages** extending over the length of several vertebrae (commonly at the level of the first two cervical vertebrae, at the thoracic inlet and the lumbar-pelvic junction).
- **Blood-stained cerebrospinal fluid** (in a subdural location, usually confined to the cervical region in an annular or banded distribution, and able to be freely moved along the cord by digital pressure).
- **Haemorrhages or congestion within the leptomeninges**.

Exposure lesions are difficult to define, describe or detect. Much depends on the age of the lamb or calf and whether it has sucked, and the severity and duration of exposure. Most affected animals will have breathed, walked and sucked. The essential lesion is a mild to moderate **generalised peripheral oedema**, cessation of milk absorption and relatively normal looking fat reserves and liver.

Starvation results in a slab-sided, dehydrated animal with dark musculature. It will have breathed and walked and there is usually no milk in the gastrointestinal tract. The liver is small and firm. All brown fat is replaced by shrunken, gelatinous, red tissue.

Neonatal navel infections can affect ruminants during the first two or three days of life (eg *Clostridium* spp, *E coli*, *Mannheimia haemolytica*, *Streptococcus* spp), while others are delayed for one to three weeks or longer. **Clostridial navel infections** cause oedema, congestion and perhaps necrosis of the abdominal wall extending around the round ligament of the bladder. The abdomen is distended with serosanguinous fluid and the serosa is markedly congested. ***Mannheimia haemolytica*** (formerly ***Pasteurella haemolytica*** type A) **navel infections** may also cause peritonitis, enlarged mesenteric lymph nodes and miliary necrotic small white foci throughout the liver.

References:

Haughey KG. Vascular abnormalities in the central nervous system associated with perinatal lamb mortality. 1. Pathology. *Aust Vet J* 1973;49:1-8.

Haughey KG. Meningeal haemorrhage and congestion associated with perinatal mortality of beef calves. *Aust Vet J* 1975;51:22-27.

Wilsmore AJ. Birth injury and perinatal loss in lambs. *In Practice: J Vet Postgrad Clin Study* 1989;11:239-243.

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References

Hartley WJ. Gross pathology of bovine foetus and foetal membranes. *Proceedings No 97 "Through the Naked Eye". Gross Pathology of Domestic Animals* Post Graduate Committee in Veterinary Science. May 1987: 85-87.

Hartley WJ. Gross pathology of ovine foetus and foetal membranes. *Proceedings No 97 "Through the Naked Eye". Gross Pathology of Domestic Animals* Post Graduate Committee in Veterinary Science. May 1987: 97-100.

Jamaluddin AA, Case JT, Hird DW, Blanchard PC, Peauroi JR, Anderson ML. Dairy cattle abortion in California; evaluation of diagnostic laboratory data. *J Vet Diagn Invest* 1996;8:210-218.

Jerrett IV. McOrist S, Waddington J, Browning JW, Malecki JC, McCausland IP. Diagnostic studies of the fetus, placenta and maternal blood from 265 bovine abortions *Cornell Vet* 1984;74:8-20.

Johnson CT, Lupson GR, Lawrence KE. The bovine placentome in bacterial and mycotic abortions. *Vet Rec* 1994;134:263-266.

Kennedy PC, Miller RB. The Female Genital System: V. Diseases of the Pregnant Uterus. In: Jubb KVF, Kennedy PC, Palmer N, editors. *Pathology of Domestic Animals Volume 3* 4th edn. Academic Press Inc, San Diego, California, 1993:387-445.

Larson RL. Diagnosing the cause of bovine abortions and other perinatal deaths. *Vet Med* 1996; 91(5):478-486.

Roberts SJ. *Veterinary Obstetrics and Genital Diseases*. Edward Brothers Inc., Ann Arbor, 197:19.

Appendix 1. Necropsy procedure for ruminant conceptus and neonate *(after Larson, 1996)*

Examination	Comment
1. Establish age of gestation.	Estimate age using foetal size, crown / rump length *(see table below for bovine foetus data).*
2. Establish time of death as pre-natal, parturient, or post-natal.	**Pre-natal**: *In utero* autolysis; no thrombus in umbilical artery. **Parturient**: Clear, localised subcutaneous oedema. **Post-natal**: Thrombus in umbilical artery; lungs aerated; milk in abomasum; hooves worn.
3. Examine intact body for congenital defects and meconium staining (of foetal skin and also amnionic sac).	eg cleft palate, atresia ani, genito-urinary defect, skeletal defects or asymmetry.
4. Examine subcutis for evidence of oedema, autolysis, cyanosis, anaemia, or icterus.	Clear oedema fluid suggests dystocia. Red oedema fluid (haemolysis) suggests *in utero* autolysis (red fluid also in body cavities and around kidneys).
5. Examine thorax and then abdomen for presence of fluid or fibrin. Assess extent of autolysis of viscera. Assess extent of catabolism of fat reserves.	Collect pericardial or thoracic fluid (or heart blood if no fluid available) for serological examination and culture. Collect urine if required.
6. Examine and assess size of thymus, thyroids and lymph nodes.	Collect and formalin-fix samples of each.
7. Examine heart *in situ* for size, shape or position change, pericardial sac fat, pericardial fluid or fibrin, or epicardial haemorrhages.	eg ectopia cordis, cardiac dilation.
8. Remove heart and lungs with trachea, oesophagus and tongue attached. Examine lungs for evidence and extent of aeration, petechiae, oedema or bronchopneumonia.	Oedematous lungs are heavy.
9. Do **not** separate heart from lungs. Dissect heart and examine for congenital defects	eg transposition of large vessels, ventricular septal defect.
10. Examine liver for rupture, size, consistency, congestive nodularity or focal necrosis.	Compare relative involvement of right (dorsal) and left (ventral) liver lobes.
11. Examine kidneys for haemorrhage, infarction, focal necrosis, or perirenal oedema (due to autolysis).	
12. Examine stomach (abomasum) for presence of milk clot in neonates, or congestion.	
13. Examine and assess size of adrenals and pancreas.	Collect and formalin-fix samples of each.
14. Examine small intestine for haemorrhage, enteritis, or for presence of chyle in lymphatics of neonates.	Collect and formalin-fix samples of each.
15. Examine large intestine for atresia or colitis.	Collect and formalin-fix samples of each.
16. Examine limb joints for mobility, enlargement.	eg arthrogryposis, arthropathy.
17. Note skeletal muscle colour.	
18. Examine spinal column for congenital malformation.	eg spina bifida, torticollis, scoliosis, lordosis.
19. Remove brain. Examine for haemorrhage, abscess, meningitis, cerebellar hypoplasia, hydrocephalus, hydranencephaly, micrencephaly, or microphthalmia.	Collect and formalin-fix brain. *Note: Even markedly autolyzed brains should be poured into formalin solution, as such brains (at least their brain stems) are usually suitable for histological examination.*
20. Examine the foetal membranes for evidence of infection or infarction. *A **fresh** placentome (maternal caruncle with attached foetal cotyledon tissue) can be removed from the postpartum uterus close to the cervix by gently twisting and pulling (Johnson et al. 1994).*	**Cotyledons** (and maternal caruncles): Size and colour, distribution of cotyledons with gross changes. **Intercotyledonary areas**: Consistency, colour, distribution of lesions. **Amnion**: Consistency, colour, distribution of lesions.
21. Microbiological sampling.	Collect fresh samples and hold at 4°C: **Bacteriology**: Stomach fluid and lung (liver optional). **Virology**: Lung and spleen.
22. Histological sampling.	Collect and formalin-fix samples: **Lung*, myocardium*. brain*, placenta** (also liver, kidney and any lesions seen). **Essential even from markedly autolysed foetuses.*

Crown-rump lengths of bovine foetuses during pregnancy *(after Roberts, 1971)*

Gestational Age (days)	Crown-Rump Length (cm)	Gestational Age (days)	Crown-Rump Length (cm)	Gestational Age (days)	Crown-Rump Length (cm)
30 / 40	1.0 / 1.75 - 2.5	80	8 - 13	180	40 – 60
50	3.5 - 5.5	90	13 - 17	210	55 – 75
60	6 - 8	120	22 - 32	240	60 – 85
70	7 - 10	150	30 - 45	270	70 - 100

Appendix 2. Infectious causes of reproductive failure in cattle

Agent	Gestation age (days) infected	Syndrome	Lesions of conceptus **Gross lesions** Microscopic lesions
VIRUSES			
Flaviviridae			
Pestivirus (Bovine pestivirus)	-10-0	Conception failure (reduced ovulation rate due to pestiviral infection of ovaries)	-
	0-30	Infertility	**Embryonic death**. *Virus, no antibody*
	30-100	Abortion, mummification, premature birth, stillbirth Stunted full-term calf (Congenital malformation) Normal but immunotolerant, persistently-infected, full term, live calf that later succumbs to Mucosal Disease or pneumonia	**Intrauterine growth retardation:** • **diffuse** • **brain, lung, thymus** • **bones: growth arrest lines long bones** **(Cerebellar hypoplasia, HE)** *Virus, no antibody*
	100-180	Congenital malformation in stillborn, premature or full-term calf	**Cerebellar hypoplasia** **HE, porencephaly, micrencephaly** Dysmyelination **Microphthalmia**, chorioretinopathy, **cataracts** **Hypotrichosis** **AG (rare)** **Intrauterine growth retardation** *Antibody usually*
	> 180	Nil	Seroconversion only. *Antibody*
Bunyaviridae			
Akabane virus	76-104	Congenital malformation, (abortion, stillbirth)	**Hydranencephaly (HE),** *normal cerebellum* *Antibody*
	104-173	Congenital malformation, (abortion, stillbirth)	**Arthrogryposis (AG)**. *Antibody*
	> 173	Nil Incoordination, recumbency, (abortion, stillbirth)	Seroconversion only. *Antibody* Encephalomyelitis
Aino virus		Abortion, congenital malformation	**HE, cerebellar hypoplasia, AG**
*Rift Valley fever		Abortion, congenital malformation	**Multifocal necrosis of liver, AG, HE**
Reoviridae **Orbivirus genus**			
*Bluetongue virus	0-85	Infertility, abortion	**Embryonic death**:(**resorption**), **foetal death (abortion)**. *Virus, no antibody*
	85-105	Congenital malformation	**HE, porencephaly**. *Antibody*
	105-145	Congenital malformation	**HE, porencephaly, necrohaemorrhagic encephalitis**. *Antibody*
	> 145	Nil	Seroconversion only. *Antibody*
*EHD 2 (Ibaraki) virus		Abortion, congenital malformation	***As for Bluetongue virus***
Palyam (D'Aguilar) virus		Abortion, congenital malformation	**Cerebellar hypoplasia**, encephalitis
*Palyam (Chuzan / Kasba) virus		Congenital malformation	**HE, cerebellar hypoplasia**
Herpesviridae			
*Bovine herpesvirus 1		Abortion, stillbirth. Live weak calf	**Multifocal necrosis of liver, lung** and adrenal, necrotising vasculitis of chorionic villi **Necrosis forestomachs (oral cavity, oesophagus)**
*Bovine herpesvirus 4 (cytomegalovirus)		(Abortion?)	-
*Bovine herpesvirus 5 (encephalitis virus)		(Abortion?)	-
Parvoviridae			
*Bovine parvovirus		Abortion, weak calves, congenital malformation	**Cerebellar hypoplasia**
Paramyxoviridae			
*Rinderpest virus		Abortion	-

Appendix 2. Infectious causes of reproductive failure in cattle (continued)

BACTERIA			
**Brucella abortus*		Abortion	**Placentitis, pneumonia**
Campylobacter fetus venerealis, C fetus fetus		Abortion	**Fibrinous polyserositis, hepatomegaly**, pneumonia, **(placentitis)**
*Leptospira pomona, *L hardjo-prajitno*		Abortion (late) *Note: L hardjo-bovis causes milk drop syndrome in Australia, but is not associated with abortion*	**Placental oedema**, nephritis, meningitis
Listeria monocytogenes L ivanovii		Abortion , stillbirth	**Placentitis, multifocal necrosis of liver, lung**, myocardium, kidney, adrenal, spleen and brain, necrotising colitis, nonsuppurative meningitis.
Yersinia pseudotuberculosis		Abortion	**Placentitis, multifocal necrosis of liver**, lymphoplasmacytic colitis
A pyogenes		Abortion	**Placentitis, pneumonia**
Salmonella spp		Abortion	**Placentitis**
Mycoplasma sp bovine group 7		Mastitis, neonatal polyarthritis, abortion,	**Mastitis, neonatal polyarthritis** **Foetal polyarthritis, polyserositis, pneumonia**
**Ureaplasma diversum (formerly T mycoplasma)*		Abortion, stillbirth, weak calves	**Amnionitis, chorioallantoitis**, non-suppurative pneumonia, erosive conjunctivitis
Haemophilus somnus		Abortion	**Cotyledonary placentitis** (with vasculitis)
**Chlamydophila abortus, C psittaci*		(Abortion)	**Placentitis** (with vasculitis)
Coxiella burnetii (Q fever)		Abortion	**Placentitis** (without vasculitis)
Other bacteria (eg *Bacillus licheniformis, Streptococcus* spp, *Pasteurella* spp)		Abortion, stillbirth	**Variable** (**placentitis**, pneumonia)

FUNGI			
Aspergillus fumigatus, Morteriella wolfii,		Abortion	**Placentitis, dermatitis**

PROTOZOA			
Babesia spp		Neonatal disease, (abortion)	**Anaemia, icterus**, erythroparasitaemia (sludging of *B bovis*-parasitised erythrocytes in cerebral capillaries)
Neospora caninum		Abortion (Neonatal ascending paralysis)	Non-suppurative necrotising encephalomyelitis, non-suppurative myocarditis and hepatitis
Sarcocystis spp		Abortion, stillbirth, neonatal deaths	Necrotising endometritis, non-suppurative encephalomyelitis, multifocal soft tissue necrosis, endothelial tropism
Tritrichomonas foetus		Abortion (early), pyometra	**Placentitis**, pneumonia (multinucleated giant cells), **pyometra**

****Disease of conceptus not reported in Australia***		**AG = arthrogryposis** **HE = hydranencephaly**

Appendix 3. Infectious causes of reproductive failure in sheep and goats

Agent	Gestation age (days) infected	Syndrome	Lesions of conceptus **Gross lesions** Microscopic lesions
VIRUSES			
Flaviviridae			
Pestivirus (Border disease virus)	30-55	Abortion, mummification Normal but immunotolerant, persistently-infected full-term lamb / kid	*Virus, no antibody*
	55-70	Hairy shaker (also hairy, weak, non-shaker) immunotolerant, persistently-infected, full-term live lamb / kid Normal but immunotolerant, persistently-infected, full-term, live lamb / kid that later succumbs to Mucosal Disease-like syndrome Congenital malformation	**Hairy fleece**, hypomyelinogenesis *Virus, no antibody* **HE, porencephaly, cerebral dysgenesis** *Antibody*
	70-90	Variable	*Antibody*
	> 90	Nil	Disseminated nodular periarteritis *Antibody*
*Wesselsbron virus		Abortion, stillbirth, congenital malformation	Diffuse hepatic necrosis, **AG, HE,**
Bunyaviridae			
Akabane virus	30-50	Congenital malformation, prolonged gestation, (abortion)	**Micrencephaly, porencephaly, AG, HE, scoliosis, kyphosis** *Antibody variable. Virus during gestation*
	> 80	Nil	Seroconversion only. *Antibody*
*Cache Valley virus	27-45	Infertility, abortion,, congenital malformation	**Resorption, mummification, AG, HE**
*Rift Valley fever		Abortion, congenital malformation	**Multifocal hepatic necrosis, AG, HE**
Reoviridae **Orbivirus genus**			
*Bluetongue virus	0-50	Infertility, abortion	Embryonic, foetal death
	40-60	Congenital malformation Stunted, full-term lamb	**HE, cerebellar dysgenesis** Intrauterine growth retardation *Antibody variable*
	60-80	Congenital malformation	**HE, porencephaly.** *Antibody*
	80-110	Variable	*Antibody*
	> 110	Nil	Seroconversion only. *Antibody*
Herpesviridae			
*Caprine herpesvirus		Abortion	-

BACTERIA			
Brucella ovis	21-90	Abortion	**Placentitis**
Brucella mellitensis		Abortion	**Placentitis**
Campylobacter fetus fetus, C lari		Abortion	**Multifocal hepatic necrosis, fibrinous polyserositis**, pneumonia, (**placentitis**)
**Flexispira rappini*		Abortion, mummification, weak lambs (sporadic)	**Multifocal hepatic necrosis, placentitis**
**Fusobacterium* spp (NZ)		Abortion	**Multifocal, hepatic necrosis , fibrinous polyserositis**, pneumonia, (**placentitis**)
Leptospira hardjo (L pomona, L bratislava)		Abortion (late), stillbirth	**Placental oedema**, nephritis, meningitis
Listeria monocytogenes L ivanovii		Abortion , stillbirth, weak lambs	**Placentitis, multifocal necrosis of liver, lung**, myocardium, kidney, adrenal, spleen and brain, necrotising colitis, nonsuppurative meningitis.
Yersinia pseudotuberculosis		Abortion	**Placentitis, multifocal necrosis of liver**, lymphoplasmacytic colitis
A pyogenes		Abortion	**Placentitis, pneumonia**
Salmonella spp		Abortion	**Placentitis**
**Chlamydophila abortus (enzootic abortion), C psittaci (sporadic)*		Abortion, stillbirth, weak lambs / kids	**Placentitis** (with vasculitis), multifocal necrosis of liver, spleen, alveolitis, meningoencephalitis

Appendix 3. Infectious causes of reproductive failure in sheep and goats (continued)

BACTERIA (cont'd)			
Coxiella burnetii (Q fever)		Abortion (late), stillbirth, weak lambs / kids	**Placentitis** (without vasculitis), mild nonsuppurative hepatitis, pneumonitis, nephritis
Other bacteria (eg *Bacillus spp*, *Streptococcus* spp, *Pasteurella* spp)		Abortion, stillbirth	**Variable** (**placentitis**, pneumonia)

PROTOZOA			
Toxoplasma gondii		Abortion	**Placentitis** (**multifocal necrosis of cotyledons**), non-suppurative necrotising encephalomyelitis, leukoencephalomalacia
Sarcocystis spp		Abortion, stillbirth, neonatal deaths	Necrotising endometritis, non-suppurative encephalomyelitis, multifocal soft tissue necrosis, endothelelial tropism

Disease of conceptus not reported in Australia			**AG = arthrogryposis** **HE = hydranencephaly**

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Chapter 8

Skeletal Muscles

Keith H Walker

Perspective on Visible Changes

Normal skeletal muscle is organised around the functional myofibre with its satellite cells. Its gross appearance is a combination of genotype (eg volume/mass viz double muscling), of activity (eg disuse atrophy or body-building hypertrophy) and of general metabolic and nutritional state viz catabolism vs anabolism (eg BCS2 prime lamb vs BCS5 fat lamb). This allows for a huge "normal" variation in volume/mass relationships which are critical to any determination and appreciation/description of abnormality (pathology). They are also best appreciated in the live animal!!

Myofibre type and its relationship to particular anatomical function(s) also has a significant influence on muscle texture and normal appearance. Type II fibre predominant muscles are fast twitch/periodic high activity in function (glycolytic) and structure with often looser texture. Hence the M. semi-membranosus or M biceps brachii are low in fascia, highly end tendoned and paler red in colour (less myoglobin, less highly vascularised). M. semi-tendinosus in race horses has 80-95% Type II fibre content.

Predominant Type 1 fibre muscles are constant load bearing, higher in fascia, less dense in glycolytic myofibre mass and generally darker and more red (myoglobin and constantly vascularised) eg vastus intermedius, Triceps Brachii, Anconeus, Tensor fascia lata, masseter muscles in ruminants. Diaphragmatic muscles in cattle are 80-95% Type 1 fibres.

Mixed fibre type muscles have intermediate features in respect to the multiple range of functions, degree of fascial anatomy, range of fibrous texture, and colour from vascularisation. They are of course the most common neck, trunk and pectoral/pelvic girdle suspensory muscles.

Muscle colour is determined by haemoglobin (vascularisation) and myofibre myoglobin (red/brownness eg "pink" Chicken vs "red" meat). Pathology may be indicated by pronounced redness eg haemorrhage, darkening/blackening eg haemorrhage with myonecrosis or varying shades of pallor eg anaemia or whiteness eg subacute to chronic myonecrosis. Massive peracute myonecrosis without haemorrhage may be virtually imperceptible to the naked eye in terms of colour change. In contrast focal or multifocal fibrotic or caseous/calcareous lesions may be highly visible eg Cysticercus ovis cysts, but of relatively minor consequence to the animal as a whole. Myositis will largely be visualised

because of inflammatory/vascular features eg eosinophilic myositis – green tinged due to eosinophils.

Muscles may undergo alteration of colour during rigor mortis and putrefaction. In a well-fed animal which dies suddenly, the muscles become pale (fish-fleshed) probably due to the leaching of myoglobin by postmortem lactic acidosis. Onset of rigor is long-delayed (>12 hours). If glycogen is depleted eg chronic disease or malnutrition, the muscles become unusually dark after death and rigor is slight or absent.

The myofibre has a very homogeneous response to damage irrespective of cause. Therefore later stages of various afflictions eg chronic myopathies are difficult to distinguish grossly or microscopically. The myofibre microscopic repair sequence involves calcification, phagocytosis, satellite cell proliferation and myoblastic regenerative repair, characterised by basophilic myofibrillar replacement/regeneration. The ability of the body to rapidly repair the damaged segment(s) of a myofibre without apparent complication to the remainder of the fibre is without parallel in other cells of the body. Thus lytic (metabolic), toxic and nutritional degenerative myopathies are frequently sub-gross and sub-lethal/sub-clinical in presentation. Hence the use of muscle biopsy and clinical pathology (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, CK (creatinekinase) and AST (asportate amino-transferase, glucose and lactic acid [muscle PH]) as essential tools for incrimination and discrimination of muscular involvement and likely clinical recovery.

Myodystrophies characteristically have no effective regenerative myofibre response and show progressive fibre abnormalities eg internal nuclei, fibre size changes, peripheral sarcoplasmic masses or storage vacuolations etc. The pathogenesis though distinct will result in medium to end stage endomysial and perimysial fibrosis, fatty replacement and volume atrophy of the muscle fibres. Grossly this equates to pallor, whole muscle atrophy (shrinkage) and fibrosis which is not vastly different to scarring resulting from inflammatory necrosis or vascular crisis/ischaemia. Clearly pale, shrunken muscles should be interpreted cautiously as to cause until microscopic evidence is available.

My experience suggests that the muscular system can pose nearly as many challenges to the gross pathologist as do the more vital organs eg liver, kidney. However, its size, scope of functions, decentralised locations(s) and low profile ("it's just the meat off the bones") condemn the muscles to being constantly overlooked or misinterpreted. This occurs despite its critical role in conditions common to grazing ruminants such as toxic and nutritional myodegeneration and inflammation eg blackleg (*Clostridium chauvoei* infection). In the latter, secluded sites of gas gangrene such as psoas muscles, tongue, deep gluteals and even diaphragm should not be overlooked.

Lesions in the skeletal musculature may be congenital/developmental or acquired, focal or diffuse, bilaterally symmetrical or unilateral and have the usual range of aetiologic influences which will be covered in detail viz

1. Inflammatory disorders
2. Degenerative disorders
3. Neoplastic disorders
4. Metabolic/toxic disorders
5. Developmental (Genetic) disorders

Finally, muscle is the most valuable, economic carcase attribute, whilst bruising of and dark-cutting in meat producing ruminant animals are the greatest economic and quality burdens to the red-meat producing industries. The veterinary profession must focus on keeping muscles normal for the sake of its industry clients.

Inflammatory Disorders

Acute haemorrhage/bruising/trauma – sterile
eg contusions, trucking injuries, injections.

Acute inflammation – Clostridial myositis
a. gas gangrene, malignant oedema/cellulitis
   eg Clostridium septicum
b. peracute/acute deep myositis/blackleg
   eg Clostridium chauvoei in cattle and sheep (See Seddon *et al* [1931])

Acute to chronic inflammation/focal necrosis/trauma – non-sterile
eg penetrating grass seeds; lead shot, bullet wounds, dog bites, irritant foreign substance injections such as Vitamin E – Dickson J *et al* (1986). AVJ. 63 : 231-233.

Abscessation/suppurative myositis – bacterial
eg Actinomyces pyogenes in cattle
a. Corynebacterium pseudo-tuberculosis in sheep and goats.

Chronic fibro-granulomatous inflammation
eg Roeckl's granuloma; skin mycobacteriosis.

Eosinophilic myositis
– principally caused by the degeneration of sarcocystis species.

Protozoan myositis including
a. Sarcosporidiosis eg S. cruzi in cattle, S. ovi-canis in sheep, S. capracanis in goats
b. Foetal neosporosis
c. Toxoplasmosis

Viral myositis
– associated with microvascular (ischaemic/thrombotic) pathology in
a. Ephemeral fever
b. Bluetongue infection in sheep

c. Ibaraki Disease in cattle in Japan
d. EHD of deer in USA
e. Foot and Mouth Disease - myocarditis – myositis in young calves/lambs and pigs (not EMC virus)

Viral arthrogryposis with myopathy in pre-term ruminants

a. Arbovirus induced including Akabane, Aino, Chuzan viruses
b. Pestivirus induced in sheep and cattle
c. Cache Vally viral arthrogryposis and encephalopathy in sheep in USA – (presumptive arboviral).
   See Edwards JF *et al* (1989) Vet. Pathol. 26 : 33-39

Parasitic myositis especially cysticercosis

a. Cysticercus bovis (Taenia saginata)
b. Cysticercus ovis (Taenia ovis)
c. Cysticercus Tarandi (Taenia krabbei)
   Larval forms in reindeer, gazelle, moose and other wild ruminants. Primary hosts are wild carnivores in temporal and arctic zones
d. Screw-worm fly myiasis
e. Elaphostrongylus cervi in Red Deer (Cervus elaphus)
   Encephalomyelitis, ganglio-neuritis (larval stages) and myositis (adult worms).
   See Handeland *et al* (2000) J. of Parasitology 86 : 1061-1066

Degenerative (Misuse) Disorders

Cachectic atrophy

– muscle texture soft, dark and sticky. Type II fibres depleted preferentially

Disuse atrophy due to pain

– preferential atrophy of Type 1 fibres; maintenance or hypertrophy of Type II fibres eg hip dislocation-uncorrected.

Degeneration atrophy

– common in congenital dysplasias eg cord lesions and birth trauma. Results in muscle paralysis and loss of mass. There is masking of fibre Type differences and presence of small fibres.

Vascular myodegeneration

a. Ischaemic (pressure) myonecrosis
   6-12 hour critical period in cattle (less in horse) before irreversibility. Severe end-stage acute myonecrosis. Thigh muscles of downer cows especially.
b. Iliac thrombosis in calves, under 6 months of age. Bacterial thrombo-embolism resulting in acute to chronic segmental necrosis or acute coagulation necrosis of whole fibres. Morley PS *et al* (1996). JAVMA 209 : 130

Myofibre hypertrophy
– this may be a normal physiologic response eg in trained racing animals. Compensatory hypertrophy occurs due to a defect/deficiency of fibres in an area eg chronic post-natal partial denervation atrophy.

Pigmentation of muscle
a. Melanosis – congenital in calves, low prevalence similar to hepatic melanosis melanin not in myofibres.
b. Yellow/lipid (xanthomatosis). Old age related (up to 0.5%) but 10-25% in aged Ayrshire cows. Pigmented phagolysosomes within the myofibres.

Steatosis
– Fatty replacement of muscle fibres – may be sequel of failed repair following acute degeneration or terminal dystrophic pathology.

Neoplastic Disorders

Rhabdomyosarcoma
– primary tumours of striated muscle are rare but very malignant. They appear in limb, neck or head muscles as hard, pink-grey, spherical masses deep in the muscle. Haemorrhage and necrosis is common. There is vigorous local invasion and metastases occur to many organs and may become confluent but retain nodularity.

Metaplastic Rhabdomyosarcoma
– those tumours arising in sites where no striated muscle is normally found eg lungs of lamb. Less likely to metastasise and are better differentiated.

Secondary Tumours
– these can involve muscle especially lymphoid and melanotic tumours.

Comment: Slaughter of aged animals in ruminant flocks/herds with normal management will mitigate against the appearance of most tumours, including muscle tumours. U-V induced skin tumours and intestinal adenocarcinomas appear to be honourable exceptions.

Metabolic/Toxic Disorders

"Dark-cutting" meat
– most important re dollars

Exertional Rhabdomyolysis
– physiologic myolysis vs pathologic myolysis
(See Bartsch *et al* 1977)
a. Transport myopathy/Honda disease
b. Azoturia draft oxen/horses (Typing-up)

c. Capture plus chase and capture myolysis in domestic and wild ruminants. Gro ssly oedema, haemorrhagic streaking, pallor and/or indistinct pale streaks may be seen.

Haemoglobinuria (brown urine) is a key clue

Nutritional myodegeneration

– usually sub-acute not myolytic, no visible haemoglobinuria

a. northern hemisphere "Spring turn-out" disease
b. complex myofibre homiostasis involving
    - Selenium – cytosolic GSHPx anti-oxidant
    - Alpha-tocopherol – cell membrane anti-oxidant
    - Polyunsaturated fatty acids – membrane structure/stability vs peroxidation
    - Prostroglandin/arachidonic acid biochemistry?

C. Not simple deficiency diseases. (*See highlighted references)

Phytotoxic nutritional degenerative myopathy

a. Australia due to
    - *Ixiolaena brevicompta* (Plains Plover Daisy) – NSW/QLD
    - *Cassia occidentalis* (Coffee Senna) – NT, QLD
    - *Malva parviflora* (Marshmellow) – WA, NSW
b. Worldwide due to
    - *Thermopsis Montana* – USA Colarado
    - *Geigeria ornativa* – South Africa
    - *Karninskia humboldtiana* (Coyotilla) - USA
c. Enzootic calcinosis of muscle caused by
    - *Solanum malagoxylon*
    - *Tricetum* spp
    - *Cestrum* spp

Toxic myopathies

a. Monensin toxicity and potentiated (Macrolide anti-biotic) Monensin toxicity
b. Maduramicin (ionophore anti-biotic) toxicity
c. Lasalocid toxicity
d. Inorganic toxins – Selenium, iron, thallium, sulphur and cobalt have caused natural muscle disease in animals

Developmental (Genetic) Disorders/Muscular Dystrophies

These conditions can be congenital (infantile) or of early (juvenile) or delayed (adult) post-natal onset. Time of onset is usually a correlate of genotype defect variation eg Human Pompe's Disease.

Information can be sourced at the University of Sydney OnLine Mendelian Inheritance in Animals (OMIA) Database at – http://www.angis.su.oz.au/databases/BIRX/omia
Currently lists 1995 disorders/defects in 13 animal species.

CPOMD Merino myopathy
– see McGavin *et al* (1969) in Queensland, Christie (1962) in Victoria and Dent *et al* (1979) in Western Australia. A Type 1 fibre Dystrophy. Must examine grossly the *M. vastus intermedius*!

Pompe's Disease in Brahman and Shorthorn Cattle and Corriedale Sheep
– generalised clinical weakness and pallor in skeletal muscles in some animals. (See Edwards & Richards [1979], O,Sullivan *et al* [1981] and Reichmann *et al* [1993]).

Genotyping technology based on DNA from tail hairs is now available at EMAI Camden (Dennis *et al* 1999, 2001 & 2002)

Bovine Myasthenia gravis in South Africa
(See Thompson PN 1998)

Hanging head lambs in Suffolk and Border Leicester sheep in United Kingdom
– cervical myodystrophies in lambs.

Arthrogryposis multiplex congenita (AMC) eg acorn calves.

Arthrogryposis and palatoschisis in Charolais, Friesian, Swedish and Danish Red cattle.

Multifocal symmetrical encephalomyelopathy (MSE) in Simmental calves.

Progressive degenerative myeloencephalopathy in Brown Swiss cattle.

Congenital myopathy in Braunvieh X Brown Swiss calves.

Diaphragm and intercostal muscular dystrophy in Meuse-Rhine-Yssel breed adult cattle in the Netherlands.

Congenital clefts of diaphragm

Congenital muscular hyperplasia in cattle and sheep (1 flock) (double-muscling).

Limb-girdle dystrophy in humans and ? in Brahman cattle.

Heritable myotonia in Angora goats (fainting goats).
Atkinson *et al* (1981) Am. J. Pathol. 102 : 324-335.

Spastic paresis of Holstein-Friesian cattle.
Baird *et al* (1974) AVJ 50 : 239-245.

Selected References

Allen JG *et al* (1986). A study of nutritional myopathy in weaner sheep. Aust. Vet. J. 63 : 8-13. *

Allen JG *et al* (1992). A lupinosis-associated myopathy in sheep and the effectiveness of treatments to prevent it. Aust. Vet. J 69 : 75-81.*

Bartsch RC *et al* (1977). A review of exertional rhabdomyolysis in wild and domestic animals and man. Vet. Pathol. 14 : 314-324.

Bindseil E (1987). Eosinophilic leucocyte infiltrations in ruptured necrotic thigh muscle of downer cows. Vet. Rec. 120 : 183-184.

Bradley R and Terlecki S (1974). Muscle Lesions in Hereditary "Daft Lamb" Disease of Border Leicester Sheep. J. Pathol. 123 : 225-236.

Christie BR (1962). A Muscular Dystrophy of Merino Lambs in Western Victoria. Aust. Vet. J. 38 : 392-394.

Confer AW *et al* (1983). Experimental Monensin Toxicosis. Vet. Pathol. 20 : 590-602.

Dennis JA, Moran C and Healy PJ (1999). The Bovine α-glucosidase gene: coding region, genomic structure, and mutations that cause bovine generalised glycogenosis. *Mamm Genome* 11 : 205-212.

Dennis JA and Healy PJ (2001). Genotyping Shorthorn cattle for generalised glycogenosis. Aust. Vet. J 79 : 773-775.

Dennis JA and Healy PJ (2002). Genotyping Brahman cattle for generalised glycogenosis. Aust. Vet. J. 80 : 21-26.

Dent AC *et al* (1979). Congenital Progressive Ovine Muscular Dystrophy in Western Australia. Aust. Vet. J. 55 : 297.

Edwards JR and Richards RB (1979) Bovine generalised glycogenosis Type II: A clinicopathological study. Br. Vet. J. 135 : 338-348.

Ford GL, Fogerty AC and Walker KH (1986). Crepenynic acid and muscle breakdown. Prog. Lipid. Res. 25 : 263-267.*

Frelier PF, Mayhew IG and Pollock R (1979). Bovine sarcocystosis: Pathologic features of naturally occurring infection with Sarcocystis cruzi. Am. J. Vet. Res. 40 : 651-657.

Fry JM, Allen JG *et al* (1994). Muscle Enzymes in the diagnosis of ovine weaner nutritional myopathy. Aust. Vet. J. 71 : 146-150.*

Henson JB and Dollabite JW (1966). Toxic myodegeneration in calves produced by experimental *Cassia occidentalis* intoxication. Am. J. Vet. Res. 27 : 947-949.

Hole NH (1938). Three cases of nodular necrosis (Roeckl's granuloma) in the muscles of cattle. J. Comp. Pathol. 51 : 9-22.

Hulland TJ (1992). Muscle and Tendon CH2. In "Pathology of Domestic Animals" 4th Edition. KVE Jubb, PC Kennedy and NC Palmer Editors pp183-265.

Kennedy S, Rice DA and Davidson WB (1987). Experimental myopathy in Vitamin E and selenium-depleted calves with and without dietary polyunsaturated fatty acids as a model for nutritional degenerative myopathy in ruminant cattle. Res. Vet. Sci. 43 : 384-394.*

Machlin LJ, Gabriel E, Horn LR, Woo D, Filipski R, Brin M and Nelson J (1980). Effects of Aspirin and related Drugs in vitamin E-deficient rats. J. Nutr. 100 : 1958-1964.*

McGavin MD, Baynes ID (1969). A congenital progressive ovine muscular dystrophy. Pathol. Vet. 6 : 513-524.

McMurray CH and Rice DA (1982). Vitamin E and Selenium deficiency diseases. Irish. Vet. J. 36 : 57-67.*

Nisbet DI and Renwick cc (1961). Congenital Myopathy in Lambs. J. Comp. Path. 71 : 177-182.

O'Sullivan BM *et al* (1981). Generalised glycogenosis in Brahman cattle. Aust. Vet. J. 57 : 227-229.

Orr MB *et al* (1984). Sarcocystis capracanis: Experimental infection of goats II Pathology. Int. Goat and Sheep Research 2 : 202-211.

Peet RL and Dickson J (1988). Rhabdomyolysis in housed, fine woolled Merino sheep, associated with low plasma α-tocopheral concentrations. Aust. Vet. J. 65 : 398-399.

Peet RL *et al* (1980). Exertional rhabdomyolysis in sheep. Aust. Vet. J. 56 : 155-156.

Reichmann KG *et al* (1993). Clinical, diagnostic and biochemical features of generalised glycogenosis Type II and Brahman Cattle. Aust. Vet. J. 70 : 405-408.

Richards RB, Passmore IK, Bretag AH, Kakulas BA and McQuade NC (1986). Ovine congenital progressive muscular dystrophy: Clinical syndrome and distribution of lesions. Aust. Vet. J. 63 : 396-401.

Richards RB, Passmore IK and Dempsey EF (1988). Skeletal muscle pathology in ovine congenital progressive muscular dystrophy.
1. Histopathology and histochemistry. Acta. Neuropathol. 77 : 161-167.
2. Myofiber morphometry. Acta. Neuropathol.77 : 95-99.

Rodemann HP and Goldberg AL (1982). Arachidonic Acid, Prostaglandin E_2 and F_2 alpha influence rates of protein turnover in skeletal and cardiac muscle. J. Biol. Chem. 257 (4) : 1632-1638.*

Rodgers RJ, Gibson J and Reichmann KG (1979). The Toxicity of Cassia occidentalis for cattle. Aust. Vet. J. 55 : 408-412.

Ross AD *et al* (1989). Nutritional myopathy in goats. Aust. Vet. J. 66 : 361-363.

Seddon HR, Belschner HG and Edgar G (1931). Blackleg in sheep in NSW. Aust. Vet. J. 7 : 2-18.

Smith GM, Allen JG (1997). Effectiveness of α-Tocopherol and Se supplements in preventing lupinous-associated myopathy in sheep. Aust. Vet. J. 75 : 341-348.*

Swatland HJ (1974). Developmental disorders of skeletal muscle in cattle, pigs and sheep. Vet. Bull. 44 : 179-202.

Terlicki S, Richardson Carol, Bradley R, Buntain O, Young GB and Pampiglione G (1978). A Congenital Disease of Lambs Clinically Similar to "Inherited Cerebellar Cortical Atrophy" (Daft Lamb Disease). Br. Vet. J 134 : 299-307.

Thompson PN (1998). Suspected congenital myasthenia gravis in Brahman calves. Vet. Rec. 143 : 526-529.

Tirgari M (1979). Ventral hernia in the sheep. Vet. Rec. 106 : 7-9.

Walker KH (1979). Differential diagnosis of muscle conditions of sheep and cattle in NSW. NSW Veterinary Proceedings 15 : 53-56.

Walker KH (1990). Pathogenesis of *Ixiolaena brevicompta* F. Muell. (Asteraceae) Poisoning in sheep: Toxicity of seed oil lipids. PhD Thesis Faculty of Veterinary Science, University of Sydney.*

Walker KH, Thompson DR and Seaman JT (1980). Suspected poisoning of sheep by *Ixiolaena brevicompta*. Aust. Vet. J. 56 : 64-66.

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Chapter 9

The Skin

Tony Ross

Disorders of Development

Developmental disorders are often but not always congenital. They may or may not be hereditary.

Epitheliogenesis imperfecta

The epithelium is absent over some areas of the body leaving naked dermis. Distinct edges of epithelium give way to raw weeping areas. Limbs are most commonly affected. Large areas become infected and traumatised and affected animals should be euthanased. Small lesions may resolve. Lesions may also affect the feet and oral cavity. The condition is congenital and inherited as an autosomal recessive disease. It occurs in many breeds of cattle and sheep.

Collagen dysplasia

This covers a complex group of autosomal recessive disorders of collagen with various names including dermatosparaxsis and cutis elastica. The skin is extraordinarily fragile and hyperextensive. Clinical signs vary in severity. Oedema may or may not be present. A rare recessive genetic disease in several breeds of cattle including the Charolais, Hereford, Simmental and Belgian Blue. It has also been seen in Border Leicester, Finnish, Romney, White Dorper and Southdown sheep with a milder form in Merinos. The thin skin wears and tears easily. Oral lesions may develop during suckling. Curiously, slow healing is not a feature. Scarring can be prominent in some cases.

Epidermolysis bullosa

A complex of inherited defects of the skin in several breeds including the South Suffolk and Dorset. In cattle it has been seen in several breeds but most notably as familial acantholysis in Aberdeen Angus calves in New Zealand. The epidermis is easily traumatised and responds to injury by forming bullae and separating from the dermis beneath. Lesions may occur anywhere but are most common on the mouth and over limb joints. Secondary infections develop quickly and are fatal.

Icthyosis

A group of cutaneous conditions in cattle resembling fish scales - with varying severity and anatomical patterns. The congenital condition may be so severe that calves may be aborted or die soon after birth. Less severe cases remain alive but are usually euthanased for welfare or aesthetic reasons. Calves are born with thick horny scaly skin which forms folds and fissures along the wrinkle lines of the skin. The fissures may become ulcerated. Partial or complete alopecia may accompany the

condition. Small ear pinnae may be present. It has been seen in Holstein Friesians, Norwegian Red Polls and Brown Swiss.

Lethal Trait A46
An inherited defect of lymphocyte maturation has been reported in a range of European cattle breeds and in beef Shorthorn calves in the USA. Calves are normal at birth. Clinical signs include poor growth rate, scales and thick crusts around the head and legs with exanthema and hair loss. Signs begin at 1 - 2 months and most calves die by 4 months unless treated. The parakeratotic disease appears to be an autosomal recessive zinc deficiency. Oral zinc therapy will return most calves to normal in a few weeks but must be continued throughout life. Lymphocyte numbers and function are reduced whilst the calf is in a zinc deficient state and there is reversible atrophy of the lymphoid organs and tissues throughout the body.

Hypotrichosis
Hypotrichosis (partial or complete absence of hair) is a rare series of conditions of the hair follicle in most breeds of sheep and cattle and most other species. Congenital hypotrichosis is often hereditary and may be accompanied by other defects, some of which are lethal. Clinically the severity varies. It can also be caused by zinc deficiency, iodine deficiency and by a genetic condition of the thyroid in Merino sheep associated with thick wrinkled skin. Hair or wool may be fine and brittle or curly. Delayed onset alopecias also occur. Symmetrical alopecia is inherited as a single autosomal recessive character in a number of breeds of cattle. Calves appear normal at birth but lose hair at 1 to 6 months of age in extensive symmetrical patterns. There is no irritation. Calves are normal except for completely bald areas of skin.

Curly Coat
A short woolly hair coat syndrome has been seen in polled and horned Herefords in Australia. The coat changes are often a marker for lethal cardiomyopathy. See cardiovascular system.

Hair Pigment Alterations
A number of disorders occur which result in a change, often a dilution, in coat colour. Sometimes this is accompanied by partial or complete alopecia. The conditions are often heritable and have sometimes become the basis for a "new" breed. Occasionally the changes are restricted to the pigmented parts of the skin. Less desirable variations may be accompanied by seborrhea (excessive secretion from sebaceous glands) and or folliculitis.

Hypertrichosis
Occurs in neonatal calves and lambs following maternal hyperthermia. There is an autosomal dominant hypertrichosis in Holstein Friesian cattle. In sheep an abnormally hairy fleece may be due to a mutant gene or Border disease virus. Maternal pestivirus infection (Border disease) in early to mid pregnancy produces some lambs which are small and hairy (hypertrichosis). A smaller proportion shake (hypomyelogenesis).

Pestivirus infection in a flock may be recognised by a combination of dry ewes, abortions and the birth of a variable proportion of small stunted lambs. Diagnosis is confirmed by detection of antibody in precolostral lamb sera. Coloured breeds may show a patch of hyperpigmentation in addition to a hairy coat. The coat appears more primitive with an increase in the percentage of medullated fibres. Ewes infected during pregnancy will be immune to reinfection and should be retained in the flock. Maidens and ewes of unknown status should be mixed with the infected flock whilst non pregnant in order to seroconvert and avoid future foetal infection. This condition is common in New Zealand but not in Australia.

Wattles in Sheep
Skin covered, pendulous structures hanging from the mandible have been noted in Merino, Dorset Down and Karakul sheep. They are similar to those normally seen in goats and are up to 6 cm long with a cartilaginous core. They are reported to be inherited by a single dominant gene.

Deficiency Disorders

Copper deficiency
Primary or secondary copper deficiency in adult sheep produces steely straight wool fibres due to defective keratinisation. In addition, the fleece of coloured sheep shows bands of lighter coloured wool. Each band representing a period where lack of a copper containing enzyme has prevented the conversion of tyrosine to melanin. Signs of copper deficiency in growing sheep include anaemia, scours, osteoporosis, poor growth and ataxia (swayback). Affected cattle develop light "spectacles" of hair around the eyes and coat colour lightens. Black coats become rusty brown and deep red coats become orange.

Vit E Responsive Dermatosis
Seen in adult and juvenile goats on a selenium deficient diet. Muscular dystrophy may also be present. They develop generalised seborrhea and periorbital alopecia. Hair becomes dull and brittle. Alopecia in calves fed milk substitutes may also be partly due to Vitamin E and Vitamin C deficiency.

Cobalt Deficiency
Cobalt deficiency causes poor growth rate and wasting in sheep and cattle. The wool and hair grow poorly and become more fragile.

Zinc Deficiency
Zinc responsive dermatoses occur uncommonly in goats, sheep and cattle. Goats show illthrift, alopecia, and parakeratotic scaly skin. Decreased fertility may occur. In cattle experimental deficiency produces scaly skin, partial alopecia, and fissures and exudation on the limbs, perineum and around the mouth and eyes. Experimental Zn deficiency in sheep causes thin, straight wool which is easily plucked. Wool eating and

excessive salivation are common. Crusts and scales develop around the eyes, nose, over joints, coronary bands and scrotum. The normal ringed structure of the horns is lost and horns may fall off. Abnormal hoof growth and lameness may occur.

Toxicological Disorders

Selenium Toxicosis

Selenium toxicosis has been reported in cattle and sheep.It is usually due to the ingestion of Se containing plants but occasionally it is due to accidental chemical overdose. Selenium accumulating plants in Australia associated with poisoning are *Morinda reticulata* (mapoon) on the Cape York Peninsula and *Neptunia amplexicaulis* (selenium weed) on the seleniferous soils of the Richmond - Hughenden area of nth western Qld. Most poisonings have been restricted to horses although sudden death has occurred in sheep. Cattle are more tolerant than sheep. However in the USA chronic poisoning in ruminants occurs with partial or general alopecia, swelling of the coronary bands, deformities and separation of hooves and severe lameness.

Mimosine toxicosis

A tropical and subtropical leguminous tree (*Leucaena leucocephala*) which is used as a protein feed source can be toxic in excessive quantities. The tree contains the toxin mimosine. Clinical signs of toxicity include symmetrical alopecia and occasional nervous signs, goitre, infertility and illthrift in cattle and sheep. Goats are more resistant. Habituation of the rumen microflora to degrade mimosine over time. Depilation in sheep can be marked.

Ergotism

The ergot of *Claviceps spp* develops in the seed heads of a range of grasses and cereal grains. It is particularly common on ryegrasses. Hyperthermia and nervous signs are common but dry gangrene of extremities occurs only occasionally in cattle and is rarely seen in sheep. Swelling of the coronary bands and lameness may be the first sign followed later by ischaemic necrosis leading to cold insensitive feet with gangrenous changes to the soft tissues of 1 or more feet and sometimes the tip of the tail and or ears.

Fescue toxicity

Fescue foot is a disease of cattle which causes gangrene of the skin and hooves. It is very similar to ergotism. It has not been reported in sheep.

Immune-Mediated Dermatoses

Urticaria

Transient, circumscribed oedematous flat topped swellings of the skin are occasionally seen in ruminants, particularly cattle. They may or may not be pruritic. Drugs, foods, inhaled and contact allergens, stings and

infectious agents have all been incriminated. The response is usually a type 1 hypersensitivity reaction. Erythema multiforme has been reported in cattle with an acute onset of symmetrical non pruritic erythematous papules and vesicles. As the lesions spread out the centres clear. The predisposing factors are drugs and infections. Severe cases may extend to full thickness epidermal necrosis. High producing dairy cows, especially Jerseys and Guernseys, can become sensitised to their own milk protein. The urticaria is part of a more generalised hypersensitivity condition.

Atopy
Atopy is conspicuous by its absence in ruminants although there is one report of a presumptive inherited condition in Suffolk sheep. Clinical signs were a recurrent seasonal pruritic condition affecting the face, ears, perineum and lower abdomen.

Cullicoides Hypersensitivty
Seasonal hypersensitivity is well known in horses but it has also been reported as causing a pruritic dermatitis of the non woolly exposed areas in sheep.

Viral Diseases

Pox virus Infections of Sheep

Orf Virus
Orf virus infection has several synonyms including scabby mouth, contagious ecthyma and contagious pustular dermatitis. It is caused by a *parapox virus* which affects sheep and goats and occasionally man.

It is a common infection of sheep of all ages in Australasia but is most common in lambs 3-6 months old. Minor lesions are present in one or two sheep in most flocks. The disease becomes important when severe lesions occur in a significant number of sheep. The infection can occur at any time of the year, but is more common in dry conditions. Housed sheep appear to be at special risk. The virus is thought to enter the skin through wounds from thistles, grass seeds, burrs and crop stubble.

Erythematous patches up to 5cm in diameter progress to papules, pustules and ulcers with persistent scab formation. Scabs dry off in 3 to 4 weeks. Lesions are most common on the lips, muzzle, tongue and teats. They can also occur on the genitalia, tongue, coronet and intergital cleft. The latter sites are important when foot and mouth disease is considered. Secondary infection leading to cellulitis, mastitis, etc can significantly increase the severity of the disease. Residual small horny papilomatous growths are occasionally found. Bodyweight loss can be severe and fatalities do occur in sucking lambs.

The clinical diagnosis can be confirmed by demonstration of virus in scabs by electromicroscopy. Differential diagnoses include

photosensitisation, dermatophilosis and staphlococcosis. The virus persists in the environment and endemic farms and areas become known to the experienced veterinarian.

Orf infection occurs in farmers and abattoir workers. In most cases a 'cigarette burn' lesion appears on the hand and remains for 3-6 weeks. It is a raised reddened painful lesion. Crust formation is not prominent.

Sheep Pox and Goat Pox

Sheep pox and goat pox are closely related diseases. They are the most serious of pox diseases of livestock and may cause heavy production losses and mortalities. They are exotic to Australia but Australia's sheep and goat populations are highly susceptible. Viruses are spread by the respiratory route. Infected animals shed virus in all secretions and in scabs. The virus is very resistant in the environment. In a susceptible flock mortalities may reach 50% but approach 100% in young animals. Goat pox is often a milder infection with a mortality rate of around 5%. Clinical signs include a rapid onset of fever, excessive salivation and nasal and ocular discharge and reluctance to move. Lesions appear within a few days and may occur anywhere on the skin and mucous membranes of the respiratory, gastrointestinal and reproductive tracts. The typical pox cycle of erythema, papule, vesicle, pustule and scab is followed over a period of 5-6 weeks.

Pox virus Infections of Cattle

Pseudo cowpox
A common mild infection of the teats of dairy cows with occasional lesions on the udder and perineum. Secondary bacterial infection of the dark circular or horseshoe scabby lesions is common. Infection of humans causes "milker's nodule". The virus is closely related to bovine papular stomatitis virus.

Bovine Papular Stomatitis
BPS is a common cause of ulcerating lesions in the oral cavity of young cattle but produces occasional pox-like lesions on the lips and muzzle and on the teats of cows with affected calves. It can also cause "milker's nodule".

Cow pox
Cow pox virus affects a very wide range of species including humans. Therefore the term is a misnomer. The most important reservoir is in small wild mammals. Infections in ruminants including cattle occur only rarely and produce pox-like lesions on teats and udder.

Lumpy Skin Disease
The capripox virus which causes lumpy skin disease in cattle is a close relative of the virus which causes sheep and goat pox. They appear to be host adapted strains of the same virus. Lumpy skin disease is NOT found in Australia. It is endemic in Africa.It affects cattle and buffalo and is

transmitted by biting insects and close contact. Fever, systemic illness, lymphadenopathy and ventral oedema accompany the multiple skin lesions. Abortions may be noted. Morbidity and mortality vary widely and inapparent infections occur. The number of lesions vary with the severity of the disease. Skin nodules 0.5 to 7 cm in diameter make a sudden appearance anywhere on the body. They are flat topped, firm, raised intradermal swellings surrounded by a zone of hyperaemia.

Most nodules become necrotic, begin separate from the surrounding skin within a day or two and eventually form a cone of dead material which leaves a raw crater when dislodged. Secondary infection and abscessation of these lesions is common and can lead to metastatic infections. Healing takes months and leaves scars rendering hides worthless. Chronic debility is common.

Pseudo Lumpy Skin Disease
This disease causes a more benign infection but is similar enough to Lumpy skin disease to cause diagnostic confusion. It is present in Australia. It is caused by bovine herpes virus 2, the cause of ulcerative mammillitis. Similar skin lesions to LSD erupt suddenly after a mild fever. The nodules only involve the more superficial skin layers and resolve as skin scabs within 3 weeks. Deep necrotic lesions are not seen.

Bovine Ulcerative Mammillitis
BUM is caused by bovine herpes virus 2 and is a localised form of infection seen sporadically in Australia. Inapparent infections are common. Transmission requires teat trauma. Transmission is via milking machines, biting flies and teat abrasions. Lesions occur on the teats with occasional lesions on the udder, perineum, and also on the muzzle, lips, chin and oral mucosa of sucking calves. Teats develop painful 1-2 cm plaques with a necrotic centre which slough to leave a ragged ulcer. Some cases show widespread coalescing lesions. Most lesions heal without scar formation.

Foot and Mouth Disease
FMD is caused by a picornavirus. It is a highly contagious vesicular disease of cattle, sheep, goats, deer, buffalo, pigs and a range of wild animals. Australia had several minor outbreaks in the early years of the colonies, the last being in Victoria in 1872. It is spread principally via the respiratory route. Cattle and pigs are the most severely affected. Persistent infection after lesion healing is common. The incubation period is 2-14 days.

In cattle fever is followed by depression, inappetence and cessation of milk production. Vesicles form at one or more of the following sites within a day or so on the tongue, lips, gums, dental pad, interdigital skin , coronary bands bulbs of heals and teats. Hyperaemic foci quickly progress to vesicles 1-2 cm in diameter which may coalesce. They contain clear fluid and are contained within blanched epithelium. They rupture within 24 hrs and leave raw, painful ulcers with ragged edges. Salivation, inappetance, lip smacking, lameness and secondary mastitis

are followed by rapid loss of body condition. Mortality in adults is usually <5%, but up to 50% in young calves which may die without gross lesions.

FMD is a much milder infection in sheep and goats. Vesicles are difficult to detect. Lameness may be the only sign but differentiation from other foot conditions is particularly difficult.

Bacterial Diseases

Abscesses

Focal pyogenic infections occur in many subcutaneous sites in sheep and cattle. They are included here because many originate from a skin lesion. Others develop subcutaneously and open onto the skin.

Grass seed abscesses occur mainly in sheep and fibre goats. They can be found anywhere on the animal but are frequently found on or under the mandible. A mixture of opportunist bacteria are involved.

Injection abscesses are found in any site where a dirty needle has been placed. *Corynebacterium pyogenes* is the most common bacterium found in these sites. They are common when vaccination procedures are carried out on wet sheep and cattle. Some vaccines, particularly the oil based footrot and campylobacter vaccines produce large sterile pyogenic local reactions, most of which open onto the skin.

Rams suffer scrotal abscesses, presumably from local abrasions.

Caseous lymphadenitis caused by *Corynebacterium pseudotuberculosis* (*C.ovis*) causes lymph node abscesses with sinus formation to the skin of sheep. In severe cases, multiple subcutaneous abscesses are seen.

Actinobacillus lignieresi enters through abrasions in the oral cavity and skin to cause fibrous lesions with caseous centres on the lips and subcutaneous tissues of the head and lower limbs of sheep and cattle . *Mycobacterium spp* can cause pyogranulomatous skin nodules.

Dermatophilosis

Dermatophilosis has several synonyms: mycotic dermatitis, lympy wool, rain scald and cutaneous streptothricosis. It is a common bacterial disease of sheep, cattle and horses which causes a marked exudative dermatitis on wet macerated skin.

Dermatophilus congolensis is a filamentous gram positive bacterium present on the skin of many sheep and cattle. Under persistently wet conditions, particularly if the temperatures are mild to warm, the normal waxy layer of the epidermis is broken down. Other contributing factors include shearing, dipping, jetting, sweating, flystrike and dermatitis. External parasites may act as mechanical vectors. The disease must be

differentiated from other causes of dermatitis including photosensitivity, orf, pseudomonas and footrot.

The 'lumpy wool' form of the disease is common in sheep. Infection causes profuse exudative dermatitis with scab formation, firstly over the ulcerated skin and later up into the wool. Scabs tend to be thick and have pointed tips. The condition can be painful and makes shearing extremely difficult. Lesions can occur anywhere on the skin but are most common along the backline. Flystrike is a common and important secondary problem.

Dermatophilosis can also cause dermatitis and thin scab formation on the dorsal midline or on the face, ears and lower legs. In severe lesions the hair may be buried in coalescing crusts. Infection of the lower limb skin of lambs and weaners in Australia leads to a condition called strawberry footrot. The name comes from the strawberry-like shallow ulcers left after crusts are dislodged.

Dermatophilosis may be a mixed infection with *Staphlococci, Fusobacterium necrophorum* and sometimes *Bacteriodes nodosus.* Diagnosis is confirmed by identifications of the bacteria in smears from scabs and ulcers and response to treatment with parenteral penicillin and dipping with antibacterial solutions such as 0.5% zinc sulphate.

Dermatophilosis can debilitate cattle and sheep and facilitate secondary infection. Deaths in debilitated cattle occur.

Staphylcoccal pyoderma

A patchy dermatitis with scab formation occurs on the head and sometimes the legs of sheep, goats and cattle. Lesions are found on the skin along the nose and around the eyes. Ulceration and inflammation may be severe, deep seated and persistent. The lesion may progress to a chronic granuloma surrounded by a zone of alopecia before healing, leaving bare scarred skin.

The condition is common but is not a prominent or well-recognised syndrome. Only some strains of *Staphylococcus aureus* cause the disease. Staphylococcal folliculitis and furunculosis also occurs, particularly on the tail, perineum, scrotum and face, but generally heals uneventfully.

Pseudomonas dermatitis

Another poorly recognised dermatitis of sheep and occasionally cattle is caused by the bacterium *Pseudomonas aeruginosa.* In addition to causing wool pigmentation some strains of this organism colonise persistently wet skin and create focal ulceration along the backline. Ulcers may become deep seated and the characteristic smelly greenish pus of Pseudomonas infection is present. Scab formation is variable. Fine and coarse wool breeds have been affected, most within 8 weeks of shearing. Recovery is very prolonged and in a few cases extends to lesions subcutaneous cellulitis, myositis and septicaemia.

Fungal Diseases

Ringworm

Ringworm is a rare condition in sheep and goats. *Trichophyton spp.* and *Microsporum canis* cause circular patches of alopecia - usually on the head. The lesions are usually multiple, show a greyish light crust and persist for 1-3 months. Diagnosis is confirmed by identification of spores and mycelia in skin scrapings.

Ringworm is very common in cattle. *Trichophyton verrucosum* is the most frequent isolate. Prevalence is highest in young cattle either housed or in large groups. Most lesions are on the head (particularly the periocular region) and neck. They can be extensive in poor animals. Individual lesions are very thick grey crusts roughly circular 2-6 cm diameter. They may persist for several months.

Photobiological Disorders

Sunburn

Sunburn is a common problem in white skinned goats and in sheep post-shearing. It is rare in cattle. It can occur with as little as two clear sunny days exposure at all times of the year in northern Australia and in all but the winter months in southern Australia. Erythema followed by exudation, necrosis and sloughing of the skin is seen. Lesions are most severe along the neck, back and around the perineum. The udder of lactating goats can also be affected. Acute lesions can lead on to dermatophilosis,flystrike and suppuration. Chronic lesions may lead to keratoses, cutaneous horns and squamous cell carcinoma.

Keratoses, cutaneous horns

Keratoses are raised scurfy areas which enlarge and eventually go through cycles of trauma and ulceration. They are equivalent to the 'sunspots' of man induced by solar irradiation damage. Common sites are the ears and other woolless areas of the sheep, with similar sites plus the udder in white skinned goats. The unpigmented eyelids, including the third eyelid and sclera of the eye of cattle are predilection sites in cattle. When sheep are radically tailed and mulesed the dorsum of the tail, vulva and perineum become affected. Keratotic lesions take several years to become obvious and some progress to squamous carcinoma.

Cutaneous horns are dry hard hyperkeratotic columns which are thought to originate from solar damage and/or chronic trauma from ear tag irritation. The sites of the lesions are similar to those of keratoses and both conditions are often found together. The prognosis is also similar ie trauma, ulceration, secondary infection, myiasis and neoplastic transformation. The involvement of papilloma viruses in the pathogenesis of both lesions is common.

Photosensitivity dermatitis
Photosensitivity diseases in sheep, goats and cattle are recognised by erythema, oedema and pruritis of affected skin followed by traumatisation, oozing, scab formation, necrosis and sloughing. The major sites are ears, eyelids, face, muzzle, teats and udder. The ears swell and droop. Jaundice may be present.

Primary photosensitisation is caused by the ingestion of a photodynamic substance or its precursor. Primary photosensitivity may be caused by St John's Wort (*Hypericum perforatum*), buck wheat (*Fagopyrum spp.*), perennial ryegrass *(Lolium perenne),* burr trefoil *(Medicago denticulata), Brassica spp, Erodim spp and Trifolium spp.*

Secondary photosensitisation is caused by accumulation of phylloerythrin in the peripheral circulation. Phylloerythrin is a product of chlorophyll metabolism which is normally excreted in the bile. Liver dysfunction or obstructive jaundice results in its accumulation in the bloodstream and skin. Plants producing secondary (hepatogenous) photosensitisation in sheep include:

- Ragwort *(Senecio jacobea)*
- Lantana *(Lantana camara)*
- Heliotrope *(Heliotropium europaeum)*
- Blue-green algae *(Anacystis spp.)*
- Blue lupins *(Lupinus augustifolius)*
- Palisade grass *(Brachiaria brizantha)*
- Coolah grass *(Panicum coloratum)*
- Native millet *(P. decompositum)*
- Hairy panic grass *(P. effusum)*
- Brown millet *(P. miliaceum)*
- Sweet grass *(P. laevifolium)*
- Guinea grass *(P. maximum)*
- Pepper grass *(P.whitei)*
- Caltrops *(Tribulus terestris)*
- Verbena *(Verbena officinalis)*

Secondary photosensitivity is also caused by a fungus named *Pithomyces chartarum* which grows in wet autumn weather on improved pastures in the southern states of Australia and in New Zealand. Severity of the lesions is dose dependent. The skin lesions are accompanied by liver pathology, usually an acute hepatitis.

In addition photosensitivity of unknown pathogenesis occurs from ingestion of:

- Oats *(Avena sativa)*
- Barley *(Hordeum vulgare)*
- Barley grass *(H. leposinum)*
- Wheat *(Triticum aestivum)*
- Sudan grass *(Sorghum sudanensis)*
- Perennial ryegrass *(Loloium perenne)*
- Black medic *(Medicargo lupulina)*
- Lucerne *(M. sativa)*
- Woolly burr medic *(M. minima)*
- Burr medic *(M. polymorpha var vulgaris)*
- Vetch *(Vicia sativa)*
- Japanese millet *(Echinochloa frumetacea)*
- Pennywort *(Hydrocotyle sp)*
- Paddy melon *(Cucumis myriocarpus)*
- ---- *(C. trigonus)*
- Ulcardo melon *(C. melo)*
- Wild watermelon *(Citrullis colocynthis)*
- Camel melon *(C. lanatus)*
- Squirting cucumber *(Echballium elaterium)*
- Windmill grass *(Chloris truncata)*

The conditions under which the above plans cause photosensitisation are poorly understood, In some cases, it is a simple dose/response relationship, in some it is confined to specific stages of growth and in others, it may reflect toxic fungi growing on the plants. Recovery of animals on removal from affected pastures and provision of shade assists in confirming the diagnosis. Dermatophilosis and flystrike are both important secondary problems.

A rare inherited defect in phylloerythrin excretion has been reported in Corriedale and Southdown sheep.

Neoplastic Disorders

Cysts

There are several types of benign cysts of the skin of cattle, sheep and goats. Some cysts are congenital and inherited, some are spontaneous developmental abnormalities whilst others are acquired after blockages of dermal glands, wounds or penetrating foreign bodies.

They are usually spherical, firm painless structures lined by epithelium and containing a variety of material. Some may leak mucoid contents onto the skin.

Epidermoid cysts contain skin only; dermoid cysts contain matted hair and inspissated sebaceous material. Other cysts may contain pus and a penetrating grass seed.

Papillomatosis
Papillomatous lesions induced by papilloma virus are very common in cattle, less common in goats and uncommon in sheep. Cattle may have either slim epithelial papillomas on the teats or in the upper alimentary tract or bulkier fibropapillomas on the skin of the head and neck, lower abdomen, penis, teats, udder and upper alimentary tract. In situ lesions can occur in the urinary bladder.

In goats epithelial papillomas occur on the face, teats and udder with fibropapillomas on the skin and udder - particularly in unpigmented areas.

In sheep small epithelial frond papillomas containing papilloma virus have been found on the lower limbs and muzzle of a small number of animals in Australian flocks. Lesions persist for a relatively short time (1-2 weeks). Secondary infection is rare and progression to squamous cell carcinoma has not been demonstrated.

Squamous cell carcinoma
Genetic and environmental factors interact in the formation of squamous cell carcinoma (SCC) in cattle. This tumor is extremely common in Australia on the unpigmented eye and eyelids of many breeds including Herefords and Holstein Friesians. Sunlight is the most important carcinogenic stimulus but bovine papilloma virus infection may also play a role. Skin pigmentation is highly protective for tumor development. The appearance of SCC depends on whether or not it arises from a precancerous skin lesion. It may be a firm, white dermal mass with indistinct borders and variable degrees of infiltration and ulceration; or it may be a raised papilliform or acanthomatous lesion.

Ocular precursor lesions are usually single or multiple hyperplastic keratotic plaques or epithelial papillomas. Not all lesions progress to SCC within the economic lifespan of cattle. SCC is most common in cattle over 5 years of age. Predilection sites are the third eyelid, the lateral canthus and the corneoscleral junction of the eye. SCC may be infiltrative or proliferative. The masses are fleshy and the surface may be granulated, haemorrhagic or ulcerated. All tumors are locally invasive and metastasis to the parotid lymph node is common. More distant metastases are uncommon. Some SCC become flyblown and others suffer bacterial infection and produce a foul odour. Affected animals become debilitated. Occasionally SCC will be found on the vulva, udder, penis and perineum.

In sheep squamous cell carcinoma affects the non-woolly areas of skin and arises from transformation of keratoses and cutaneous horns. The most common site is the dorsal surface of the ear with the muzzle and eyelid being occasionally affected. In flocks which have been short tailed

and/or radically mulesed, lesions are common on the dorsum of the tail, vulva and perineum.

Prevalence rates in adult sheep often exceed 1% in the drier areas of Western Australia and Queensland. Prevalence rates in older sheep (over 5 years) may exceed 5% per annum. Mulesed flocks may have even higher rates.

Cancers grow slowly with bouts of traumatisation, ulceration, flystrike and secondary infection being common. Some lesions are proliferative and form irregular nodules of tumour tissue. Others are predominantly erosive. Without surgical intervention, squamous cell carcinomas continue to enlarge and erode surrounding tissues. Loss of half or more of an ear is common. Metastases to the local lymph node occur in approximately 10% of cases.

Marked discomfort leads to anorexia, debilitation and death from a combination of stress, flystrike and secondary septicaemia.

The prevalence rate can be lowered by providing ample shade, keeping the average age of the flock at 5 years or younger, and reducing or eliminating the amount of skin removed during mulesing. Other factors include leaving three coccygeal vertebrae and some woolly skin on the dorsum when tailing and keeping ear tags and marks to a minimum.

SCC is a relatively common tumour of older white skinned goats in Australia. It occurs on the udder and vulva and occasionally at other sites. Saanen breeders successfully introduced "orange" pigmented strains into Australia which greatly reduced the prevalence of SCC. A perculiar form of SCC develops in castrated male cattle in India. It originates in the horn core, eventually destroying it and extending to adjacent sinuses and bone.

Melanomas

Pigmented melanomas are sometimes seen in young sheep goats and cattle. They are more common in dark skinned breeds. Angoras have a higher prevalence than other goat breeds. Primary lesions are firm black, brown or grey irregular masses of 20-60 mm in diameter with a shiny cut surface, usually located along the backline. In contrast to the benign nature of most cattle lesions, sheep and goat melanomas are rapidly invasive. Metastases are common.

Other Neoplasms

A range of other neoplasms occur in the skin at much lower prevalence rates than SCC. They include haemangioma, haemangiosarcoma, lymphoma, mastocytoma and basal cell carcinoma

Ectoparasites

Flystrike and lice (together with internal parasites and footrot) are the most important disease of sheep in Australia. They are a significant source of economic loss (wool, pelts, bodyweight) and mortality (flystrike). They are of much less importance in goats and sheep.

Flies

Flystrike (myiasis) is most frequent during warm moist conditions when faecal contamination, fleece rot or skin wounds attract blow flies. Primary fly larvae led by the green blowfly (*Lucilia cuprina*) infest the skin of living sheep. They are followed by the larvae of so called secondary blowflies which cannot initiate attack but infest existing lesions and extend them. There are three major sites. Head strike is most common in rams as a sequel to fighting wounds. Although important in individual animals its prevalence rate is usually low.

The second site for flystrike is around the perineum and prepuce. Urine and faecal staining predispose these areas to strike. Once the most important type of flystrike, it can now be adequately controlled by the application of good managerial techniques. They include correct tail docking, mulesing, crutching in the early stages of the fly season, internal parasite control (to reduce diarrhoea) and, if necessary, jetting or dipping. Therefore, in well managed sheep populations breech and pizzle strike usually have low prevalence rates.

The third site is body strike which is usually a sequel to fleece rot although dermatophilosis and other skin conditions also predispose to flystrike. It is now the most important type of lesion as its prevention is the most difficult. Prevalence rates and case mortality rates can reach epidemic proportions in favourable circumstances. Susceptibility of an animal to fleece rot and body strike has been associated with certain fleece characteristics. Prevalence of the disease varies with the season and degree of susceptibility of the sheep population.

The gross appearance of the lesion may be masked by the fleece and the first signs are often toxaemic debilitated or dead sheep. On inspection of the affected site, early lesions show patches of wool bathed in a wet brown exudate with an offensive smell. The area feels hot and the skin is reddened and oozing serum. Foci of white maggots 10-20 mm in length hatch out from fly ova within 24 hours, ingest the inflammatory exudate and grow rapidly. Necrosis from the proteolytic enzymes secreted by primary fly larvae extend the lesion and attract the even more destructive secondary blowflies.

Moist putrefactive changes, irregular ulceration and pruritis characterise the extensive lesion and quickly lead to shock and toxaemia. Deaths within one week of infestation are common. Healing lesions show wool loss, superficially dry scabs and underlying ulceration.

Screw Worm Fly
The screw worm fly (Chrysomia bezziana) attacks fresh wounds in a wide range of animals including ruminants. It is common in Asia including New Guinea. Whilst not in Australia yet, climate, host range and management practices (castration, branding, ear tagging) would allow its establishment. Australia has a monitoring program in northern Australia with fly traps and sentinel animals. The flies lay larvae in fresh wounds. Wet umbilical cords and abraided vulvas post calving are also targets. Larvae invade the edges of the wounds enlarging them and producing deep wounds with foul smelling brown exudate. Prevalence rates can be minimised by releasing sterile male flies and conducting management procedures causing wounding in the cooler months.

Buffalo Fly
These small blood sucking flies of cattle and buffalo (Haematobia exigua) cause serious nuisance to cattle, interfering with grazing and reducing production. It is common in northern Australia and has gradually moved into northern NSW in recent years. Its bites cause intense pruritis resulting in rubbing and raw weepy areasaround the withers, shoulders, flanks and eyes. Simulid and stable flies also cause serious fly worry to cattle in more temperate areas.

Ked
Sheep ked (*Melophagus ovinus*) is a blood sucking wingless fly about 7 mm long. Light infestations cause few problems but heavy infestations lead to severe skin irritation and self mutilation. The importance of the condition has declined in recent years with the widespread use of more effective insecticides. It is now a threatened species and is rarely seen! Affected sheep have a ragged fleece from biting and rubbing and the wool may have a musty odour and brown stain from the adult insects' excreta. Anaemia is an occasional problem, particularly in lambs. Diagnosis is by visual identification of the insect.

Mites
Chorioptes bovis is a cause of minor hyperkeratotic mange problems in cattle and goats at the backline,base of the tail, lower limbs, scrotum and muzzle. However chorioptic mange on the lower legs of sheep and scrotal mange in rams can become an important problem. Whilst widespread in Australia, its importance is limited to the scrotal condition in rams. Extensive dermatitis, serum exudation and scab formation causes inflammatory changes which raise the scrotal temperature and cause sperm degeneration. Infertility may be partial or complete but usually returns to normal 2 to 4 months after the condition is controlled by topical acaricides. Small lesions cause few problems. Microscopic examination of the exudate and superficial skin scrapings will show oval shaped mites.

Demodex spp are species specific mites which infest hair follicles of all species of domestic animals. Demodectic mange is a minor nodular mange problem on the shoulders, neck, dewlap and muzzle of cattle.

Mange in goats has a similar distribution but a slightly higher clinical importance. Demodectic mange is rare in sheep.

Trombidiform mites are mites which primarily attack grain. They infest animals accidentally and usually cause a dermatitis around the face. In sheep they sometimes attach to the skin of the caudal pastern. Erythematous papules with tiny orange mites on their surface burst and ulcerate. Lesions later dry up and a scab is formed. Pruritis is intense and the sheep bite affected areas. Secondary infection and flystrike are common.

Sarcoptic mange is a sporadic problem in goats, sheep and cattle. In goats and cattle it is usually found on the head but may become generalised. In sheep it infests the haired areas of the lips, nostrils, ears and occasionally the lower legs. Thick scales and crusts are formed. Pruritis and self trauma are common. Some individual animals display hypersensitivty reactions to the mites. It occurs most frequently in poorly managed, debilitated animals.

Itchmite (*Psorergates ovis*) is a cause of pruritis and self inflicted trauma in sheep throughout Australia. It and its relatives can also cause serious mange problems in cattle and goats. The pruritis appears to be a hypersensitivity reaction as fleece derangement is present in only a proportion of infested sheep. Other suggestive signs include the presence of scurf, thickened skin and occasionally, yellow discolouration of the fleece. Biting and tubbing are most severe along a line between the elbow and hip. Differential diagnosis should include lice, ked and grass seeds. Transmission from infested ewes to their lambs in an important method of spread. Itchmite is very susceptible to the ivermectin group of chemicals and has been largely eradicated from sheep in Australia.

Ticks

Cattle tick is an important problem in northern Australia. Tick worry and tick paralysis from Boophilus microplus are a significant cost to the cattle industry in losses and preventive measures. Tick paralysis will not be considered here and tick worry will be confined to the gross skin lesions. Skin irritation leads to interruption of grazing, growth and production. Some animals may show self trauma,alopecia and fissured skin. Hypersensitivity to tick products can occur. Scarring leads to downgrading of hides at slaughter. Extensive tick infestation is obvious with several hundred ticks attached to various parts of the body. However light infestations may be confined to the perineum, neck or ears. Other tick species infest cattle in Australia but do not normally cause extensive skin disease.

Ticks are not an important ectoparasite of sheep in Australia but a 3 host tick (*Haemaphysalis longicornis*) is found on sheep in the northern half of the North Island of New Zealand. It does not act as a vector for other disease in sheep and its importance is restricted to pelt damage and occasional weight loss and anaemia.

Lice

Louse infestations (pediculosis) are common in sheep, goats and cattle throughout the world. Species specific biting and sucking lice occur in all 3 species.They are particularly important in sheep in Australia where the income from wool is more important than from sheep meat. The economic importance of ovine pediculosis lies in the high prevalence and severity of fleece damage.

Bovicola ovis is the most common and most important louse of sheep. It occurs throughout Australia and is present in the majority of sheep flocks. It becomes important when poor management practices allow louse populations to dramatically increase.

B. ovis is a small light grey insect up to 1.8 mm long with a broad reddish head. Females lay eggs which attach near the base of wool fibres and the life cycle is completed in approximately one month. Numbers are lowest in shorn sheep in summer and build up through autumn and winter to a peak in spring. The summer decline in numbers is related to the inability of lice to survive high skin temperatures and exposure at shearing which causes dessication. Generally, at least 4 to 5 months are required from time of initial infestation to levels which produce significant pruritis.

Transmission is by direct contact between sheep. Feeding by biting the cornified layers of the skin causes pruritis and self trauma. The sheep disturbs its fleece by rubbing and biting. Initially, the fleece has a ragged hairy appearance which extends to irregular areas of wool loss, particularly along the shoulder, side and flank. Heavily affected sheep show illthrift and some become debilitated. Diagnosis is confirmed by observing lice on the skin. Inspections should be made by parting the fleece in several places over the neck, withers, shoulder and side. Good light and experience are needed as the lice congregate in colonies and move quickly away from bright light. The level of infestation will vary amongst individuals in a flock and light infestations can be easily overlooked.

Linognathus pedalis is a sucking louse approx. 2 mm long with a hairy abdomen. It mostly occurs in the hairy rather than the woolly areas of the sheep ie lower legs, but can extend to the scrotum and belly wool. *L. pedalis* can survive on pasture for 2-3 weeks. Light infestations cause no clinical signs but heavy build ups in the late winter and spring can cause stamping and biting of the affected parts. Most problems occur in rams, young lambs and housed sheep.

Linognathus ovillus is the face louse. It occurs in all east coast states of Australia but causes few clinical problems. It is the largest of the sheep lice with a head twice as long as it is wide. Infestations are found at the hair/wool junction on the head.

In goats the sucking louse (Linognathus stenopsis) is more pathogenic than the biting lice (Bovicola spp). The hair coat of fibre goats may be seriously deranged from rubbing and biting.

In cattle infestations are common, particularly in colder months and on poor, illthrifty or overcrowded animals. There is usually little effect on most animals. Sucking and biting species may both be present. Pruritis is a feature but self trauma is uncommon, however damage to trees and fences from rubbing can be considerable. Some lice are widely distibuted on the body, others cluster. The head and neck are the most commonly affected sites. Scurf and variable alopecia may be seen.

Wool Disorders

Wool break

A localised weakness in the tensile strength of the wool fibre is a common fault in sheep fleeces. It is also referred to as tenderness. Growth checks related to levels of nutrition, pregnancy, lactation and disease are thought to be the cause of tenderness. There is also a seasonal (photo-periodic) effect on wool growth rate being slowest in winter.

A decrease in the diameter of the wool fibre is the most common reason for wool break although some fibres are structurally weak as in copper deficiency. In addition, some fibres stop growing and are shed into the staple, thus making the strength of the staple dependent on fewer fibres. Masses of tangled shed fibres in the fleece are referred to as cots.

Fleece rot

Persistently wet skin encourages skin maceration, proliferation of bacteria and a superficial exudative dermatitis called fleece rot. *Pseudomonas seruginosa* is the bacterium associated with most cases of fleece rot. Other predisposing factors include high humidity in the fleece, long wool, high wax and low suint content and open fleece structure with shaggy staple tips.

Most cases occur in the warm wet periods of the year and therefore the frequency of fleece rot is highest in high rainfall areas. The prevalence and severity of the condition varies widely. It is diagnosed by observation of dirty greyish green or greyish yellow band across the wool staple, particularly along the backline. Wool fibre damage does not occur so that the term is misleading. The discolouration can be removed by scouring. Severe cases show matting and marked discolouration. Fleece rot can be differentiated from dermatophilosis by the latter's heavy characteristic scab formation however, mixed infections do occur.

In sheep affected by fleece rot, cutaneous hotspots of serum exudation and Pseudomonas proliferation attract *Lucilia cuprina* the primary sheep blowfly and body flystrike is a common sequel.

Small framed fine wool Merinos are said to possess a high degree of natural resistance to fleece rot and body strike. This type of sheep predominates in high rainfall areas.

Genetic predisposition and resistance to fleece rot have been documented and programs to select resistant sheep appear worthwhile.

Fleece pigmentation

The conditions mentioned for development of fleece rot (above) may also produce fleece pigmentation. Pigmentation by *Pseudomonas aeruginosa* can produce bands of green, grey-green, brown and occasionally blue and pink discolourations. The pigment is scourable.

Diffuse yellow scourable pigmentation may be due to ectoparasitism or an heritable pigmentation of skin gland secretions.

Diffuse yellow or apricot unscourable pigments are found in the ventral body areas and are caused by high suint levels exposed to prolonged warm wet conditions.

Black non-scourable discolouration of the staple tip can occur under wet conditions due to the fungus *Peyronella glomerata*. It does not penetrate deeply but the damaged wool tip is lost during the scouring process.

A range of pink, bue and purple fleece discolourations without a known cause have been described but are uncommon.

Grass seed infestation

The majority of sheep in Australia have grass seeds from some grass species accumulate in the eyes, ears, gums, interdigital clefts, anus and external genitalia of sheep. Others accumulate in the wool and penetrate the skin. Woolly faced sheep and lambs and young sheep (which have thin skin) are particularly severely affected. Major offenders are Barley grass (*Hordeum leporinum*), Spear grasses, (*Stipa spp., Heteropogon spp., Aristida spp.)*, Storksbill and Crowsfoot (*Erodium spp.*).

Lesions include conjunctivitis and blindness, mouth and ear impaction and injuries, lameness, puncture wounds and tracts throughout the woolly skin. Resultant reluctance to graze, ill thrift and secondary infection are important, the latter particularly after dipping. Grass seed puncture wounds predispose to other conditions including orf, caseous lymphadenitis, tetanus, malignant oedema, erysipelas, footrot and flystrike. Grass seed infestation causes major economic and welfare problems. Downgrading of wool, pelts and carcases cause losses of many millions of dollars to the Australian sheep industry.

Chapter 10

Exotic Diseases

Deborah Middleton

This presentation will focus on the Office International des Epizooties (OIE) List A diseases of particular interest to ruminant practitioners. OIE List A diseases are transmissible diseases that have the potential for very serious and rapid spread, irrespective of national borders, that are of serious socio-economic or public health consequence and that are of major importance in the international trade of animals and animal products.

Reports are submitted to the OIE as often as necessary to comply with Articles 1.1.3.2 and 1.1.3.3 of the *International Animal Health Code*.

Reference should also be made to AUSVETPLAN (http://www.aahc.com.au/ausvetplan/)

- Foot and mouth disease
- Vesicular stomatitis
- Rinderpest
- Peste des petits ruminants
- Sheep pox and goat pox
- Lumpy skin disease
- Bluetongue
- Contagious bovine pleuropneumonia

Vesicular and erosive diseases

Foot and mouth disease

FMD is a highly contagious viral vesicular disease of cloven-hoofed animals. Although not highly lethal in adult animals, it causes serious production losses and is a major constraint to international trade in livestock and livestock products. There are seven distinct serotypes of FMD that do not cross-protect. Serotypes O and A are found globally, with serotype O responsible for the recent outbreaks in both Japan and UK; Asia 1 occurs in Asia; C has most recently been reported in Europe and South America; and SAT 1, 2 and 3 are confined to Africa with some incursion into the Middle East.

FMD virus is relatively stable in cool, humid environments but is rapidly inactivated at pH<5 and is susceptible to formalin, glutaraldehyde and hypochlorite disinfection.

Pathology

Pathogenesis
Infection of susceptible animals occurs primarily through inhalation of airborne droplets but also through breaks in the skin or oral mucosa. Initial replication occurs in the mucosa or lymphoid tissues of the oropharynx with localisation to the stratum spinosum of selected areas of the epidermis and proliferating myocardial cells of young animals. Development of vesicles may be exacerbated in frictional areas of the skin.

Clinical signs and gross pathology
The first case of FMD in Australia is likely to be in a pig as pigs may eat contaminated offal and they are an efficient amplifying host. However, infected cattle usually develop obvious clinical signs of FMD and so are also considered a good indicator species. Cattle are most infectious when they have early acute signs of disease, whereas sheep excrete a large proportion of the total virus excreted over a 1 to 2 day period before the occurrence of clinical signs.

- Incubation period of 2 to 5 days
- Fever, cessation of milk production, depression
- Inappetance, loss of condition
- Ropey saliva and lip smacking
- Vesicles in mouth and on feet (interdigital spaces, coronary bands, bulb) and on teats of lactating animals. Early coronary band lesions may simply appear as blanching of the area.
- Lameness, reluctance to move and shuffling of feet
- Death in young animals due to myocarditis
- Rapid healing of ruptured vesicles – usually within two weeks

In sheep, one third of infected animals may not show clinical signs. Where present, FMD lesions in this species are often small, rupture easily and heal quickly. Minor erosions following vesicular rupture are no longer identifiable as FMD, and the duration of lesion presence in an individual sheep averages only two days. Most lesions in sheep occur on the feet, usually in the interdigital cleft. Non- specific signs such as lameness, pyrexia and nasal discharger may also be identified. Where oral lesions occur, they are usually on the dental pad.

Some cattle, sheep and goats carry virus persistently in the pharynx in the face of a humoral immune response. This state may persist in cattle for up to 3 yrs and in sheep for up to 8mths. Experimental transmission of disease from carriers has not been established but epidemiological evidence suggests that cattle at least may be responsible for initiating field outbreaks of disease.

Specimens for laboratory diagnosis

- For virus isolation - Vesicular fluid; nasal swabs; epithelial covering of vesicles, or epithelial tags from freshly ruptured vesicles; whole blood; esophageal /pharyngeal fluid (probang). From dead animals tissue samples including heart, spleen, lymph node, adrenals, kidney and thyroid should be included. Foot lesions tend to have higher concentrations of virus for longer periods than lesions at other sites.
- For serology - serum from affected animals and unaffected herdmates
- For histopathology (to assist with later differential diagnosis) – lesional tissue including gastrointestinal tract, together with the range of tissues submitted for virus isolation.

Unfixed tissues and blood should be forwarded chilled in an AAHL-approved transport container. If a transit time of more than 48hrs is envisaged then ship the specimens on dry ice. Esophageal/pharyngeal fluid samples should be shipped frozen on dry ice unless they will be received at AAHL on the same day.

Differential diagnosis

Don't – all cases of vesicular disease are FMD until proved otherwise.

Vesicular stomatitis does not occur in Australia. Although responsible for considerable production losses, its primary importance is as a differential diagnosis for FMD. Vesicles may also occur following exposure to chemical irritants or scalding. More advanced cases of FMD, that is past the initial vesicular stage, may be mistaken for bovine papular stomatitis, mucosal disease, bovine malignant catarrh, IBR, rinderpest/PPR, bluetongue, photosensitization, foot rot and trauma.

Vesicular stomatitis

See Foot and Mouth Disease. Unlike FMD, vesicular stomatitis also affects horses and it is a zoonosis. Infection and disease of sheep is rare.

Rinderpest

Rinderpest is an ancient disease that probably originated in Central Asia. It is of considerable historic interest as the threat of its occurrence was the catalyst for the foundation of modern veterinary schools and state veterinary services in Europe.

The host range of rinderpest comprises all cloven-footed animals including kudu, eland, warthogs, giraffe and yaks but it causes disease principally in cattle and buffaloes. Current areas of endemicity include East Africa (Sudan, Uganda, Kenya, Ethiopia) and Asia where epizootics still occur in spite of vaccination programs. In these areas yearlings in

particular are affected as adults are protected by vaccines or natural immunity and calves by colostral antibody. Introduction of infected animals into susceptible populations is generally followed by high morbidity and mortality. There has been a single outbreak of rinderpest in Australian cattle near Fremantle in 1923. These animals had been transported from Derby following contact with infected pigs loaded onto the source ship in Asia and subsequent eradication was by rigorous application of quarantine procedures and slaughter of infected herds.

FAO (Food and Agriculture Organisation) has a Global Rinderpest Eradication Program the aim of which has been to eliminate the disease by 2010 using targeted vaccination and enhanced disease surveillance followed by active surveillance without vaccination. Technically, the ingredients for eradication are present and include excellent heat stable vaccines, good diagnostic tests, absence of carrier state in infected animals, no true reservoir in wildlife or insects and poor virus survival outside host. However, as in the past, such eradication programs continue to be blighted by breakdown of infrastructure services with global eradication of a major pandemic disease so far only achieved with smallpox.

The rinderpest virus is very unstable in the environment and survives a few days only in secretions, excretions or carcases. Infection by large droplets occurs following close contact between animals, with the virus present in expired air, tears, nasal secretions, saliva, urine, feces and milk.

There is a short incubation period of 2-6 days thus disease outbreaks can be explosive. Virus excretion commences at the end of the incubation period and may continue for the next 14 days or so.

Very few sequence changes are required to alter virus virulence and some strains cause extremely mild disease. The molecular basis of pathogenicity is not understood. In areas of endemicity the disease tends to be a milder syndrome with lower incidence and lower mortality rates than the classical highly lethal disease seen on first introduction to a susceptible population.

Pathology

Penetration of upper respiratory tract (URT) mucous membranes is followed by viral replication in URT lymphoid tissue, followed by viremia with virus attachment to mononuclear cells and proliferation in systemic lymphoid tissues, gastrointestinal tract and respiratory tract. Lesions observed at gross post mortem examination and histopathology naturally reflect the pathogenesis of the infection.

Clinical signs

- febrile illness with nasal and ocular discharge, constipation 1-2d
- necrotic plaques (no vesicles) on oral mucous membranes, nose, tips of cheek papillae, urogenital tract; dry flaky muzzle

  1-2 d
- fluid, dark foul smelling feces containing mucus, blood, necrotic mucosa

  2-3d
- death

  6-12d

Gross pathology

- Mucosal erosions – mouth, pharynx, esophagus, urogenital tract, nasal turbinates
- Erosions – abomasum especially pylorus, Peyer's patches of small intestine
- Hemorrhages with erosions in cecum and colon especially on the crests of the longitudinal mucosal folds ("tiger" or "zebra" striping)
- Swollen and congested lymph nodes

Specimens for laboratory diagnosis

Samples should include

i) 20ml of clotted blood from several animals (affected and unaffected) for serology

ii) Early clinical cases (fever, mucosal lesions, no diarrhea)
   - anticoagulated blood (20ml)
   - prescapular lymph node aspiration biopsy (by 14g sterile needle and syringe)
   - tears (cotton wool swab) in sterile saline
   - necrotic plaques

   Transport fresh and chilled. If transit time is expected to be greater than 72hrs then freeze to –80°C and ship on dry ice.

iii) Freshly killed acute cases (at least 2 animals)
   - 20g spleen, tonsil, lymph nodes Transport fresh and chilled
   - tonsil, liver, spleen, lymph nodes, kidney, brain, lesional gut fixed in formalin

Where possible avoid collecting samples from carcases as they rapidly become non-infectious following the pH changes occurring in autolysis and putrefaction.

Differential diagnosis

- Mucosal disease – usually affects a small number of animals in a herd. Note that the presence of pestivirus does not invalidate a provisional diagnosis of rinderpest

- Malignant catarrhal fever – corneal opacity reflecting uveitis, sporadic occurrence, lack of in contact transmission, association with pregnant sheep
- IBR – oral lesions fairly uncommon, no severe gut signs
- FMD (healing lesions) – feet lesions, no severe gut signs, no mortalities in adults

Peste des petits ruminants

PPR is a disease of sheep and goats endemic in the Middle East, sub-Saharan Africa and South Asia and is very similar clinically and pathologically to rinderpest (from which it probably evolved) that also occurs in sheep and goats. PPR may also be difficult to recognise on first introduction as respiratory signs may dominate due to the secondary complication of pneumonic pasteurellosis. Mortalities may be especially severe in goats compared to sheep.

Differential diagnosis

- Rinderpest/ PPR
- Bluetongue – feet lesions, hemorrhage at base of pulmonary artery
- **FMD (healing lesions)**
- Capripox – skin lesions

Capripox

Capripox causes sheep and goat pox and lumpy skin disease in cattle. Goat pox may in fact be identical to sheep pox, but host adaptation has occurred in endemic areas.

The threat of introduction of capripox to Australia is quite low, although it might occur through persistence of virus on livestock vessels, peoples' clothing and equipment, and unprocessed animal products. It is theoretically possible for infected insects to introduce lumpy skin disease.

Capripox infection is established via the subcutaneous route by biting insects (cattle) or the respiratory route via aerosols e.g. dried scabs (sheep). Local multiplication is followed 4-7 days later by viremia with organ localisation after 10-14 days. The sites of viral replication account for the nature of lesions that develop, namely

- Epithelium – vesicular skin lesions with both epithelial degeneration and hyperplasia
- Endothelium – dermal and subcutaneous vasculitis leading to edema, ischemia and infarction

Evolution of capripox lesions
This occurs over 2 to 3 days with progression through erythematous macules, papules, and vesicles (especially in sheep pox) through to depressed pustules with a grey necrotic centre ("sit fast"), crusts and slowly healing ulcers. The full thickness of the hide may be involved.

Sheep pox

The disease is endemic in sheep in Africa, Asia, and the Middle East and outbreaks have occurred more recently in Italy, Bulgaria and Greece. Mortalities of 80-100% can be expected in susceptible populations especially in young animals. Lower mortalities may be seen in adults, with fewer lesions confined to the areas under the tail and between the legs.

The virus is resistant to dessication and viable for up to 3mths on the wool of recovered animals or 6mths in dried crusts, particularly if these are protected from sunlight. In considering the trade implications of an outbreak of sheep pox it is worth remembering that the major markets of Australian wool are to sheep pox free countries. There is a much smaller market of live sheep export to sheep pox free countries as the main market is to the Middle East where sheep pox is endemic. Entry of sheep pox into Australia would be followed by major economic loss due to severe systemic disease with high mortality, decreased wool and meat yields, banning of exports of sheep products, and cost of disease prevention programs. Fine wool Merinos are especially susceptible to infection.

The occurrence of classical acute sheep pox in Australia would in all likelihood be readily diagnosed but low virulence isolates may prove a diagnostic challenge. Immunity to sheep-pox is predominantly cell mediated and infected animals and vaccinates may develop only low levels of neutralising antibody.

Control measures including slaughter, ring vaccination and the imposition of quarantine depend entirely upon confirmatory diagnosis in the laboratory.

Pathology

Clinical signs

- Fever, lacrimation, serous nasal discharge, salivation, hyperesthesia
- 2 to 3 days later, skin lesions develop especially in sparsely woolled areas and mucous membranes; respiratory distress
- survival is followed by prolonged convalescence

Gross pathology

- skin lesions – macules; wart-like oozing wheals; vesicles; necrotic crusts; ulcers
- pulmonary nodules – grey/white, small, generally subpleural

Specimens for laboratory diagnosis

- a range of skin lesions, lymph nodes and lung – fresh (chilled) and fixed in formalin
- 10ml of clotted blood from several animals (affected and unaffected) for serology

Lumpy skin disease

In cattle the disease occurs in South-East Africa, the Middle East and Madagascar. There is variable but often prolonged morbidity and variable mortality, with calves more likely to die than adults. The disease is not highly contagious, and mechanical transmission by biting insects is believed to be of more epidemiological importance than in sheep pox. Viral replication in the dermis occurs at the site of inoculation with the formation of a primary skin nodule. Viremia and fever ensue, followed by the development of generalised skin lesions in which virus persists for several weeks. Secondary lesions may also develop in upper respiratory tract, lung, esophagus, rumen, abomasum, kidney, testis and uterus.

Pathology

Clinical signs

- fever, salivation, oculonasal discharge, ventral edema, lymphadenopathy
- sudden appearance of a few to hundreds of skin lesions over most of the body including the heavily haired skin and mucous membranes
    - firm, flat, round nodules 0.5 to 5cm diameter involving the entire thickness of the skin
    - skin lesions may resolve or persist as intradermal masses; most undergo necrosis and sequestration to form a cone-shaped flat topped core of pink/grey necrotic tissue ("sit-fast")
    - sloughing of the necrotic tissue is followed by slow healing of the ulcer and permanent scarring of the hide
- respiratory distress

Specimens for laboratory diagnosis

- a range of skin lesions, lymph nodes and lung – fresh (chilled) and fixed in formalin
- 20ml of clotted blood from several animals (affected and unaffected) for serology

Differential diagnosis-sheep

- scabby mouth – transient vesicular stage with heavy crust formation; primarily on the mouth and feet of lambs and kids and the udder of dam; high morbidity, low mortality
- bluetongue – feet lesions, hemorrhage at base of pulmonary artery

- photosensitization
- dermatophilosis
- parasitic skin disease including Psoroptes ovis

Differential diagnosis-cattle

- Bovine herpesvirus-2 – superficial skin only involved with sloughing of scabs in about 3 weeks, usually without scarring; no lymphadenopathy, no internal lesions, no mortality
- Papular stomatitis – muzzle of calves and udder of dam
- Photosensitization
- Insect and tick bites
- Dermatophilosis
- Urticaria

Bluetongue

The major arboviral groups of veterinary significance present in the Asia-Western Pacific region include *Orbiviruses* of the bluetongue serogroups. The life cycle of arboviruses includes replication in both a vertebrate host and an arthropod vector. In the case of bluetongue the vector is a *Culicoides* midge and the virus is transmitted between hosts by the vector. The most common and widely distributed vector in Australia is *Culicoides brevitarsis* and its distribution currently delineates that of bluetongue viruses in the mainly cattle-raising areas of Australia.

Historically, bluetongue has been considered to be an African virus, possibly originally involving an antelope/midge cycle. All ruminant species including sheep, goats, cattle, buffaloes, antelope and deer are susceptible to BT infection. Ecologically and epidemiologically speaking, bluetongue is now best considered an infection of cattle as a higher % of exposed animals will seroconvert, it is easier to get an isolate from cattle, and there is a long viremia (~ 60 days). This new role for cattle may have followed agricultural expansion of cattle in African countries and thence elsewhere.

However, BT is regarded as a *disease* of sheep as this is the species in which the clinical expression is most severe with mortalities up to 70%, although there is variation in breed susceptibility and in the virulence of different strains.

Pathology

Clinical signs sheep

- may be somewhat protracted (into several weeks) and are exacerbated by exposure to sunlight
- fever: four to eight days after infection lasting for about a week

- face: swollen muzzle, hyperemic and congested tongue (deeply cyanotic tongue is rare) and mucous membranes; salivation; serous nasal discharge
- feet: erythema, congestion, and ultimately hemorrhage of coronary band due to acute coronitis; lameness.
- Necrotic lesions in oral cavity, hemorrhagic diarrhea, respiratory difficulties, loss of skeletal muscle mass

The clinical signs and gross pathology reflect the underlying pathogenetic process, namely vasculitis with endothelial cell injury.

Gross pathology

- Petechial or ecchymotic hemorrhages on oral mucosa, intestinal mucosa, base of pulmonary artery in tunica media
- Erosions with diphtheritic membranes on oral mucosa
- Edema and hemorrhages in subcutaneous tissues
- Pale foci of skeletal and myocardial muscle necrosis
- pulmonary edema and hydrothorax

Specimens for laboratory diagnosis
The best specimen for isolation attempts and PCR is clotted blood from febrile sheep – the virus is in the clot and is stable at refrigeration temperatures (do *not* freeze). The serum from these specimens can be decanted and, together with serum samples from apparently healthy herdmates, used for antibody determinations. In the case of dead animals, lymphoid tissues including spleen may also be submitted.

Differential diagnosis

- **FMD (healing lesions) –** no mortalities in adults, generally mild disease in sheep
- Peste des petits ruminants/ rinderpest
- Sheep pox – skin lesions
- Photosensitization
- Footrot
- Pneumonia
- Acute hemonchosis

Contagious bovine pleuropneumonia

Contagious bovine pleuropneumonia is caused by *Mycoplasma mycoides mycoides* and infects cattle, water buffalo and yaks. The disease is currently a serious problem in Africa.

CBPP is one of the three great cattle plagues of history and is the most devastating disease Australian livestock has seen. CBPP was introduced in 1858 in Melbourne, at a time when half the Australian population lived in Victoria. Millions of cattle suffered a slow and agonising death from

pleurisy and pneumonia and many more suffered prolonged convalescence and disability. By 1864 it had reached the Gulf of Carpentaria and became endemic in the great cattle herds of Northern Australia. Infection repeatedly returned to southern herds through cattle movements to major markets in the south.

In 1958 the Standing Committee on Agriculture initiated the process of developing a control and eradication program. Two key techniques that could be applied cheaply and simply to animals, many of which were wild and in inhospitable landscapes, underpinned the successful eradication of the disease. These were a diagnostic test that would reliably detect infected animals and a durable vaccine. The field program began in 1961, the last disease was found in 1967 and Australia was declared free in 1973.

CBPP organism is fragile outside the host and sensitive to dessication and to disinfectants. Infection of susceptible animals occurs following close contact between animals, probably via infected droplets. The incubation period varies from 3wks to 4mths and introduction of disease is followed by slow spread within the herd. Chronically infected animals that may have recovered from the acute disease or be subclinically infected are important vehicles for disease persistence in the herd and for spread to new areas.

Clinical signs

- Fever
- Rapid respiratory rate and dry cough
- Signs persist for 2 to 8 wks after which the animal dies (50%) or undergoes a slow recovery (50%).

Gross pathology

- Fibrinonecrotic lobar or bronchopneumonia with distension of interlobular septa by fibrinous exudate and alternation of normal lobules with red or grey consolidation or necrosis – "marbling"
- Serofibrinous pleuritis
- Formation of sequestra following vasculitis and thrombosis leading to infarction. Organisms remain viable in sequestra for years.
- Tendency to diaphragmatic lobe involvement

Specimens for laboratory diagnosis

- Lung, bronchial lymph node, pleural fluid (10ml) – fresh chilled and fixed in formalin
- Joint fluid (calves)– fresh chilled and fixed in formalin
- 20ml blood for serology from clinically affected animals plus healthy herdmates

Differential diagnosis

- Bacterial pneumonia
- Aspiration pneumonia

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Chaper 11

Macroscopic Lesions of the Respiratory Tract of Ruminants

Professor Ronald F. Slocombe

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.

References:

1. **Dungworth, D. The respiratory system**, in *Pathology of Domestic Animals, 4th edition, 1993, Volume 2:* editors - Jubb, Kennedy and Palmer, *pp 539-698.*
2. **Lopez, A. Respiratory system,** in *Thomson's Special Veterinary Pathology, 3d edition, 2001:* editors – Carlton and McGavin, *pp* 125-195.

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Chapter 12

Goats

Keith Thompson

Introduction

Veterinary practitioners and pathologists in Australia and New Zealand are very familiar with the common diseases of sheep and cattle, but many do not feel comfortable when dealing with disease problems in goats. This is not surprising considering the relatively small size of the goat industries in both countries and the infrequency with which we are invited to provide advice on goat health and production. Because of a lack of reliable sources of information on goat diseases there is a tendency to extrapolate from our knowledge of sheep or cattle, but this is often inappropriate. Not only do goats have different susceptibility to many of the common diseases of sheep and cattle, they are susceptible to certain diseases that are seldom if ever diagnosed in these species.

The pathology of goat diseases cannot be covered in a single presentation. Instead, I will present an overview of selected clinical syndromes, indicating similarities and differences between goats and other ruminants. Much of the information presented here is based on my experience over the last 20 years as both a goat farmer and a pathologist with a special interest in goat diseases. My farming experience has largely been with fibre and meat goats and that will be my emphasis in this paper. For convenience, the disease syndromes will be considered under different age groups.

Diseases of kids from birth to weaning

Neonatal mortality

Dystocia is less common in goats than in either sheep or cattle, although breed differences exist in all species. Impatient owners sometimes cause problems by trying to assist a doe without ensuring that the head is in the birth canal before pulling on the forelimbs. The diagnosis is based on gross lesions (discussed elsewhere in this seminar).

Newborn kids, especially Angoras, are much more susceptible to **exposure** than lambs because their birth coat does not possess the same insulating properties and they have less subcutaneous fat. This may be a major cause of kid loss on some properties. The danger period is the first hour or so after birth. If the weather is cold and wet or windy, kids born in an exposed site may die of exposure before they have a chance to stand and feed. Such kids are often mistaken for abortions or stillbirths. Small kids (<2.0kg) have particularly low viability unless they

are born in a sheltered environment. Gross lesions are unremarkable although there will be partial aeration of the lungs, represented by few to many pale pink lung lobules contrasting with dark purple areas of atelectasis. Death usually occurs too rapidly for there to be any depletion of fat reserves. There may be some evidence of suckling, depending how soon after birth the kid became chilled.

Mismothering is relatively common, especially with multiple births. Some kids may stand and wander away from the birth site before they have bonded adequately with the doe. The risk is increased if kidding occurs in hilly paddocks. The gross changes in mismothered kids are similar to those in lambs. Footpads are worn and there is depletion and serous atrophy of body fat reserves. Adipose tissue in coronary grooves is usually reddened and gelatinous. The same changes, but in a slightly older age group, may be seen in kids that die of **starvation** due to inadequate milk production by the dam.

Iodine deficiency goitre has been responsible for major losses of newborn kids on properties where there have been no problems in newborn lambs or calves, suggesting that goats have a higher requirement for this trace mineral. Affected kids are either born dead or die soon after birth. Abortion does not appear to be a feature. The thyroid glands are often markedly enlarged and some deaths may be due to tracheal compression or to dystocia. In severe cases the hair coat is poorly developed, the tongue may be protruding and there may be an overshot lower jaw, presumably due to the pressure of the enlarged glands. Many kids with moderately severe goitre are able to survive with treatment. Grossly the thyroid glands are bilaterally enlarged and dark red. Subclinical iodine deficiency may contribute to the increased neonatal losses through exposure on some properties. Supplementation of pregnant does with iodine should be routine.

Congenital white muscle disease due to **intra-uterine selenium deficiency** may be underestimated as a cause of neonatal mortality on some properties, as the lesions are more subtle than those of WMD in older kids (see below).

Enteric diseases

Rotavirus and ***E coli*** are common causes of diarrhoea during the first week of life, especially in kids deprived of colostrum. Lesions and diagnosis are the same as for calves and lambs.

Cryptosporidium sp is common during the first 3-4 weeks of life, especially in artificially-reared and late kids. Infection is often concurrent with rotavirus and/or *E coli.* Gross lesions are not specific but at necropsy, affected kids usually have distended, gas filled loops of large intestine with a small amount of yellow/white content. The diagnosis is best confirmed by microscopic examination of small intestine from freshly dead kids. Cryptosporidia are not species specific and may infect other ruminants in addition to human beings.

Coccidiosis is common and important as a cause of diarrhoea, and even death of kids, usually from around 1-4 months of age, but sometimes in older kids. Several species of *Eimeria* infect goats, but they are species specific and will not cause problems in lambs or calves. Late kids are usually the most severely affected as the level of environmental contamination is massively amplified by earlier kids. A diagnosis based on demonstration of oocysts in faeces is not reliable. Postmortem examination provides the most useful information. Some species of coccidia in goats (and lambs) produce grossly visible, 1-2 mm diameter, pale nodules in the mucosa. These consist of hyperplastic epithelial cells packed with coccidial stages. They are often found incidentally in small numbers, but if present in large numbers they are likely to be significant, especially if the intestinal content is watery. Mucosal scrapings and/or histology provide more precise information as there may be many additional coccidial stages in the mucosa between nodules. Always consider the possibility of concurrent nematode parasitism and/or yersiniosis in a kid with lesions of coccidiosis.

There are occasional reports of **giardiasis** in dairy goat kids, but its significance is uncertain.

Nematode parasitism can affect kids during this period but is usually more common after weaning and will be discussed later.

Tapeworm infestations (*Monezia expansa*) are common in kids, but do not appear to be clinically significant.

Sudden death

White muscle disease (WMD) caused by deficiency of selenium (or sometimes vitamin E) has caused major losses of kids on some properties in New Zealand. There is convincing evidence that goats are more susceptible to selenium deficiency than either sheep or cattle, at least with regard to the occurrence of WMD. Although it may be congenital, it more often affects well-grown 4-6 week old kids. Affected kids are often just found dead. Lesions are consistently present in the myocardium (especially right ventricle), but may also involve skeletal muscles, including the tongue.

Gross lesions include clear fluid (plus fibrin clots) in body cavities, congested, oedematous lungs, enlarged congested liver (if subacute) and chalky white/yellow lesions in the myocardium. Lesions are usually less prominent in kids with congenital WMD and such cases may be misdiagnosed as stillbirths or exposure.

Rapid diagnosis and treatment with Se and/or vitamin E will reduce further losses but some kids will eventually die of congestive heart failure due to residual cardiac lesions. The disease can be easily prevented by annual pasture Se applications or supplementation of pregnant does, although there have been occasional outbreaks in New Zealand where vitamin E rather than selenium deficiency appeared to be involved.

Clostridial diseases should always be considered in cases of sudden death in young ruminants but their prevalence in goats is not clear. Some authors have claimed that **enterotoxaemia** caused by the epsilon toxin of *Clostridium perfringens* type D is one of the most important diseases of goats, but its occurrence in this species is poorly documented. Some useful experimental work has been conducted over the last 10 years but much of the published information on the natural disease is anecdotal. In my experience in New Zealand, enterotoxaemia is an uncommon disease of goats grazing pasture, although it clearly does occur. Even in zero-grazing dairy goat operations in New Zealand, the disease appears to be rare.

The diagnosis of enterotoxaemia is never easy and the results of experimental studies suggest that the gross lesions in goats may differ from those in lambs. Necrotising colitis with pseudomembrane formation was a feature of the disease in experimentally infected goat kids, but this is not recognised as a lesion of enterotoxaemia in lambs. I have not seen this lesion in the few natural cases of enterotoxaemia that I have seen in goats in New Zealand. The demonstration of glycosuria adds support to a diagnosis of enterotoxaemia but is not specific and may occur in association with other diseases. For example, sheep with listeriosis or polioencephalomalacia will sometimes have glycosuria. The presence of epsilon toxin in ileal contents is widely used to confirm enterotoxaemia but the limitations of such tests should be recognised. Demonstration of perivascular proteinaceous oedema on histological examination of the brain probably remains the most definitive lesion of enterotoxaemia in both sheep and goats, even though there are suggestions that this is less common in kids than in lambs.

In early reports of enterotoxaemia in goats there is mention of a "chronic form" characterised by intermittent diarrhoea and wasting. This seems to have been based on anecdotal observations and there is no convincing evidence to support the existence of such a syndrome. It is clear that more information on the disease in goats is required before we can make useful recommendations on prevention.

Tetanus occurs sporadically in goats, usually associated with injuries caused by penetrating wounds, dehorning, castration or ear tagging. The disease is best diagnosed clinically as there are no useful gross or microscopic lesions, other than a potential site at which proliferation of *Cl. tetani* would have occurred.

A **braxy-like syndrome** characterised by necrotising abomasitis in association with *Cl. septicum* has been recognised in goats in Australia and New Zealand. There is diffuse or patchy reddening of the abomasum, necrosis of the mucosa and marked submucosal oedema.

Abomasal bloat is a sporadic problem of artificially reared kids, usually from 4-12 weeks of age and is most common in greedy kids that engorge on milk. Fermentation of milk in the abomasum results in excessive gas formation and bloat. Affected kids are usually found dead with a

markedly distended abdomen. The abomasum may rupture terminally or soon after death, in which case milky fluid and lumps of clotted milk will be present throughout the peritoneal cavity.

Volvulus is another common but sporadic cause of acute death in kids (and older goats). Most cases occur in artificially reared kids. As in abomasal bloat, affected kids have a distended abdomen and may just be found dead. At necropsy, the involved segment of bowel is dark red and distended. Almost any part of the GI tract from the abomasum to the colon may be involved. The mesenteric root should be palpated to identify the twist before removing the GI tract.

Herpesviral enteritis has been associated with outbreaks of abdominal pain, weakness and death in young kids around 1- 2 weeks of age. In one outbreak in a dairy goat flock in New Zealand, it was responsible for the deaths of approximately 80 of 120 kids. At necropsy, affected kids have ulcerative lesions in the gastrointestinal tract, particularly caecum and colon. Eosinophilic, intranuclear inclusion bodies can be detected histologically in intestinal epithelial cells at sites of ulceration. The presence of herpes virus can be confirmed by electron microscopy and/or virus isolation.

Nervous diseases

The encephalitic form of **caprine arthritis/encephalitis** (CAE) occurs in this age group and may be confused clinically with "**swayback**" caused by copper deficiency. The disease is more likely to occur in dairy goats than fibre or meat goats due to pooling of colostrum and increased risk of spreading infection amongst dairy goats. Clinically, affected kids show hind limb ataxia progressing over a few days to recumbency and more severe nervous signs, depending on the regions of brain and spinal cord involved. Gross lesions may be visible in the spinal cord or brain (particularly the cerebellar white matter) as swollen pink or brownish areas of malacia. The lesions are usually unilateral and may be quite localised. Extensive sectioning of the brain and spinal cord is therefore required in some cases before lesions are detected. The diagnosis can be confirmed by histology of the CNS and/or viral culture.

Vertebral osteomyelitis ("spinal abscess") leading to vertebral collapse and damage to the spinal cord is a relatively common cause of sudden onset hind limb paralysis in young kids, usually a few months of age. Bacteria such as *E coli, Streptococcus sp, Fusibacterium necrophorum,* etc may localise in the bone during bacteraemia, usually in the neonatal period. The infection gradually destroys the bone until a pathological fracture occurs. A similar clinical syndrome may follow trauma to the spinal column.

Skin diseases

Dermatophilosis is a common skin disease of fibre goats in New Zealand, presumably due to the combination of wet weather and the lack

of oil in the fleece of goats. Because of the drier conditions experienced in most areas of Australia the disease is less likely to be a significant problem in this country. Lesions in goats occur most commonly on the nose, lips and ears. They appear as small, elevated scabs surrounding a group of hairs, which often stand erect. In this early stage the lesions can best be detected by palpation, but as they progress large crusts develop and hair-loss occurs. Removal of the crusts reveals a moist, reddened epidermis. A syndrome resembling strawberry footrot of sheep has also been recognised in goats with dermatophilosis, and is manifest as a severe crusty dermatitis of distal limbs. Angora goats sometimes develop extensive lesions of dermatophilosis over large areas of their body during long periods of wet weather. This is most likely to occur in goats that spend much of their time in recumbency on wet ground due to footrot.

The major differential diagnosis for dermatophilosis is contagious ecthyma but the two diseases can be readily differentiated histologically. Impression smears prepared from scabs may also assist by allowing identification of the branching filamentous organisms typical of *Dermatophilus congolensis*.

Contagious ecthyma (scabby mouth, orf) is a common pox viral disease of lambs throughout the world and may also affect goats, particularly young kids. The lesions start as small papules and progress to vesicles, pustules and thick crusty scabs elevated 2-4 mm above the skin surface. As in lambs, the lesions frequently occur at the commissures of the mouth but proliferative oral lesions, on the tongue and gums, are more common in kids than in lambs. The gross lesions may be confused with those of dermatophilosis but are generally more proliferative and have a different distribution. Confirmation of the diagnosis by histological examination or electron microscopy is advisable before recommending prevention by vaccination.

Diseases of weaned kids

Gastrointestinal parasitism

Unlike sheep and cattle, adult goats do not develop a strong immunity to gastrointestinal parasites. As a result, many goat farmers have relied heavily on anthelmintics for parasite control and resistance to the three major drench families has become widespread. The problem is of particular significance on small properties where goats are the predominant or only species. Such properties may become massively contaminated with infective larvae and goats of all ages suffer reduced growth or productivity. The stress of clinical or subclinical parasitism may also predispose to other disease problems, such as yersiniosis or pneumonia. Although gastrointestinal parasitism can occur in goats of any age it is usually of greatest significance in young growing kids in the post-weaning period.

The most important nematodes in goats are usually *Haemonchus contortus, Ostertagia (Teladorsagia) circumcincta*, and *Trichostrongylus* spp. Mixed infestations are common but under some circumstances one or other of these nematodes may predominate. The clinical signs and pathology will vary accordingly. Anaemia is a feature of haemonchosis and may cause acute death in goats of any age. At necropsy, the carcass is pale and large numbers of *Haemonchus contortus* can usually be seen grossly in the abomasum. Pinpoint haemorrhages may be scattered over the abomasal mucosa.

Larvae of *Ostertagia circumcincta* burrow into the abomasal mucosa and induce focal hyperplasia of mucus neck cells. These foci appear grossly as 1-2 mm pale nodules in the abomasal mucosa and are commonly present in small numbers as an incidental finding at necropsy. In severe infestations these nodules may become confluent, creating an irregularly thickened mucosa, likened to Morocco leather, but this lesion is more typical of the disease in cattle caused by *O. ostertagi*.

Trichostrongylus colubriformis can be an important intestinal parasite in goats, causing severe weight loss, diarrhoea and death. Gross lesions are not specific but may include depletion and serous atrophy of body fat reserves, variable quantities of fluid in body cavities, subcutaneous and mesenteric oedema and skeletal muscle atrophy. The serosal surface of the duodenum may be reddened in very heavy, acute infestations with *T. colubriformis*.

The intestine is usually filled with green, foul smelling, fluid and mesenteric lymph nodes are enlarged and moist. When gastrointestinal parasitism is suspected the contents of the entire tract should be collected for a worm count. This is the most precise method of determining the significance of a worm burden, unless the animal was drenched with an anthelmintic within a few days of death. If the majority of nematodes are of one species the possibility of anthelmintic resistance should be suspected.

Lungworm

Lesions caused by *Muellerius capillaris* infestation are common incidental findings in the lungs of goats at necropsy. The lesions consist of firm, slightly raised, grey nodules primarily in the dorsal diaphragmatic lobes. In some cases there are multiple large nodules (up to 1.5 cm diameter), which may coalesce to involve extensive areas of pulmonary parenchyma.

Muellerius capillaris has been incriminated as a cause of diffuse interstitial pneumonia in goats, resulting in chronic progressive respiratory embarrassment and eventual death. However its role in such lesions is difficult to assess, even when degenerate larvae are found histologically throughout the lung, and the possibility of concurrent *Mycoplasma* or retroviral infections must be considered.

Yersiniosis

Yersiniosis is now recognised as a significant disease of young goats in New Zealand. It occurs most frequently in late autumn or winter and is usually triggered by stress. Inadequate nutrition in combination with winter shearing, cold wet weather and lack of shelter has been responsible for major losses on some properties, particularly in feral goats. The disease may also occur soon after prolonged transport or may be associated with concurrent disease (e.g. coccidiosis or gastrointestinal parasitism).

Affected goats may die acutely after a short period of foul-smelling diarrhoea, or may develop a more prolonged syndrome characterised by diarrhoea, dehydration and weight loss. In live animals, diagnosis depends on culture of the organism from the faeces but positive results should be interpreted with caution as various *Yersinia* species can be cultured from the faeces of clinically normal animals. *Y. enterocolitica* is the most common cause of caprine yersiniosis although some cases are associated with *Y. paratuberculosis*.

Gross lesions include mild reddening of the small intestines, fluid-filled intestinal contents and enlarged mesenteric lymph nodes, but are non-specific. The histological lesions are sufficiently characteristic to allow confirmation of the diagnosis.

Polioencephalomalacia

Thiamine responsive polioencephalomalacia (PEM) is common in goats from a few months of age to early adulthood. Clinical signs include blindness (without ocular lesions), recumbency, opisthotonos, nystagmus and extensor rigidity. Death usually occurs after one to several days. Rapid response to thiamine administration is considered to be a useful diagnostic aid, but such treatment is only likely to be successful if administered early in the disease process.

The gross lesions of PEM are confined to the brain. Cerebral gyri are often flattened due to swelling of the brain and there may be herniation of the medulla and posterior cerebellum into the foramen magnum. The cerebral grey matter, particularly in occipital and parietal regions, is discoloured yellow and on cut surface is swollen softened and sometimes partly separated from the underlying white matter. The cerebral lesions are bilaterally symmetrical and have a segmental distribution with a discrete margin between normal and abnormal grey matter. Similar yellow malacic foci may be present in the caudal colliculi, thalamus and caudate nuclei. Necrotic nervous tissue fluoresces under UV light in a dark room and this can be a useful technique in cases where the gross lesions are equivocal. The diagnosis can usually be confirmed by histological examination of fixed brain.

Listeriosis

The encephalitic form of listeriosis is more common in goats than in either sheep or cattle. It occurs primarily in adults during the winter months, but is discussed here for convenience. The disease is usually sporadic, although outbreaks have followed silage feeding in New Zealand. Clinical signs include depression, increased salivation, facial paralysis, nystagmus, head tilt and circling (in the direction of the tilt) progressing to recumbency

Gross lesions are generally unremarkable although the meninges may be slightly cloudy and small foci of malacia may be present in the brain stem or cerebellar peduncles. Definitive diagnosis requires histological examination of the brain and/or culture of the organism *Listeria monocytogenes*. The lesions are largely confined to the brain stem and spinal cord and consist of non-suppurative meningoencephalitis and multifocal suppurative encephalitis with microabscess formation and variable necrosis. In some cases of caprine listeriosis the lesions are restricted to the spinal cord, resulting in paresis or hind limb paralysis.

"Water belly"

The accumulation of oedema fluid in the subcutis of the intermandibular region ("bottle jaw") and along the ventral thorax and abdomen is a well-recognised consequence of diseases causing either severe hypoalbuminaemia or right-sided heart failure. The first consideration when presented with a young goat with such a lesion is therefore likely to be gastrointestinal parasitism but in Angora goats of South African and/or Texan origin there is a syndrome commonly referred to as "water belly" that appears to be related to stress rather than to hypoalbuminaemia or heart disease.

The syndrome is very common in young Angora goats during the first week or so after shearing, sometimes affecting up to 15% of the mob. In severe cases there is a massive quantity of clear fluid in the subcutis along the ventral body wall and even extending down into the legs. In mild cases the fluid is only obvious on palpation. Affected animals are usually healthy, continue to eat and the oedema fluid may come and go over a period of a few days before it resolves spontaneously. In some animals the oedema persists for a week or more, leading to thickening of the distal limbs with oedema fluid and early fibrosis. The syndrome also occurs sporadically in association with other forms of stress, such as transport, cold weather or concurrent disease.

Angoras with uncomplicated "water belly" have normal or slightly low serum albumin concentrations, but not low enough to cause oedema through reduced colloid osmotic pressure. The aetiology is unknown, but it may be due to excessive release of aldosterone (in addition to cortisol) from the adrenal gland in response to ACTH. Increased aldosterone would cause sodium retention and hypervolaemia. The slightly low serum

albumin would therefore be due to dilution rather than increased loss or reduced formation.

The challenge for the practitioner is to decide whether the ventral oedema is just stress-related and will resolve spontaneously or whether there is some underlying disease process that requires treatment. Clinical history, clinical examination and laboratory tests can all contribute significantly to the decision-making process.

Diseases of adult goats

Diseases causing weight loss

Starvation, possibly combined with subclinical parasitism, is probably more common in grazing goats than in sheep or cattle. The feed requirements of goats are often underestimated, especially during pregnancy, lactation or after shearing, as they are unable to graze as low as sheep and will lose condition if presented with short pasture (<4cm). Goats grazing such pastures are also likely to be ingesting larger numbers of nematode larvae. A poor condition score in fibre goats (especially Angoras) may be masked by a bulky fleece.

Chronic **gastrointestinal parasitism** should always be considered as a contributing factor, if not the sole cause, of weight loss or poor condition in goats. Confirmation in the live animal should be based on clinical history and faecal egg counts. In goats, as in sheep, faecal egg counts usually reflect the magnitude of the worm burden (providing the infestation has reached patency). Gross lesions in animals that die or are sacrificed include depletion of body fat reserves, fluid-filled intestines and enlarged oedematous lymph nodes (+/- mineralised foci). Serosal lymphatics in the small intestine may be prominent due to blockage of afferent lymphatics by parasitic granulomas. There may be mesenteric and subcutaneous oedema in severe cases due to hypoalbuminaemia. Nematodes may be visible grossly in abomasum, but worm counts (on abomasal and small intestinal contents) are recommended for objective assessment of the worm burden.

Johne's disease has been diagnosed in goats (primarily dairy breeds) on properties both in Australia and New Zealand. In North America and Europe it is common in dairy goat flocks and is considered to be of economic importance. The disease is uncommon in fibre and meat goats, presumably because of their more extensive management. In New Zealand, goats have been shown to be susceptible to both the ovine and bovine strains of *Mycobacterium avium* subsp *paratuberculosis.* The clinical signs in affected goats are similar to those in sheep. Gross lesions are also similar to those in sheep, although caseation and mineralisation of mesenteric lymph nodes is a feature of the disease in goats and must be differentiated from tuberculosis (by culture).

Chronic **fascioliasis** presents as weight loss, anaemia and bottle jaw (in severe cases) and therefore may be mistaken for nematode parasitism or Johne's disease. Goats, like sheep, are highly susceptible to reinfection after initial exposure. Clinical pathology typically reveals anaemia, panhypoproteinaemia (due to blood loss) and moderate elevations in serum GGT activity. Demonstration of fluke eggs in faeces (by sedimentation technique) is necessary for confirmation of a diagnosis in the live animal.

Gross lesions at necropsy include tissue pallor (anaemia) and a firm liver with an irregular, scarred capsular surface, sometimes with evidence of old migratory tracts. Intrahepatic bile ducts are prominent on cut surface due to their thickened, fibrous wall and may be present in their lumen. In acute fascioliasis multiple tortuous haemorrhagic tracts are present throughout the liver.

The lentivirus of CAE has been associated with **chronic progressive pneumonia** and weight loss in adult goats, but the disease has not been reproduced experimentally with the virus and its involvement is uncertain. At necropsy, the lungs fail to collapse and are diffusely firm and pale grey/pink. A similar chronic pneumonia in goats may occur in association with severe *Meullerius capillaris* infestations.

Reproductive disorders

Herpes viral vulvovaginitis and **balanoposthitis** is relatively common in goats in New Zealand and probably Australia. In one serological survey in New Zealand, the prevalence rate of reactors in feral goats was 9.8% and in dairy goats 1.2%. Outbreaks of vulvovaginitis typically occur following introduction of an infected buck or teaser to a group of naive does. Lesions around and inside the vulva are initially ulcerative and cause considerable discomfort to the doe. They then become encrusted with seropurulent to haemorrhagic exudate before resolving spontaneously over a period of 2-3 weeks. Affected does usually do not conceive during the active phase of the disease but will conceive at the next cycle. The infection becomes latent and may reappear later in life following a period of stress. The virus causes ulcerative lesions in the mucosa of the penis or prepuce of bucks, but these may not be apparent at the time of examination.

Caprine herpes virus has also been incriminated as a cause of abortion in a flock that had experienced an outbreak of vulvovaginitis, but this is an uncommon manifestation of the infection.

Unlike sheep and cattle, most **abortions** in goats are non-infectious. The stress of shearing, inadequate nutrition or inclement weather (or combinations of these) during late pregnancy commonly causes abortion in fibre or meat goats reared in extensive conditions. The losses can be substantial on some properties but early abortions often go undetected and may just present as low kidding percentages. In sheep, nutritional

deprivation in late pregnancy is more likely to result in pregnancy toxaemia, but this is uncommon in goats.
The most common cause of infectious abortion in goats is **toxoplasmosis**. As in sheep, the manifestations of intrauterine infection with *Toxoplasma gondii* vary from mummification of foetuses to the birth of weak kids that die soon after birth. Characteristic foci of necrosis may be visible grossly on cotyledons and occasionally in the liver or lungs of aborted foetuses, but the diagnosis is best confirmed by histological examination of the brain and cotyledons. Lesions may also be detected histologically in the heart, liver and lungs. *Listeria monocytogenes* is also recognised as a cause of infectious abortion in goats, but *Campylobacter spp* is not. *Salmonella Brandenburg* has recently become a major cause of abortion in sheep in the South Island of New Zealand and is also recognised in cattle, but has yet to be reported as a cause of abortion in goats.

As a rule, foetuses that have aborted as a result of maternal stress are relatively fresh while those that have died of infection *in utero* are in a relatively advanced state of autolysis.

There are few significant reproductive diseases reported in bucks. Epididymitis due to *Brucella ovis* infection has been reproduced in goats experimentally but does not appear to be a significant natural pathogen of goats.

Skin diseases

Squamous cell carcinoma occurs in the perineal region, especially around the vulva, of Angora goats and to a lesser extent in other breeds. Angora goats have pale skin and tend to hold their tails in the air, exposing the perineum to sunlight. The tumour is probably more common in Australia than New Zealand and was relatively common in aged Angora does imported from Australia to New Zealand during the mid 1980's. In dairy goats, particularly Saanens, the udder is a predilection site. By the time veterinary opinion is requested the lesions are usually large and ulcerated. In some cases the ulcerated surface will be almost black due to the presence of dried blood and dirt and could be misdiagnosed as a melanoma on gross inspection. The diagnosis can be easily confirmed by histopathology or cytological examination of scrapings from a cleaned surface. Local invasion of squamous cell carcinoma may be extensive but metastasis is uncommon.

Malignant melanoma is common in Angoras and Saanens in Australia and New Zealand, usually originating on the ears, muzzle or perineum and rapidly metastasising to regional lymph nodes and/or lungs. Most are heavily pigmented and appear black grossly. By the time they are detected they have often metastasised, so the prognosis should always be guarded, even if the primary lesion appears to have been completely removed.

Papillomas (warts) are also relatively common and are found most frequently on the udder of dairy goats. Some cases appear to progress to squamous cell carcinoma.

Lice are very common in goats, especially fibre breeds, and are becoming increasingly difficult to control. Since heavy infestations reduce the quality of mohair and cashmere, control of lice is important. Many synthetic pyrethroid-based pour-on formulations developed for sheep have been used in goats but now appear to be less effective in controlling lice, probably due to the development of resistance. Also, goats do not have as much oil in their fleece as sheep and the spread and persistence of the insecticide is therefore less. Some goat farmers in New Zealand are now using plunge or spray dips for lice control, although good results are currently being achieved with the insect growth regulators ("Zapp", "Magnum").

The biting lice *Damalinia caprae* and *D. limbata* and the sucking louse *Linognathus stenopsis* are the most common species found on goats in New Zealand and Australia. Although *D. ovis* has been shown to infect goats experimentally, establishment and persistence of infection in the field is unlikely. Lice in goats and sheep should therefore be considered species specific.

Demodectic, **sarcoptic** and **chorioptic mange** are reported in goats, but are of limited importance in New Zealand. As in other species, *Demodex caprae* invades hair follicles, but the skin nodules may be quite large and filled with material resembling pus. A smear of the contents will reveal large numbers of mites. *Sarcoptes scabei* var. *caprae* cause intense pruritis as they burrow through the epidermis. *Chorioptes bovis* infects the scrotum and feet of goats but is seldom clinically significant.

Ticks are a problem in goats in some areas of New Zealand, and may cause significant blood loss in heavy infestations. Hide damage also occurs.

Fly strike is less common in goats than in sheep but does occur. Footrot lesions often become struck during the summer, as does the skin beneath the urine-stained fibre around the pizzle of Angora bucks.

Summary of differences in disease susceptibility between goats and sheep

Diseases to which goats are less susceptible than sheep

- **Enterotoxaemia**

Very common in lambs but rare in goats in New Zealand (and probably overseas). The disease in goats may differ slightly from that in sheep and needs further work.

- **Brucellosis**

Brucella ovis is not recognised as a cause of epididymitis in bucks. Nor does it appear to cause any disease problems in does.

- **Campylobacteriosis**

Although there are occasional overseas reports of abortions caused by Campylobacter spp in goats, these are of questionable validity. There is no doubt that C. fetus subsp. fetus is an important cause of abortion in sheep.

- **Salmonellosis**

Goats appear to be relatively resistant to enteric forms of salmonellosis, although there are occasional reports of infection following stress (e.g. transport).

- **Facial Eczema (sporidesmin toxicity)**

Goats are approximately 4 times more resistant than sheep to direct dosing with sporidesmin. Furthermore, the grazing habits of goats make them less likely to be ingesting large numbers of spores from pasture. As a result, clinical facial eczema in goats is uncommon.

- **Pregnancy Toxaemia**

Unlike sheep, goats subjected to nutritional deprivation in late pregnancy are likely to abort rather than develop pregnancy toxaemia.

- **Fly Strike**

Goats are susceptible to fly strike but it is much less common than in sheep and tends to involve specific sites, such as feet and pizzle.

- **Vaginal prolapse (bearing)**

A very common and annoying problem in sheep in New Zealand but rarely, if ever, seen in goats.

Diseases to which goats are more susceptible than sheep

- **Footrot/footscald**

Probably the most significant disease problem of goats in New Zealand (especially Angoras and Boer goats) and a significant impediment to their widespread acceptance by commercial farmers.

- **Yersiniosis**

A common stress-related disease of goats in winter, sometimes causing significant losses. Is seldom a problem in well-fed goats in good condition.

- **Coccidiosis**

Kids appear to be much more susceptible to the effects of enteric coccidiosis than lambs. Infection is often combined with yersiniosis and/or nematodiasis.

- **GI parasitism**

Goats do not develop the same age-related immunity to internal parasites as occurs in sheep and cattle. Furthermore, they tend to metabolise anthelmintics more rapidly than sheep. As a result, anthelmintic-resistant nematodes are more common in goats than in sheep.

- **Trace element deficiencies**

There is good circumstantial evidence that goats are more susceptible to deficiencies of selenium, iodine, copper and possibly cobalt than either sheep or cattle.

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Chapter 13

The Nervous System

C.R. Huxtable

Introduction

Aims and scope of the presentation

There are numerous important neurological diseases in which there are no microscopic let alone macroscopic lesions, but in keeping with the theme of the meeting, the presentation will be based around a selected range of conditions that are common or well known, and in which gross pathological changes are significant in diagnosis. In the course of the discussion of these specific entities, aspects of a more general nature will also be addressed. These notes are summary in nature, there being adequate detail available in standard reference texts and on the web. The accompanying Power Point slideshow however should provide a useful body of complementary visual material.

Since the theme of this meeting is gross pathology, no reference list or bibliography is provided, as the basic information is readily available in standard texts. However a list of websites for visual material will be made available at the meeting.

The pathological conditions to be discussed are:

- Polioencephalomalacia
- Focal Symmetrical Encephalomalacia
- Acute Bacteraemic leptomeningitis
- Acute Bacterial and Mycotic Meningoencephalitis/myelits
- Cerebro-spinal Abscess and Suppuration
- Caprine Lentivirus Myeloencephalitis
- Ovine Foetal Copper Deficiency
- Phalaris poisoning
- Ceroid-lipofuscinosis

Sampling the CNS

The nervous system is the problem child when it comes to necropsy in the field, especially of cattle and other large ruminants. I think most pathologists would agree that there is a high rate of poor sample submission for the CNS. The first problem is getting the brain and/or cord out with a minimum of effort, and without "mooshing" the tissue. Various cunning techniques have been devised but it can still be a chore

and takes practice and a good attitude. The second problem is the need for some very basic neuroanatomical knowledge coupled with an understanding of which clinical signs correlate with certain regions of the brain and cord. Oftentimes diagnostic sweat and toil are negated by the submission of the wrong bits. This problem also puts the onus back on the sampler to be well prepared. With the right understanding and background knowledge, any operator can devise his/her own tricks of various trades to obtain diagnostic samples efficiently and even enjoyably. My advice – use your imagination but make it soundly based. All sorts of tools from angle-grinders to embryotomy wire to axes and tomahawks can with practice be used to good neurodiagnostic effect. Small gashes and slashes don't usually spoil the tissue –squashing and mushing does.

Hot tip - if sampling in the field is a big problem, consider taking heads and spinal segments back to base and working on them there.

Pseudolesions

- Meningeal melanosis
- Meningeal vascular prominence
- Venous sinuses

Polioencephalomalacia (PE)

General

This "disease" is really a reaction pattern following a single episode of acute necrotizing injury to cerebral grey matter. Aetiological factors include thiamine deficiency, thiamine unavailability (including rock fern poisoning), hydrogen sulphide poisoning (cattle) and perhaps others. The pathogenesis probably involves interference with oxidative energy metabolism at sites of high demand.

Distribution and character of the lesions

Typically bilaterally symmetrical and extensive, and classically involving the dorso-lateral cerebral cortex, with involvement of thalamic and brainstem nuclei, particularly the caudal colliculus.

Lesions consistent with this diagnosis will vary in appearance according to their age.

1. In most situations **acute phase** lesions are to be expected, i.e. involving tissue actively undergoing necrosis and removal, and reflecting ischaemia and vascular injury of **one to several days** duration.

2. In a few cases, inactive, end-stage changes will be found i.e. reflecting permanent loss of neural tissue with stable residual cavitations or surface distortions. This takes **weeks to months** to achieve.

3. Sometimes changes will reflect a time course intermediate between acute and end-stage disease.

Acute phase changes

The brain overall is frequently **swollen**, as detected by flattening of cortical gyri and herniation of the cerebellar vermis (through the foramen magnum) and caudal cerebral hemispheres (under the tentorium cerebelli). This may also compress the brainstem dorso-ventrally.

The directly affected tissue is softened, discolored (yellowish) and sometimes haemorrhagic. It is important to remember that **changes may be subtle**. In such cases, transection of the fresh brain and careful inspection may reveal lines of separation where necrotic cortical grey matter cleaves away from adjacent normal tissue.

An additional useful feature is that necrotic tissue will often fluoresce under UV light (Wood's lamp), even when not otherwise conspicuous. This also applies to fixed tissue.

Submission for histologic confirmation should include at least a hemibrain.

End-stage changes

Progression to this stage requires that the animal has survived the initial insult by several weeks or months. Net tissue loss at lesional sites leaves cystic cavities or surface deformities. In many cases these can be subtle, but in some very spectacular.

Focal Symmetrical Encephalomalacia (FSE)

General

This is a tissue lesion that is recognized as a disease-specific diagnosis in sheep when it occurs in the basal forebrain. The cause is the epsilon toxin of Clostridium perfringens type D, and FSE is thus part of the spectrum of classical clostridial enterotoxaemia, being a manifestation of a subacute rather than a peracute form.

Distribution and character of the lesions

Bilaterally symmetrical in the **internal capsule** and often **cerebellar peduncles**. Sometimes there is another pattern involving the subcortical white matter and dorso-lateral thalamus. In contrast to PE it is predominantly a **white matter** lesion.

The lesions are caused by toxic injury to blood vessels at these sites, producing fluid effusion, haemorrhage and ultimately infarction. The gross changes seen are thus somewhat similar to PE in that early

changes involve softening and often haemorrhage in the affected areas. Lesions would cavitate over time, but most animals die in the acute/subacute phase.

It is worth remembering that even if gross changes are not present, the vascular injury is often evident **microscopically** and the submission of brain is very useful for trying to establish a diagnosis of ET, which is often a "garbage bin" diagnosis when ruminants die suddenly and are variably autolysed at necropsy. The brain undergoes PM autolysis relatively slowly and can be a very useful specimen in these circumstances.

Acute Bacteraemic Leptomeningitis

General

The great majority of bacterial infections of the CNS of ruminants are haematogenous, and according the agent involved, may 1) extensively involve both the neuroparenchyma and meninges (see below), or 2) remain largely restricted to either the meninges or parenchyma. The common organisms are coliforms, streptococci and pasteurellae.

Infections whose localization tends to be meningeal, while sparing the parenchyma may however also involve the choroid plexuses and ependymal surfaces of the ventricles. Not infrequently they also involve the serous membranes, joints and eyes (particularly streptococcal infections).

These infections often involve animals in the first days of life, in which case they reflect deficiencies in resistance, such as failure of adequate transfer of colostral antibodies. The organisms involved may not be classical primary pathogens.

In somewhat older animals the organisms may be more typical primary pathogens.

The clinical disease produced is generally acute, severe and rapidly fatal. It may begin with anorexia, pyrexia and drowsiness and progress to diffuse neurologic signs that may include paresis, ataxia, abnormal nystagmus and head tremor. Terminally prostration, opisthotonus and semi-coma supervene. Occasionally there may be seizures.

Distribution and character of lesions

As there is extensive to diffuse acute inflammation of the leptomeninges, varying degrees of leptomeningeal hyperaemia with fibrinous or purulent effusion are expected. Inflammatory exudates gravitate ventrally and accumulate over the ventrum of the brainstem. Dorsally it pools in the cerebral sulci. Inflammatory effusion may give the leptomeninges a grayish to yellowish and thickened opacified appearance.

Considerable swelling of the brain may be in evidence. This can be manifested in various ways – 1) flattening of cerebral gyri, 2) herniation of the cerebellar vermis, 3) herniation of the parahippocampal gyri under the tentorium with dorso-lateral compression of the brainstem.

Transverse sections of the brain may reveal swelling and reddening of choroid plexuses and discoloration and roughening of the ependymal surfaces of the ventricles (and also the compression of the brainstem mentioned above). In animals that survive several days, dilation of the lateral and third ventricles will follow plugging of the aqueduct, and exudate may be found within the ventricles.

As noted above fibrinous to fibrinosuppurative exudates may be found in serous cavities, joints and eyes.

Acute Bacteraemic Meningoencephalitis/myelitis

General

Here we consider those acute haematogenous bacterial infections, which while often involving the meninges, target the parenchyma of the CNS for major injury, albeit indirectly via the production of vasculitis.

The archetype for this pattern of disease is **Bovine Thrombotic Meningoencephalitis (TME)**, caused by septicaemic infection with Hemophilus somnus. It has classically been documented as a disease of lot-fed beef cattle at around a year of age, but can occur in other situations.

Clinical signs are similar to those described above for leptomeningitis.

Distribution and character of the lesions

Septicaemic localization is primarily onto the endothelium of blood vessels in various organs, including the CNS. The resulting underlying disease processes of vasculitis and thrombosis produces haemorrhagic septic infarcts deep within the substance of the brain and spinal cord. These appear as soft red-brown foci from a few millimeters to several centimeters in diameter, which often are concentrated at the junction of grey and white matter, or close to the surface.

Since there is also meningeal localization, hyperaemia, exudation and opacification of the leptomeninges are expected.

The acute, severe and extensive nature of the process will also predispose to the changes associated with brain swelling (see above).

In other organs systems, vasculitis and secondary infarction often occur in the myocardium and skeletal muscles, and fibrinopurulent synovitis and serositis may be seen.

A similar disease but with typically much less spectacular gross lesions in the CNS is **Sporadic Bovine Encephalomyelitis (SBE)**, caused by a strain of Chlamydia spp. Animals 6 months to 1 year of age are most susceptible. Like TME the fundamental process is generalized vasculitis that involves blood vessels throughout the brain and cord. However infarction is on a much smaller scale, probably because smaller vessels are involved, and grossly visible haemorrhages and infarcts are not reported to be common except in unusually florid cases. Some brain swelling may often be appreciable, and this in combination with fibrinous polyserositis would be suggestive findings.

Cerebro-spinal Abscesses/suppuration

General

Here we are highlighting those sporadically occurring, subacute to chronic pyogenic infections that tend to result in one or a few localized suppurating lesions. Organisms commonly implicated are Arcanobacterium pyogenes and Pasteurella sp.

Abscesses involving the CNS are generally either epidural or intramedullary, and the route of infection may be embolic or by extension from an adjacent structure.

Epidural lesions frequently arise via the extension of infection from adjacent skeletal structures, although this itself, particularly in the spinal column, may be haematogenous in origin. Common loci from which extension may occur include the ethmoid, the nasal sinuses, the middle ear, and the vertebral bodies. The infection may be contained and confined by the dura, or may extend to the underlying nervous tissue. Subdural containment is rare.

Intramedullary lesions that are the result of septic thrombo-embolism are usually located in the cerebral cortex at the junction of the grey and white matter, or in the hypothalamus. Large septic emboli are most likely to arise from bacterial endocarditis. Abscesses that result from direct extension will be adjacent to the site from which extension arose. Infections in the nasal and paranasal cavities may extend into the brain via passage through the complex of valveless veins that connect with the dural sinuses. A similar situation can occur in the spinal canal when infections associated with tail docking can track along vertebral venous sinuses.

Distribution of lesions as a guide to pathogenesis

Frontal/olfactory abscess/suppuration suggests extension from the ethmoid or sinuses and may be associated with dehorning wounds, nose rings, fighting wounds in males, nasal bots in sheep,

Superficial cerebral or epidural abscess/suppuration suggests extension from adjacent sinuses or infected calvaria

Deep cerebral or hypothalamic abscess/suppuration suggests septic embolic infection

Pituitary abscess/suppuration suggests infection tracking from the nasal tissues via venous channels.

Cerebello-pontine abscess/suppuration suggests extension from the middle ear/tympanic bulla

Spinal epidural abscess/suppuration when thoraco-lumbar suggests extension from vertebral body osteomyelitis, usually septic embolic, and often located dorsal to the heart or the kidneys. In the lumbo-sacral region it may reflect infection tracking along vertebral venous sinuses from the base of the tail.

Haematogenous Mycotic Meningoencephalitis/myelitis

General

Haematogenous mycotic infections are sporadic events that generally reflect some severe defect of resistance or immunocompetence at any stage of life. This is likely to be severe debility, lack of colostrum, prolonged antibiotic therapy etc. Agents likely to be involved include Aspergillus and Mucor sp. A more specific association occurs in adult cows that abort because of placental infection with the fungus Mortierella wolfii. The process of abortion may result in fungaemia and potential localization in tissues including the CNS.

Character of lesions as a guide to pathogenesis

Because these agents love to invade arterial walls, the character of the lesions is heavily influenced by vasculitis, thrombosis and infarction. Thus large lesions may appear as areas of discoloration and softening or even cavitation.

No particular sites of localization are documented, but it is my impression that the caudal fossa is often the major site in calves and lambs.

Caprine lentivirus (CAEV) myeloencephalitis

General

As part of the disease spectrum associated with the caprine lentivirus, this neurologic disease is mostly encountered in goat kids around 2-4 months of age. The fundamental disease process is an intense, immune-mediated demyelinating inflammatory reaction, and is thus centered on white matter. Severe demyelination may progress to necrosis, mineralization and cavitation over some weeks. Clinically there is acute onset, rapid progression and lack of recovery.

Distribution and character of lesions

Single (sometimes unilateral) or multiple focal lesions are produced predominantly in the caudal brainstem and spinal cord, and clinical signs reflect this fact with upper motor neuron and general proprioceptive deficits predominating. However a range of signs is possible, since focal lesions can extend all the way to the frontal lobes in rare cases.

Acute lesions (less than one week) in the spinal cord consistent with this diagnosis will appear as localized, random, asymmetric areas of dull white to brown discoloration at the periphery, extending from the surface to impinge on the grey matter, and often with considerable associated tissue swelling.

In the caudal brainstem lesions have a similar character and are centered on white matter tracts but may extend to grey nuclei. In the cerebrum focal lesions are often periventricular.

More chronic lesions (one to several weeks) may exhibit softening and even cavitation.

Foetal Copper Deficiency (Swayback)

General

Primary or secondary deficiency of copper in foetal lambs can produce two different clinical entities – congenital "swayback" in the neonate and "enzootic ataxia" in lambs from a few days to several months of age. In the former about half the cases will have gross changes in the cerebral white matter. In the latter, and the remaining 50% of neonates, no gross changes are evident, but degeneration of populations of neurons is detectable microscopically.

In copper deficient foetal goats however, congenital disease and gross cerebral lesions are rarely produced, and delayed-onset disease with microscopic lesions is more typical, often with cerebellar degeneration and marked degeneration of spinal motor neurons and nerves (both rare in lambs)

Distribution and character of lesions

Typically in swayback there is bilateral symmetrical transformation of the white matter throughout the cerebral hemispheres (corona radiata and centrum semiovale) ranging from gelatinous oedema to porencephaly/hydranencephaly. In extreme cases the hemispheres are reduced to a state of collapse when the calvaria is removed. In less severe cases there will be varying degrees of cystic degeneration of white matter and ventricular dilation.

Phalaris Poisoning

General

Neurologic manifestations of phalaris poisoning (Phalaris staggers) may be delayed for weeks after exposure to the plant and grossly visible changes may be in evidence in the CNS in some cases. This is due to the accumulation of a pigment within neurons, leading to the discoloration (sometimes marked) of grey matter. It will also cause a similar discoloration of the renal medulla. This storage lesion is probably an epiphenomenon rather than causally related to the functional deficits, which are thought to be due to serotonin-related phytotoxins. The stored pigments are probably indolic metabolites.

Distribution and character of lesions

Pigment storage occurs throughout the brain, cord and ganglia, and can cause a distinctly greenish discoloration which is universal if severe. If less intense it will be evident in brainstem nuclei, spinal grey matter and dorsal root ganglia.

Ceroid-lipofuscinosis

General

This type of storage disease process centers around the accumulation of lipopigments in neurons to the extent that the color of the fresh brain may be altered. Ovine inherited Ceroid-lipofuscinosis is, as far as the author is aware, documented only in South Hampshire sheep in New Zealand. However in Western Australia neuronal lipofuscinosis has been documented in livestock exposed to the introduced South African pant Trachyandra divaricata. As is the case with Phalaris, the storage process probably has no direct correlation with clinical deficits, but that is not the case with the inherited disease. It should be pointed out that at this point in time, the only thing these two diseases have in common is neuronal pigment storage, and metabolically they may well be (probably are) fundamentally different.

Distribution and character of lesions

In both diseases lipopigment accumulation causes rusty brown discoloration of grey matter. In the case of Trachyandra-associated disease, the pattern is similar to that described for phalaris, except that the kidney is not involved. However, in the genetic disease the storage process is neuronotoxic, and after about four months of age neuronal loss progressively leads to atrophy particularly of the cerebral cortex.

Chapter 14

Acute Systemic Conditions:
Diagnosis and Management of Sudden Death in Ruminants

Roger Kelly

Introduction

Perhaps we'd better first **define** sudden death for the purposes of this discussion. One could start with: 'The discovery of dead, well-nourished non-perinatal animals within 2 days of them having been observed apparently healthy". One might quibble about the interval; it could depend upon the management system and species.

Gross necropsy findings

A sad feature of sudden deaths is that they are, by definition, unexpected and rarely observed, so the post-mortem interval is more likely to be long. Couple that with more rapid decomposition (see below), and it is understandable that post-mortem changes usually complicate the interpretation of the gross pathology in this class of mortality.

If there are any specific pathological findings, these will often be obscured by the more spectacular non-specific changes. To make matters worse, stockowners quite naturally believe that a dramatic event such as sudden death should be accompanied by equally dramatic gross necropsy findings, and they tend to question your diagnostic competence when you can't immediately point out to them the cause of death. They of course expect some clear-cut directions to be given to protect the remainder of the group from loss.

If the animals really have died quickly, with few if any signs observed (*ie*, the lack of observed illness is not merely the result of poor observation by an absentee manager), then certain assumptions can be made about the gross **necropsy findings**. The most important of these is the fact that most of the pathological changes will be probably be **unspectacular** and **non-specific**, since it usually takes time for classical text-book pathological changes to develop (think of abscesses, bronchopneumonia, etc).

Pulmonary congestion and oedema can be almost guaranteed, since blood flow to lungs reflexly increases with hypoxia. After death this congestion is exacerbated by gravity in the lower parts of the lung (**hypostasis**). Hypoxia and various substances like fibrin degradation products also damage the endothelium of pulmonary capillaries, which therefore tend to leak protein-rich fluid into the pulmonary interstitium and alveoli. This is **oedema**, whose most obvious feature is the stable foam produced when the fluid mixes with air and surfactant from the alveolar wall. The volume and tenacity of this foam can be an effective asphyxiant which rapidly finishes the animal off. We will all die with

some measure of pulmonary congestion and oedema (unless someone cuts our throat).

Rumenal tympany is likewise expected as a post-mortem change after sudden death; it will be enhanced by the fact that the animal's body temperature is either normal or elevated at the time of death, and the rumen is more likely to be more filled with fermentable ingesta than that of an inappetent animal dying more slowly.

Non-specific **intestinal changes** will be inevitable: the enzymes from enterocytes and bacteria loosen the villous epithelium within 10 minutes of death, and can even cause enterocytes to slough in the live animal if circulation in the bowel is sufficiently compromised (a common complication of circulatory shock). Since blood tends to pool irregularly in the bowel as the circulation fails, it is usual for parts of the small bowel in particular to show irregular and sometimes intense congestion. The lumen will always contain sloughed epithelium mixed with mucus (a very convincing facsimile of pus), and when this is mixed with blood that has oozed from the capillaries in a shocked individual, only an arrogant investigator would exclude haemorrhagic enteritis from the diagnostic possibilities without laboratory confirmation.

Serosal haemorrhage. Mention has been made above of the endothelial damage caused by hypoxia. Severe systemic illness also results in circulation of bacterial endotoxin and nasty substances absorbed from the bowel. All these insults prevent the endothelium from doing one of its most important functions, which is inhibition of the coagulation cascade. The resulting initiation of the clotting cycle (**disseminated intravascular coagulation**) results in rapid non-endothelial-mediated fibrinolysis (to keep the blood flowing), followed by rapid exhaustion of soluble clotting factors and then by spontaneous bleeding. This is usually most evident and spectacular on serous membranes such as pleura and epicardium. Perhaps the negative pressure in the thorax combines with agonal gasping to produce the pleural bleeding, while the poor old heart has to thrash away after everything else has closed down, so it can be excused for bleeding a little in the agonal period.

Thus, in a case of necrotic hepatitis (black disease), there will often be spectacular diffuse serosal congestion and haemorrhage, as well as pulmonary congestion and oedema, while the characteristic focus of necrotic liver, with its tell-tale fine haemorrhagic border, may be relatively small and lurking deep in the liver parenchyma and can be easily overlooked. To complicate the picture in this disease, the liver is notoriously susceptible to rapid post-mortem putrefaction that can rapidly obscure the pathognomonic lesion.

Causes of Sudden Death

Sudden death is broadly attributable to one or more of the following crudely classified causes: **acute infections**, **intoxications** and **physical** or **environmental disasters** such as electrocution, asphyxia and trauma, acute water deprivation and hyperthermia and the like. Of

these, only trauma is likely to be diagnosed easily at gross necropsy. So now we should look at the other causes in turn for strategies of diagnosis.

Acute infections

Clostridial infections are some of the most important cause of sudden death, and their diagnosis is difficult to confirm because of the rapidity with which saprophytic and pathogenic anaerobes proliferate after death. Routine bacteriological samples will usually contain these organisms, whether or not they are pathogenic, and they will tend to overgrow significant pathogens. In order for the microbiologist to get a better idea of the situation at the time of death, it is essential to include a panel of **impression smears** from likely parts of the carcass: from oedematous fascial planes in muscle, for example. Immunofluorescence can be used on these to make specific diagnoses, but even with simple Gram stains they can be very useful. Although the gut will obviously contain numerous bacteria of great variety, the importance of a smear of jejunal content for Gram-staining cannot be over-emphasised, since a surprisingly pure lawn of *Clostridium perfringens* can often be seen in direct smears of small bowel in cases of enterotoxaemia (absorption of epsilon toxin produced by this bacterium in the gut in sheep and calves). A segment of rib can also be a very useful submission, since it is slow to be invaded by post mortem invaders and can be easily chilled for transport.

Enterotoxaemia will always present diagnostic difficulties, since its definitive diagnosis rests on the demonstration that sufficient ε toxin has been absorbed from the gut to fatally affect the animal. Unfortunately, methods of detection of this toxin are only sensitive enough to detect its presence in the gut lumen, where, unfortunately, it may be produced after death by *C. perfringens* type D. Until we develop methods of detection of the toxin in fluids such as aqueous humor or cerebrospinal fluid, probably the most confident diagnosis of this disease is made on the histological demonstration of a peculiar periarteriolar oedema in certain parts of the brain, at least in sheep. Recent work has shown that this brain lesion is also seen in naturally occurring cases of enterotoxaemia in goats, and in experimental enterotoxaemia in cattle. So brain should always be submitted from all cases of suspected enterotoxaemia, no matter what the species.

Smears taken at necropsy are of supreme importance in cases of **anthrax**, of course. Ideally, anthrax is suspected on the basis of history of being endemic in the area and of sudden death with bloodstained discharge from several orifices, and a blood smear will be made from an ear vein before the carcass is disturbed, and stained with new methylene blue and examined on the spot for the large bacilli with metachromatic capsules. In practice, of course, this is rarely if ever done: few field people carry a suitable microscope or stains to field necropsies, or have the confidence to interpret such preparations under field conditions. So the necropsy will probably go ahead and the cause of death (with luck) will be suspected on finding the huge, pulpy black spleen. Realisation

will then be accompanied by a nasty sinking feeling as the zoonotic risks are remembered from long-past lectures, and frantic efforts at personal clean-up and carcass incineration will get under way (probably on a day of maximum fire danger). None of this worst-case scenario should, however, distract from the fact that the smear made in the field will usually be better than one made in the lab from fermenting internal organs, even if the smears have to go to the diagnostic laboratory to be examined. So **always submit direct smears**.

The same sorts of principles apply to cases of sudden death caused by **piroplasmosis**, which will also have large dark blackberry-jam spleens. Peripheral blood smears are just as important in these cases; in particular, the smear should be of **capillary** blood, since erythrocytes parasitised by *Babesia bovis* tend to stick to endothelium of cutaneous and cerebral capillaries. In a rotten carcass dead of babesiosis, scraping the tip of the tail until it is moist, then squeezing capillary blood to the surface, will yield smears in which the parasites can be seen or their antigens demonstrated by immunofluorescence. Better still is to examine the brain: even in a rotten carcass, the gray matter of the brain will usually show the deep pink blush of erythrocyte-plugged capillaries in *B. bovis* infection, making this one of the few specific gross changes that will survive putrefaction in these cases. The other textbook features of babesiosis (red urine, haemoglobinuric nephrosis) may easily be lost by bladder emptying or destruction by rot. Cerebral tissue tends to be much better preserved than internal organs.

Investigation of **intoxications** is dealt with in another session of these workshops.

Physical and environmental catastrophes

History is of course critically important in these investigations. An outbreak of sudden deaths in a group of Victorian Angus cattle, which had recently been transported to a Queensland feedlot in summer, initially puzzled investigators because there were no deaths in Brahman cattle at the same time in the same feedlot. Perhaps some plague endemic in the Queensland Brahmans had infected the poor Victorians? Turned out that the watering system had broken down during a weekend heat wave, and the stoic Brahmans were better acclimatized to the extreme conditions.

Five dairy cows were found dead in one corner of a holding yard. They'd been heard bawling frantically seconds before, and survivors were still careering around the metal enclosure. The owner in that instance had the presence of mind to check the wiring in the adjacent shed; otherwise he might have been electrocuted, too. He said he made the diagnosis because "The bellowing had exactly the same pitch as that of a cow that once got an electric shock in the bails" and he'd never forgotten it. Some things they don't teach in vet school.

A Strategy for Investigators of Sudden Death

The notes above show that there are some extra stresses placed on the investigator of sudden death; presumably that is why television scriptwriters seem to be endlessly obsessed with them. What is really useful in these circumstances is a flexible but logical investigative framework upon which to hang the investigation; a planned sequence that can nevertheless be modified to suit the circumstances. What follows is one version which might reduce the regrettable omissions that so often confound diagnosis.

Animal/s reported dead by owner/manager, who wants you to attend

During the first phone contact, reel off a list of the questions below, to be answered when you get to the property (this will allow checking of records, if necessary: better than guessing, and wasting time on the phone):

Questions

- Age, breed, sex, numbers & origin of animal/s and cohorts.
- Duration of current location.
- Feed management.
- Water.
- Most recent introductions.
- Vaccination history.
- Treatment.
- Precise timetable of current event.
- How are the cohort animals?
  (*i.e.*, manager to go and check them, and have a good look at the environment, while awaiting your arrival).

Action when you get there

- Look at any survivors that are showing clinical signs.
- Think about alternatives to routine necropsy (*i.e.* for the anthrax cases).
- Get stuck into necropsies (owner can answer the questions at the same time).
- At display stage of necropsy, stop and try to select which option of the three basic **causes** is the best bet.
- Take samples, with emphasis according to most likely cause.
- Advise on management of survivors according to most likely cause (*e.g.* alternative pasture/rations when poisoning is, on balance, the most likely option). Some sort of advice is nearly always appropriate before you leave the property.

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Chapter 15

The Urinary System

C R Huxtable

Introduction

Aims and scope of the presentation

With these notes and an accompanying powerpoint slide show, we will review some pathological states of the ruminant urinary tract. The focus will be on the most common conditions and the gross anatomical changes associated with them. The emphasis as far as practicable, will be on FIRST making an assessment of the basic nature of any disease process thought to be present, before SECOND, listing possible aetiologies.

In terms of frequency of occurrence there is little doubt that the most significant urological problem across the ruminant species is urethral obstruction, with nephrotoxic injury likely to run second. Primary nephritis is generally of sporadic occurrence as is primary urinary tract neoplasia, apart from that associated with exposure to bracken fern. Also sporadic are renal amyloidosis (included) and developmental anomalies (not included)

In terms of making **gross** diagnoses of renal disease, it is frequently not possible to be highly specific. Oftentimes, renal lesions are merely part of a multisystem disease (e.g. malignant catharral fever, lymphoma), or simply reflect severe disease in another system (e.g. haemolysis,myolysis, hepatic disease, enterotoxaemia). Regardless of aetiology, **acutely** damaged or inflamed kidneys tend to be symmetrically swollen and either pale mottled or dark mottled. **Chronically** damaged or inflamed kidneys may also be greatly enlarged, but variably distorted by fibrosis, or they may be pale, contracted and toughened by fibrosis. There is thus no shame in making an initial diagnosis of "acute" or "chronic nephropathy" and in the absence of additional gross clues, leaving further refinement of the diagnosis to the microscope or lab test

In the lower urinary tract the detection of uroliths and associated pathologies is generally fairly straightforward, as is the differentiation of acute versus chronic injury to the mucosa of the bladder. The major intellectual exercise involves identifying predisposing and underlying causes.

Since the theme of this meeting is gross pathology, no reference list or bibliography is provided, as the basic information is readily available in standard texts However, a list of websites for visual material will be made available at the meeting.

Obstructive Urolithiasis

General

Although macro-uroliths can form and grow in the renal pelvis as well as in the bladder, they seldom obstruct the renal pelvis or ureters. Urethral obstruction however, is possibly the most common fatal affliction of the male urinary tract in all ruminant species. The various structural peculiarities of the ruminant penis provide ample opportunity for urethral obstruction and the predilection sites are well known. In addition, castrated animals are at higher risk due to suppressed development of the penis and urethra. The pathogenesis of urolithiasis is complex and beyond the scope of this presentation. Suffice it to say that diet, body water balance, urine flow and infection have been implicated to varying degrees in relation to different types of uroliths. The major culprits in ruminants are struvite, silica, carbonates, oxalate, and "Clover stones" in sheep. According to the chemical nature of the precipitated material, the obstructing mass can be a hard "stone", or a plug of fine crystalline or soft sludge. As well as causing the problem of urine retention, obstructions promote bacterial growth in the stagnant urine, a significant factor in many cases.

Location and character of lesions

The common sites of obstruction in the **penile urethra** are the ischial arch, and the sigmoid flexure. Lodgement of a hard stone will generally cause ulceration at the site; acute secondary bacterial infection will frequently occur, sometimes ascending to the bladder. Ulceration and acute urethritis predispose to urethral rupture, and the leaking urine will track into the subcutis of the prepuce and perineal area, leading significant oedematous swelling. The presence of infection and the irritant nature of the urine rapidly cause acute cellulitis, a major factor in fatal outcomes. In these situations rupture of the bladder is not common, and there is insufficient time for hydronephrosis to develop (see below). However, in occasional cases circulatory compromise in the kidneys can lead to quite massive intra- and peri-renal haemorrhage.

In sheep, obstruction of the **vermiform appendage** may allow the penile urethra to remain intact, thus placing maximum pressure stress on the bladder. Over-distension of the bladder compromises blood flow within its wall, leading to oedema, degeneration and after several days eventual rupture, usually at the vertex. By this time some dilation of the renal pelvis and calyces may also be evident.

Hydronephrosis

General

Hydronephrosis is the anatomical alteration of the kidney(s) that results when there is continued glomerular filtration in the face of significant obstruction of the free-flow of urine from the renal pelvis. Thus it can be unilateral or bilateral and its severity depends upon the degree and acuteness of obstruction, which might occur anywhere from the proximal

ureter to the urethra. Obstructing lesions may be external and compressive, intramural, or intraluminal, and be due to malformations as well as acquired lesions. Hydronephrosis can be a congenital condition.

Initially, the pelvis and calyces expand, the renal medullary tissue regresses, and in the most severe case there is progressive transformation of the affected kidney to a urine-filled cyst with a rim of cortical tissue. Regression of renal tissue is due both to apoptosis and to ischemic necrosis brought about by vascular compromise. **Partial** or **intermittent** rather than complete obstruction to urine flow provides the most potential for a severe lesion since this allows glomerular filtration to continue over a long period even as renal tissue disappears.

Character of the lesion under various circumstances

Some generalizations can be made on the effects of different sites and degrees of obstruction.

Long term partial/intermittent **urethral** obstruction (an uncommon event), would be expected to cause bilateral hydro-ureter and moderate bilateral hydronephrosis. **Acute complete** urethral obstruction (a common event) causes death before there is much opportunity for hydronephrosis to develop. Generally the kidneys are swollen and the pelvis and calyces dilated but not enlarged. Occasionally massive intra- and peri-renal haemorrhage can occur.

Long term, unilateral, partial/intermittent **ureteral** obstruction would have the potential to cause the maximum degree of hydronephrosis on the affected side, together with compensatory hypertrophy of the unaffected kidney. Alterations in the affected ureter would depend upon the nature and site of the obstruction. Acute, complete, unilateral ureteral obstruction might produce a moderate degree of hydronephrosis before renal circulation would shut down, glomerular filtration would cease and renal atrophy would follow.

Patterns of Cystitis

General

Cystitis is mostly caused by bacterial infection derived from the rectal/perineal flora, and predisposed to by urinary stasis/stagnation and/or mucosal trauma induced by such things as catheterization or uroliths. Sometimes it stems from associated genital tract infections. There is a fairly constant threat of bacterial infection even in the absence of urolithiasis, and any animal subject to urinary stasis/stagnation of whatever cause is at risk.

In **acute** cystitis reactions, the characteristic appearance of the lesion (see below) will make a morphologic diagnosis relatively straightforward. A specific diagnosis will depend on the identification of associated lesions or underlying predisposing causes. As mentioned in the preceding segment, severe acute bacterial cystitis is a frequent complication of urethral obstruction by uroliths in cattle. Apart from bacterial infections,

acute cystitis is often a major gross lesion of Malignant Catharral Fever in cattle and deer, and in some instances it may be caused by the presence of an irritant or toxin in the urine (as exemplified by cyclophosphamide in small animals or blister beetle toxin in herbivores in the U.S.). This is a possibility to keep in mind in cases where no other obvious cause can be identified.

Occasionally an acute change known as **"emphysematous cystitis"** will be encountered, in which the mucosa is transformed by the accumulation of interstitial gas bubbles. This is generally taken to indicate glucosuria and subsequent bacterial fermentation. In ruminants it has been recorded in animals receiving intravenous dextrose medication, and sometimes in enterotoxaemia.

In **chronic** cystitis reactions the gross pathology is dominated by the effects of hyperplastic changes in the mucosa and the massive accumulation of inflammatory cells within and beneath it. The least intense reactions occur in response to mechanical irritation by vesical calculi, while more intense reactions reflect chronic infection.

Distribution and character of lesions

In **acute bacterial cystitis** there is usually a diffuse lesion in which the mucosa is swollen and hyperaemic over its entire surface, and the bladder content sanguinous or even containing blood clots. In lesions of greatest severity, fibrino-necrotic changes can produce a dirty, yellowish adherent sheet over the mucosal surface. In **Malignant Catarrhal Fever** mucosal hyperaemia may be patchy and submucosal haemorrhage is localized and variably extensive.

In **chronic cystitis** the entire mucosal surface may be irregularly reddened, thickened, folded, and in greatest severity, polypoid. Individual polyps may break down and haemorrhage focally, or undergo cystic mucoid degeneration. Occasionally the formation of myriad aggregations of lymphocytes under the mucosa gives rise to a **follicular** pattern of chronic cystitis, in which the surface is covered with small grayish nodules.

Bracken Fern and Bladder Lesions

General

The clinical state of enzootic haematuria in cattle, and occasionally sheep, is highly associated with chronic exposure to strains of bracken (*Pteridium sp.*) and perhaps other ferns, producing a range of toxins and carcinogens (notably ptaquiloside). A bovine papilloma virus may also play a role. A spectrum of proliferative lesions can develop in the bladder, beginning with mucosal angiomatous, fibromatous and papillomatous tumours, but progressing to malignancies such transitional or squamous cell carcinoma, haemangiosarcoma, fibrosarcoma or leiomyosarcoma, often in combination.

Distribution and character of lesions

The changes tend to be patchy rather than diffuse, but may be extensive and confluent. When benign they are expected to be confined to the mucosal surface and may be in multinodular clusters. When malignant they are expected to be extensively ulcerated and more deeply penetrating, and metastatic deposits may occur in iliac lymph nodes and in advanced cases, in the lungs.

Acute Nephrotoxicity

General

Nephrotoxicity is a reasonably frequent event in our part of the world, usually arising from plant toxins, and usually manifesting as an acute and often fatal episode. Occasionally the toxin is a drug, or environmental chemical. The prime target for chemical nephrotoxins is the proximal tubular epithelium, and the classical response is acute necrosis of these cells with shedding of necrotic debris into the tubule lumens (acute tubular necrosis or ATN), leakage of filtrate from the damaged tubules, and reflex changes in renal blood flow (because these tubular changes predispose to massive wasting of sodium due to failure of resorption, there is a rapid vascular response to minimize glomerular filtration by shutting down blood flow). In general, an animal with acute renal failure resulting from ATN will take several days to die from the resulting metabolic crises, and gross changes in the kidneys are expected. The general term for this predominantly degenerative type of lesion is **Nephrosis**, to distinguish it from predominantly inflammatory disease (Nephritis), but there is a degree of overlap between the two.

Character and distribution of lesions

Chemical nephrotoxicity affects both kidneys diffusely and evenly, and the dominant change is symmetrical swelling, probably largely due to leakage of filtrate into the renal interstitium. Despite the tightness of the renal capsule, this can lead to considerable renomegaly. The cut surface may appear "wet", and in some instances there is marked peri-renal oedema (something **not** seen in acute nephritis of any form). Reduced renal blood flow often produces cortical pallor to varying degrees. In some instances, mineralization of degenerate tissue will cause focal whitish spots and streaks, and perhaps a gritty texture. The intensity of all these changes can vary with particular circumstances and different toxins, and often it is not possible to grossly differentiate this lesion from some forms of nephritis (see below).

Pigment Nephrosis and Renal Microlithiasis

General

The general term "pigment nephrosis" can be applied to any state where a heavy load of pigment is accumulated in the renal tissues in sufficient quantity to cause gross renal discoloration. In one group are pigments

released into the plasma and entering the glomerular filtrate. In another group are pigments stored by metabolic disturbances such as in phalaris poisoning and lipofuscinosis.

"Renal microlithiasis" is the pathological state caused by the precipitation of crystals within the tubules. An alternative name might be "crystal precipitate nephrosis", and the archetypal lesion for this category is oxalate nephrosis. Crystal precipitation has also been seen in cases where sulphonamide drugs, administered to dehydrated animals, crystallize out in the collecting ducts, and can also be a finding in severe dehydration when endogenous solutes precipitate out at this site.

Character and distribution of lesions

In an acute severe episode of **haemoglobinuric nephrosis**, the kidneys are initially diffusely discolored brownish red to varying degrees of intensity according to severity. Any urine present in the bladder will also be discolored, and there is usually icterus and evidence of anaemia. In the ruminant world the archetypal haemoglobinuric disease is ovine (and occasionally bovine) chronic copper poisoning, with the added factor of acute hepatic necrosis and eventual bilirubinuria thrown in. This together with severe intravascular haemolysis will produce shock and hypotension, and this in turn can damage the kidneys, predisposing to some swelling as well as the discoloration.

Should the animal survive for a few days the diffuse renal discoloration disperses to become multiple streaks and foci in the cortex. With the passage of more time the residual haemoglobin is metabolized and retained as rusty-brown haemosiderin for many weeks. This is pattern is also seen in chronic relapsing haemoglobinuria.

Caprine "cloisonné kidney" is a benign pigmentary nephrosis involving the accumulation of ferritin and haemosiderin in the renal cortex, in the reticulated pattern that gives rise to the name for the condition.

Rhabdomyolyis has a similar potential to stain the kidneys, but is often not a feature of nutritional myopathies in the very young due to the low myoglobin content in the muscle of young animals.

In **bilirubin nephrosis** the kidneys are diffusely discolored to a kaki-olive drab or green/yellow shade, and if urine is present in the bladder, its froth will have a similar tone after being shaken up in a tube. Newborn calves and lambs may have congenital bilirubin nephrosis which probably reflects a temporary delay in the maturation of hepatic bile conjugation machinery.

In ovine **phalaris poisoning** greenish discoloration of the renal medulla (and cerebral gray matter) is a diagnostically useful finding although there is no renal malfunction. It is due to the lysosomal storage of indolic metabolites of the phytotoxins.

An incidental finding of this type is **melanosis**, either localized or extensive.

Acute **crystal precipitation** often produces produces pallor and a pattern of radial streaking particularly at the cortico-medullary junction. Sometimes close scrutiny of the cut surface and gentle scraping will reveal crystals to the naked eye.

Patterns of Nephritis

General

Nephritis can have infectious, toxic, or immune-mediated causes and the recognition of particular gross morphologic patterns, lesions in other organs systems and clinical correlations can provide a guide to aetio-pathogenesis. In this discussion we will refer to **five** different patterns of nephritis, categorized to give some indication of aetio-pathogenesis. As with all such schemes, it is not perfect and there are hazy and overlapping boundaries, but it basically works.

1. Interstital nephritis (also sometimes called "tubulo-interstitial")
2. Pyelonephritis
3. Septic embolic nephritis
4. Granulomatous nephritis
5. Glomerulonephritis.

At this stage it is also worth having a brief review of the **pathways of renal infection**

Infectious agents reach the kidneys via two major routes - 1) via the blood (**hematogenously**) or 2) by **ascending** from the lower tract. The agents are usually bacteria from the ano-perineal flora, and occasionally fungi.

Haematogenous infection

The characteristics of the common forms of hematogenous infection depend on the particular agent involved and exactly how it arrives in the kidneys. Thus bacteria may be "free" in the blood or carried "on board" clumps of septic embolic material of various sizes.

If the organisms are free in the blood they have the capacity to permeate the kidneys widely; if carried in emboli they will lodge wherever those emboli stick in vessels too narrow to give passage. Wherever they do end up their presence will provoke tissue injury, vigorous inflammation and therefore a form of **nephritis.** The characteristics of the inflammatory reaction will also depend on the type of agent - e.g. pus forming, granuloma forming etc.

In **leptospirosis** the organisms arrive in the kidneys via the blood, enter the nephrons and like a chemical toxin, cause diffuse **acute tubular**

necrosis, which is soon accompanied by extensive infiltration of the interstitial tissues by lymphocytes, plasma cells and varying numbers of neutrophils. There is no large scale focal destruction of tissue or abscess formation.

Small septic emboli tend to lodge in **glomeruli** and **peri-tubular cortical capillaries** although hematogenous infection can often extend right through the kidney to the deep medulla and pelvis (the renal medulla offers a very supportive environment for the growth of many organisms by virtue of its low oxygen tension, interstitial hypertonicity and high content of electrolytes and urea). The lodged emboli set up multiple small discreet sites of injury and depending on the nature of the organism, these sites may be suppurative or non-suppurative, and may predominate in the cortex **or** the medulla. This reaction is referred to as **septic embolic nephritis**.

Large septic emboli tend to lodge in **arterioles** or even **arcuate arteries** and therefore set up large focal sites of ischemic injury. This reaction is referred to as **septic infarction**, and is a serious potential complication of **bacterial endocarditis.**

Ascending infection

Particularly in female animals, the lower urinary tract is constantly at risk of bacterial infections from the heavily populated external genitalia and perineal region. Infection may ascend further to involve the **kidneys**, particularly as reverse peristalsis causes ureteral **refluxing** of septic urine during micturition.

Since the infection comes via this route the first part of the kidney to be involved is usually the renal **pelvis** and adjacent tissue, producing a **pyelitis**. Extension of the process can track it deep into the kidney and even right to the capsular surface. Because of this sequence of events the disease is called ascending **pyelo-nephritis.**

Character and distribution of nephritic lesions

Interstitial nephritis (IN) is a fairly loose term to describe a reaction pattern in which inflammation is judged to flare up diffusely throughout the kidneys, but without a focus on any particular tissue element. The formation of abscesses or granulomas is NOT a feature. Acute or subacute interstitial nephritis is the classical renal lesion of leptospirosis and malignant catarrhal fever, but is not particularly associated with any other specific **infectious** diseases. In some chemical intoxications, the initial tubular necrosis is followed by a tubulo-interstitial inflammatory reaction severe enough to be classed as IN, for instance acorn or oak-but poisoning.

In **acute leptospirosis**, renal pathology is often dominated by haemoglobinuria (see above), but if this is not present, swelling and multi-focal red/grey mottling reflect the extensive inflammatory infiltrates. In animals that survive and enter the **chronic phase**,

multiple, frequently confluent, gray/white cortical foci mark the sites of inflammation. This is not a specifically diagnostic lesion.

As interstitial nephritis of whatever cause becomes chronic, it is characterized by renal atrophy and fibrosis, rather than distortion and enlargement. In many of terminal cases it is difficult to discern what the original disease pattern may have been.

Pyelonephritis is a pattern of inflammation judged to begin in the pelvis (pyelitis) and/or peripelvic medullary tissue, from where it may extend further into the kidneys. Pyelonephritis has a couple of distinguishing features as a renal disease:

1. It always involves an **infectious agent**, usually organisms associated with the lower gut and perineal skin. Infections are often mixed.
2. It is a form of nephritis that can be **assymetric** and even **unilateral** on rare occasions.

The severity of the disease (and it can be **very** severe) depends on the destructiveness and the **extent** of the inflammation. Acute severe PN can be associated with extensive papillary/medullary **necrosis**; chronic PN with irregular **fibrosis** and either renomegaly or atrophy

Septic embolic nephritis is the pattern produced when bacteria or fungi localize at distinct multiple sites in the cortex (mostly) and medulla (less), after arriving in the bloodstream (obviously there is some overlap here with interstitial nephritis). The meat-inspection lesion known as "white spotted kidneys" in calves is an example of the process caused probably by E.Coli bacteraemia. **Septic infarction** is a more extreme manifestation of this process, and renal **abscess formation** is induced by certain agents such as *Corynebacterium ovis*, and *Arcanobacterium pyogenes.*

Granulomatous nephritis refers to the formation of distinct inflammatory masses that enlarge and distort the kidneys, usually due to sporadic infection with certain specific agents such as *Candida sp*, or other miscellaneous fungi. However, noteworthy in this context is the interesting lesion produced both in "hairy vetch" (*Viccia vilosa*) and citrus pulp poisonings in cattle.

Glomerulonephritis describes a reaction that begins with injury to glomeruli, but may extend into adjacent tubular and interstitial tissue. It is almost always caused by type 3 hypersensitivity reactions (deposition of circulating antigen-antibody complexes).

Since the pathologic processes begin in glomeruli, a major clinical feature is expected to be heavy persistent **proteinuria** ("protein-loosing nephropathy") which may progress to the **nephrotic syndrome** (hypoproteinemia and edema). Proteinuria is the result of the failure of the glomerular **protein filtration barrier**, a physiologic and structural

feature of the healthy glomerulus that in a healthy state prevents the urinary loss of plasma proteins.

As a glomerular disease intensifies, it will have adverse effects on the rest of the nephron because the renal tubules are "downstream" from glomeruli in terms of blood flow. When glomerular blood flow is impaired by glomerular disease, full-blown renal failure can ensue as tubular health and function deteriorate as well.

Macroscopically, in severe **acute** and **subacute GN**, both kidneys can become significantly **enlarged** and often mottled with a very fine pin-point stippled pattern, but they retain their basic shape.

In **chronic GN**, there is usually significant **renal atrophy and fibrosis**, with a fairly symmetrical reduction in kidney size and some distortion of shape.

Amyloidosis

General

Renal amyloidosis is a sporadic, usually idiopathic condition, and amongst ruminants most likely to be encountered in dairy cows. It is essentially an extra-cellular protein storage disease, resulting when highly protease-resistant amyloid fibrils are generated at a rate which far exceeds any capacity to remove them. Most often the disorder is of the "secondary" type, arising when precursor amyloid SAA protein is released excessively into the plasma (mostly from the liver) as one of the "acute phase reactants" in states of persistent antigenic stimulation. The stored amyloid protein is derived from SAA protein by macrophage activity and accumulates selectively at preferred sites, of which is the renal glomeruli, and interstitium are major examples .

Sometimes an associated chronic inflammatory lesion can be found somewhere in the body to provide an underlying cause, but frequently this is not so.

Clinically glomerular amyloidosis has a similar pathophysiology to glomerulonephritis, dominated by massive urinary protein loss and eventual renal failure.

Character and distribution of lesions

Even though amyloid accumulation is centered on glomeruli, the kidneys tend to become symmetrically and often massively enlarged and uniformly pale with a somewhat rubbery consistency. Close examination of the intact and cut cortical surfaces may reveal pin-point yellowish spots which correspond to glomeruli. These are clearly highlighted when the classical staining reaction is performed with acidified iodine solution. This is a quick means of grossly differentiating the disease from glomerulonephritis.

Lymphoma

General

Renal involvement in lymphoma (lymphosarcoma) is common enough and sometimes will be the most obvious gross finding. The neoplastic cells seem to prefer the cortical tissue and most of the lesions are found there. The diagnosis is fairly straightforward in those cases where distinct tumour masses are formed, but less so when neoplastic cells invade the tissue in a more diffuse manner, akin to inflammatory cells.

Distribution and character of lesions

Nodular tumour masses are white to off-white in colour, frequently bulge from the surface of the intact kidney and are not associated with any encapsulating fibrosis. On the other hand, diffuse infiltration causes irregular cortical mottling and enlargement of the kidney and can be easily confused with interstitial nephritis. In either case, an impression smear may provide a quick confirmation of the diagnosis.

Type D Clostridial Enterotoxaemia

General

Often suspected and often misdiagnosed in the midst of heat, dust, flies and rot and brought up for consideration here by the mantra "pulpy kidney". The issue of diagnostically useful renal changes is worth an airing.

Renal changes in ET across the ruminant species

The issue of accelerated renal autolysis as a diagnostic aid is really most applicable to lambs, and is of less value in adult sheep, calves, and goats. In lambs "pulpy kidneys" are not in evidence immediately after death, but can be a useful indicator in carcasses in which autolytic change is mild in other organs. In any class of animal, the evaluation of renal autolysis in a putrefying carcass is a dubious exercise. However, in lambs, sheep and calves the kidneys are frequently congested to haemorrhagic in appearance, and in calves there may be significant subcapsular haemorrhage, providing a useful piece of diagnostic evidence. Haemorrhage in the mucosa of the bladder may also be present occasionally.

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Chapter 16

Pathology and Diagnosis of Internal Parasites in Ruminants

Stephen C.J. Love & Gareth W. Hutchinson

Introduction

Parasitic infections are generally regarded as the most prevalent and important health problems of grazing ruminants in Australia, with losses associated with nematodes and ectoparasites causing a combined annual loss of approximately a billion dollars (McLeod 1995). Liver fluke, although having a restricted distribution in temperate regions, has been estimated to cost upwards of $100 million a year (Boray 1999).

Scope of paper

The purpose of this paper is to overview the gross pathology and diagnosis of gastrointestinal and other parasites in ruminants, with particular emphasis on the economically important parasites of sheep, goats and cattle.

Economic importance of parasites

McLeod (1995) modelled the costs of various parasitic diseases of grazing livestock in Australia. His findings are summarised in Figure 1. The economic impact of these diseases is significant, and production costs, including subclinical parasitism, are often a major component of the total costs.

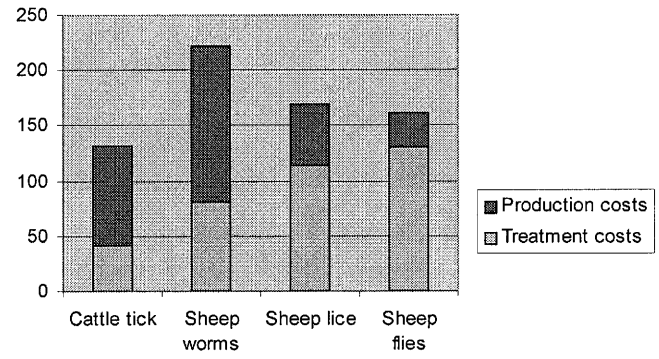

Fig.1. Combined control and production loss costs derived from cost-benefit model for 1994 ($M). (McLeod 1995)

Distribution of important parasites

Sheep & Goats

The three most important sheep/goat roundworms in Australia are *Haemonchus contortus* (barber's pole worm), *Trichostrongylus* spp (black scour worm) and *Ostertagia* (*Teladorsagia*) *circumcincta* (brown stomach worm). Worms of lesser or occasional importance include *Nematodirus* spp, *Oesophagostomum* spp and *Chabertia ovina*. Liver fluke (*Fasciola hepatica*) is also important in some locations. Sheep worm infections in Australia are often mixed, with dominant species varying according to climatic zone. *H. contortus* is most important in regions with summer dominant rainfall, especially northern New South Wales (NSW) and south eastern Queensland, and in coastal areas of south western Australia. *Trichostrongylus* and *Ostertagia* spp are more cold- and desiccation-tolerant, and hence dominate in areas with non-seasonal rainfall (eg, central and southern NSW), and in winter rainfall areas (Victoria, Tasmania, southern areas of South Australia, and south-west WA). (Besier and Love 2003).

Cattle

Ostertagia ostertagi is the most important nematode of extensively grazed cattle in temperate regions of the world, including the southern half of Australia. However, in the temperate non-seasonal to winter rainfall areas of Australia, *Ostertagia* is usually found in mixed infections, including species such as *Trichostrongylus axei* and *Cooperia oncophora*. In sub-tropical to tropical summer rainfall areas of Queensland and the North Coast of New South Wales, important helminths include species such as *Haemonchus placei*, *C. pectinata*, *C. punctata*, *Bunostomum phlebotomum* and *Oesophagostomum radiatum*.

Alpaca

Although not strictly ruminants, we include alpaca (which have a stomach with three compartments) here because they have become more common in Australia. These South American camelids are being used in animal husbandry either in their own right, or as guardians for lambing-ewe flocks. Alpaca are susceptible to both cattle and sheep parasites including liver fluke. Because of their use of dunging "latrines" this helps to control internal parasites, and worm burdens are not usually of pathogenic proportions. Occasional heavy *Haemonchus* burdens are reported, especially in high rainfall coastal areas.

Table 1. Harmful helminths and their distribution (adapted from Coles 1986)

Sheep and goats	Cattle
Causing common outbreaks of disease	
Summer-rainfall areas	
Haemonchus contortus	*Haemonchus placei*
	Ostertagia ostertagi - Cooperia punctata - C. pectinata (as a complex)
Ostertagia spp	
Trichostrongylus spp	*Bunostomum phlebotomum*
Fasciola hepatica	*Oesophagostomum radiatum*
Non-seasonal to winter rainfall areas	
Ostertagia spp	*Ostertagia ostertagi*
Trichostrongylus spp	*Trichostrongylus axei*
Fasciola hepatica	*Cooperia oncophora*
Occasionally significant or mainly subclinical effects or sometimes present in large numbers	
Nematodirus spp	*Fasciola hepatica*
Cooperia spp	*Paramphistomum spp*
Chabertia ovina	*Calicophoron calicophorum*
Strongyloides spp	*Strongyloides spp*

Diagnosis – general comments

In diagnosing helminthiasis, the three pillars of veterinary diagnosis apply:

- History,
- Clinical signs and gross pathology, and
- Laboratory aids.

Also knowledge of the local nuances of parasite epidemiology and control is invaluable.

Faecal worm egg counts (FECs) in particular (preferably with speciation by way of larval culture and differentiation), and total worm counts are the tests most commonly employed in the diagnosis of helminth infections in ruminants. See Table 2 for a summary of laboratory tests for worms available through NSW Agriculture and other laboratories.

FEC does not always correlate well with the number of adult worms present, particularly in cattle over 9-12 months. 'Diagnostic drenching' may be a useful tool in such cases. FECs may also be low or zero in the presence of large numbers of immature worms. An example of this may be seen with acute *Nematodirus* infections in young sheep after drought breaking rains in south western NSW. Type 2 ostertagiosis in cattle is

another example. Also, *Ostertagia* burdens in small ruminants do not always correlate well with FECs.

Ova of the ruminant nematodes *Nematodirus*, *Bunostomum*, *Strongyloides* and *Trichuris* are distinctive, but differentiation of the more common species requires examination of third-stage larvae produced by faecal cultures.

Necropsy is the most direct method to diagnose gastrointestinal (GI) parasitism. *Haemonchus*, *Bunostomum*, *Oesophagostomum*, *Trichuris* and *Chabertia* adults can be easily seen. However, important infections with *Ostertagia*, *Trichostrongylus*, *Cooperia* and *Nematodirus* are difficult to see (particularly those species spread over metres of intestine), except by their movements in fluid ingesta. In field investigations, these smaller nematodes can be better seen in GI tract washings, particularly against a white background, by staining for 5 minutes with strong iodine solution followed by decolourising background gut material with 5% sodium thiosulphate ('hypo'). Unfortunately the relatively high cost of total worm counts in the laboratory often precludes the use of this test, but it is recommended to confirm difficult diagnoses or where anthelmintic resistance is of major concern.

Multifactorial causation should be considered when evaluating the evidence. Mixed infections are the rule.

For an overview of diagnostic techniques, see Smeal (1995).

Anthelmintic resistance

Resistance in sheep and goat worms to most anthelmintics is now fairly common in Australia (Besier and Love 2003, Love 2002) and should be considered in the diagnosis and management of GI parasitism. Confirmed drug resistance in cattle worms in Australia has not been reported. In New Zealand, however, a number of isolates of macrocyclic lactone-resistant *Cooperia* have been found in cattle.

Summary tables

Information on gross pathology and other aspects of various parasites is summarised in Tables 4 and 5 at the end of this paper.

Parasites of the forestomachs

Trematodes

Paramphistomum spp and Calicophoron calicophorum ('stomach flukes')

Paramphistomosis occurs occasionally in cattle and rarely in sheep, with significant disease mainly due to duodenitis caused by migrating

immature fluke. Paramphistomes occur commonly in cattle throughout the sub-tropical and wet tropical areas of eastern Australia and the Kimberley region of Western Australia, although infections have been reported elsewhere, including Victoria and the south coast of NSW.

Paramphistomes or stomach flukes are conical shaped trematode parasites. Adult flukes are found mainly in the reticulum but also in the rumen. They have a fleshy, pear-shaped body, 5-12 mm by 2-4 mm in diameter, and are pink or light red. Juvenile fluke are small (1-2 mm long).

Most infections of adult fluke are harmless although large numbers of fluke can cause a chronic ulcerative rumenitis with atrophy of ruminal papillae. Peak conical fluke numbers are usually seen in late summer or early winter following prolonged inundation of pasture (Rolfe *et al.* 1991). Clinical paramphistomosis is usually diagnosed in cattle 4-18 months of age and is associated with invasion of the duodenum and upper jejunum by large numbers of immature fluke. Counts of up to 30,000 immature paramphistomes may be associated with diarrhoea after 8 weeks grazing in tracer calves (Rolfe and Boray 1993). Juvenile fluke are attached to the intestinal mucosa and, being small, are easy to overlook at necropsy. Catarrhal to necrotic and haemorrhagic duodenitis with little thickening may be seen in the early stages, progressing to thickening (mucosal oedema, submucosal hypertrophy), haemorrhages and ulceration. Anaemia, hypoproteinemia (manifested as submandibular oedema) and emaciation of the host ensue. After juvenile fluke migrate to the rumen, the intestine repairs, leaving a thickened duodenum and jejunum as a result of diffuse mucosal and submucosal hypertrophy and fibrosis.

Oxyclozanide, present with levamisole in Nilzan®, is the most effective anthelmintic for the treatment of acute and subacute paramphistomosis with two treatments given two days apart (Rolfe and Boray 1987, 1988) and combined with fencing to restrict access to wet snail habitats. However, there are currently no anthelmintics, including Nilzan, which are specifically registered for use against stomach fluke in Australia.

Parasites of the abomasum

Haemonchus ('barbers pole worm')

Haemonchus spp are among the most pathogenic helminth species of ruminants in Australia. Haemonchus contortus is mainly a parasite of sheep and goats (sometimes cattle) and H. placei is mainly a parasite of cattle (sometimes sheep and goats). Haemonchus are most dominant in summer rainfall areas.

Female worms are 18-30 mm long and are easily recognised by the 'barbers pole' appearance of the white ovaries and uteri twisting for the length of the worm around a red blood-filled intestine. Males are 10-20 mm long and uniformly reddish-brown.

Both the developing 4th larval stages (L4s) and adults cause punctiform haemorrhages at sites of feeding on the abomasal mucosa which may be oedematous. The ingesta may be reddish brown and fluid. Worms may be attached to the mucosa and free in the lumen.

Clinical signs include anaemia and hypoproteinemia (manifested as submandibular oedema). In South Africa, the Famacha© system of standard colour charts is used for assessing/scoring the level of anaemia by comparison of the colour of the inner lower eyelid and is used for tactical treatment of heavily infected sheep. In heavy and rapid infections, even animals in fat condition may die relatively quickly. Scouring is not a feature in sheep and goats unless the parasite infection is mixed and includes 'scour worms' (notably Ostertagia and Trichostrongylus spp).

Ostertagia ('small brown stomach worm')

Ostertagia spp in small ruminants and cattle tend to be more important in winter and non-seasonal rainfall areas. Heavy infections (particularly if accompanied by *Trichostrongylus* spp in sheep and goats) can cause profuse scouring, ill thrift and possibly deaths. *O. ostertagi* is considered to be the most pathogenic cattle nematode in southern Australia and other temperate cattle raising regions in the world. The free living stages of *Ostertagia* spp can develop at lower temperatures than most other trichostrongylid species.

Ostertagia are small, brown hair-like worms. Adult females are 8-12 mm long and males are 7-9 mm long.

Type 1 *O. ostertagi* infections in cattle are composed almost entirely of adult worms resulting from the majority of ingested larvae developing normally to adults in 18-20 days. White, raised, umbilicated nodules (containing developing L4 worms) occur mainly in the fundic mucosa. As the larvae develop and emerge from gastric glands, hyperplasia of gastric epithelium may cause enlargement and coalescing of nodules, the mucosa classically referred to as having a 'Morocco leather' appearance. Mucosal congestion and oedema is also evident, with thickening of abomasal folds. In Australia, type 1 infections occur mainly in dairy calves 3-10 months of age and weaned beef calves 6-12 months of age during late winter and early spring. Clinical signs include inappetence, profuse watery diarrhoea (scours) and rapid weight loss.

Pre-type II infections consist of large numbers of inhibited (hypobiotic) early L4s in the gastric glands with minimal tissue reaction and clinical signs apart possibly from ill thrift. This form occurs mainly in beef cattle during spring and summer, with inhibited larvae resuming development 4-6 months later in late summer / early autumn.

Type II infections in cattle consist of adult worms arising from simultaneous maturation of many inhibited early L4s, with glandular hyperplasia, loss of gastric structure, abomasitis, impairment of protein digestion, and leakage of plasma proteins especially albumin into the gut

lumen. The mucosa appears thickened and oedematous. Outbreaks of type II ostertagiosis with diarrhoea and rapid weight loss may be seen in 18 month old beef cattle in autumn and in heifers and cows soon after calving. However, the incidence of type II and other forms of clinical ostertagiosis has tended to decrease with the introduction of anthelmintics with greater efficacy against inhibited and other stages of parasitic worms. These drenches include the third generation benzimidazole carbamates (fenbendazole, oxfendazole, albendazole etc.), but more particularly the macrocyclic lactones (ivermectin, abamectin, moxidectin, doramectin, eprinomectin), which tend to have consistently high efficacy, especially with respect to inhibited stages, as well as persistent activity against incoming ingested L3s.

In sheep and goats, *O. circumcincta* usually occur in mixed infections including intestinal *Trichostrongylus* spp, causing scouring and ill thrift. In heavy infections, the abomasal mucosa may be covered in confluent, whitish nodules, with thickening and congestion of the folds. Goats can also be infected by *O. ostertagi*.

***Trichostrongylus axei* ('stomach hair worm')**

Trichostrongylus axei occurs commonly in ruminants, often in association with *Ostertagia*, and also in other host species, such as horses, but appears to be relatively non-pathogenic.

Adult *T. axei* are very small, smaller than *Ostertagia.* They are slender, hair-like and reddish-brown. Females are 5-8 mm and males 4-7 mm long.

In heavy infections in cattle, aggregations of worms occur mainly in the fundus, with localised hyperaemia progressing to catarrhal inflammation with white raised circular plaques. Heavy burdens (40-70,000 or more worms) may exacerbate *Ostertagia* - associated gastritis and accompanying clinical signs. The seasonal pattern of larval availability is similar to that for *O. ostertagi*.

Parasites of the intestines

Small intestine

(Intestinal) *Trichostrongylus* spp ('black scour worms')

Trichostrongylus colubriformis and *T. vitrinus* occur commonly in sheep in Australia, the former tending to be more important in summer rainfall areas and the latter in winter rainfall areas. Commonly they occur in mixed infections with *Ostertagia*, producing similar clinical sings (inappetence, weight loss and scouring). (*T. axei* may also be found in the intestines of sheep and cattle). Sub-optimal nutrition exacerbates pathogenicity. Intake of *Trichostrongylus* larvae is believed to be the primary agent responsible for 'hypersensitivity scouring' in sheep in the winter dominant rainfall areas of Victoria/South Australia and south-western Western Australia

Intestinal *Trichostrongylus* spp are small, hair-like reddish brown worms (females 6-8 mm and males 6-7 mm long), not readily seen at necropsy.

Trichostrongylus colubriformis and *T. longispicularis* are recorded in Australian cattle (the latter more so in Western Australia). Small numbers are relatively harmless to young cattle and are usually mixed with larger numbers of *Cooperia* spp.

Cooperia spp

Cooperia spp are widespread but relatively uncommon and non-pathogenic parasites in sheep.

Adult *Cooperia* are small (females 6-10 mm and males 5-9 mm long), reddish hair-like worms.

Cooperia punctata, *C. pectinata* and *C. oncophora* occur commonly in the proximal half of the small intestine of cattle in Australia, with the first two being more pathogenic and occurring together as a complex particularly in subtropical and tropical areas. *Cooperia oncophora* occurs mainly in cooler southern regions of Australia and appears to be relatively non-pathogenic.

From 6 months of age, most cattle become increasing resistant to reinfection with *Cooperia* larvae.

Gross pathology and clinical signs are those of parasitic gastroenteritis (PGE), and include inappetence, intermittent, watery diarrhoea and weight loss. Mucosal inflammation and thickening, epithelial erosions (with leakage of plasma proteins into the gut lumen) and a profuse mucous exudate may be found at necropsy.

Large worm burdens in cattle often in excess of 500,000 may be acquired over a short period, with inhibited early L4s comprising up to 50% of the population, but even such large numbers are not usually particularly pathogenic on their own.

Nematodirus spp ('thin-necked intestinal worm')

Nematodirus spathiger is a very common parasite of young Australian sheep, and is usually relatively non-pathogenic unlike the situation in New Zealand where this parasite inexplicably became more important from the 1960s. Heavy infections, scouring and ill thrift with mortalities can be seen in young sheep under or soon after drought conditions in Australia (south western NSW, for example), presumably because *Nematodirus* eggs are relatively desiccation–tolerant. Clinical nematodirosis is also not uncommon in young lambs in irrigation areas such as the Riverina area of southern New South Wales.

Nematodirus is whitish, relatively long (females 18-12 mm, males 10-17 mm long) compared to other trichostrongyle nematodes, with the anterior portion thinner than the posterior end (hence 'thin–necked intestinal worm').

Nematodirus helvetianus occurs commonly but in small numbers in dairy calves, usually mixed with much larger numbers of *Cooperia*. Alone they appear to be of little significance although in the United States they have been regarded as an important parasite.

Bunostomum spp ('hookworm')
Bunostomum trigonocephalum is a potentially pathogenic parasite of sheep recorded from all states, but is relatively uncommon and burdens tend to be light and of little consequence. Ill thrift and anaemia has been attributed to this parasite in New Zealand.

These reddish worms are one of the larger intestinal parasites of cattle (females 24-28 mm and males 10-18 mm long).

Bunostomum phlebotomum, the hookworm of cattle, occurs principally in the proximal small intestine. It mainly occurs in mixed infections in dairy calves in southern Queensland and NSW. Worms attach to the mucosa by a large buccal capsule, causing mucosal inflammation, thickening and punctiform haemorrhages. Clinical signs include anaemia, inappetence, ill thrift, a dark scour, and submandibular oedema. Infection in calves maintained in wet/muddy conditions can be associated with skin penetration by the infective larvae.

***Strongyloides* spp ('threadworms')**
Strongyloides papillosus eggs are often seen in faecal counts in sheep, but this parasite is of doubtful significance. Its importance if any is overshadowed by parasites such as *Ostertagia* and *Trichostrongylus*.

Female adults are very small (3-6 mm long) and parasitise the proximal small intestine, deep in the mucosal crypts, and so are usually overlooked on necropsy except by the most diligent pathologist.

Strongyloides papillosus can infect animals by ingestion, skin penetration (in wet conditions) and through the milk of lactating ewes. Only female worms occur as parasites in the small intestine and these are parthenogenetic.

Clinical signs reported in experimental infections include anorexia, weight loss, variable anaemia, lassitude, dyspnoea (due to larvae migrating through the lungs) and lameness.

Losses in lambs with heavy natural infections during a wet period following a drought have been reported from Kenya.

Strongyloides papillosus is commonly found in young dairy calves. Clinical parasitism is seen rarely and usually when animals are confined or under wet, muddy conditions. Clinical signs include dull demeanour, inappetence, harsh cost and diarrhoea.

Trematodes

Paramphistomes ('stomach fluke')

Migrating immature paramphistomes can cause duodenitis (See 'Parasites of forestomachs').

Cestodes

Moniezia spp ('tapeworms')

Moniezia and less commonly *Thysaniezia giardi* infect sheep. These tapeworms are generally regarded as relatively harmless. However, anthelmintic combinations containing praziquantel, which is highly effective in removing tapeworms, are actively promoted.

Moniezia benedini and *M. expansa* are similar in appearance and may reach a length of 600 cm.

Whereas *M. expansa* occurs mainly in sheep, *M. benedeni* is found chiefly in young cattle, and is believed to be of little significance.

Protozoa

Eimeria spp (small and large intestine)

Coccidiosis is a parasitic enteritis of small and large intestines of cattle, sheep and goats caused by *Eimeria* species. Oocyst counts may not correlate with severity of infection. Infection may be exacerbated by various stressors and other pathogens – viruses, bacteria and worms. The stress of weaning, even (for example) in calves grazing in extensive conditions under dry tropical conditions, has been known to precipitate clinical disease. Coccidiosis usually occurs in younger animals, or in adults introduced to higher rainfall areas from the drier pastoral zones, and with high stocking rates or overcrowding under wet and cool conditions.

Lesions in acute and subacute coccidiosis include a catarrhal enteritis (mucosa appears velvety), multiple well-defined whitish lesions ranging in size from less than 1 mm to patches 7 mm in diameter, and whitish, polyp-like lesions or cone-shaped spots depending on the species of *Eimeria* and the stage of parasite (meronts (schizonts) or gamonts) contained within the lesion. Infections with a mixture of species are common but clinical disease is normally associated with only a small number of species, for example *Eimeria zuernii* and *E. bovis* in cattle. In clinical disease, characteristic bloody diarrhoea is often seen.

Cryptosporidium (small and large intestine)

Once considered a benign coccidium, *Cryptosporidium* is now regarded as a cause of disease in birds, reptiles and various mammals including man.

Cases in farm animals in Australia have mainly involved calves, with isolated diagnoses in lambs, birds and other species.

Calves are clinically affected mainly in the first 3 weeks of life with the enteritis being self limiting due to rapid development of host immunity. A diagnosis of cryptosporidiosis is suggested by demonstration of moderate to large numbers of the very small (~5 µm diameter) oocysts in faeces of affected animals, or identification of *Cryptosporidium* in ileal mucosa post-mortem. These oocysts are easily confused with yeasts and appropriate stains or interference microscopy is usually required to confirm the diagnosis. Clinical signs include profuse non-haemorrhagic diarrhoea of variable colour (often creamy-yellow). Other causes of neonatal diarrhoea need to be considered.

Giardia

These characteristic flagellates may rarely be associated with acute episodes of diarrhoea in young calves or weaner cattle.

Parasites of the large intestine

Oesophagostomum spp ('nodule and large bowel worms')

Oesophagostomum columbianum (nodule worm) and *O. venulosum* (large bowel worm) occur in sheep and goats. Until the introduction of improved pastures (better nutrition) and more efficacious anthelmintics (eg thiabendazole, 1961 in Australia), *O. columbianum* was second in importance only to *H. contortus* in summer rainfall areas. *Oesophagostomum columbianum* has virtually disappeared from higher rainfall areas (eg northern NSW tablelands and slopes), which have relatively cold winters and fairly frequent anthelmintic treatments (drenching). However, the parasite still occurs in the lower rainfall pastoral zones (western plains) of northern NSW and southern Qld, and processors sourcing sheep from those areas can suffer significant economic losses due to condemnation of intestines ('runners') affected by *Oesophagostomum*-associated 'pimply gut'.

Histiotrophic phases of larval stages (L3/L4) of *O. columbianum* cause caseous nodules 0.5 – 1 cm diameter (histologically eosinophilic granulomata) in small intestines and colon, although small intestinal nodules may be more 'gritty' than 'cheesy'. Nodules can also be found in the lung, liver, mesentery and mesenteric lymph node. Clinical signs in heavy infections include variable diarrhoea, emaciation, a humped appearance and stiff gait. Intussusception has also been reported.

Oesophagostomum venulosum is a mildly or non-pathogenic species, prevalent in winter rainfall areas. It also seems to have partly filled the niche vacated by *O. columbianum* in summer rainfall areas. *Oesophagostomum venulosum*-associated nodules occur infrequently, are small, and occur mainly in the caecum and colon.

Oesophagostomum radiatum ('nodular worm') and *O. venulosum* occur in cattle, the former being the significant parasite and the most frequently encountered large bowel parasite of cattle. *Oesophagostomum radiatum*

particularly favours subtropical and tropical zones. Adults (14-22 mm long) are whitish and found in thick mucus in the caecum and proximal colon. Numerous nodular lesions, 3-6 mm diameter and resulting from the histiotrophic phase, appear scattered on the serosa of the small intestine and to a lesser extent the caecum and colon. In heavy infections, the caecal and proximal colonic mucosa is congested, oedematous and thickened with excessive amounts of turbid mucus being produced. Such infections may cause severe clinical disease in young animals with signs including inappetence, ill thrift, intermittent diarrhoea, anaemia, emaciation and death. Infections are usually mixed including *H. placei* and *Cooperia* spp.

As with *O. venulosum* (large bowel worm) in small ruminants, this parasite in cattle is relatively harmless and prefers cooler, winter rainfall climates. Adults are 10-25 mm long and are found in the caecum and proximal colon. There is a histiotrophic phase but little nodule formation.

Chabertia ovina ('large-mouthed bowel worm')

This parasite widely occurs in sheep, cattle and goats, usually in low numbers, and with a preference for winter rainfall zones. It has little pathogenic significance in cattle and occasionally causes clinical disease in small ruminants.

Adult females are 17-20 mm and males 12-14 mm long.

Like *Oesophagostomum*, there is a histiotrophic phase, with L3s entering the wall of the small intestine, re-emerging and then maturing in the caecum and proximal spiral colon. Adults take a plug of mucosa into the buccal cavity, causing haemorrhage, protein loss and oedema. Faeces of affected sheep are soft, mucoid and perhaps blood-flecked. Ill thrift may occur.

Trichuris spp ('whipworms')

This parasite occurs commonly in Australia and throughout the world. The most common species in Australian cattle, sheep and goats are *T. ovis* and *T. globulosa*.

Adults are 40-80 mm long, creamy-white, with the anterior three-quarters of the body being very slender.

Larvated ova are resistant to environmental effects and are ingested with soil. L3 larvae are released from ingested eggs, enter the small intestinal mucosa, and then re-emerge to undergo maturation in the caecum. They attach by their filamentous anterior ends to the mucosa. The eggs are lemon shaped with bipolar plugs. *Trichuris* spp are considered harmless except in very heavy infections (eg large soil intake by grazing animals in drought) in which case there may be a sub-acute typhlocolitis, diarrhoea and ill thrift.

Parasites of the liver

Trematodes

Fasciola hepatica (liver fluke)

The distribution of *F. hepatica* is determined by that of its lymnaeid snail intermediate host. The parasite is generally limited to high rainfall and irrigation areas of NSW, Victoria and Tasmania, with pockets also in South Australia and Queensland. *Fasciola* is absent from Western Australia and importation of livestock requires pre- and post-import faecal sedimentation examinations plus border treatment with triclabendazole. This fluke was inadvertently introduced to Western Australia (since eradicated) in horses infected with drug-resistant *F. hepatica* from the Goulburn valley of northern Victoria in the early 1990s.

Where endemic, *F. hepatica* is an important parasite of cattle, but more particularly sheep and goats. Patent infections can develop in other wild and domestic animals and in humans. (Take care when eating water cress).

These flukes are leaf shaped and ~25 mm long in sheep and slightly larger in cattle.

Adult flukes are found in the main bile ducts of the liver, but occasionally small adults are found encapsulated in caseous nodular lesions in the lungs. Juvenile fluke (8-12 mm long) can be squeezed from cut surfaces of the liver. Being hermaphroditic, only one fluke is required to establish a patent infection. Egg production at up to 20,000 per adult per day rivals or exceeds that of *Haemonchus*, that other fecund blood-sucker. Individual fluke may live several years or more, as long as the host.

Migrating juvenile fluke cause haemorrhagic tracts in liver parenchyma, with associated peritonitis. Some juveniles become encysted in the parenchyma. Healing proceeds and the tracts are replaced by scar tissue. Heavy infestations by immature flukes may cause death in the stage of acute hepatitis (acute fasciolosis). Black disease (*Clostridium novyi* intoxication) may result during the acute stage also. Acute fasciolosis is not common but occurs in sheep.

Mature flukes in bile ducts cause cholangiohepatitis, with changes most severe in the left lobe. From the visceral surface affected ducts may stand out as whitish, firm, branching cords due to distension by flukes and bile. Connective tissue proliferates, particularly in cattle, resulting in fibrosis. Mineralisation of old lesions is also common in affected cattle livers.

Acute and sub-acute forms of fasciolosis develop 2-3 weeks after massive infections and signs include anorexia, abdominal pain, yellowish and pale conjunctivae, weight loss and sudden death. Clinical signs develop more slowly in the chronic form and include ill thrift, anaemia, and sub-mandibular oedema ('bottle jaw'). Production losses can be economically

significant even in relatively light fluke infections. Clinical signs are less well-defined in cattle, particularly adult cattle, which are more resistant to fasciolosis than sheep.

Parasites – respiratory tract

Nematodes

Lungworms in cattle, sheep and goats are generally not economically important although they occasionally cause significant disease in Australia, usually in host animals debilitated by other parasitic diseases and sub optimal nutrition.

Dictyocaulus spp ('large lungworm')

Dictyocaulus filaria, the large lungworm of sheep and goats, is a slender, whitish worm 3-10 cm long. Adults live mainly in the small bronchi. Verminous pneumonia is mainly a disease of cool, moist climates as further development of L1 passed in faeces to the infective L3 stage requires such conditions.

Dictyocaulus viviparus occurs in cattle. This is an extremely important parasite in Britain and increasingly so in continental Europe. *Dictyocaulus viviparus* causes parasitic bronchitis, known in Britain as 'husk'. It occasionally causes disease in Australia in young cattle, mainly dairy cattle.

In the pre-patent phase, *Dictyocaulus* spp may cause patchy interstitial pneumonia in heavy infections. As worms mature, emphasis shifts to the bronchial lesion. Dorsocaudal and ventrocaudal (diaphragmatic) lobes are most affected. Worms are usually bathed in mucinous, foamy bronchial exudate. There may be patchy to large wedge-shaped areas of dark red or grey consolidation in the caudal lobes in heavy infections. Clinical signs in heavy infections include coughing, polypnea, nasal discharge, inappetence and ill thrift.

Protostrongylus ('small lungworm') and *Muellerius* spp ('small or nodular lungworm')

Species from these genera occur in Australia but are of little importance. *Protostrongylus rufescens* is parasitic in sheep, goats and deer. Adults are reddish, mainly inhabit bronchioles and are 16-35 mm long, smaller than *D. filaria*. Lesions are broadly similar to those produced by *D. filaria* and *M. capillaris*.

Muellerius capillaris parasitizes sheep and goats. Adults live in the alveolar parenchyma, rarely the bronchioles, and usually provoke an enveloping granulomatous response, hence a common name, 'nodular lungworm'. There is rarely clinical evidence of disease in affected sheep.

Other internal parasites

Although largely beyond the scope of this paper, we mention other parasites below.

Larval cestodes

Information on larval tapeworms of sheep and cattle is summarised in Table 3.

Hydatid cysts (metacestodes of *Echinococcus granulosus*) are fluid filled cysts, some up to the size of oranges or grapefruits, found in the lungs and livers, and rarely free in the peritoneal cavity of cattle and sheep. Estimates of prevalence up to 20-30% have been reported historically in defined regions of Australia. Recent studies suggest a decreasing occurrence, probably associated with increased awareness of the dangers of feeding uncooked sheep offal to dogs and public health awareness campaigns in Tasmania, NSW and the Australian Capital Territory. Recently Tasmania has applied for declaration of freedom from hydatids following a lengthy eradication campaign.

Hydatid cysts have a typical multilaminar wall which is characteristic even if the cyst is degenerating, necrotic or caseous. In cattle cysts are mostly sterile (devoid of the protoscolices, "hydatid sand"), and are probably derived from accidental ingestion of *E. granulosus* eggs from the sylvatic cycle involving dingos and macropods.

In sheep hydatid cysts are usually smaller, are fertile and contain protoscolices.

Tick fevers – *Babesia, Theileria* and *Anaplasma* spp

There are four tick fever parasites affecting cattle in Australia. Three are blood protozoan parasites called piroplasms: *Babesia bovis, B. bigemina* and *Theileria buffeli*. The fourth is a blood rickettsia: *Anaplasma marginale*. The primary effect of these parasites is haemolytic anaemia. The economically important tick fevers are caused by *B. bovis* and *A. marginale*, which are transmitted by the cattle tick *Boophilus microplus*. These occur throughout northern Australia, eastern coastal areas of Queensland, and sporadically in New South Wales. For more information, see Smeal (1995). A finding of *any Babesia* sp in NSW is regarded as significant.

Eperythrozoon ovis

Eperythrozoon ovis is a rickettsia that parasitises erythrocytes in sheep and goats, causing haemolytic anaemia and icterus. Disease is often subclinical, but severe clinical signs, particularly in stressed animals, may be encountered.

Oestrus ovis ('nasal bot')

The sheep nasal botfly *Oestrus ovis* is a cosmopolitan parasite, the larvae of which inhabit the nasal passages and paranasal sinuses of sheep and

goats. The larval period can vary from one to 10 months. Sneezing and a mucopurulent nasal discharge results. The main effects for the host are persistent annoyance and associated debility. Vary rarely secondary bacterial infection spreads from the olfactory mucosa to the meninges. In Australia, ivermectin, abamectin, moxidectin and closantel are registered for use against nasal bot.

Onchocerca spp ('beef nodules')

These are filariid worms. Three species occur in cattle in Australia, mainly northern Australia, but also coastal districts of New South Wales.

Major infections are due to *O. gibsoni*, which forms 10-20 mm diameter nodules in the connective tissue of brisket, stifle and hip regions. The nodules are often caseous or partly calcified. The adult female worms are up to 20 cm long and lie intimately coiled in the honeycomb-like fibrous nodules. Adult male worms are slender and only about 2 cm long.

The other two species do not form nodules. *Onchocerca gutturosa* is found in the ligamentum nuchae and *O. lienalis* in the gastrosplenic ligament and are difficult to see *in situ*. Microfilariae of *Onchocerca* are ingested by intermediate hosts, which include biting flies of the Family *Ceratopogonidae* including biting midges (*Culicoides* spp.). Simulids (in Australia, 'black fly', 'buffalo gnat') are vectors for human onchocerciasis (River Blindness) in West Africa and South America but not for onchocerciasis in cattle.

Stephanofilaria spp

Stephanofilaria spp are filariid parasites of cattle, which cause localised dermatitis. The distribution (mainly Queensland) follows that of the intermediate host which is probably the buffalo fly (*Haematobia irritans exigua*). They are small parasites 2.5-4.5 mm long and found in small cysts (up to 4 parasites per cyst) just beneath skin surface in *Bos indicus* cattle. Lesions are raised, circumscribed hairless areas on head, especially around the eyes, neck, dewlap and sternum. Cattle rub and scratch lesions. The disease can cause severe damage to hides.

Thelazia spp ('eye worms')

Species belonging to this nematode genus occur in the eyes of cattle, sheep, horses, dogs, other domesticated animals and man. *Thelazia gulosa* and *T. skrjabini* have been found in Australia. These white nematodes (5-20 mm) occur in the conjunctival sac, lacrimal ducts, and nasolacrimal canals of cattle. They have been associated with conjunctivitis and keratitis severe keratitis that can lead to corneal opacity and even blindness. However, they are also found in normal eyes.

The worms are found behind the third eyelid and in lacrimal ducts, and can be difficult to detect clinically. Worms can be recovered from saline eye washings. Muscid flies are the intermediate host.

Thelazia spp once were endemic on the north coast of NSW but may have disappeared because of anthelmintic usage (benzimidazoles and more recently macrocyclic lactones). They have been reported from Queensland, northern Victoria and south western Western Australia

Setaria labiato-papillosa

Setaria labiato-papillosa is a long thin filarial nematode occurring in the peritoneal cavity cattle in north Queensland. It has no apparent pathogenic effects, although in the Middle East and Russia related worm species cause cerebrospinal nematodiasis and lumbar paralysis in sheep and goats. Adults are 35-100 mm long (females up to 130 mm) and occur in the peritoneal cavity. Microfilariae are found in the blood. Intermediate hosts in Australia probably are mosquitoes and possibly the stable fly, *Stomoxys calcitrans*.

Ascaris suum, Toxocara and *Gongylonema* spp

See Tables 4 and 5.

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Main references/bibliography

In producing this paper we have relied particularly on the following:

Cole VG (1986). Helminth Parasites of Sheep and Cattle. Animal Health in Australia, Volume 8. Australian Agricultural Health and Quarantine Service, Department of Primary Industry, Canberra, pp255.

Jubb KVF, Kennedy PC and Palmer N (Eds) (1993). Pathology of Domestic Animals, Fourth Edition, Academic Press.

Smeal MG (1995). Parasites of Cattle, Veterinary Review No.32, The University of Sydney, Post Graduate foundation in Veterinary Science, pp358.

Other references

Besier RB & Love SCJ (2003). Anthelmintic resistance in sheep nematodes in Australia: the need for new approaches. *Australian Journal of Experimental Agriculture* (In press).

Boray JC (1999). Liver fluke disease in sheep and cattle. Agfact A0.9.57 (second edition) NSW Agriculture, pp15. <www.agric.nsw.gov.au>.

Love SCJ (2002). Sheep worm control and drench resistance – no worries? *Agnote DAI/87* 2nd edition February 2002. NSW Agriculture. <ww.agric.nsw.gov.au/reader/2566>.

McLeod RS (1995) Cost of major parasites to the Australian livestock industries. *International Journal for Parasitology* **25:** 1363-1367.

Rolfe PF and Boray JC (1987). Chemotherapy of paramphistomosis in cattle. *Australian Veterinary Journal* **64:** 328-332.

Rolfe PF and Boray JC (1988). Chemotherapy of paramphistomosis in sheep. *Australian Veterinary Journal* **16:** 149-150.

Rolfe PF and Boray JC (1993). Comparative efficacy of moxidectin, an ivermectin/clorsulon combination and closantel against immature paramphistomes in cattle. *Australian Veterinary Journal* **70**: 265-267.

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Table 2. Some laboratory tests for worms – Example from NSW Agriculture Veterinary Laboratories

Test	Purpose	Sample required	Cost of test incl GST	Comments
WormTest "Gold" (Faecal egg count +/- larval culture)	Monitor worm egg counts. Can be used after drenching to check drench effectiveness.	Faecal samples from 10 animals.	Worm egg count $42.50. Worm egg count plus larval differentiation $57.30. Liver fluke egg count (2 counts of pooled faeces) $37.40 (5 counts of pooled faeces) $61.95	10 individual egg counts + average count +range. Worm type (larval diff.) also if requested. Use a WormTest kit, available from Rural Lands Protection Boards, stock and station agents and NSW Agriculture.
WormTest "Basic" (Faecal egg count +/- larval culture)	Monitor worm egg counts. Can be used after drenching to check drench effectiveness. Check with your adviser.	Faecal samples from 10 animals.	Worm egg count $26.65. Worm egg count plus larval differentiation $39.50. Liver fluke egg count (2 counts of pooled faeces) $37.40 (5 counts of pooled faeces) $61.95	Egg counts are done on two pools each consisting of five samples i.e. two egg counts + average. Worm type also if requested. Use a WormTest kit, available from Rural Lands Protection Boards, stock and station agents and NSW Agriculture.
Liver Fluke ELISA	Test for liver fluke infection.	Blood samples (serum).	Single sample $16.25. More than one sample $10.75 each.	Can detect infected animals before they shed fluke eggs. Best as herd/flock test (12-15 samples preferred).
DrenchRite™ (*In vitro* larval development assay)	Test for drench resistance.	Bulk faecal sample from 20 animals.	$262.10	Sheep should **not** have been drenched in the last 8 weeks. Can test BZ, LEV, BZ+LEV, and in some cases, ML drenches. Little on-farm effort required.
DrenchTest (Faecal egg count reduction tests)	Test for drench resistance.	Faecal samples from untreated and treated animals.	$220.45 for a test with 3 treatment groups and the control group. ($57.50 per extra group).	Can be customised to test any drench. More on-farm effort required, however, DrenchTest is more flexible and yields more information than DrenchRite™.
Closantel Resistance Test (*In vitro* larval migration assay)	Test for closantel resistance in barber's pole worm.	Bulk faecal sample from 20 animals.	$248.50 Also requires single egg count ($11.40) + larval diff. ($24.05) = Total $283.95.	Sheep should **not** have been drenched with a closantel drench in the last 8 weeks. Little on-farm effort required.

Note: [1] Similar parasitology tests are available from other accredited government and private laboratories around Australia. [2] The tests outlined above are mostly relevant to sheep and goats, but the 'WormTests' and liver fluke ELISA are applicable to cattle also. [3] Prices are current at time of writing (Dec 2002) and are included to indicate relative costs of different tests. [4] Other available parasitology services – including total worm counts, and parasite identification – are not listed. Contact your laboratory for further information.

Table 3. Larval cestodes of sheep and cattle (adapted from Coles (1986))

Definitive host		Intermediate host/larval stage				
Tapeworm, length, location	**Definitive host**	**Larval stage**	**Intermediate hosts**	**Location**	**Size**	**Appearance**
Echinococcus granulosus, 4-6 mm (4-6 segments), small intestine	dog, dingo	*E. granulosus* (hydatid cyst)	Sheep, cattle, goat, pig, wallaby, kangaroo, man	Liver, lung, kidneys, spleen, heart, brain, bone	4-5 mm at 3 months, 20 mm at 6 months	Viable cysts enclosed within fibrous capsule and embedded in substance of affected organ. If fertile, contain many scolices ('hydatid sand'). Degenerated cysts contain caseous material that 'shells out'.
Taenia ovis, 2 m, small intestine	dog	*Cysticercus ovis* (sheep measles)	Sheep, goat	Heart, diaphragm, masseter muscles, oesophagus, all striated muscle	3-6 mm at 7 weeks. Oval shape, up to 10 mm long.	Viable cysts contain fluid and a single protoscolex. Dead cysts become calcified.
Taenia saginata, 4-10 m, small intestine	man	*Cys. bovis* (beef measles)	Cattle, buffalo, deer, giraffe	Heart, tongue, masseter muscles, diaphragm, all striated muscle	Variable in size: 2-20 mm, average 5 mm Fully developed in 16 weeks.	Viable cysts contain fluid and a single protoscolex. Degenerated cysts become caseous and calcified.
Taenia hydatigena, 3 m, small intestine	dog, dingo	*Cys. tenuicollis* (bladder worms)	Sheep, cattle, goat, pig	Liver and abdominal cavity	Average 50 mm; range 1-60 mm.	Cysts loosely attached to surface of viscera. Contain clear, jelly-like fluid and a single large scolex.

Note: *Taenia pisiformis*, *T. serialis* and *Dipylidium caninum* are common tapeworms of dogs, foxes and dingoes that need to be differentiated from *T. ovis* and *T. hydatigena*. The intermediate hosts of *T. pisiformis* and *T. serialis* are the rabbit and hare. The flea and possibly the biting louse are the intermediate hosts for *D. caninum*.

Table 4. Sheep parasites - summary (adapted from Coles 1986)

Parasite, length, location	Gross pathology	Clinical signs	Significant faecal egg counts (FECs) and worm counts (WC); other
Haemonchus contortus -'barbers pole worm'. 10-30 mm. Abomasum.	Abomasum oedematous in heavy and chronic infections. Pinpoint haemorrhages. Red and white 'barbers pole' appearance of females. Abomasal contents brown from leakage of blood.	*Heavy infections* Mainly in young sheep but all ages can be affected. Exercise intolerance. Anaemia, submandibular oedema, constipation, rapid death. *Light infections* Ill thrift, mild anaemia.	*FECs* 2 000+ may be clinically significant. Around 30 000 in heavy infections. Eggs typically strongyle. *WCs* Heavy infections: 2 000-10 000 worms Light infections 500-1000 worms. *Egg output* 5-10 000 per female per day. Blood loss from host ~ 0.05 ml per worm per day.
Ostertagia spp - 'small brown stomach worm'. 6-10 mm. Abomasum.	*Heavy infections* Weight loss; worms visible on mucosa in clumps, whitish nodules from worms in gastric glands; folds oedematous, congested.	Weight loss, scouring and even deaths depending on severity of infection.	*FECs* 500+ may be clinically significant, however significant disease can occur with lower FECs. Eggs typically strongyle. *WCs* Heavy infections: 5 000-10 000+ worms Light infections 1000-2000 worms. *Egg output* 100-200 per female per day
Trichostrongylus axei - 'stomach hair worm' 3-4 mm. Abomasum.	Infections usually light. Much smaller than *Ostertagia* and difficult to see. Worms mainly in pyloric region. Gastritis in heavy infections.	May contribute to scouring-ill thrift syndrome in mixed/heavy infections.	*FECs* Counts usually low. Moderate infections may contribute 500-1000 epg to mixed infections. Eggs typically strongyle. *WCs* Range 2 000-7 000 worms in mixed infections.
Trichostrongylus spp - 'black scour worm'. 4-7 mm. Small intestine.	*Heavy infections* Carcase emaciated; mucous exudate, flattening of mucosa (villous atrophy). Worms in first 3 m of SI but hard to see. Mesenteric lymphadenomegaly and oedema.	Especially affects young sheep. *Heavy infections* Rapid weight loss, scouring, death. *Note* Pathogenic effects of *Trichostrongylus* and *Ostertagia* appear to be more than additive.	*FECs* 500-2000 may be significant; over 2000 in heavy infections. Eggs typically strongyle. *WCs* Heavy infections: 5 000-10 000+ worms Light infections 1000-2000 worms. *Egg output* 200 per female per day.

Nematodirus spp -'thin-necked intestinal worm'. 10-23 mm. Small intestine.	*Heavy infections* Worms visible as tangled red mass, concentrated in middle of SI. No specific gross lesions.	Usually non-pathogenic. *Heavy infections* May be seen in young sheep under dry conditions. Profuse diarrhoea, deaths.	*FECs* Heavy infections: 500-2000, but sometimes quite low. Light infections: 50-300. Eggs large and easily distinguishable from strongyle. *WCs* Heavy infections: 5 000-15 000+ worms Light infections 1000-2000 worms. *Egg output* 25-30 per female per day
Cooperia spp. 5-8 mm. Small intestine.	No evidence of specific effects. Relatively uncommon in sheep.	No characteristic signs. Usually in mixed infections.	
Bunostomum trigonocephalum - 'hookworm'. 12-26 mm. Small intestine.	Uncommon. Worms clearly visible. Infections usually light. Focal haemorrhages in intestinal mucosa and lungs. Variable anaemia.		*FECs* Low and of little diagnostic value. Eggs typically strongyle. *WCs* Range 300-1000 may cause ill thrift, anaemia.
Strongyloides papillosus. 4-6 mm. Small intestine.	Heavy natural infections seldom seen. Experimentally: ascites, catarrhal enteritis, mucosal oedema.	Experimentally: dyspnoea (migrating larvae in lungs) and diarrhoea. *Heavy infections* Most likely in young sheep under wet conditions.	*FECs* Heavy experimental infections: 2000-10 000. Eggs smaller than common strongyles and embryonated. *WCs* Experimental: 100 000-300 000.
Trichuris spp - 'whipworm'. 40-80 mm. Caecum.	Common in tip of caecum, but mostly unimportant. May be important in some conditions eg drought. *Heavy infections* Thickening and haemorrhage of mucosa; accumulation of mucus.	Usually non-pathogenic. *Heavy infections* May be seen in young sheep under dry conditions. Ill thrift, mucoid diarrhoea, deaths.	*FECs* Generally low but useful to diagnose presence of *Trichuris*. Eggs characteristic (brown with transparent polar plugs). *WCs* Several hundred in heavy infections but hard to count as worms clump together.

Oesophagostomum columbianum - 'nodule worm'. 12-21 mm. Colon.	Stout white worm with hooked head. Larvae develop in nodules of SI (small gritty lesions) and LI (caseous lesions). Nodules elsewhere in viscera also. *Heavy infections* Colon thickened, oedematous. Adhesions between loops of bowel. Once a major summer - rainfall parasite, second only to *Haemonchus*. Still causes losses at some abattoirs (condemnation of nodule-affected small intestines).	Rarely seen now. Weight loss, stiff gait, weakness, intermittent scour.	*FECs* Heavy infections: 500-1000. *WCs* 100 worms pathogenic in weaners; 200-300 in adults. *Egg output* 5-12,000 per female per day.
Oesophagostomum venulosum - 'large bowel worm'. 11-24 mm. Caecum.	Similar to *O. columbianum* but head not hooked. Relatively non-pathogenic. Results in few if any nodules. *Heavy infections* Patchy mucosal congestion.	Relatively non-pathogenic. Experimental: scouring, ill thrift. May have partly filled niche vacated by *O. columbianum* eg in NSW Northern Tablelands.	*FECs* Uncertain significance. Eggs typically strongyle. *WCs* Heavy infections; 200-300. *Egg output* probably similar to *O. columbianum* (5-12,000 per female per day).
Chabertia ovina -'large mouthed bowel worm'. 14-20 mm. Colon.	Stout greyish-white worm. Attached to mucosa by buccal capsule (visible as a knob), resulting in petechiae. *Heavy infections* Mucosa thickened, oedematous, longitudinally ridged.	Widely distributed in winter rainfall areas. Heavy infections uncommon. Light infections: passage of soft faeces with brown mucus and flecks of blood.	*FECs* Not a specific guide however 1000-2000 may be significant. Eggs typically strongyle. *WCs* Heavy experimental infections; 500-700 worms Light infections: less than 100 worms. *Egg output* 5,000 per female per day.
Dictyocaulus filaria - 'large lungworm'. 30-100 mm. Lungs.	*Heavy infections* (uncommon) Adults in bronchi and bronchioles cause dark red-grey consolidation of caudal lobes and chronic catarrhal bronchitis.	Usually in small numbers, and mostly in young sheep. May cause coughing. *Heavy experimental infections* Dyspnoea, secondary pneumonia, deaths.	*FECs* First stage larvae (with distinctive knob on head) passed in faeces. *WCs* White thread-like worms clearly visible in bronchi. Heavy infections: intertwined worms extend to bifurcation of trachea. Light infections: less than 50 worms.
Muellerius capillaris - 'small lungworm'. 12-22 mm. Lungs.	Adults in (lead) shot-like nodules in lung, immediately under pleura.	Ill thrift in artificially infected sheep.	*FECs* First stage larvae (no knob on head, but dorsal spine on tail) passed in faeces. *WCs* Adults live in nodules under lung surface.

Protostrongylus rufescens - small lungworm. 16-35 mm. Lungs.	Rare in Australia. Slender worms which may cause bronchiolitis and focal pneumonia.		*FECs* First stage larvae (no knob on head, or dorsal spine, but tail is pointed) passed in faeces. *WCs* No guidelines. Worms reddish and slender.
Ascaris suum. Liver *[Note: Rare, academic interest only?]*	Rare infections in sheep, infected from pigs. No specific lesions reported in sheep.	No specific signs reported (Il thrift in pigs)	*FECs* Characteristic eggs: brown, thick with pitted outer walls. *WCs* Worms large and clearly visible in small intestine and bile ducts.
Gongylonema spp. Oesophagus, rumen *[Note: Rare, academic interest only?]*	Rare parasite in Australia. Found tightly coiled or as a zigzag in mucosa of oesophagus and forestomachs. No known pathogenic effects. Adults are large nematodes: 60-150 mm long.		Worms long, threadlike, red.
Fasciola hepatica - liver fluke. 20-30 mm. Liver.	*Acute fasciolosis* (massive infection) Severe anaemia, bloody peritoneal fluid, peri-hepatic fibrinous peritonitis, haemorrhagic tracts in liver. *Subacute form* Some adults in bile ducts, anaemia, haemorrhagic tracts. *Chronic form* Bile ducts fibrosed thickened and may contain adult fluke.	Variable, ranging from abdominal pain, severe anaemia and deaths to milder anaemia, submandibular oedema and production loss.	*FECs* 100+ may be associated with disease (acute and subacute: 150-2500; chronic: 2000-4000), however low counts may be associated with significant production loss. Eggs large yellowish brown, with operculum. *Total fluke counts* Acute: 1000+ Subacute: 500-1000 Chronic: 100-400 *Egg output* 10-20,000 per female per day, possibly for life (5-10 years or more)
Paramphistomes. 5-12 mm. Rumen, reticulum, Small intestine.	Most damage done by immature parasites embedded in or attached to SI mucosa causing erosions, haemorrhage and oedema. Necrosis of ruminal papillae also may occur.	Rarely causes clinical disease in sheep. Anorexia, watery diarrhoea, submandibular oedema.	*FECs* Low in acute disease. Eggs large, transparent with operculum. *Total fluke counts* Acute: 10 000 (up to 100 000) immature fluke in SI.

Moniezia spp., *Thysaniezia* sp. 1-6 m. Small intestine.	Little or no pathology.	Questionable importance.	*FECs* Variable numbers. Eggs medium size, triangular, dark grey. *WCs* Worms may fill the SI of young lambs. No specific lesions.

Important note: This is an overview only. Egg and worm counts are merely indicative. Opinions vary on the significance of different counts for various worms. Additionally, egg and worm counts need to be interpreted in light of the age and nutritional and physiological status of the host.

Table 5. Cattle parasites -summary (adapted from Coles 1986)

Parasite, length, location	Gross pathology	Clinical signs	Significant faecal egg counts (FECs) and worm counts (WC); other
Haemonchus placei. 10-30 mm. Abomasum.	Blood clots and mild abomasitis in heavy infections. Red and white 'barbers pole' appearance of females; worms clearly visible. Light infections: no gross lesions.	*Heavy infections* Mainly in young cattle in summer rainfall areas. Usually with *Oes. radiatum* and *Cooperia spp.* Exercise intolerance. Anaemia, submandibular oedema. *Light infections* Ill thrift, mild anaemia.	*FECs* 700-1500+ may be clinically significant. Eggs typically strongyle. *WCs* Heavy infections: 5 000-10 000+ worms. Mainly in calves. Generally less important than *Haemonchus* in sheep.
Ostertagia spp - 'small brown stomach worm'. 6-10 mm. Abomasum.	An important pathogenic parasite of young and adult cattle. Larvae entering gastric glands produce small white crater-like nodules which coalesce to give mucosa 'morocco leather' look. Inflammatory response with oedema and congestion when larvae emerge from glands. Type I and II lesions similar. Gross distension of folds seen in type II.	Type I affects young dairy calves and beef weaners in post-weaning period. Type II affects yearlings, pregnant heifers and old cows. Typical acute symptoms: anorexia, severe weight loss, scouring, submandibular oedema and deaths depending on severity of infection. Lighter infections: ill thrift, moderate scour.	*FECs* 300+ may be clinically significant; however significant disease can occur with lower FECs. Counts generally low, up to 1500+. Eggs typically strongyle. *WCs* Up to 100 000 - 600 000+. Up to 80% may be arrested in type II disease.
Trichostrongylus axei - 'stomach hair worm'. 3-4 mm. Abomasum.	Infections usually light. Much smaller than *Ostertagia* and difficult to see. Worms mainly in pyloric region. Gastritis in heavy infections with congestion and ringworm-like lesions.	May contribute to scouring-ill thrift syndrome in mixed/heavy infections.	*FECs* Counts usually low. Moderate infections may contribute 500-1000 epg to mixed infections. Eggs typically strongyle. *WCs* Heavy infections: 100 000 - 5000 000 worms.
Trichostrongylus spp. 4-7 mm. Small intestine.	Rarely produces lesions or clinical disease in cattle and is an uncommon parasite.		*FECs* No diagnostic value. Eggs typically strongyle. *WCs* No information.

Nematodirus spp. - 'thin-necked intestinal worm'. 10-20 mm. Small intestine.	No specific gross lesions. A rare parasite of beef cattle; seen occasionally in dairy calves in mixed infections.	Usually non-pathogenic.	*FECs*. Eggs large and easily distinguishable from strongyle. Useful for diagnosis. *WCs* Heavy infections: rare but may be seen in diary calves (10 000 worms).
Cooperia spp. 5-9 mm. Small intestine.	The most common small intestinal worm. Usually in mixed infections with *Ostertagia (or Haemonchus in (sub) tropical areas. Heavy infections* are pathogenic for young calves. Catarrhal enteritis, patchy necrosis, haemorrhages. Emaciation.	Mainly in calves: Intermittent diarrhoea, ill thrift. Listlessness, death. Usually in mixed infections.	*FECs* Counts in young calves up to 1000 - 5000. In acute disease, from 10 000 - 30 000. Eggs typically strongyle. *WCs* Heavy infections (eg dairy calves): 50 000 - 200 000 worms.
Bunostomum phlebotomum - 'hookworm'. 10-28 mm. Small intestine.	Infection can be percutaneous. Focal haemorrhages in intestinal mucosa, and lungs, though which larvae migrate en route to the gut. Variable anaemia. Parasite's large buccal capsule strips off villi, producing inflammation and exudation. Mainly affects dairy calves in (sub) tropical coastal areas.	Dull demeanour, anaemia, submandibular oedema, dark foetid scour.	*FECs* 500 - 800 in heavy infections. Eggs typically strongyle. *WCs* 100-500+ may cause ill thrift, anaemia in young dairy claves.
Strongyloides papillosus. 4-6 mm. Small intestine.	Common in dairy claves in Queensland, especially if cross grazed with lambs. Percutaneous infection occurs. Calves can be become heavily infected, but infections rapidly eliminated naturally.	Heavy infection said to produce 'white scour' syndrome.	*FECs* Eggs smaller than common strongyles and embryonated. *WCs* Infections of 5000 worms have been found in calves.
Trichuris spp - 'whipworm'. 40-80 mm. Caecum.	Not a serious parasite of cattle. Pathogenic importance unknown.	Usually non-pathogenic.	*FECs* Generally low but useful to diagnose presence of *Trichuris*. Eggs characteristic (brown with transparent polar plugs). *WCs* Several hundred in heavy infections but hard to count as worms clump together.

Oesophagostomum radiatum - 'nodular worm'. 14-22 mm. Colon.	Very pathogenic parasite. Common in young cattle 4-12 months old in tropical and sub-tropical areas. Third stage larvae form nodules, mainly in ileum but also caecum and colon. Colon thickened, oedematous. Excess mucus.	Heavy infections: weight loss, scour, anaemia, submandibular oedema, and death. Histiotrophic phase may also cause ill-effects.	*FECs* Low counts usual: 300-500. A count of 500 may be significant. Eggs typically strongyle. *WCs* Heavy infections: 1500 - 4000 worms. Light to medium: 500 - 800.
Oesophagostomum venulosum - 'large bowel worm'. 11-24 mm. Caecum.	Not an important parasite of cattle. Usually present in small numbers.	Relatively non-pathogenic.	*FECs* Uncertain significance. Eggs typically strongyle. No value for diagnosis.
Chabertia ovina -'large mouthed bowel worm'. 14-20 mm. Colon.	Rare parasite of cattle. Occurs in sheep areas, e.g. tablelands of NSW. Pathological lesions have not been reported.	No specific clinical signs reported.	*FECs* As for *Oes. columbianum*.
Dictyocaulus viviparus - 'large lungworm'. 40-80 mm. Lungs.	A serious parasite of calves in Europe but relatively unimportant in Australia, although heavy infections are seen in dairy calves. Heavy infections (uncommon): Adults in bronchi and bronchioles cause dark red-grey consolidation of caudal lobes and chronic catarrhal bronchitis.	May cause coughing, weight loss. Often seen in conjunction with gastrointestinal helminthosis.	*FECs* First stage larvae (with distinctive knob on head) passed in faeces. *WCs* Blockage of bronchi and bronchioles with white thread-like worms indicative of pathogenic effects.
Onchocerca spp. Brisket, ligamentum nuchae, gastrosplenic ligament.	*O. gibsoni* forms nodules 10-20 mm in connective tissue of brisket, stifle and hip regions, *O. gutturosa* mainly in the lig. nuchae, and *O. lienalis* in the gastrosplenic ligament.	No clinical signs. Lesions may be palpable. Microfilariae in skin snips. Lesions normally detected at meat inspection.	Insect borne (midges).
Thelazia spp. Eye.	White nematode in conjunctival sac, lachrymal ducts, and nasolacrimal canal. Associated with conjunctivitis and keratitis but also found in normal eyes.	Worms behind third eyelid and in lachrymal ducts, so worms are difficult to detect clinically. Larvae recoverable from saline eye washings.	Insect borne (flies).

Toxocara vitulorum Adult worms large: ~20-25 cm. Small intestine.	Rare parasite in Australia. No specific lesions/signs. Adult worms large: ~ 20-25 cm.		*FECs* Eggs characteristic: spherical with thick pitted outer shell and granular contents.
Ascaris suum Lungs.	Pneumonia. Presence of *A suum*.	Case reported from South Australia where infected yearling cattle developed respiratory distress. Also Atherton Tablelands (northern Queensland).	
Stephanofilaria spp. Small parasite 2.5. -4.5 mm long Skin	Found in small cysts (up to 4 parasites per cyst) just beneath skin surface in *Bos indicus* cattle. Lesions raised circumscribed hairless areas on head, neck, dewlap and sternum.	Cattle rub and scratch lesions.	Insect borne (buffalo fly).
Setaria labiato-papillosa. Adults 35-100 mm long. Peritoneal cavity	Found in north Queensland. No pathogenic effects. Adult sin peritoneal cavity 35-100 mm long.	Microfilariae found in blood.	Insect borne. Found in north Queensland.
Gongylonema spp. Adults are large nematodes: 60-150 mm long Oesophagus, rumen.	Found in oesophageal and ruminal submucosa or mucosa. No known pathogenic effects. Adults are large nematodes: 60-150 mm long.		
Fasciola hepatica - liver fluke. 20-30 mm. Liver.	*Acute fasciolosis* (massive infection) Severe anaemia, ascites, haemorrhagic tracts in liver. *Chronic form* (most common in cattle) Bile ducts fibrosed, thicken	Variable, but usually mild/non-specific in cattle but sometimes with significant production losses. Anaemia and deaths may occur rarely. An important cause of liver condemnations at abattoirs.	*FECs* Little correlation between FECs and worm burdens. Low counts can be associated with significant production loss. Eggs large yellowish brown, with operculum. *Total fluke counts* Light infestation up to 50; medium 50-100; heavy >100.

Paramphistomes. 5-12 mm. Rumen, reticulum, small intestine.	Most damage done by immature parasites embedded in or attached to SI mucosa causing erosions, haemorrhage and oedema. Necrosis of ruminal papillae also may occur. Adults provoke little reaction.	Young cattle: Anorexia, watery diarrhoea, submandibular oedema (due to immature paramphistomes). Adult cattle: production loss and mild clinical signs (rough coat, mild anaemia) has been reported (adult parasites).	*FECs* Low in acute disease. Eggs large, transparent with operculum. *Total fluke counts* Acute: 10 000 (up to 100 000) immature fluke in SI.
Moniezia spp., *Thysaniezia* spp. 1-6 m. Small intestine.	Little or no pathology.	Questionable importance. Common, particularly in calves grazed with sheep.	*FECs* Variable numbers. Eggs medium size, triangular, dark grey. *WCs* Tapeworms are large but few are present.

Important note: This is an overview only. Egg and worm counts are merely indicative. Opinions vary on the significance of different counts for various worms. Additionally, egg and worm counts need to be interpreted in light of the age and nutritional and physiological status of the host.

Chapter 17

Necropsy Findings in Ruminant Poisonings by Plant, Fungal, Cyanobacterial and Animal-Origin Toxins in Australia

R A McKenzie

INTRODUCTION

Poisoning of ruminants affects virtually all body systems. These notes will deal with lesions detectable at necropsy of ruminants poisoned by natural toxins from (1) a clinical perspective and system by system and (2) a toxin perspective. Major toxin sources, pathology and appraoches to diagnosis are listed Suggestions for confirmation of diagnoses are also included. All data in this work are drawn from McKenzie RA (2002) *Toxicology for Australian Veterinarians.* (published by the author: 26 Cypress Drive, Ashgrove 4060; phone 07 3366 5038; e-mail yapunyah.house@bigpond.com) which should be consulted for more information on the syndromes and toxins included and references to the data.

CLINICAL CONSPECTUS

This section gives an overview of natural toxins and toxin sources affecting ruminants arranged by syndrome or affected organ system to help with differential diagnosis of cases.

Sudden death syndromes

'Sudden' death is defined as death occurring so rapidly that affected animals are **found dead** without being seen to be ill or **die within a few minutes to a few hours** of clinical signs being noticed. Of course, the transition from life to death itself is always sudden, that is, instantaneous.

Plants

- Cyanogenic glycosides [→ Cyanide, HCN or Prussic acid]
- Nitrate-nitrite
- Oxalates (acute poisoning)
- Fluoroacetate
- Cardiac glycosides
- Andromedotoxins (grayanotoxins)
- Taxine diterpenoid alkaloids
- *Erythrophleum* spp. (diterpenoid alkaloids & cinnamic acid derivatives)
- Pyrrolizidine alkaloids
- S-methylcysteine sulphoxide (SMCO) & N-propyl disulphide / thiosulphates

- Phytotoxin-induced cardiomyopathies (see below under Heart & Vascular disease for specific toxins)
- *Trachymene* spp. (wild parsnips)
- Galegine
- Phyto-oestrogens - bladder rupture (wethers)
- Ifforestine
- Diterpenoid alkaloids - *Delphinium* spp.
- Nicotine (pyridine) alkaloids
- Tropane alkaloids [scopolamine (=hyoscine), hyoscyamine, atropine and others]
- *Phalaris aquatica* poisoning – sudden death
- Cucurbitacins (tetracyclic triterpenes)
- Aliphatic nitro compounds (nitrotoxins)
- *Parsonsia* spp.
- Selenium

Fungi

- *Aflatoxins*
- *Corallocytostroma ornicopreoides toxicity (black soil blindness)*

Cyanobacteria

- Cyanobacterial alkaloid neurotoxins – paralytic shellfish poisoning (PSP) toxins and anatoxins

Acute liver necrosis:

Plants

- Diterpenoid (kaurene) glycosides - atractyloside, carboxyatractyloside, parquin, carboxyparquin & wedeloside
- Furanosesquiterpenes
- Methylazoxymethanol (MAM)
- Trema tomentosa [liver-necrosis-inducing phytotoxin]
- Gossypol
- Argentipallium blandowskianum [liver-necrosis-inducing phytotoxin]
- Ozothamnus diosmifolius [liver-necrosis-inducing phytotoxin]
- Cynosurus echinatus (rough dog's tail grass) [liver-necrosis-inducing phytotoxin]
- Lythrum *hyssopifolia (lesser loosestrife)*

Fungi

- Macrofungal peptides
- Aflatoxins
- Mouldy sprouted barley - suspected mycotoxicosis

Cyanobacteria

- Cyanobacterial hepatotoxic cyclic peptides – microcystins and nodularin
- Cylindrospermopsin

Animals

- Sawfly larval peptides

Nephrosis:

Plants
- Oxalates (acute poisoning)
- Tannins (hydrolysable)
- Pennisetum clandestinum (kikuyu -grass)
- Lythrum hyssopifolia (lesser loosestrife)
- Ifforestine

Fungi
- Corallocytostroma ornicopreoides toxicity (black soil blindness)

Photosensitisation:

Primary

Plants
- Dianthrone derivatives (hypericin, fagopyrin)
  - *Hypericum perforatum*
  - *Fagopyrum sagittatum*
- Furanocoumarins (furocoumarins, psoralens)
  - *Ammi majus*
  - *celery, parsley, parsnip*
  - *Cullen (Psoralea) patens*
  - *Citrus aurantifolia*

Secondary (hepatogenous)

Plants
- Lantadenes (pentacyclic triterpenes)
- Steroidal or lithogenic saponins
  - *Panicum spp.*
  - *Brachiaria spp.*
  - *Tribulus terrestris*
- Tannins (hydrolysable) - Terminalia oblongata ssp. oblongata

Fungi
- Sporidesmin
- Phomopsins

Sporadic - unknown toxins

Plants
- *oats, barley, wheat, millets*
- *lucerne, clovers, medics*
- *Sorghum sudanense*
- *Brassicaceae – Glucosinolates*
- *Polygonum spp.*

- Pyrrolizidine alkaloids
- Liver necrosis-inducing plants, cyanobacteria, mycotoxins
- Cynosurus echinatus (rough dog's tail grass) [liver-necrosis-inducing phytotoxin]

Haemorrhage (including haematuria)/Haemolysis/ ethaemoglobinaemia/Myoglobinuria/Red urine pigments (non-haem):

Widespread Haemorrhage

Plants

- Ptaquiloside
- Dihydroxycoumarin (dicoumarol)
  - mouldy Melilotus spp.
  - Anthoxanthum odoratus
  - Ferula communis
- Daphnoretin (presumed toxin in Wikstroemia indica)
- Colchicine and related alkaloidal amines

Fungi

- Aflatoxins
- Trichothecenes (Type A)

Haematuria

Plants

- Ptaquiloside (bovine enzootic haematuria)

Haemolysis

Plants

- Pyrrolizidine alkaloids
- Pyrrolizidine alkaloidosis + Copper
- S-methylcysteine sulphoxide (SMCO) & N-propyl disulphide / thiosulphates
- Glycosidic steroidal alkaloids (glycoalkaloids) of Solanum spp. (nightshades)
- Gossypol
- Acer spp. (maples)
- Berteroa incana (hoary alyssum)
- Raphanus raphanistrum (wild radish)

Fungi

- Gyromitra esculenta (false morel)

Methaemoglobinaemia

Plants

- Nitrate-nitrite
- Acer spp. (maples)

Myoglobinuria

Plants

- Senna spp. [= Cassia spp.]
- Malva parviflora (mallow, marsh mallow, small-flowered mallow)

Red Pigments (non-haem) in urine

Plants

- Xanthorrhoea minor (grasstree) - cattle
- Haloragis odontocarpa (mulga nettle) - sheep
- Trifolium pratense (red clover) – deer

Chronic ill-thrift:

Liver damage

Plants

- Pyrrolizidine alkaloids
- Heliotropium spp.
- Echium plantagineum
- Senecio spp.
- Crotalaria spp.
- Indospicine
- Glucosinolates
- Schinus spp.
- Raphanus raphanistrum (wild radish)

Fungi

- Aflatoxins
- Phomopsins
- Sporidesmin
- Mouldy sprouted barley - suspected mycotoxicosis

Kidney damage

Plants

- Tannins (hydrolysable)
  - *Quercus* spp.
  - *Terminalia oblongata*
- Oxalates
- Pyrrolizidine alkaloids - pigs
- Pennisetum clandestinum (kikuyu grass)
- Iforrestine
- 3-methoxy-2(5H)-furanone [Liliaceae nephrosis – cats, cattle, deer]
- Lythrum hyssopifolia (lesser loosestrife)
- Schotia brachypetala (drunken parrot tree)

Fungi

- Ochratoxins
- Citrinin

Alimentary tract damage

Plants

- Ptaquiloside - neoplasia
- Dittrichia graveolens enteritis (mechanical damage)

Connective tissue damage

Plants

- Plant calcinogenic glycosides

Thyroid damage

Plants

- Glucosinolates
- Mimosine
- Cyanogenic glycosides
- Pennisetum typhoides

Skin & appendage damage

Plants

- Selenium (chronic selenosis)
- Vicia spp. (vetch toxicity)
- Citrus pulp

Poor weight gain/Weight loss

Plants

- Swainsonine
- Swainsonine + calystegines (Ipomoea spp.)
- Cyanogenic glycosides - sulphur-responsive

Fungi

- Aflatoxins

Anaemia

Plants

- Irritant diterpenoids of Pimelea spp. – simplexin (& huratoxin)

Depressed wool growth in sheep

Bacteria

- Corynetoxins (tunicaminyl-uracils)

Nervous syndromes I (CNS): Convulsions, tremors, deranged behaviour, deep depression:

Convulsions (seizures) - clonic

Plants

- Fluoroacetate
- Thiaminase
- Terminalia oblongata (yellow-wood) - sheep
- Tropane alkaloids [scopolamine (=hyoscine), hyoscyamine, atropine and others]
- Cynanchosides
- Piperidine & nicotine (pyridine) alkaloids
- Sulphur (S-associated polioencephalomalacia of ruminants)

Fungi

- Cyclopiazonic acid

Bacteria

- Corynetoxins (tunicaminyluracils) (ARGT)

Convulsions (seizures) - tetanic

Plants

- Strychnine (& brucine)
- Alstonine, alstonidine and other indole alkaloids of Alstonia constricta
- Indole (pyrrolidinoindoline) alkaloids - calycanthine, chimonanthine, idiospermuline
- Cynanchosides
- Musa sp. (bananas) (?)

Tremors

- *Plants*
- Indole alkaloids of Phalaris spp (phalaris) - Phalaris staggers
- Pyridine (nicotine) and piperidine alkaloids
- Chamaecytisus proliferus

Fungi

- Lolitrems
- Paspalitrems (Claviceps paspali tremorgens)
- Aspergillus clavatus tremorgenic mycotoxins

Deranged behaviour (mania), deep depression

Plants

- Dianthrone derivatives (hypericin, fagopyrin)
- Prosopis juliflora (mesquite) – neuronal vacuolation in cranial nerve nuclei
- Avena sativa (oats) – "red-tipped" or "rusty" oats crops
- Swainsonine
- Swainsonine + calystegines (Ipomoea spp.)
- Calystegines (nortropane alkaloids) - probable aetiology of Solanum spp.-associated cerebellar degeneration
- Quinolizidine alkaloids of Lupinus spp.
- Hepatoencephalopathy
- Pyrrolizidine alkaloids
- Acute liver necrosis toxins
- Dendrocnide spp. (stinging trees)
- Glycosidic steroidal alkaloids (glycoalkaloids) of Solanum spp. (nightshades)
- Pisum sativum var. arvense (field pea)
- Dialkylimidazoles (indole alkaloids) - Ammoniated forage toxicity
- Tetrahydrocannabinol - Cannabis sativa (marijuana)

Fungi

- Lysergic acid amide (ergot alkaloid)
- Ethanol (ethyl alcohol)

Nervous syndromes II (CNS/PNS):
Ataxias, paralyses, gait abnormalities:

Ataxias

Plants

- Cycads
- Xanthorrhoea spp. (grasstrees) –posterior ataxia syndrome
- Aliphatic nitro compounds (nitrotoxins)
- Indole alkaloids of Phalaris spp (phalaris) - Phalaris staggers
- ß-carboline alkaloids [indole alkaloids] – Coonabarabran staggers
- Swainsonine + calystegines (Ipomoea spp.)
- Calystegines (nortropane alkaloids) - probable aetiology of Solanum spp.-associated cerebellar degeneration
- Tribulus micrococcus (yellow vine)
- Pyridine (nicotine) and piperidine alkaloids
- Hoya australis (hoya, wax flower)

- Trachyandra spp.
- Cyanogenic glycosides - Sorghum spp. spinal cord damage
- Other plant staggers syndromes –
- Stachys arvensis
- Lamium amplexicaule
- Malva parviflora
- Echinopogon spp.
- Gomphrena celosioides (gomphrena weed, soft khaki weed)
- Tetrahydrocannabinol - Cannabis sativa (marijuana)
- Solanum spp.-associated cerebellar degeneration
- Cumulative bufadienolide cardiac glycosides (cotyledonosis)
- Chamaecytisus proliferus (tagasaste)
- Humpyback of sheep
- "Scrub ataxia" of suckling calves in south-eastern Queensland

Fungi

- Aspergillus clavatus tremorgenic mycotoxins
- Cyclopiazonic acid
- Diplodia maydis neurotoxin

Paralysis/paresis

Plants

- Tropane alkaloids [scopolamine (=hyoscine), hyoscyamine, atropine and others]
- Aliphatic nitro compounds (Nitrotoxins)
- Cumulative bufadienolide cardiac glycosides (cotyledonosis)

Fungi

- Diplodia maydis neurotoxin

Gait abnormality

Plants

- Swainsonine
- Swainsonine + calystegines (Ipomoea spp.)
- Indole alkaloids of Phalaris spp (phalaris)
- Phalaris staggers

Fungi

- Paspalitrems (Claviceps paspali tremorgens)
- Lolitrems
- Diplodia maydis neurotoxin

Blindness:

Retinal ± optic nerve degeneration

- Plants
- Stypandrol
- Ptaquiloside – "bright blindness"
- Rhodomyrtus macroparpa (finger cherry)

Cataracts

Plants

- Mimosine
- Xanthorrhoea johnsonii (northern forest grasstree)

Corneal opacity

Plants

- Furanocoumarins (furocoumarins, psoralens)
- Glucosinolates

Fungi

- Ramaria flavo-brunnescens (a coral fungus)

CNS Damage

Plants

- Swainsonine
- Swainsonine + calystegines (*Ipomoea* spp.)

Polioencephalomalacia

Plants

- Thiaminase
- Sulphur (S-associated polioencephalomalacia of ruminants)

Hepatoencephalopathies

Plants

- Pyrrolizidine alkaloids
- Acute liver necrosis

Unknown mechanism

- Fungi
- Corallocytostroma ornicopreoides toxicity (black soil blindness)

Respiratory syndromes:

Pneumonitis

Plants

- Andromedotoxins (grayanotoxins)
- Zieria arborescens (stinkwood)
- Glucosinolates

Fungi

- Furans - Mouldy sweet potatoes

Pulmonary oedema (dominant sign)

Plants

- Galegine
- Aliphatic nitro compounds (Nitrotoxins)

Pyrexia, hyperpnoea

Plants

- Ptaquiloside
- Dianthrone derivatives (hypericin, fagopyrin)

Fungi

- Ergot alkaloids (ergopeptide alkaloids)- ergotism
- Balansia sp. in Paspalidium jubiflorum (Warrego summer grass)

Heart & vascular disease:

Phytotoxin-induced cardiomyopathies – sudden death

Plants

- Fluoroacetate
- Gossypol

- Unsaturated fatty acids, particularly crepenynic acid
- Persin
- Theobromine (a xanthine alkaloid)
- Senna spp.
- Trachymene spp. (wild parsnips)
- Castanospermum australe (Moreton Bay chestnut, black bean) (rare)

Heart failure

Syndromes including jugular vein distension, subcutaneous oedema (head, brisket, limbs), ascites, hydrothorax, cardiac dilation. There may be some overlap with cardiomyopathies producing sudden death.

Plants

- Irritant diterpenoids of Pimelea spp. – simplexin (& huratoxin)
- Gossypol
- Persin
- Isoquinoline alkaloids - Argemone spp. (Mexican poppy)
- Parsonsia spp.

Vascular disease

Fungi

- Ergot alkaloids (ergopeptide alkaloids)- ergotism

Diarrhoea and other alimentary syndromes:

Diarrhoea

Diarrhoea is a common sign attributed to plant and other poisonings. The main syndromes included here are the better characterised ones and are *not inclusive of all plants or other toxins capable of producing diarrhoea.*

Plants

- Cardiac glycosides
- Irritant diterpenoids of Pimelea spp. – simplexin (& huratoxin)
- Irritant diterpenoids of Families
- Thymeleaceae & Euphorbiaceae
- Glycosidic steroidal alkaloids (glycoalkaloids) of Solanum spp. (nightshades)
- Cucurbitacins (tetracyclic triterpenes)
- Castanospermum australe (Moreton Bay chestnut, black bean)
- Senna spp. [= Cassia spp.]
- Meliatoxins (tetranortriterpenes)
- Trachymene spp. (wild parsnips)
- Phytolacca spp.
- Avena sativa (oats) – "red-tipped" or "rusty" oats crops
- Schinus spp.
- Dittrichia graveolens enteritis (mechanical damage)
- Pyrrolizidine alkaloids
- Colchicine and related alkaloidal amines
- Terpenoids of Pachyrhizus erosus (yam bean)
- Berteroa incana (hoary alyssum)
- Raphanus raphanistrum (wild radish)

Fungi
- Ramaria flavo-brunnescens (a coral fungus)
- Trichothecenes (Type A)

Buccal irritation (stomatitis) or ptyalism (excessive salivation, sialorrhoea)
Plants
- Calcium oxalate raphide crystals
- Mimosine
- Protoanemonin
- Grass awns

Fungi
- Ramaria flavo-brunnescens (a coral fungus)
- Trichothecenes (Type A)
- Slaframine
- Diplodia maydis neurotoxin

Forestomach lesions
Plants
- Pennisetum clandestinum (kikuyu grass)
- Cucurbitacins
- Glucosinolates

Fungi
- Corallocytostroma ornicopreoides toxicity (black soil blindness)

Vomiting/regurgitation (ruminants, horses)
Plants
- Andromedotoxins (grayanotoxins)

Phytobezoars (plant fibre balls)
Plants
- Romulea rosea var. australis (onion grass, Guildford grass)
- Anemone patens (pasque flower)

Neoplasia
Plants
- Ptaquiloside – upper alimentary tract (cattle), intestines (sheep)

Hair loss or dermatitis:

Hair loss
Plants
- Mimosine
- Selenium (chronic selenosis)

Fungi
- Ramaria flavo-brunnescens (a coral fungus)

Dermatitis
Plants
- Vicia spp. (vetch toxicity)
- Grass awns
- Schinus spp.
- Parsonsia spp.

- Citrus pulp
- "Scrub ataxia" of suckling calves in south-eastern Queensland

Fungi
- Trichothecenes Type A

Goitre:

Plants
- Cyanogenic glycosides – congenital goitre
- Mimosine
- Glucosinolates
- Pennisetum typhoides (pearl millet seed) – goats; Africa

Skeletal muscle syndromes:

Plants
- Unsaturated fatty acids, particularly crepenynic acid
- Senna spp. [= Cassia spp.]
- Malva parviflora (mallow, marsh mallow, small-flowered mallow)

Fungi
- Phomopsins

Bone syndromes:

Plants
- Trachymene spp. (wild parsnips)

Reproductive syndromes:

Congenital abnormalities

Plants
- Cyanogenic glycosides (putative agent) - Sorghum sudanense hybrids
- Cyanogenic glycosides – congenital goitre
- Trachymene spp. (wild parsnips)
- Piperidine, pyridine (nicotine) & quinolizidine alkaloids - *Conium,* Lupinus, Nicotiana teratogens
- Steroidal alkaloids- Veratrum, Solanum tuberosum
- Chamaecytisus proliferus (tagasaste)

Mastitis/Agalactia

Plants
- Persin (Persea americana)

Fungi
- Ergot alkaloids (ergopeptide alkaloids)- ergotism

Reduced fertility

Plants
- Phyto-oestrogens
- Gossypol
- Swainsonine
- Romulea rosea var. australis

Fungi
- Zearalenone - cattle
- Trichothecenes (Type A)

Abortion/premature birth

Plants
- Isocupressic acid (bicyclic labdane diterpene acids) and/or Vasoactive lipids
- Swainsonine
- Gossypol
- Nitrate-nitrite
- Salvia coccinea (red salvia, Texas sage)
- Trigonella foenum-graecum (fenugreek)
- Mentha longifolia (horse mint)
- Mentha saturioides (native pennyroyal)
- Tanacetum vulgare (tansy)
- Indospicine (Indigofera spicata)
- Raphanus raphanistrum (wild radish)
- Romulea rosea var. australis
- Verbena spp.
- Ranunculus repens (creeping buttercup)
- Berteroa incana (hoary alyssum)
- Leucaena leucocephala

Fungi
- Ergot alkaloids (ergopeptide alkaloids)- ergotism
- Trichothecenes (Type A)

Neoplasia:

Plants
- Ptaquiloside

Fungi
- Aflatoxins

Immunological suppression:

Fungi
- Aflatoxins
- Trichothecenes (Type A)

PHYTOTOXINS (*TOXINS* OF VASCULAR PLANT ORIGIN)

INORGANIC TOXINS

Nitrate-nitrite

Common sources:

- Avena sativa (oats)
- Sorghum spp. (sorghum)
- Lolium spp. (rye grasses)
- Portulaca spp. (pig weed)
- Salvia reflexa (mint weed)
- Silybum marianum (variegated thistle)
- Arctotheca calendula (cape weed)

+ many others

Pathology:
At necropsy, **chocolate-brown blood** (methaemoglobin) is usually seen. Note that the colour fades with time after death as methaemoglobin is reconverted to haemoglobin and the abnormality is not always observed.

Diagnosis:
The **diphenylamine test for nitrate** may be applied to **plants, aqueous humour** (up to 6-12 hrs after death) and rumen contents. Note that microbial action after sampling can decrease nitrate content, so chill aqueous humour samples for transport to a laboratory and test rumen contents very soon after death.

Plants with greater than 1.5% KNO_3 equivalent in their dry matter are regarded as potentially toxic to ruminants.

Aqueous humour nitrate concentrations in normal cattle are about 5 mg/L. In poisoned cattle they can be 100-150 mg/L. Interpretation of aqueous humour nitrate concentrations in aborted foetuses suspected of being associated with dam exposure to toxic pasture have been suggested as: <25 ppm = definite negative; 25-50 ppm = probable negative; >50 ppm = suspicious. Cases associated with a source of nitrate and with no infectious agent or inflammatory change demonstrated in foetal tissues usually have aqueous humour nitrate >>50 ppm.

Post mortem blood samples may also be tested for nitrate content (half-lives in blood: nitrate = 5.0 hr; nitrite = 0.5 hr), but *post mortem* bacterial decomposition may destroy it more rapidly than aqueous humour nitrate, so negative results must be interpreted with caution.

Diphenylamine spot test for nitrate in plants or body fluids

Reagent
0.5 g diphenylamine in 20 ml distilled water with enough sulphuric acid added to bring the total volume to 100 ml. Cool and store in a brown bottle. Dilute with 80% sulphuric acid to half strength to make the test solution.

Procedure
Place 1 drop of test solution on the cut surface of a plant,
OR place a drop of serum, urine or other body fluid on a white plate and add 3 drops of test solution.
A green to blue colour is a positive test.

Alternatively
Commercial test strips for nitrate testing are available from Merck [Merckoquant® Nitrate Test in packs of 100 or 25 test strips]; [Note: work well for plants and water, but seriously under-estimate nitrate concentrations in ocular fluids (MP Carlson, personal communication, VETTOX discussion list 1997)]

Urinalysis test strips (Combur 9 test strips; Boehringer) may be used to test aqueous humour as well as urine for nitrate/nitrite (Montgomery & Hum 1995)

Garlic press field spot test method for use on plant samples

Use garlic press + Merckoquant strips + fresh plant

Squeeze fresh plant in garlic press; place a drop of sap on the end pad of test strip, shake gently to remove excess sap; time for 1 min; compare colour with NO_3 scale on strip container

Result: 500 mg/L nitrate or more (= 0.8% KNO_3) may be hazardous to ruminants. Confirm hazardous concentrations by submitting samples to a laboratory.

Selenium (chronic selenosis)
Common sources:

- *Morinda reticulata* (mapoon, ad-a)
- *Neptunia amplexicaulis* (selenium weed)

Syndrome names:

- *chronic selenosis*
- *alkali disease (USA) ("the alkali", "bob tail disease")*

So-called "blind staggers", attributed to Se intoxication in USA for decades, is now recognised not to be a Se intoxication, but most commonly polioencephalomalacia (S-associated) (*q.v.*) or due to other encephalopathies. The geochemistry associated with Se-accumulator plants often produces water with a high S content in the same landscape.

Pathology:
Cattle (natural cases are rare)

- dystrophic hoof lesions: separation of horn from lamellar and coronary epidermis
- tubules in the stratum medium of hooves replaced by island of parakeratotic cellular debris separated by more normal hoof matrix ± hyperplasia, acanthosis, parakeratosis and disorganised germinal epithelium of varying severity in hoof epithelium, particularly at the tips of epidermal lamellae. Distinguished from chronic laminitis which has predominantly dermal (chorial) lesions

- loss of tail switch: follicles atrophic and devoid of hair shafts, dyskeratosis and mild superficial follicular keratosis.
- no lesions outside the integument

Diagnosis:
Assay liver, kidney [hair, hoof] for Se

SIMPLE ORGANIC TOXINS

Fluoroacetate

Common sources:

- *Gastrolobium* spp. (poison bushes) – 34 known and 8 suspected toxic species in south-western Australia, central Australia (2 species) and central Queensland (1 species)
- *Acacia georginae* (Georgina gidyea) – western Queensland, eastern Northern Territory

Pathology:

- hyperglycaemia, acidosis
- increased citrate concentrations in blood, kidney
- rapid onset of *rigor mortis* similar to cases of strychnine toxicity (*q.v.*)
- multifocal myocardial degeneration and necrosis has been seen in sheep and myocardial scarring is reported in survivors of *Acacia georginae* poisoning.

Diagnosis:
Assays for fluoroacetate may be done on stomach/rumen contents, liver, kidney, plants and suspected baits. A modified HPLC method has been developed in South Africa. The recommended sampling protocol from necropsies is: Collect 100g each of liver & kidney & stomach/rumen contents into separate scrupulously-clean glass or plastic containers as soon after death as possible and freeze immediately. Submit to the laboratory frozen (to be assayed within 14 days of collection). If samples are not frozen, assay within 7 days of collection. In rumen samples spiked with fluoroacetate and held at room temperature (10-27°C), the concentration after 83 days was 85% of the starting concentration. In spiked liver samples, concentration decreased to 52% after 104 days. Further time lapse revealed no further decreases. A fluoroacetate assay is available from Queensland Department of Natural Resources, Alan Fletcher Research Station, 27 Magazine Street (PO Box 36), Sherwood 4075; Phone 07 3375 0700. Samples are tested in batches, usually monthly at a cost about $70 per sample (2001).

Botanical examination of rumen contents for the presence of source plants is useful, given that herbovores die rapidly from intoxication.

Histopathology of the myocardium may be helpful in ruminants. Lesions may be present if the animal survives more than 24 hrs.

The difficulty of field diagnosis of fluoroacetate poisoning due to the lack of unequivocal clinical signs and lesions may lead to over-diagnosis

(misdiagnosis) of this intoxication in endemic areas. In the endemic area for *Gastrolobium granidflorum* toxicity in Queensland, introduction of vaccination of cattle against botulism virtually halved the number of deaths in cattle in vaccinated herds. All these deaths had been previously ascribed by owners to fluoroacetate poisoning.

Oxalates (acute poisoning)

Common sources:

- *Oxalis pes-caprae* (soursob)
- *Portulaca* spp. (pigweed)
- *Setaria sphacelata* (setaria)

+ others

Pathology:

Acute oxalate poisoning: Clinical pathology reveals **hypocalcaemia** and **azotaemia** (increased concentrations of serum urea and creatinine). Necropsy may reveal minimal changes. In severe cases there may be pulmonary congestion and oedema, hyperaemia of forestomach walls or rumenitis. Kidneys are pale and swollen and may have petechial or ecchymotic haemorrhages. Histopathology reveals **nephrosis with rosettes of calcium oxalate crystals** in tubular lumens.

Chronic oxalate poisoning: Clinical chemistry reveals azotaemia and hypoproteinaemia. Kidneys are shrunken and fibrotic.

Diagnosis:

Acute oxalate poisoning:

- access + hypocalcaemia + calcium oxalate crystals in kidney tubules
- assay plants for soluble oxalate content. Hazardous plants contain over 2.0 - 2.5% soluble oxalate in dry matter. N.B. the other conditions of poisoning must be satisfied before poisoning can take place.

ALKALOIDS

Pyrrolizidine alkaloids

Common sources:

- Senecio spp. (groundsels, fireweeds)
- Heliotropium spp. (common & blue heliotropes)
- Echium spp. (Paterson's curse, viper's bugloss)
- Crotalaria spp. (rattlepods)

Pathology:

Hepatotoxic syndrome

Clinical pathology findings are variable. There may be increased plasma concentrations of bilirubin and liver-associated enzymes and decreased plasma concentrations of albumin and urea. **The most consistent finding is hyopalbuminaemia.** Anaemia may be found also. Pyrrolic metabolites can be detected on haemoglobin by TLC techniques.

The major lesion is a **chronic hepatopathy** characterised by atrophy of hepatic parenchyma (reduced numbers of hepatocytes) with

megalocytosis of the survivors, bile ductule proliferation and fibrosis (usually periportal, less commonly centrilobular). Multiple regeneration nodules of hepatocytes may occur. Pyrrolic metabolites can be detected in liver by TLC techniques.

Secondary and minor lesions may include ascites, status spongiosis of cerebral white matter (sometimes also grey matter), pulmonary emphysema and interstitial fibrosis, and megalocytosis of renal or pulmonary epithelium.

Acute pneumotoxicity - ruminants
Pulmonary oedema with tracheobronchial foam and distension of interlobular septa with fluid is the main lesion. Hydrothorax, hydropericardium and sub-pleural haemorrhages are also seen. Fibrin is present in the thoracic fluid and it coagulates on exposure to air. Histologically, there is proteinaceous fluid and some haemorrhage in alveoli. No significant hepatic lesions are seen.

Diagnosis:
Field tests are available to detect PAs and PA N-oxides in plants. Results obtained should be confirmed by laboratory assays.

Plant access by affected animals can be difficult to establish due to the lag between ingestion and the onset of signs weeks to months later.

Hepatotoxicity

Liver histopathology: **megalocytosis**, biliary ductular hyperplasia, fibrosis (note differential diagnosis includes aflatoxicosis)

Serum γGT may be used as a screening test for subclinical liver damage in horses.

Pyrrolic metabolites (PM) bound to tissue macromolecules may be detected in liver or blood using TLC (thin layer chromatography), but only in specialised laboratories.

Conditions for successful PM detection by this means include

- large sample sizes (at least 10 g liver or 20 ml whole blood in EDTA) are required to detect the small concentrations involved, so liver samples obtained by biopsy are unsuitable for testing.
- blood sample collection during or within about 2 weeks of access to the PA source so that sufficient PMs remain bound to haemoglobin of circulating erythrocytes for detection. As erythrocytes turn over (normal 120 day lifespan), dilution of the PM concentration occurs.
- liver samples fixed in formalin are suitable for PM detection

Jaagsiekte
Lung histopathology is characteristic.
Acute pneumotoxicity - ruminants
Plant access & pathology. Differential diagnoses should include poisoning by galegine (*q.v.*).

Indole (pyrrolidinoindoline) alkaloids - calycanthine, chimonanthine, idiospermuline

Idiospermum australiense is a rare lowland rainforest tree of northern Queensland in the monotypic Family Idiospermaceae. Its "seeds" are 3-6 cm in diameter and comprise naked embryos each with 3-4 massive fleshy cotyledons.

Pathology:
Numerous "seeds" in rumen contents (> 1kg in the field case), haemorrhages in epicardium, rumen, abomasum and upper small intestine with free blood in the lumen of the small intestine in one case.

Diagnosis:
Syndrome + access + seeds in rumen. Differential diagnoses include strychnine poisoning (hypersensitivity leading to tetanic spasms) and arsenic poisoning (alimentary haemorrhages)

Taxine diterpenoid alkaloids

Common source:
Taxus spp. (yew trees)

Pathology:
- plant in mouth and rumen/stomach
- **no significant lesions**
- gastric congestion (if death delayed for a few hours)

Diagnosis:
- access + sudden death + plant demonstrated in mouth/stomach [more likely in ruminants than monogastrics]
- assay of stomach contents for taxine alkaloids or other chemical markers of *Taxus* spp. is available in some labs; stomach contents preserved with ethanol are suitable for some assays

Swainsonine [an indolizidine alkaloid]

Common sources:
- Swainsona spp. (Darling peas)

Pathology:
- no specific lesions at necropsy; emaciation
- yellow discoloration of brainstem in chronically-emaciated sheep
- cytoplasmic vacuolation of circulating lymphocytes
- fine cytoplasmic vacuolation of neurones and visceral parenchyma (liver, kidney, pancreas, thyroid, placenta)
- persistent eosinophilic spheroids in axons

Diagnosis:
Access + pathology

Swainsonine + calystegines (Ipomoea spp.)

Sources:

- Ipomoea sp. aff. calobra (Weir vine) confined to the Maranoa district, Q;
- Ipomoea muelleri (poison morning glory) widespread in tropics (WA, NT, Q)

Pathology:

- nephrosis
- cytoplasmic vacuolation of neurones, persistent spheroids in axons (cerebellum particularly susceptible)

Diagnosis: pathology

Calystegines (nortropane alkaloids) - probable aetiology of Solanum spp.-associated cerebellar degeneration

Sources:

- Solanum dimidiatum Raf. [= S. carolinense L.] (potato weed, western horsenettle). Naturalised in Australia in the Bundaberg area of Queensland. No poisoning cases recorded in Australia.
- Solanum cinereum (Narrawa burr) - goats, sheep

Pathology:

Cattle

- *cerebellar atrophy at necropsy*
- *paucity or absence of Purkinje cells in cerebellar cortex*
- *foamy cytoplasmic vacuolation of remaining Purkinje cells*
- *swollen axons of Purkinje cells*

Goats

- cerebellum: deficit of grey matter compared with white matter; lesion only in cerebellum; other organs normal at necropsy
- brain weights and cerebellar weights similar to normal goats
- absence of Purkinje cells in many cerebellar folia
- some remaining Purkinje cells degenerative and some with fine foamy cytoplasmic vacuolation
- similar but milder vacuolation in hippocampus and choroid plexus
- proximal portions of Purkinje cell axons swollen and degenerate ("torpedoes")
- limited spheroidal neuroaxonal dystrophy scattered through brain
- mild Wallerian degeneration in white matter of cerebellum and spinal cord

Diagnosis: syndrome + plant access

Indole alkaloids of Phalaris spp (phalaris) - Phalaris staggers

Common sources:

- Phalaris aquatica

Pathology:

- **greenish pigmentation** in CNS (brain, spinal cord & dorsal root ganglia) and kidney medulla = indole-like pigments
- pigments thought to indicate neurones affected by the syndrome, but pigments themselves not responsible for dysfunction; stored in lysosomes
- CNS pigment distribution: neurones in brain stem nuclei (thalamus to caudal medulla), cerebellum and in spinal cord dorsal root ganglia and dorsal and ventral horn cells

Diagnosis:
Access + syndrome, pathology

ß-carboline alkaloids [indole alkaloids] – Coonabarabran staggers

Source: *Tribulus terrestris* (caltrop)

Pathology:
± demyelination of some peripheral nerves
± Wallerian degeneration of spinal cord white matter
± neurogenic degeneration skeletal muscles
Diagnosis: syndrome + access

Piperidine, pyridine (nicotine) & quinolizidine alkaloids - Conium, Lupinus, Nicotiana teratogens

Common sources:

- *Conium maculatum* (hemlock) – coniine (piperidine)
- *Lupinus spp. (lupins) – anagyrine (quinolizidine), ammodendrine (piperidine)*

Pathology:
congenital arthrogryposis (± brachygnathia, palatoschisis, torticollis, scoliosis, lordosis)

Diagnosis: pathology + access

Pyridine (nicotine) and piperidine alkaloids

Common sources:

- *Nicotiana spp. (tobaccos)*
- *Duboisia hopwoodii (pituri)*
- *Conium maculatum (hemlock)*

Pathology:
alimentary tract congestion in cases with diarrhoea

Diagnosis: access + clinical signs

Erythrophleum spp. (diterpenoid alkaloids & cinnamic acid derivatives)

Common source:

- *Erythrophleum chlorostachys (Cooktown ironwood); northern Australia*

Pathology:

- *recognisable leaves (or other plant parts) present in rumen contents (whole in some cases)*
- *gastrointestinal congestion*
- *± haemorrhagic colitis*
- *subepicardial, subendocardial and myocardial haemorrhage*

Diagnosis: history of access + sudden death + identify plant in ingesta

Glycosidic steroidal alkaloids (glycoalkaloids) of Solanum spp. (nightshades)

Pathology: gastroenteritis

Diagnosis: syndrome + access

Isoquinoline alkaloids - Argemone spp. (Mexican poppy)

Cattle fed whole plants in hay in South Africa and Australia develop ventral subcutaneous oedema, ascites, hydrothorax, cardiomyopathy.

Isoquinoline alkaloids - Papaver spp.

Pathology:
Sheep (*P. nudicaule*): No significant lesions were seen, but the plant could be recognisedin the rumen

Diagnosis:
History of access + syndrome + identification of plants in rumen contents

Iforrestine

Sources:

- ***Isotropis*** spp. (Family Fabaceae) 14 species in Australia, 7 associated with poisoning

Pathology:
- ↑ serum urea & creatinine
- perirenal oedema
- pale kidneys
- necrosis of proximal renal convoluted tubules
- oedema of abomasal wall
- ± liver necrosis

Diagnosis: access + pathology

Colchicine and related alkaloidal amines

Sources:

- *Colchicum autumnale L. (meadow saffron, autumn crocus, naked ladies, naked boys)*
- *Gloriosa superba L. (glory lily, flame lily, gloriosa).*

Pathology:

- *acute gastrointestinal inflammation*
- *widespread haemorrhages*
- *lysis of lymphocytes in lymphoid organs*

Diagnosis:

- *Access + syndrome + plant parts in rumen (difficult to identify)*
- *Assay rumen contents for colchicine*

AMINO ACIDS & PROTEINS

Thiaminase

Common sources:

- *Marsilea drummondii (nardoo)*
- *Cheilanthes sieberi (mulga or rock fern)*
- *Pteridium esculentum (bracken) - insufficient thiaminase to threaten ruminants*

Pathology:
Sheep

- *large amount of fern in the rumen*
- *polioencephalomalacia: all cerebral lobes affected, sometimes sparing the temporal lobes*
- *autofluorescence of lesions under UV illumination @ 365 nm wavelength*

Diagnosis:
Sheep: access + pathology

Mimosine

Common sources:

- *Leucaena leucocephala*
- *Mimosa pudica*

Clinical signs & Pathology:
Cattle
Rapid effects (days):

- *stomatitis, mucosal erosions (mouth, pharynx, tongue), drool saliva*
- *hair loss (tail switch, other parts of coat)*

Chronic effects (months):

- *hyperplastic goitre*
- *oesophageal erosion*
- *↓ fertility, low birth weight, congenital goitre*
- *bilateral cataracts*

Sheep

- *fleece shedding*

Diagnosis: syndrome + access

S-methylcysteine sulphoxide (SMCO) & N-propyl disulphide / thiosulphates

Common sources:

- SMCO: *Brassica* spp. (kale, rape, canola, cabbage, swede)
- N-propyl disulphide & thiosulphates: *Allium* spp. (onions, garlic)

Pathology:

Clinical pathology

- Heinz body anaemia, ± eccentrocytes (erythrocytes with haemoglobin contracted to one side of the cell)
- ± azoturia
- ± increased concentrations of liver-associated enzymes & bilirubin

Necropsy

- haemoglobinuria (dark red-brown urine in bladder; red-brown-black kidneys)
- ± jaundiced carcase
- ± strong small of onions from the carcase (if fed onions)

Histopathology

- haemoglobinuric nephrosis
- ± periacinar hepatocyte necrosis (hypoxia)
- splenic haemosiderosis

Diagnosis:

- access + Heinz bodies in erythrocytes
- assays for SMCO in plants are available in some laboratories

Indospicine

Common sources:

- Indigofera spicata (creeping indigo)
- Indigofera linnaei (Birdsville indigo)
- indigofera suffruticosa

Cattle, sheep: hepatotoxicity, abortion. Feeding experiments in Hawaii and Fiji caused abortions in sheep and cattle; rations contained 25-50% *Indigofera spicata.*

Toxalbumins (lectins)

Common sources:

- seeds of *Ricinus communis, Abrus precatorius, Robinia pseudoacacia*
- bark of *R. pseudoacacia*

Pathology:

- severe **gastroenteritis**
- ± liver & kidney degeneration/necrosis

Diagnosis: syndrome + access

GLYCOSIDES

Cyanogenic glycosides [sources of Cyanide (HCN) = Prussic acid]

Common sources:

- Acute poisoning
  - *Sorghum* spp. (sorghum)
  - Numerous other plants
- Chronic poisonings
  - *Sorghum spp.*
  - *Cynodon spp. – congenital goitre, sheep*
  - *Sorghum sudanense and hybrids – foetal arthrogryposis*

Pathology:

Acute poisoning (sudden death):

- **bright red blood**
- **non-specific** lesions related to respiratory and circulatory failure such as agonal haemorrhage and congested organs.
- a fleeting "bitter almond" odour may be noticed immediately on opening the stomach. Benzaldehyde, a break-down product of amygdalin (the cyanogenic glycoside in bitter almond (*Prunus amygdalus* var. *amara*) kernels and some other plants), is responsible for the odour. Benzaldehyde is readily oxidised in air to benzoic acid, rendering the odour fleeting. About 40-60% of humans are thought genetically unable to detect the odour.
- leucoencephalomalacia may occur in some of the rare cases where animals (including humans) survive sufficiently long.

Posterior ataxia & urinary incontinence:

- cystitis
- **spinal cord white matter degeneration**

Sheep grazing *Sorghum* that develop a variant neurological syndrome have pathology including axonal spheroids throughout the brain (most numerous adjacent to the cerebellar roof nuclei) and focal Wallerian degeneration in cerebellar white matter and spheroids in ventral grey matter of cervical cord. Mild neurological damage has been produced experimentally in the

brainstem, spinal cord and cerebellum (mild axonal swelling, gliosis, reduction in Purkinje cell numbers) by PO administration of 1.2 or 3.0 mg KCN/kg/day for 5 months.

Foetal arthrogryposis:

- fixation of foetal limb joints (arthrogryposis)
- Wallerian degeneration of foetal white matter of spinal cord, medulla, pons and cerebellum
- cerebral oedema

Diagnosis:
Acute poisoning (sudden death):

- Assay suspected source plants for HCN potential
- Assay skeletal muscle, liver and rumen contents (in descending order of usefulness) for HCN. Continued microbial activity in rumen samples will produce a negative result very soon after death.

A rapid field spot test, the **picric acid test for free HCN** (also called the Henrici test), can be used on **plants, rumen contents, liver or skeletal muscle**. The test papers are yellow, turning brown-red if positive (details are given below). Using these spot tests, which do not include an exogenous β glucosidase, on hays may indicate a falsely small HCN potential because haymaking can destroy the enzyme but not the glycoside. This *caveat* also applies to the testing of plants that do not naturally contain β glucosidase.

The smallest concentration *in plants* to suggest toxicity is 200mg HCN/kg plant dry matter (0.02%) (> 7.5 μmol/g fresh weight). Plant material subjected to assay for HCN production **must be unwilted at the time of testing**. When submitting plants to a laboratory for testing, collect the whole plant with a clump of soil enclosing the roots; wrap the root ball and soil in damp paper and send the whole plant to arrive as soon as possible to try to prevent wilting. Carefully and gently packing it into an insulated container with freezer bricks is acceptable for short transport periods.

Muscle samples can be usefully analysed up to 20 hr after death, liver samples 4-5 hr and rumen samples < 1 hr. The smallest concentration *in skeletal muscle* suggestive of toxicity is 0.63 μg HCN/g tissue.

Blood cyanide concentrations in a cow that survived poisoning have been reported as 60 – 173 μ*M*. Reference ranges for HCN in cattle determined by GC-MS method are: serum <0.7 to 35.0 μ*M*; rumen fluid < 0.7 to 28.1 μ*M*. In humans, cyanide concentrations of > 40 μ*M* in blood are considered toxic and 100-200 μ*M* are considered lethal.

Foetal arthrogryposis:

- pathology + access
- differentiate from viral and genetic aetiologies

Picric acid spot test for cyanide (Henrici test) in rumen contents or plants

Test papers

0.5 g sodium bicarbonate + 0.5 g picric acid dissolved in 100 ml distilled water - solution keeps for 4 months if well-stoppered and kept cool.
Saturate strips of filter paper in the solution and allow to almost dry before use.
Strips may be dried and stored in a stoppered container, but lose sensitivity in about 1 week. Moisten before use.

Procedure

Place rumen contents in a flask and add enough water to make contents slushy,
OR a couple of grams of moist shredded plant material in the flask and add 4 drops of chloroform.
Fix a picric acid filter paper strip above the sample by jamming it into the neck of the flask with a stopper - do not let the paper touch the sides of the flask or the sample. Run a negative control sample (a blank) simultaneously. Incubate in a warm place.
Positive test = red/brown to violet colour. Incubate test for at least 24 h before declaring it negative.

Cardiac glycosides

Common sources:

- *Nerium oleander* (oleander)
- *Cascabela thevetia* [= *Thevetia peruviana*] (yellow oleander)
- *Cryptostegia grandiflora* (rubber vine)
- *Bryophyllum* spp. (mother-of-millions)
- *Homeria* spp. (cape tulips)
- *Adonis microcarpa* (pheasant's eye) - plants in hay, seeds in grain
- *Digitalis purpurea* (foxglove)
- *Corchorus olitorius* (jute) - seeds in grain

+ others

Pathology:

- increasing plasma urea, creatinine and glucose concentrations with time after ingestion
- **cardiomyopathy** (multifocal degeneration & necrosis). Lesions can be expected in animals that survive for over 24 hours. Animals dying earlier may not have had time for lesions to develop to a stage that is detectable microscopically.
- **haemorrhage into alimentary tract** or congested, fluid-filled alimentary tract
- pulmonary atelectasis (associated with dyspnoeic cases) and/or pulmonary oedema
- omasal ulceration (in cases surviving several days - related to uraemia)

Diagnosis:

- Access to plants, including seeds
- ± recognise plant fragments in rumen contents
- Cardiac arrhythmia + diarrhoea + azotaemia

- Myocardial histopathology (collect multiple samples: both ventricles, both atria & interventricular septum)
- Assay stomach contents/faeces for some toxins [limited availability of chromatographic assay: TLC, HPLC]
- Radioimmunoassay has been used to confirm the presence of cardiac glycosides in serum of intoxication cases. In human medicine this technique is used to monitor the therapeutic use of cardenolides and medical laboratories may provide assays in veterinary cases.

Ptaquiloside

Common sources:

- *Pteridium esculentum* (bracken)
- *Cheilanthes sieberi* (mulga or rock fern)

Pathology:

'Bracken' poisoning:

- thrombocytopaenia
- leucopaenia
- anaemia
- multiple haemorrhages (subcutaneous, intramuscular, subserosal, subepicardial etc.)
- ulceration of intestine (over Peyer's patches)
- ± oedema of larynx (calves)
- ± liver septicaemic infarcts

Bovine enzootic haematuria:

- anaemia
- usually normal leucocyte and platelet numbers
- various bladder mucosa lesions: chronic cystitis with various neoplasms. Haemangiomas, haemangiosarcomas or both are usually present. Transitional cell carcinomas, adenomas, adenocarcinomas or other types of neoplasms may also be present.

Bright blindness: Not reported in Australia. Sheep in UK only.

- leucopaenia
- retinal atrophy (loss of rods & cones)

Alimentary neoplasia: Not reported in Australia. Cattle in South America & UK

- Squamous cell carcinoma of the pharynx and oesophagus

Diagnosis:

'Bracken' poisoning:

- access to above fern species
- haemorrhagic disease
- + thrombocytopaenia, leucopaenia
    - ❖ live: blood smear assessment
    - ❖ dead: bone marrow histopathology [Hint: take sample from the sternum rather than a rib or long bone]

Bovine enzootic haematuria:

- live: access to ferns + clinical syndrome (microurine to differentiate haematuria from haemoglobinuria or other pigments). Transrectal ultrasonography of the urinary bladder may be an adjunct to diagnosis.
- dead: bladder pathology

Bright blindness:

- Syndrome + chronic bracken access

Alimentary neoplasia:

- Syndrome + chronic fern access

Diterpenoid (kaurene) glycosides - atractyloside, carboxyatractyloside, parquin, carboxyparquin & wedeloside

Common sources:

- Cestrum parqui (green cestrum)
- Xanthium occidentale (Noogoora burr) - only burrs or cotyledonary leaves toxic
- Wedelia asperrima (sunflower daisy)

Pathology:

- Ruminants: Acute hepatic necrosis (q.v.)

Diagnosis:

- Access to plants; plants detected in stomach contents
- Ruminants: Acute hepatic necrosis (q.v.)

Plant calcinogenic glycosides (cholecalciferol, vitamin D_3)

Cestrum diurnum, *Solanum torvum*, *Solanum linnaeanum* and *Trisetum flavescens* occur in Australia, but poisoning of this sort has not been reported. *Solanum torvum* (devil's fig) has been reported to produce the syndrome in New Guinea.

Pathology:

- serum Ca & P ↑ 20-25%
- anaemia
- anasarca, ascites
- calcification of blood vessels & endocardium, pleura, lungs, tendons & ligaments

Diagnosis: access + pathology

Glucosinolates

Common sources:

Plants in the Family Brassicaceae -

- Brassica spp.
- Sinapis spp.
- Raphanus raphanistrum (wild radish)
- Rapistrum rugosum (turnip weed)

Pathology:
Goitre
- Hypertrophy and hyperplasia of the thyroid glands

Atypical interstitial pneumonia
- Pulmonary oedema and emphysema (interstitial)
- ± subcutaneous emphysema
- ± liver necrosis (presumably hypoxic in origin)

Rumenitis
- Acute rumenitis with marked oedema of the wall attributed to damage to submucosal and intramuscular blood vessels.

Diagnosis:
Goitre
- Syndrome + pathology + access to sources either directly or through placenta/milk

Atypical interstitial pneumonia
- Syndrome + access to lush source plants

Rumenitis
- Differential diagnosis should include other forms of chemical rumenitis such as inorganic arsenic, cucurbitacins (*q.v.*)

Aliphatic nitro compounds (Nitrotoxins)

Toxicity not recorded in Australia to date.
Common sources (North America): *Astragalus* spp., *Lotus* spp., *Coronillia* spp., *Indigofera* spp. + others (some of which occur in Australia)

Pathology:
Acute intoxication
- pulmonary oedema, hydrothorax, tracheal petechiae
- methaemoglobinaemia

Chronic intoxication (ruminants)
- congested liver
- ulceration of cardiac region of abomasum
- pulmonary emphysema, bronchoconstriction ± bronchopneumonia
- Wallerian degeneration of spinal cord & peripheral nerve white matter
- focal brain haemorrhage

Diagnosis:
- access + syndrome + pathology
- assay methods available for miserotoxin, NPA and NPOH in plants

Cynanchosides

Common source (suspected):
- Sarcostemma brevipedicellatum [= Sarcostemma australe] (caustic vine, caustic creeper, pencil caustic)

Pathology: no significant lesions reported

Diagnosis: access + syndrome

Dihydroxycoumarin (dicoumarol)

Common sources:
mouldy hays/silage of

- *Melilotus* spp. (sweet clovers)
- *Anthoxanthum odoratum* (sweet vernal grass)

Pathology

- *↑↑ prothrombin time, APTT & clotting time*
- *platelet numbers are normal*
- *anaemia*
- *extensive haemorrhages & haematomas*

Diagnosis: clinical pathology; serum & feed dicoumarol assay

Daphnoretin (presumed toxin in Wikstroemia indica*)*

Wikstroemia indica (tie bush) [Family Thymeleaceae] is suspected of producing a haemorrhagic syndrome in farmed deer in Queensland on one occasion. Widespread haemorrhage occurred, but circulating platelet and leucocyte numbers remained normal. Daphnoretin has been isolated from the plant stems (Kato *et al.* 1979).

Furanocoumarins (furocoumarins, psoralens)

Common sources:

- *Ammi majus* (bishop's weed)
- *Apium graveolens* (celery) ± infected with microbes
- *Petroselinum crispum* (parsley)
- *Pastinaca sativa* (parsnip) ± infected with fungus

Pathology:

- Photosensitisation
- Corneal oedema/keratoconjunctivitis is a feature of furanocoumarin photosensitisation (uncommon in other kinds)
- Skin vesication or bulla formation is seen in white pigs (snout, forelegs), but has not been described in ruminants. It may possibly occur on the muzzle from direct contact with source plants.

Diagnosis:
skin lesions of photosensitisation (± corneal oedema) + absence of liver damage determined by clinical examination for jaundice and confirmed by clinical chemistry (liver function tests on serum or plasma).

Phyto-oestrogens

Common sources:

- isoflavones in *Trifolium subterraneum* (subterranean clover), *Trifolium pratense* (red clover)
- coumestans in *Medicago* spp. (medics including lucerne)

Pathology:
Classical clover disease (ewes)

- uterine prolapse

- hydrops uteri
- cystic hyperplasia of endometrium
- permanent `defeminisation' after 1-2 years high intake → reduction in uterine size, metaplasia of mucosa of cervix →↓ flock fertility

Classical clover disease (wethers)

- enlarged teats
- bulbo-urethral gland cysts
- blockage of urethra → bladder rupture
- Diagnosis: syndrome + access

TERPENES AND TERPENOIDS

Furanosesquiterpenes

Common sources:

- Eremophila deserti [= Myoporum deserti] (Ellangowan poison bush)
- some Myoporum spp. (boobiala, water bush)

Pathology: See acute hepatic necrosis

- Lesions may vary in location within the hepatic acinus from periacinar to periportal depending on the metabolic state of the xenobiotic biotransformation enzyme systems.

Diagnosis: See acute hepatic necrosis

Lantadenes (pentacyclic triterpenes)

Common source:

- Lantana camara - toxic flower-colour forms: red & orange, Helidon white, pink (only north of Rockhampton)

Pathology

- *jaundice*
- *swollen, yellow-orange liver*
- *severe distension of gall bladder with watery bile, sometimes to as much as 30 times normal, due to smooth muscle paralysis.*
- *swollen pale kidneys (nephrosis)*
- *colon contents dehydrated*

Andromedotoxins (grayanotoxins)

Common sources:

- *Rhododendron spp. (rhododendrons, azaleas)*

Pathology:

- *gastroenteritis*
- *± aspiration pneumonia*

Diagnosis:

- *syndrome + access*
- *assay rumen contents/faeces [limited availability of test]*

Irritant diterpenoids of Pimelea *spp. – simplexin (& huratoxin)*

Syndrome names:

- *Pimelea* poisoning of cattle
- St.George disease
- Marree disease

Common sources:
- *Pimelea trichostachya*
- *Pimelea simplex*
- *Pimelea elongata*

Pathology:
- dilation of right ventricle
- hydrothorax
- subcutaneous oedema of brisket and submandibular space
- liver: peliosis hepatis = swollen blue-black liver engorged with blood in massively dilated sinusoids
- capillary dilation in adrenal glands and kidney

Diagnosis:
- Diagnosis is based on clinical syndrome + pathology. It is important to note that the responsible Pimelea sp. is likely to be absent from pastures when animals are affected; winter plant growth precedes summer poisoning.

Irritant diterpenoids of Families Thymeleaceae & Euphorbiaceae

Common sources:
- *Pimelea* spp. (flaxweeds)
- *Euphorbia* spp. (spurges)
- *Jatropha* spp.

Pathology:
- *alimentary tract congestion*
- *haemorrhagic, necrotising gastroenteritis*

Diagnosis: syndrome + access

Cucurbitacins (tetracyclic triterpenes)

Common sources:
- *Cucumis spp.*
- *Citrullus spp.*

Pathology:
- *congestion/haemorrhage of alimentary tract*
- *oedema of forestomach walls*
- *seeds numerous in rumen contents*
- *microscopic rumenitis*
- *± focal myocardial degeneration & necrosis*

Diagnosis: syndrome + access

Meliatoxins (tetranortriterpenes)

Common sources:

- *Melia azedarach var. australasica (white cedar) - fruits of some trees toxic*

Pathology:

- *severe gastroenteritis*
- *fatty degeneration of liver & kidneys; scattered or periacinar hepatocyte necrosis in experimental cattle*
- *necrosis of lymphoid follicles in alimentary tract*
- *myodegeneration and necrosis of skeletal muscles were reported in experimental cattle*

Diagnosis: syndrome + access

LIPIDS, OILS, GLYCERIDES, FATTY ACIDS

Unsaturated fatty acids, particularly crepenynic acid

Common sources:

- *Ixiolaena brevicompta seedheads*

Pathology:

- *skeletal muscle pallor*
- *muscle fibre degeneration* and necrosis in skeletal muscle and heart

Diagnosis:

- *pathology + access*
- *identify seeds in rumen contents*

Isocupressic acid (bicyclic labdane diterpene acids) and/or Vasoactive lipids

Common sources:

- *Pinus ponderosa (Ponderosa pine)*
- *Cupressus macrocarpa (Monterey cypress, macrocarpa*)

Pathology:

- *late-term abortion*
- *serosal haemorrhages, oedema and flaccidity of uterus; no gross lesions in the foetus*
- *histologically, a profound constriction of the caruncular arterial bed in the uterus*
- *± cerebral leucoencephalomalacia in bovine foetus - ? anoxia*

Diagnosis: syndrome + access

Persin

- Common sources:
- *Persea americana* (avocado) - Guatemalan & Guatemalan x Mexican hybrid cultivars (not pure Mexican)

Pathology:
Cardiotoxic syndrome:

- cardiac muscle necrosis
- hydrothorax
- pulmonary oedema

Mammary gland syndrome:

- sterile mastitis with necrosis of the acinar epithelium of the mammary gland

Diagnosis: syndrome + access

Protoanemonin

Common sources:

- *Ranunculus spp.*

Pathology:

- *inflammation of the alimentary tract, sometimes with ulceration*

Diagnosis:

- *access + syndrome*
- *detection of plants* in rumen

PHENOLIC COMPOUNDS

Gossypol

Common sources:

- *pigment glands of cotton seeds (Gossypium spp.)*

Pathology:
Cardiac and associated effects:

- cardiomyopathy (cardiac dilation ± pale myocardial streaking; histologically cardiac muscle necrosis)
- pulmonary oedema, fluid in thorax and abdomen
- periacinar hepatic congestion and necrosis
- mild nephrosis

Reproductive effects:

- testicular cessation of spermatogenesis

Diagnosis:

- access + pathology
- assay feed for free gossypol (note that the relevant feed batch may no longer be available)

Dianthrone derivatives (hypericin, fagopyrin)

Common sources:

- Hypericum perforatum (St.John's wort)

Pathology:

- primary photosensitisation (q.v.)

Diagnosis:

- syndrome + plant access

Steroidal or lithogenic saponins

Common sources:

- Panicum spp. (French millet, Bambatsi panic, etc.)
- Brachiaria spp. (signal grass)
- Tribulus terrestris (caltrop)

Pathology:

- ± jaundice
- ± swollen yellow-orange liver
- diffuse hepatocellular hydropic degeneration and hyperplasia of smooth endoplasmic reticulum indicative of prolonged cholestasis.
- crystals in hepatocytes, small bile ducts & Kupffer cells
- ± crystals in renal tubules
- ± crystals in macrophages are reported in intestinal submucosa, liver, spleen, mesenteric and hepatic lymph nodes in cases of weight loss without photosensitisation.

Diagnosis: access + pathology

Tannins (hydrolysable)

Common source:

- Terminalia oblongata ssp. oblongata (yellow-wood)
- Quercus spp. (oaks)

Pathology:

Oak poisoning

- serum ↑ urea & creatinine, ↑ protein, Na, Cl & Ca
- perirenal oedema
- pale swollen kidneys - tubular necrosis
- alimentary mucosal erosions/ulcers
- ± numerous acorns in rumen contents

Yellow-wood poisoning

Acute toxicity

- multiple erosions of abomasal mucosa
- swollen greenish-grey kidneys
- swollen pale to orange liver

Chronic toxicity

- fibrotic greenish-grey kidneys - pigment in nephrotic kidneys
- distended thickened bladder
- abomasal ulcers

Diagnosis: access + pathology

Methylazoxymethanol (MAM)

Common sources:
Cycads in the genera

- Cycas
- Macrozamia

Pathology: See acute hepatic necrosis

Diagnosis: See acute hepatic necrosis

Stypandrol

Common sources:

- Stypandra glauca (blind grass, Candyup poison, nodding blue lily)

Pathology:

- vacuolation (oedema) of CNS white matter → resolves in 6-8 weeks
- optic nerve axonal degeneration → complete atrophy, sclerosis
- 12 weeks → retinal atrophy

Diagnosis: access + histopathology (eye, optic nerve, brain)

Galegine

Common sources:

- Galega officinalis (goat's rue, French lilac)
- Verbesina encelioides (crownbeard)
- Schoenus asperocarpus (poison sedge)
- Schoenus rigens

Pathology:

- fluid from nostrils
- severe pulmonary oedema & hydrothorax
- thoracic fluid clots rapidly on exposure to air

Diagnosis: access + pathology

Tetrahydrocannabinol - **Cannabis sativa** *(marijuana)*

Pathology: Nil

Diagnosis:

- history often incomplete or misleading
- ± identify plant in rumen contents
- ± assay plasma, urine for THC (only at certain laboratories)

MECHANICAL DAMAGE BY PLANT PARTS

Dittrichia graveolens *enteritis (mechanical damage)*
Pathology:

- dark bristles embedded in the intestinal mucosa (grossly visible)
- intestinal wall oedema & haemorrhage with multiple white nodules
- pyogranulomatous enteritis; histologically, bristles + bacteria in the mucosa and submucosa with neutrophils, macrophages & foreign body giant cells

Diagnosis:

- differentiation from common causes of diarrhoea is required
- access + intestinal pathology/histopathology

Grass awns
Strictly-speaking a mechanical injury, not an intoxication, but included for convenience.
Examples include:

- Triticale (variously classified as X *Triticosecale,* X *Triticale* or *Triticum aestivum* x *Secale cereale*) fed as hay after seedhead maturation causing stomatitis through the penetration of the buccal mucosa by the awns on the seeds
- *Stipa neesiana* (Chilean needle grass) [present in NSW] seed awns penetrate the skin causing subcutaneous and intramuscular abscesses and granulomas.

PLANTS WITH UNKNOWN OR UNCHARACTERISED TOXINS
[Plants are listed by syndrome/organ system affected, then by plant family]

LUNG
Lung – Family Rutaceae
Zieria arborescens *(stinkwood)*
Pathology

- pulmonary oedema & emphysema
- degeneration of pulmonary arteriole walls

LIVER

Liver – Family Asteraceae
Argentipallium blandowskianum *(woolly everlasting)*
Pathology: As for acute hepatic necrosis syndromes (*q.v.*)
Diagnosis: As for acute hepatic necrosis syndromes (*q.v.*)
Liver – Family Poaceae

Cynosurus echinatus (*rough dog's tail grass)-associated liver necrosis*
Pathology:
As for acute hepatic necrosis syndromes (*q.v.*).

Clinical pathology results are variable, often including increased activities of serum GLDH, γGT and an increased concentrations of bilirubin; less

frequently, increased values for AST, creatinine, urea, chloride, bicarbonate, phosphorus and magnesium may occur (Gunn & Clarke 2003).

Necropsy reveals an enlarged, grey, friable liver with massive distension of the gall bladder which has thickened walls and contains black bile. Subcutaneous oedema and jaundice occur. Ecchymotic or petechial haemorrhages occur in many tissues including the subcutis, omentum, peritoneum, gall bladder, epicardium, myocardium abomasum, duodenum and kidney capsules.

Massive hepatocyte necrosis has been reported in Tasmanian and South Australian cases, severe acute periportal hepatocyte necrosis with early biliary ductular hyperplasia and necrosis of portal veins is more typical of South Australian cases and necrosis of scattered individual and small groups of hepatocytes with no distinct zonal pattern was seen in the Western Australian case.

Diagnosis:
As for acute hepatic necrosis syndromes (*q.v.*). Differential diagnoses should include sporidesmin (*q.v.*) toxicity and other causes of secondary photosensitisation (*q.v.*). Clinical and environmental examinations should be supplemented by clinical pathology and liver biopsy of affected and in-contact animals, as currently, confirmation of cases requires histopathology as well as other evidence.

Liver – Family Ulmaceae

Trema tomentosa *(poison peach)*
Pathology: acute periacinar hepatic necrosis
Diagnosis: As for acute hepatic necrosis syndromes (*q.v.*)

KIDNEY

Kidney – Family Caesalpiniaceae
Schotia brachypetala *(drunken parrot tree, boer bean)*
Associated with nephrosis in cattle which browsed on flowering branches at Maryborough in September 1998. 80 2-3 year-old Brahman cattle introduced to a paddock with branches of *S. brachypetala* overhanging the fence line; onset of illness 2 weeks after introduction; 6 died; clinical signs – loss of weight, crusty nasal exudate, pale mucous membranes, tarry faeces; clinical pathology (2 steers) – dehydration with either slight leucopaenia or slight absolute neutrophilia + increased concentrations of creatinine, urea & Mg, decreased Ca; necropsy (1 steer) – pale kidneys, haemorrhages throughout the alimentary tract, swollen liver, congested lungs; histopathology – severe subacute diffuse necrosis of epithelium of proximal renal cortical tubules, no oxalate crystals detected.

Kidney – Family Lythraceae
Lythrum hyssopifolia *(lesser loosestrife)*
Pathology:
Clinical pathology
- ↑ serum creatinine & urea ± ↑ serum bilirubin & liver-associated enzymes (including GLDH)

Necropsy
- scattered petechial haemorrhages (subcutis, kidneys, diaphragm, thoracic wall, omentum, mediastinum, heart)
- perirenal oedema, mild ascites
- pale swollen kidneys
- ± jaundice
- ± tan or orange-coloured swollen liver

Histopathology
- renal tubular necrosis: coagulation necrosis of tubular epithelium, hyaline casts
    - ❖ interstitial fibrosis & loss of tubules (cases with access > 5 days)
    - ❖ dilated ascending loops of Henle & distal convoluted tubules + some tubular regeneration (cases with access > 10 days)
    - ❖ ± slight to moderate haemoglobinuric nephrosis and/or renal haemosiderosis
- ± hepatocellular damage
    - ❖ ± periacinar or mid-zonal hepatocyte necrosis + biliary hyperplasia
    - ❖ ± hepatocyte fatty change
    - ❖ ± individual hepatocyte necrosis

Diagnosis: access + pathology

NERVOUS – ATAXIA

Nervous – Ataxia – Families Cycadaceae & Zamiaceae
Cycads
Common sources:
- *Cycas* spp.
- *Macrozamia* spp.
- *Bowenia* spp.

Pathology:
- **Degeneration of spinal cord white matter** occurs in the fasciculus gracilis, dorsal spinocerebellar & corticospinal tracts.
- Chronic liver damage (fibrosis, enlarged hepatocytes) may result in ataxic cattle from the action of MAM

Diagnosis: access + pathology

Nervous – Ataxia – Family Fabaceae
Chamaecytisus proliferus *(tagasaste)*

Pathology:
Congenital leucoencephalopathy:

- histological lesions of CNS white matter: vacuoles and faintly eosinophilic plaques 40-50 μm in diameter (H&E), plaques slightly pink (PAS) or non-staining (LFB) with special stains; some plaques contained peripheral nuclei resembling those of oligodendroglia; plaques contained normal axon segments demonstrated in LFB-Holmes silver stained sections; occasional microglial phagocyte in empty axonal tubes but no other inflammation; glial cell reaction limited to occasional isolated dense shrunken microglial nuclei near injured axons
- moderate-severe lesions of white matter in internal capsule, midbrain, medulla and cerebellum; severity increasing towards the mid and hindbrain
- lesions present in optic tracts and chiasma, but not optic nerves or retina
- severe lesions in spinal cord white matter, but not cauda equina or peripheral nerves
- lesions similar to those of progressive ataxia of Charolais cattle in which signs occur at 8-24 months of age and progress over 1-2 years
- ultrastructure of CNS lesions: plaques = intramyelinic expansions containing numerous vesicular membranous profiles and myelin bodies dispersed throughout a granular matrix possibly containing remnants of microtubules; remnant myelin sheaths around these foci and very thin with only a few lamellae. Around the plaques, numerous glial cells and their processes are similarly affected with numerous vesicular profiles; oligodendrocytes and possibly astrocytes affected. Some smaller diameter myelinated fibres have periaxonal vesiculation, apparently from the inner lamellae of myelin sheathes. Some brains have focal plaques of disorganised and tangled myelin.

Diagnosis:
Congenital leucoencephalopathy: syndrome + dam access

Nervous – Ataxia – Family Iridaceae
Romulea rosea *var.* australis *(onion grass, Guildford grass)*
Pathology:

Romulosis (reproductive effects)
fluid accumulation noted in non-pregnant uteri

Romulosis (ataxia/paralysis)
Histological lesions attributed to this disease included degeneration of myelin with axonal swelling and fragmentation, particularly of motor nerve roots. Peripheral nerves were less affected. There was usually a light infiltration of lymphocytes (rarely more than one cell layer deep)

about blood vessels in the brain stem. There was mild swelling of axons and nerve sheaths in the ventro-medial columns of the spinal cord white matter. In more chronic cases, macrophages containing golden-brown lipochrome pigment were found in perivascular spaces in the brain stem, cerebellar white matter and spinal cord. Rarely, there was also fine vacuolation of the white matter of the cerebrum, brain stem and cerebellum.

Phytobezoars
Bezoars in stomach/abomasum or blocking the tract downstream of these sites.

Diagnosis:
Syndrome + association with a pasture dominated by the plant.

Nervous – Ataxia – Family Liliaceae
Trachyandra divaricata *(branched onion weed)*
Pathology:

- no lesions at necropsy
- intense **lipofuscin pigment granule deposition in neurones** (brain, cord, ganglia)
- spheroids in spinal cord grey matter and brain stem
- axonal degeneration, demyelination, lipid storage by Schwann cells

Diagnosis: histopathology

Nervous – Ataxia – Family Mimosaceae
Prosopis juliflora *(mesquite) – neuronal vacuolation in cranial nerve nuclei*
No cases recorded in Australia to date.
Pathology:

- rumen full of mesquite pods & seeds
- denervation atrophy of masseter, temporal, hyoglossus, genioglossus, styloglossus, medial pterygoid, lateral pterygoid and mylohyoid muscles: marked variation in muscle fibre diameter, some myofibre degeneration, some fibrous replacement
- spongiosis & gliosis of CNS
- trigeminal motor nuclei neuronal lesions
- loss of Nissl substance
- fine cytoplasmic vacuolation of pericaryon or one pole of cell
- trigeminal ganglion lesions
- loss of neurones
- proliferation of satellite cells & neuronophagia
- Wallerian degeneration in trigeminal & mandibular nerves

Diagnosis:

- prolonged access + pathology
- differentiate from transmissible spongiform encephalopathies, lysosomal storage diseases, swainsonine & calystegine intoxication

Nervous – Ataxia – Family Xanthorrhaceae
Xanthorrhoea *spp. (grasstrees) – posterior ataxia syndrome*
Species associated with toxicity:

- *Xanthorrhoea johnsonii* (northern forest grasstree - Q)
- *Xanthorrhoea fulva* [= *X. resinosa, X. hastile*] (swamp grasstree - Q)
- *Xanthorrhoea australis* (yacca - Tas)
- *Xanthorrhoea quadrangulata* or *Xanthorrhoea semiplana* (SA)

Pathology:
± degeneration of spinal cord, brain stem and cerebellar white matter. Lesions are usually slight.

Diagnosis: syndrome + access

ALIMENTARY

Alimentary – Family Fabaceae
Castanospermum australe *(Moreton Bay chestnut, black bean)*
Pathology:

- cytoplasmic vacuolation of 1-5% of lymphocytes in peripheral blood; cytoplasmic PAS-positive granules present in 78-92% of lymphocytes (15-20% positive in unexposed animals)
- haemorrhagic gastroenteritis
- ± focal myocardial necrosis
- ± nephrosis (vacuolation of renal cortical tubular epithelium, hyaline casts, dilation of collecting ducts)

Diagnosis: syndrome + access to ripe seeds in large amounts

Alimentary – Family Phytolaccaceae
Phytolacca *spp.*
Phytolacca dioica (packalacca, bella sombra): A tree native to South America with separate sexes; cultivated for shade and fodder in south-eastern Australia, NSW, Vic; Leaves are very palatable to cattle. Ingestion of fruit & leaves by cattle and fowls in Australia has been associated with enteritis.

Alimentary – Family Poaceae
Avena sativa *(oats) – "red-tipped" or "rusty" oats crops*
Sources: stressed *Avena sativa* (oats) used as fodder crops

Pathology:
Cattle

- ↓ plasma concentrations of P
- lesser decreases in plasma Ca, Mg
- ruminal acidosis: rumen pH of 5 or less and urine pH of less than 7; serum D-lactate concentrations increased (9.18-15.15 mmol/L in 3 cows; normal <0.4)
- no necropsy findings reported

Diagnosis:

- access to "red-tipped" oats + syndrome
- rule out nitrate-nitrite toxicity, hypomagnesaemia

Pennisetum clandestinum *(kikuyu grass) – "kikuyu poisoning"*
Pathology:
- dehydration (↑ PCV)
- ↑ serum urea & creatinine, ↓ serum Cl
- ruminal contents fluid (pH may be acid)
- ruminal and abomasal distension & hyperaemia
- histological lesions
  - ❖ **microvesication of forestomach mucosa** with neutrophil infiltration
  - ❖ **renal tubular necrosis**

Diagnosis: syndrome + access

MUSCLE

Muscle – Family Caesalpiniaceae
☑ Senna *spp. [= Cassia spp.]*
Sources:
- *Senna occidentalis* (L.) Link [= *Cassia occidentalis* L.] (coffee senna, ant bush)
- *Senna obtusifolia* (L.) H.S.Irwin & Barneby [= *Cassia obtusifolia* L.] (sicklepod, Java bean)
- *Senna didymobotrya* (Fresen.) H.S.Irwin & Barneby [= *Cassia didymobotrya* Fresen.]

Pathology:
- ↑↑↑ serum creatine phosphokinase & AST concentrations
- myoglobinuria (red urine)
- skeletal & cardiac muscle pallor
- necrosis of muscle fibres

Diagnosis:
- pathology + access
- differential diagnoses include haemolytic diseases (babesiosis, Cu poisoning)

Muscle – Family Malvaceae
Malva parviflora *(mallow, marsh mallow, small-flowered mallow)*
Pathology:
- ↑ CPK , AST, urea, creatinine
- skeletal muscle oedema, degeneration ± necrosis (particularly in large muscle groups of hindlimbs)
- multifocal myocardial necrosis
- ± myogobinuric nephrosis
- Vitamin E & Se concentrations normal
- no CNS lesions detected

Diagnosis: access + pathology

BONE

Bone – Family Apiaceae
Trachymene *spp. (wild parsnips)*
Sources:

- *Trachymene ochracea* (wild parsnip)
- *Trachymene glaucifolia* (wild parsnip)
- *Trachymene cyanantha* (wild or blue parsnip)

Pathology:
Bent leg of lambs

- lateral and medial deviation of carpal joints
- posterior peromelia (deformity of the limbs) - reduction or absence of bones distal to metatarsals
- irregularity of epiphyseal plates

Sudden death, Diarrhoea

- No pathology has been described.

Diagnosis: syndrome + access

SKIN AND APPENDAGES

Skin & Appendages – Family Fabaceae
Vicia *spp. (vetch toxicity)*
Sources:

- *Vicia villosa* (woolly-pod vetch)
- *Vicia benghalensis* (Popany vetch)

Pathology:

- all lesions **eosinophilic granulomas**, often associated with blood vessels
- dermatitis (head, neck, shoulders, tail base, udder, perineum, ± trunk, ± limbs)
- pale foci in kidneys, heart
- enlarged adrenal glands & lymph nodes
- ± jaundice

Diagnosis:

- syndrome (pathology) + access
- differential diagnosis: photosensitisation, dermatomycosis, dermatophilosis
- similar syndrome seen in cattle fed citrus pulp

PHOTOSENSITISATION

Clinical signs (various combinations depending on species and toxin)

- abnormal **behaviour**
  - restlessness
  - head shaking
  - rubbing, scratching, kicking affected parts
  - seeking shade

- effects on the eyes
  - blepharospasm / photophobia
  - ocular discharge / conjunctivitis
  - corneal oedema / keratitis (`blue eye')
- skin
  - drooping swollen ears
  - swollen lips, head
  - raw muzzle
- skin **erythema**
- skin **necrosis**
  - ear tips curl up, lips become immobilised

ACUTE HEPATIC NECROSIS

Common effects of acute hepatotoxins from plants, mycotoxins, cyanobacteria, macrofungi and sawfly larvae

Pathology:

- liver-associated serum enzymes (AST, GLDH), ↑ serum bilirubin
- ± jaundice
- liver swollen, congested, zonally mottled
- **coagulation necrosis of hepatocytes** (periacinar; periportal; rarely midzonal), ± haemorrhage
- gall bladder oedema
- haemorrhage in the lower alimentary tract (?portal hypertension) and elsewhere (?exhaustion of clotting factors in damaged liver)

MYCOTOXINS (TOXINS OF FUNGAL ORIGIN)

MOULDS

Aflatoxins

Common sources:

- *Aspergillus flavus* growing in carbohydrate-rich feeds: peanuts, grain, bread

Pathology:

- Lesion manifestation depends on dose and duration od intake
- acute → widespread **haemorrhage**, severe **liver necrosis**
- subacute → liver necrosis & haemorrhagic gastroenteritis
- chronic → **chronic liver lesions** with **megalocytosis**, fatty change, biliary retention, biliary ductular hyperplasia, fibrosis

Diagnosis:

- pathology + detection of aflatoxins in feed, stomach contents, liver

Phomopsins

Syndromes:

- Lupinosis
- Lupinosis-associated myopathy (LAM)

Common source: hexapeptide mycotoxins

- *Diaporthe toxica* growing as a saprophyte in stubble of dead lupins (*Lupinus* spp.)
- WA, Vic, NSW

Pathology:
Lupinosis:
Necropsy
Sheep

- ↑ rumen fluid
- jaundice & swollen pale liver
- **or** no jaundice & fibrotic liver
- ± ascites, anasarca

Cattle

- jaundice
- swollen pale liver
- **or** fibrotic liver
- Histopathology of liver
- **mitotic figures** in many hepatocytes
- necrosis of individual hepatocytes (necrobiosis)
- biliary ductular hyperplasia
- portal fibroplasia
- ± fatty infiltration & post-necrotic scarring

LAM:

- degeneration and necrosis of skeletal muscle fibres

Diagnosis:
Various assay methods for phomopsins have been developed (nursling rat bioassay, sheep bioassay, HPLC, ELISA) and the currently-preferred method is the ELISA technique.

Lupinosis:

- lupin stubble or seed access + phomopsin assay + syndrome + liver histopathology

LAM:

- pathology + access
- differentiate from white muscle disease (WMD = myopathy mostly affecting heart; liver Se <0.67□g/g d.m.; Se responsive)

Sporidesmin
Syndrome: facial eczema
Common source: spores of *Pithomyces chartarum* on *Lolium* sp. pasture litter

Pathology:

- Liver: cholangitis, fibrosis
- Severe chronic cases produce complete atrophy of the left liver lobe. The pathogenesis of this lesion probably results from there being a longer intrahepatic biliary system compared with that of the right lobe of ruminant livers. Cholestasis is worse in left lobe leading in turn to portal fibrosis, reduced blood flow to worst-affected

parenchyma, deprivation of hepatotrophic factors and thus atrophy of the left lobe to a much greater extent than the right lobe.

Diagnosis:

- Spore count on pasture: > 70,000 spores/g pasture litter is hazardous. Spores may be detected in scrapings of the exudate from the gland just near the medial canthus of the eyes in sheep. An assay is available for sporidesmin in pasture.
- Clinical pathology: ↑ plasma GGT concentration
- Necropsy: Hepatic lesions

Confirmation of sporidesmin toxicity in areas where it is not commonly seen requires demonstration of

- hazardous spore counts
- sporidesmin production by *Pithomyces chartarum* isolates because many isolates outside New Zealand are atoxicgenic
- typical gross and histopathology of livers

Furans - Mouldy sweet potatoes

Common sources:

- *Ipomoea batatus* (sweet potato) tubers infected with *Fusarium* sp. or *Ceratocystis fimbriata*

Pathology:

- acute severe **interstitial pneumonia**, pulmonary oedema & emphysema

Diagnosis: access + pathology

Zearalenone

Common sources:

- *Fusarium graminearum* growing on maize, sorghum and other grains
- *Fusarium* spp. growing on pasture

Cattle (rarely-affected)
- decreased fertility
- prolonged oestrus, some with oestrus during mid-cycle
- vulval swelling

Aspergillus clavatus *tremorgenic mycotoxins*

Sources:

Sprouted grains infected with *Aspergillus clavatus*

- barley (malt, distiller's culms)
- wheat
- maize
- sorghum

Pathology:

No necropsy lesions are visible, but histological changes of **neuronal degeneration & necrosis** are seen in **brainstem** (midbrain, medulla oblongata), **spinal cord & spinal ganglia**. The larger neurones are affected, often in groups. There is central to complete chromatolysis, often

with intense cytoplasmic eosinophilia. There may be cytoplasmic vacuolation. Nuclei are frequently flattened, pyknotic and displaced peripherally or may undergo kayrolysis. Wallerian degeneration occurs in spinal cord white matter tracts.

Diagnosis: access + syndrome + pathology

Diplodia maydis *neurotoxin*

Source:

Diplodia maydis (Berk.) Sacc. infecting *Zea mays* (maize, corn). *D. maydis* causes stem and ear rot of maize, producing a white mycelial mat and characterised by the black fruiting bodies (pycnidia) produced on affected plant structures towards the end of the growing season. The black pycnidia allow differentiation from *Fusarium moniliforme* or other fungal infections of maize. *D. maydis* infects maize in Australia, but is not prominent or widespread.

Pathology:

- No lesions are reported in natural cases. In a few experimental animals, laminar cortical status spongiosis of the cerebrum and cerebellum was seen in badly-affected sheep and cattle.

Diagnosis:

- Syndrome + access to remnant maize cobs on standing crops after harvesting. Differential diagnoses should include botulism and *Paspalum* staggers.

Mouldy sprouted barley - suspected mycotoxicosis

Cattle (late pregnant and recently-calved heifers) at Merredin, WA, fed sprouted barley produced in a hydroponic system were affected by a syndrome of weight loss, sore hind feet to hindquarter stagger to collapse and death. Severe liver damage was detected in about 33% of the herd by clinical chemistry (very high GLDH activity) 3-4 weeks after the sprouted barley was removed from the ration, but no necropsy material revealed any liver lesions. Removal of the barley from the ration resulted in recovery. The producers observed a blueish fungus unevenly distributed on the sprouted barley and also white material, probably fungal hyphae, on the green sprouts. *Aspergillus* spp. were cultured from the material. *Pyrenophora semeniperda* was common on barley grain in WA in 2002. This fungus is believed to be capable of producing mycotoxins that could produce a similar syndrome.

See *Aspergillus clavatus* tremorgenic mycotoxicosis and sprouted barley above.

ERGOTS

Ergot alkaloids (ergopeptide alkaloids)- ergotism

Common sources:

- *Claviceps purpurea* ergots in *Lolium rigidum* seed or grain crops
- *Claviceps africana* ergots in sorghum grain
- *Neotyphodium coenophialum* endophyte in *Festuca arundinacea*

Pathology:
Hyperthermia:
- no specific lesions

Gangrenous ergotism:
- **gangrene of extremities** (cattle)
- ulcers of mouth, pharynx & rumen (sheep)

Paspalitrems (*Claviceps paspali *tremorgens)
Common sources:
- *Claviceps paspali* ergots in seedheads of *Paspalum* spp.

Pathology: no significant lesions

Diagnosis: syndrome + ergotised pasture

GALL-FORMING FUNGI

Corallocytostroma ornicopreoides *toxicity (black soil blindness)*
Sources:
- ***Corallocytostroma ornicopreoides*** fungal growths ("corals"; sclerotia & conidiomata) on **Mitchell grasses (*Astrebla* spp.)** in the Kimberley (WA) & Victoria River (NT) districts. The fungus has also been seen on *Dicanthium* sp. (bundle bundle, blue grass) and *Iseilema vaginiflorum* (Flinders grass).

Pathology:
- perirenal oedema
- nephrosis
- ruminoreticulitis
- "corals" (sclerotia) in reticulorumen
- ± jaundice & swollen liver
- ± individual hepatocyte necrosis
- no lesions of eyes, optic nerves or brain detected despite clinical blindness

Diagnosis: dry season + "corals" in pasture, rumen + pathology

ENDOPHYTES

Lolitrems
Common sources:
- fungal endophyte *Neotyphodium lolii* in *Lolium perenne*
- lolitrem B concentrated in leaf sheath & seed

Pathology:
- usually no lesions
- sheep, deer: ± swollen Purkinje cell axons ("torpedoes") in cerebellar granular layer (significance unclear)
- atypical interstitial pneumonia has been associated with perennial ryegrass staggers in calves in Oregon USA

Diagnosis:

- **Poppi stain** of leaf sheath → presence and density of endophyte: > 20 hyphae/mm leaf sheath width in toxic swards.
- **Iolitrem B assay** (HPLC) of pasture: > 2mg/kg significant, > 4 mg/kg usually → clinical signs

MACROFUNGI (MYCETISM)

Ramaria flavo-brunnescens *(a coral fungus)*

Cases unrecorded in Australia to date.

Source:

- *Ramaria flavo-brunnescens* (a coral fungus: Family Clavariaceae) occurs in the south & south-eastern regions of Brazil and in Uruguay where toxicity is recognised. It is also known from Australia, North America, China and possibly Europe, but no cases have been reported from these localities.

Pathology:

Cattle:

- atrophy of lingual papillae
- multifocal fibrinonecrotic lesions at the tongue margins and linear lesions in the oesophagus
- vacuolation & irregular keratinisation of the laminar epidermis of hooves
- degeneration of epidermis of tail switch hair follicles
- decreased thickness of epithelium of the tongue with loss of papillae

Sheep:

- feet and tongue epithelium: endothelial degeneration and occasional thrombosis of arterioles followed by necrosis and ulceration of the mucosal epithelium.
- eye: haemorrhage into the anterior chamber; severe congestion and haemorrhage of the iris, ciliary body.

Diagnosis:

- access & syndrome
- differential diagnoses include toxicity from selenium, mimosine

CYANOBACTERIAL TOXINS

TOXINS OF FRESH & BRACKISH WATER CYANOBACTERIA

☑ Cyanobacterial hepatotoxic cyclic peptides – microcystins and nodularin

Common sources:

- *Microcystis aeruginosa* [= *Anacystis cyanea*]
- *Nodularia spumigena*

Other sources include

- *Microcystis flos-aquae*
- *Microcystis viridis*
- *Anabaena flos-aquae*
- *Anabaena* spp.

- *Oscillatoria agardhii*
- *Oscillatoria limosa*
- *Nostoc* sp.
- *Anabaenopsis milleri*

Pathology: acute hepatic necrosis (*q.v.*)

Diagnosis:
- Evidence of access to blooms
- Identification of toxigenic cyanobacteria in bloom material (microscopic examination of bloom samples allows recognition of known toxigenic cyanobacterial species and justifies the expense of toxin assays, mouse toxicity tests or both)
  - For laboratory examination, two (2) samples are required from each bloom:
    - **For Identification of organisms**: 20 ml of bloom material + 1 ml 10% formalin for preservation [N.B. alcohol may produce distortion of cells, so formalin is preferred].
    - **For Toxicity testing**: 1 litre of the most concentrated bloom material (minimum useful quantity is 20 ml) chilled and transported as swiftly as possible; do **not** add preservative to this material.
- Mouse bioassay has been the standard toxicity testing method for cyanobacterial blooms, but is being superseded by assays for specific toxins. Mouse bioassay results should be expressed as LD_{50} or LD_{100} values in units of mg dry weight of cyanobacteria / kg mouse body weight.
- Assay methods for microcystin and nodularin are available for water and cyanobacterial bloom material
  - HPLC
  - ELISA - microcystins
- Gene probes are being developed to allow identification of potentially toxigenic strains of *Microcystis* without the need for toxicity testing.

Cyanobacterial alkaloid neurotoxins – paralytic shellfish poisoning (PSP) toxins and anatoxins

Common source:
- *Anabaena* spp.

Pathology: No significant lesions recorded

Diagnosis:
See section on cyanobacterial peptide toxins above.
Saxitoxins (paralytic shellfish poisoning toxins) assays available

Cylindrospermopsin

Common source:
- *Cylindrospermopsis raciborskii*

Pathology:
Cattle:
Necropsy: jaundice, pale liver, distended gall bladder

Histologically: liver, kidney and heart degeneration and necrosis

sub-acute cases: biliary ductular proliferation, swelling of hepatocytes with foamy vacuolation of cytoplasm, scattered individual hepatocyte necrosis in periacinar areas; foamy vacuolation and swelling of renal proximal tubular epithelium with protein and cellular casts in tubular lumens; scattered mild focal myocardial degeneration and necrosis

chronic case: extensive hepatic fibrosis and biliary ductule proliferation with marked reduction in hepatocyte numbers and foamy vacuolation of hepatocyte cytoplasm.

ZOOTOXINS (TOXINS OF ANIMAL ORIGIN)

ARTHROPODS - INSECTS

Sawfly larval peptides

Common sources:

- *Lophyrotoma interrupta* (Australian cattle-poisoning sawfly larvae)

Pathology :

As for acute hepatic necrosis (*q.v.*).
In many cases, the extent of hepatocyte necrosis is total (panacinar coagulation necrosis).

Diagnosis: As for acute hepatic necrosis (*q.v.*)

*Piperidine alkaloids (solenopsins) & peptide allergens of fire ant venom (*Solenopsis *spp.)*

Source:

- ***Solenopsis invicta*** Buren (red imported fire ant, RIFA [USA]), native to central Brazil, northern Argentina, Paraguay and (arguably) Uruguay in South America, invaded the southern USA in the early to mid 20th century (1918, 1940s), Mexico and the West Indies. They were confirmed in Brisbane, Queensland, in February 2001 and have probably been present in south-eastern Queensland for at least 5 years before detection.

Pathology: Pustules at sting sites

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Chapter 18

Practical Sessions

Keith Walker

The Postmortem Examination

Definitions

Webster's Medical Dictionary

necr-, necro-, [Greek nekros, corpse]. A combining form meaning "pertaining to death".

necr-rop-sy (neck"rop.see) η. [necr+-opsy]. To look at/in the dead.

Autopsy. Compare "biopsy"

au-top-sy (au'top-see) η. [Greek. autopsia, seeing with one's own eyes, from auto+opsis, sight, seeing]. A medical examination of the body after death to confirm or correct the clinical diagnosis, to ascertain the cause of death, to improve understanding of disease processes and aid medical teaching. SYN. necropsy, postmortem examination.

Very Useful Reading on the Purpose of Autopsies

Majorie J. Williams - The Autopsy: A Beginning, Not an End (1978) Am J. Clin. Path. Vol 69 (2)S:215-265.

King LS, Meehan MC – A History of the Autopsy, A Review (1974) Am J. Pathol 73:514-544.

Quotation

King says, "it is a pernicious misconception that the mere performance of postmortem dissection leads to progress in medical science. Progress depends not on the autopsy but on the person who is examining the material. Those who believe that the more autopsies we perform the more medical science will progress are pleading not for more autopsies but for more persons who can profitably utilise the data of autopsies, persons who have imagination, originality, persistence, mental acuity, sound education and background and the indispensable prepared mind. It is a grave disservice to confuse the performance of autopsies with the spark of insight which the autopsy may trigger".

Recording the Autopsy

Pritchard RW "Descriptions in Pathology" (1955) A.M.A. Archives of Pathology 59:612-617. Reprinted in full as an editorial in 1966 in Path.Vet. 3:169-177.

A few quotations might stimulate curiosity!

Quotation 1

The recording of pathological material in words is not a literary exercise, but a utilitarian method for the preservation of certain features of gross and microscopic examination. Despite its humble nature, it should be concise, grammatical, and, especially, precise. No interpretation should

appear in descriptions, and it is theoretically possible for a person with a command of the language to describe perfectly a surgical specimen or an autopsy, although he knows nothing of its significance. The time such a task would require of the untutored would be great, and special knowledge permits a rapid choice of words. If description and interpretation are intermingled, the total value of the effort declines rapidly; their separation is hygienic, forcing the observer to check himself and to cast the scales of preconceived diagnosis from his eyes. The power of the latter should not be underestimated. For a thousand years anatomists saw pores in the interventricular septum of the heart because they believed Galen, and he said pores were there. One good way to foster this objectivity in gross description, until experience makes it second nature, is first, to look the material over, then, describe it as it is gone over a second time, and, finally, read the description back to oneself as the material is scanned again to see if what is described can be demonstrated. The practically universal convention of putting descriptions in the present tense recognises the necessity of immediate objective description.

Brevity is not only the soul of wit but the sign of a mind in good training when it comes to descriptions in pathology. The beginner, who must grope for words which he wishes would roll off his tongue, stuffs his descriptions full of sentences such as, "When the uterus is opened, it is seen that a polypoid projection of endometrium is present, which when lifted up is seen to attach to the right cornu". As the final word is reached, one has either lost the reader or bored him. One's audience is only rarely interested in the mechanics of dissection; they look for one's findings and know full well that the uterus had to be cut open to see inside it, etc. The sentence would be more readily digestible as, "As polypoid endometrial projection is attached to the right cornu". It is hard to carry such trimming too far. It is my own view, opposed by some of my colleagues, that it is also superfluous to precede weights and measurements by confession of the act, eg, "The thyroid weigh 22gm and measures 5.0 x 3.0 x 1.0cm". When one records a weight or measurement, res ipsa loguitur, as our legal confreres would say. In the same vein, it is not a matter of taste to point out that it is sheer redundancy to follow a statement of colour by "in colour", as, "The tissue is blue in colour". What else would it be blue in? We are not given to describing the mood in which we find tissue.

Quotation 2

One matter which deserves special attention has been purposely avoided above. That is the serious one of where to get one's supply of words. A teacher of mine said that after he had been in pathology for a few months he found himself rapidly losing appetite and weight. Considering the matter, he soon realised that he had been describing foul and loathsome specimens as "like a tomato", or "filled with a material resembling pea soup", and so on ad nauseum. He resolved that, even if Virchow's father had been a grocer (an unfounded rumour), he was not so poor in his native tongue and limited in experience of the world as to draw all his descriptive terms from the table. I share his sentiments

completely. It certainly is poverty of intellect which makes one fall back on such terms, or sheer laziness. A concise statement of fact is preferable to an example. Many people have pointed out, furthermore, that the wide variation in fruits, vegetables, etc, makes descriptions of things, as "the size of an orange", hazardous, since one never knows from whence the orange comes. To La Fontaine, who said, "Example is a dangerous lure; where the wasp got through the gnat sticks sure", I doff my hat.

Animal Autopsy

The following veterinary paper by Paul Stromberg DVM PhD gives a concise summary of how to describe what you might behold in the "veterinary" autopsy.

Remember that for veterinary clinicians doing their own postmortem examinations this represents the ideal opportunity to confirm or correct the clinical diagnosis and to ascertain the cause of death.. It is a quality control much to be desired in any medically-based profession! Indeed the recent Rural Veterinary Review touched on the effects of economic rationalism on the conduct of autopsies in laboratories. The Review is quoted as follows – "Significantly, the Review was informed the closure of regional laboratories and the general inability of private laboratories to conduct gross postmortems on large animals has led to a marked reduction in the number of gross postmortems on production animals. A comprehensive diagnosis of a suspect disease may rely on a wide range of investigative tests including gross pathology services (ie postmortems) and laboratory-based services involving histological pathology, virology, microbiology and serology to confirm the presence or absence of disease. In NSW there has been a fall of approximately 50% in the numbers of postmortems and diagnostic investigations in the government laboratories".

However it may be no bad thing overall if less autopsies are done in laboratories, provided as a consequence more were done by clinicians in the field. Armed with a sharp knife and an inquiring mind veterinary clinicians can, and do, well serve the production livestock industries with valuable autopsy information. This information should be captured and paid for by state and national disease surveillance systems and be valued as the mainstay of disease intelligence, especially when further validated by appropriate laboratory confirmation. Failure to perform autopsies condemns livestock owners, veterinary clinicians and the National Animal Health Information System (NAHIS) to self-imposed ignorance of the deepest and most fatuous kind.

DESCRIPTION OF POSTMORTEM LESIONS AND SURGICAL SPECIMENS

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The final pathologic diagnosis in every necropsy depends upon information from multiple inputs. Contrary to popular belief histopathologic or microscopic examination is not necessarily the most important or definitive tool. In most cases, the pathologist evaluates a lcm x 2cm x 5μm piece of tissue. This is all he sees with the microscope! In order to make an accurate diagnosis, additional information is nearly always necessary. A complete signalment is the minimal requirement (i.e. species, age, sex, breed). In addition, an accurate, concise medical history of the relevant facts together with current clinical findings and a differential diagnosis is extremely useful in focusing a pathologist's attention on your case. This need not be long. Indeed, brief and to the point, including key laboratory results (BUN = 348; WBC = 56,000; PCV = 12; etc.) is optimal. Don't inundate him with lots of needless information. These data should be part of a good medical record and readily accessible to you. Take the time to share it with the pathologist.

Those of you practicing in a medical centre where there is good pathology support need only be concerned with providing the information mentioned above. Pathologists doing the postmortem examination will be responsible for identifying and recording the gross findings. However, the vast majority of you are not going to practice medicine in that setting. Most of you will perform necropsies in the field or the back room of your clinic WITHOUT THE BENEFIT OF HAVING A PATHOLOGIST PRESENT. Therefore, you must perform that function yourself. Generally, you do the necropsy (or surgical biopsy) and send the tissues to a laboratory for a pathologist to examine. Because of this separation, the quality, speed, and accuracy of the diagnosis you receive depend in large part upon the information you send. The information should be complete and accurate. HELP THE PATHOLOGIST HELP YOU!

Beside the relevant clinical information you provide from your medical record, what the pathologist wants most is to know what the gross lesions looked like. Often, he does not even see the specimen when it is trimmed. Therefore, he must rely upon your description of the lesions to make the correct diagnosis and interpret its significance. Your ability to accurately describe lesions and communicate with the pathologist is of the utmost importance.

Elements Of Description

1) Location
2) Distribution
3) Shape and Contour
4) Size
5) Colour
6) Consistency and Texture
7) Special Features

The first step in describing lesions or abnormal findings is to determine if the tissue or organ is in fact abnormal. Often this decision , is made intuitively or subconsciously without knowing why because "it just looks abnormal". For instance numerous white dots in a liver are abnormal because the liver should be homogeneous reddish-brown. Or, 2 kidneys that are not the same size is abnormal because you know that they should be equal in size. Thus the first question:

Is It Normal Or Abnormal?

This decision should immediately be followed by the next question:

What Is The Abnormal Part?

You may have decided that the kidneys are of unequal size but before you begin describing the "lesion" you need to decide whether the large one or the small one is abnormal. Likewise, the white dots on the liver are abnormal but white areas on a dark lung may be normally aerated alveoli in a severely congested lung. If you submit these areas, the pathologist will diagnose "normal lung" even though there may be severe congestion and possible heart failure.

This is where you need to draw upon your experience and medical knowledge of what constitutes normal (colour, shape, size etc.). Remember that sometimes there is no detectable gross abnormality. However, your clinical history indicates a problem with that tissue which you would like to have examined (i.e. the BUN was 400 and I think the animal is in renal failure but the kidney looked normal). It is still important to record that the tissue appeared normal (the gross lesion of acute renal failure is subtle and often appears normal).

1) Location

Once you have decided on what is abnormal (or what you want to submit for analysis) the first data bit is the location from which you sampled the lesion. Although this may be obvious to you, it is one of the most frequently omitted pieces of data.

For instance, not uncommonly I see specimens labelled "from the abdomen". This may be from the skin, subcutaneous or the peritoneal cavity. If it is an undifferentiated neoplasm, the prognosis may be very different for a skin tumour than for an abdominal one. Apocrine gland tumours look alike wherever they originate. However, topographical site data indicating that the specimen is from the mammary gland now allows definitive identification as mammary carcinoma. Therefore, accurate descriptions should always begin with ORGAN OR TISSUE IDENTIFICATION AND TOPOGRAPHICAL SITE. For instance, skin abdomen; left kidney; lung, caudal lobe; left popliteal lymph node etc. This should alway be the first element you write down.

2) Distribution

Knowing the distribution or spatial pattern of the lesion is the first key to interpreting the pathogenesis and the significance of the lesion. Distribution patterns can often be related to certain general disease mechanisms and sometimes indicative of specific disease entities. This data bit, when recognised and recorded, helps to see the whole picture. Remember, the pathologist only sees a small piece. It may be important to know, if this was the only lesion or if there were many similar lesions or even if this lesion represents a process occurring in the entire organ or tissue.

A) FOCAL - usually a single abnormal area.

B) FOCALLY EXTENSIVE - I use this to indicate one large lesion or a single area which is severely affected.

C) MULTIFOCAL - many abnormal areas. The range of this term is extremely variable. It may mean more than one to many. Often when I want to connote more than just a few, I will use the term MULTIFOCAL WIDESPREAD. In all cases it means discrete foci or areas of abnormalcy surrounded by normal.

D) MULTIFOCAL COALESCING - discrete focal lesions which appear to be growing together.

E) MILIARY - literally means thousands, but I use it when there are so many focal lesions I can't count them easily.

F) DIFFUSE - appropriate term when the entire organ or topographic site is uniformly or nearly all affected.

   BECAUSE THERE IS NO CONTRAST WITH NORMAL, DIFFUSE LESIONS MAY BE EASILY OVERLOOKED!

G) SEGMENTAL - best used to describe a portion of a tubular organ like ileum. For instance: "Intestine, ileum, segmental diffuse dark red" means that portion of the ileum was diffusely affected.

H) RANDOM this refers to the spacing of lesions. Lesions which occur without any particular relationship to anything are said to be random.

I) UNIFORM - lesions which are regularly or evenly spaced or occur at some organised interval.

Remember that pathologic processes are usually independent random events. If you detect some symmetry in the distribution of the lesions, it is likely that some anatomic feature is being highlighted by the process. A uniform miliary distribution of white areas in the liver is likely to be hepatic lobules. A similar distribution in the spleen is lymphoid tissue or white pulp. These areas many be abnormal (centrilobular lipidosis; lymphoid hyperplasia) but the uniformity or symmetry helps you interpret what the change could be.

Although diffuse lesions generally are more significant than focal lesions because more tissue is involved or more function is compromised, it does not mean that all focal lesions are insignificant. The significance of a particular lesion is related to the "3 R's" of the tissue or organ in which it occurs: REDUNDANCY, RESERVE and REGENERATION. A large neoplasm in the right kidney may not be life threatening because there are 2 kidneys (redundancy) and the contralateral kidney has enough reserve function to compensate. On the other hand, a small abscess in the cardiopulmonary centre of the brainstem may be fatal because there is only one centre (no redundancy), its very small (no reserve) and it doesn't regenerate if destroyed.

3) Shape

There are 2 important implications in the shape of a lesion. These are related to whether it is raised or depressed.

A) RAISED - elevated above the level of the adjacent tissue. Also bulging or nodular. Raised is implied when the term "mass" is used. A raised lesion means that SOMETHING EXTRA IS ADDED. That's why it bulges. The something extra may be fluid, exudate, normal tissue (hyperplasia) or abnormal tissue (neoplasia). Other elements in the description will help you to determine which interpretation is most likely to be correct.

B) DEPRESSED - the abnormal area is below the level of the adjacent tissue. A depression means that SOMETHING IS MISSING OR LOST. This often means necrosis has occurred but it could also mean atrophy or, in dynamic tissues like the lung, a lack of air. When necrosis has been resolved by fibrosis or scar tissue, there is traction on the adjacent tissue. This "pulls" the tissue creating an irregularity in shape. This gives an asymmetrical or unorganised look to the area.

C) FLAT - the abnormal area is neither raised nor depressed. Flatness may imply an acute process which has not had time to either accumulate cells or fluid or lose tissue through architectural loss.

Beyond the contour of a lesion, its precise geometric shape is not of critical importance. Most neoplasms, abscesses and granulomas generally grow as spheres. Acute necrosis originating from a bacterial colony may spread centripetally as a circle. Other geometric shapes such as squares, triangles etc. may imply a unit of anatomic structure. Vascular obstructions (infarcts) are often discrete lesions outlining the geometric shape of a vascular bed. Atelectasis in the lung may outline discrete groups of lobules whose common airway is obstructed.

An additional dimension of shape relates to how WELL DEMARCATED OR POORLY DEMARCATED the lesion is. This means how easy it is to see where the normal ends and the abnormal begins. This data bit helps the pathologist predict whether or not the lesion is likely to recur after you resected it. Well demarcated inflammatory lesions are often surrounded by fibrosis and therefore are old or chronic. Poorly demarcated inflammatory lesions are often younger. Benign neoplasms are often well demarcated masses because they grow by expansion.

4) Size

The size of a lesion is important in determining its significance and impact. Often you will need to determine if the postmortem lesions you observed could explain the clinical signs or even the cause of death. Therefore, ALWAYS INCLUDE AN ESTIMATE OF SIZE OR EXTENT in your descriptions.

Ideally you should give a relatively precise estimate in numeric units (millimetres, centimetres, inches, feet etc.). However, if you don't have a ruler or can't estimate linear dimensions well, use a common cultural reference to indicate absolute size (golf ball, tennis ball, pea, thumbnail etc.). The key here is that it does not need to be exact, only approximate, so that later you or the pathologist could estimate its significance. Large neoplasms often have necrotic areas which when submitted for histopathology will be diagnosed as "necrosis", when clinically you "know" the lesion is a tumour. If a size estimate accompanies the specimen, the pathologist will be aware of this possibility.

Related to absolute size is the estimation of relative size or extent. HOW MUCH OF THE ORGAN OR TISSUE IS INVOLVED? This is very important in determining the functional significance of the lesion. Usually it is estimated as a percentage of the organ involved and it is most useful when the lesion is not a discrete mass which can be easily measured For example, pneumonia is usually a focally extensive lesion involving a certain portion of the lung or a lobe. Rather than measuring it, simply state that"25% of the right lung" or "90% of the right cranial lung lobe" was abnormal. If the signalment is properly included with the specimen, the pathologist should be able to interpret the significance of a 2 cm infarct in the kidney of a 5 year old Great Dane differently from a similar lesion in a 3 week old Chihuahua. Nevertheless, an additional statement indicating that it obliterated the cranial 15% of the kidney in the first

case (insignificant) or 90% of the kidney in the second case (significant) would be helpful. Without it, all that you will receive is a diagnosis of "coagulation necrosis" and no indication of significance.

Most pathologic processes begin at the microscopic level and are thus small early in their development. If they progress (neoplasms and abscesses grow) it takes time. Therefore, as a rule large lesions are older than small ones. Similar lesions of 2 different sizes may imply a continuing process or repeated events. For instance, separate embolic "showers" or metastatic events might appear as miliary lesions of different sizes.

5) Colour

Colour is probably the easiest change to detect because it is so obvious. Coupled with other elements, it provides a basis for accurate interpretation of changes. The normal colour of organs and tissues is a net result of the relative amount of parenchyma, connective tissue, fat, blood, other pigments and in the case of lung, air.

The most important of these colour elements is blood because it is found everywhere, and it is very dynamic, ie the amount present is variable depending upon many physical, physiological and pathologic factors. Organs that are well perfused or very vascular are pink to dark red. Changes in the amount of blood in a tissue can be inferred by increases or decreases in the shade of red.

A) RED TO REDDISH BLACK - A common colour and almost always due to increased amounts of blood. Significant haemorrhage is usually very dark because the haemoglobin is depleted of oxygen. Focal or segmental lesions are usually interpreted as haemorrhage while diffuse lesions are probably congestion. Because of the contrast, this colour is most obvious and spectacular in light tissues (brain, lung, GI, kidney etc.) and more difficult to see in liver and spleen. If the reddish-black area is a nodule, think about a vascular neoplasm, haematoma or possibly an abscess with haemorrhage.

B) BLACK TO BROWNISH-BLACK - Usually due to melanin or exogenous carbon. Sometimes putrefactive bacteria can cause a black necrotic exudate. If the lesion is a mass, think about a melanin-containing neoplasm (melanoma). If not raised, it may be a non-neoplastic accumulation of melanocytes (melanosis). Hydrogen sulphide from the GI lumen is a common cause of postmortem black discolouration.

   "DIFFERENTIATION OF BLOOD FROM MELANIN CAN BE VERY DIFFICULT SO LOOK CAREFULLY"!

C) BROWN TO GOLDEN BROWN - Usually caused by haemosiderin. Haemosiderosis implies old or chronic congestion or haemorrhage. When focal, think haemorrhage. When diffuse, think passive congestion.

D) GREEN - Usually bile pigment. Bile commonly stains tissues green to greenish-black. Some fungal agents growing in body cavities or airways have a green to greenish-black colour.

E) YELLOW - This colour may be due to the presence of fat, bile pigment (bilirubin), fibrin, cellular exudate or neoplasms. Information from the other descriptive elements is needed to fully interpret it. A diffuse yellow colour may be due to icterus (bilirubin) or lipidosis. Focal nodules of yellow are likely to be inflammation or neoplasms. Dirty yellow, dry, stringy stuff on membranes is probably fibrin.

F) WHITE - Somewhat similar to yellow. May be exudate, neoplasia or connective tissue (fibrous, cartilage, bone).Elevated lesions (something extra) are probably inflammatory or proliferative (hyperplasia/neoplasia) including granulation tissue. Depressed, contracted irregular areas may be scar tissue. White foci often indicate necrosis. Because it takes time for a response to either elevate or depress the area, flat foci may be interpreted as acute necrosis.

"REMEMBER THAT DARK COLOURS MAY OBSCURE CHANGES ASSOCIATED WITH LIGHT COLOURS".

If haemorrhage occurs into an area of necrosis, it will appear red. Likewise, necrosis in the spleen is often red because there is so much blood in the organ.

Autolysis causes a distinct, diffuse dirty light reddish colour which has a non-vital look about it. It too can be modified by darker colours. It is best appreciated in an aborted fetus.

6) Consistency And Texture

CONSISTENCY relates to the physical firmness of the area as measured by palpating. There are distinct interpretations associated with different levels of consistency.

A) FLUID - There are a limited number of possibilities for fluids. Clear fluid is always excess extra vascular fluid (oedema). If it contains fibrin (serofibrinous) it means inflammation. Serofibrinous effusion is usually tinted yellow and, if it contains abundant fibrin, may clot. Urine is clear also but has a distinct odour (see special features). Blood is dark red. Real haemorrhage into body cavities is thick, and often has clots. Most "blood" observed at autopsy is really blood-tinged oedema (serosanguinous) fluid. Turbid fluid indicates cellular elements and may be due to inflammatory exudate, lymphatic or neoplastic effusion. The accumulation of fluid may indicate a vascular problem, either vessel leakage or fluid equilibrium disturbance, inflammation, or obstruction.

B) SOFT - Probably fluid-rich cellular elements, loosely organised tissues, fat etc. Tissues without much stroma. The normal consistency for many tissues.

C) FIRM - fluid-poor, cell rich tissues. The occurrence of many cells in an enclosed area will give it a firm feel. Many inflammatory as well as proliferative lesions feel firm. This is the normal consistency of many tissues. The addition of fibrous scar tissue will increase the firmness of a tissue or organ. End stage kidneys are firm, with irregular depressions, contracted, lighter in colour and small because of fibrosis. Pneumonia feels firm because of the dense accumulation of exudate.

D) HARD - usually implies mineral density i.e. cartilage, bone or deposition of mineral salts.

TEXTURE refers to the smoothness or roughness of the area and is best evaluated on a fresh cut surface. I use it to compare the similarity of the lesion cut surface to that of the adjacent normal tissue. The difference in texture of a lesion is likely to indicate the degree to which the lesion differs from normal. If the lesion is white but has the texture of adjacent heart muscle, it probably means the lesion is composed of heart muscle but altered usually interpreted as coagulation necrosis. If the white area appears to have structure, and holds together but is smooth, I interpret it to be tissue but not myocardium. If it is also a discrete, bulging mass, I will conclude that it is probably a neoplasm. If the lesion has no structure, but is a cheesy material which can't hold its shape, I will conclude that it is inflammatory exudate and diagnose an abscess or granuloma. If the texture is normal, and the abnormalness is simply that there is more myocardium than I think should be there, I conclude that it is normal myocardium which has hypertrophied.

7) Special Features

These differ for many tissues, organs and processes but can provide valuable information. For me, this includes data from sense modalities other than my eyes. You have already used your sense of touch in evaluating consistency, but the weight of an organ, especially dynamic organs like lung, spleen, urinary bladder can be important. Indeed, the most important data bit about a lung is usually if it feels heavy. The odour of a lesion or the lack thereof is often a useful characteristic. Putrefactive bacterial infection is best diagnosed with your nose. Pyometras and canine parvoviral enteritis have distinct odours. Uraemic animals often have an ammoniacal odour in their stomach or GI. Gastric haemorrhage smells like apple cider. The crepitant sound that air or gas in tissue makes is characteristic and could indicate postmortem autolysis or clostridial infection. I've never tasted anything in the postmortem room, but if I could figure out an acceptable way to use this sense, I'm sure we could find useful information with it.

Building A Complete Description of Lesions

Once you know the elements that constitute a description, putting them together is simple. The order is not critical but I recommend you do it the same way each time so that you don't omit anything important. Although we all like to read nice flowing prose, the only essential thing is that you accurately communicate what you discovered. Not all of the elements are critical to an adequate description and many lesions do not need every element. The minimum should always include **LOCATION, DISTRIBUTION, SIZE, COLOUR, and SHAPE**. When submitting masses suspected to be neoplasms, demarcation is helpful in predicting likelihood of recurrence and metastasis.

Below are some examples of what I consider to be good descriptions of lesions:

Skin, left hock: Multifocal, raised, 2x2mm yellow white, firm, ulcerated nodules arranged linearly. Cut surface was amorphous and well demarcated.
INTERPRETATION - probably granulomas in a lymphatic. Possible ulcerative lymphangitis.

Lung: Diffuse, dark red, wet and heavy with foamy fluid running out of airways. Cut surface looked similar. 100 % of lung involved. (Probably blood and fluid filled).
INTERPRETATION - pulmonary congestion and oedema.

Liver: Miliary 1mm white flat foci. (In this case, the lesion is too small to gather additional information).
INTERPRETATION - probably acute necrosis. The distribution suggests a recent shower of particulate emboli such as would occur in viral or bacterial septicaemia.

Kidney right: On the cut surface there is a focal, well demarcated, pale, wedge-shaped area spanning the cortex. The overlying capsule is depressed.
INTERPRETATION - probably an infarct. The depression is probably caused by fibrosis and therefore it is an old lesion.

Colon left, ventral and dorsal: Segmental (12 feet) diffuse, transmural, dark red, wet and bulging. INTERPRETATION - Congestion and oedema with probable coagulation necrosis. Most likely infarction due to mechanical displacement of GI.

Heart, ventricles: Multifocal to coalescing, irregular, flat, pale white areas which look like myocardium. 30% of heart involved
INTERPRETATION - Acute coagulation necrosis. In a ruminant, most likely white muscle disease.

Description Versus Interpretation

Description is the listing of empirical physical characteristics or facts you observed which identify the lesion. It is the common usage terms which tell about distribution, size, shape, colour, firmness, odour etc.

Interpretation is your translation of what the collective presence of those characteristics is most likely to mean in medical or pathological terms. I encourage you to interpret your descriptions. Its your right and privilege as a medical professional. In addition, the pathologist wants to know what you think the findings mean. After all, it was your eyes which made the observations, and that is usually better than a written description. However, the price of admission to interpretation is a good description.

IF YOU INTERPRET WITHOUT DESCRIBING YOU MAY COMPLICATE DIAGNOSIS IF YOUR INTERPRETATION IS INCORRECT. Therefore, ALWAYS DESCRIBE THE LESION FIRST THEN INTERPRET IT!

For instance, the lung was "diffuse dark red" not "haemorrhagic". Haemorrhagic is an interpretation of your observation that the lung was red. In fact, diffuse dark red lungs are usually not due to haemorrhage but congestion. A very real and important difference. If you describe accurately, you can always go back and re-interpret your findings. If you don't, later you may not be confident about what you saw. An easy way to do both is to describe the lesion and immediately afterwards give your interpretation in parentheses. The lung was diffuse, dark red, wet and heavy (congestion and oedema). This way, later, you or your pathologist know what you saw and what you thought it represented at the time. Interpretation of gross lesions is always a guess. We are often wrong. There is no shame in being wrong about gross lesions. With diligence and experience, though, it can become an educated guess and provide you and your clients with immediate data about what the likelihood of the problem is. In addition, you can help your pathologist give you a more definitive diagnosis. Interpret (guess), but ALWAYS DESCRIBE!

An integral part of your interpretation is the sorting out of LESIONS from POSTMORTEM CHANGES. A lesion is a defect in a living tissue caused by a pathologic process. It may be biochemical or structural. Postmortem changes are abnormalcies that occur after death usually as a result of the process of autolysis. AGONAL CHANGES are lesions that occur just before death and may not be clinically significant (pulmonary congestion is often an agonal change). NON-LESIONS are normally occurring structural changes that are not caused by a pathologic process (melanosis). These interpretations are based on experience which takes time.

What Should You Expect From The Pathologist?

The pathologist will give you a brief description or morphologic diagnosis. Morphologic diagnosis indicates a kind of pathologic process or anatomic change in the tissue that the lesion represents. This will be based upon what he can see in that small piece of tissue he examines. If the specimen is a neoplasm, he will identify the specific neoplasm if it is differentiated sufficiently. If it is a benign neoplasm, the pathologist will indicate that. If the tumour is malignant, you can expect a comment about how well differentiated it is, whether or not surgical excision was complete, and the likelihood of recurrence and metastasis. The pathologist will expect you to be familiar with the names of tumours. I recommend you purchase Tumours of Domestic Animals by Moulton. A new edition of this book is available. It will be a valuable source of information for you.

Non-neoplastic lesions will be identified as precisely as possible. When causes are present in the specimen, they should be identified. Quite often, the cause is not present but the pattern of pathologic change is characteristic enough to indicate or suggest a certain disease or class of diseases. In this case, often you will see that a certain change is "compatible with" or "suggestive of a certain disease or syndrome.

Pathologists vary in their willingness to speculate on what the lesion might represent. It is here that the difference between a veterinary pathologist and a human pathologist reading your biopsy is most evident. You want someone professionally experienced with the diseases you see clinically to interpret the findings. The degree to which the pathologist can do this is related to his experience and very dependent upon the completeness of the data you provide about the case and the lesions. This is where you help the pathologist to help you. It often makes the difference between giving you the generic name of a pathologic process and confirming a specific disease or syndrome.

Chapter 19

Suggested Check List of Equipment for Clinical and Necropsy Examinations

Laboratory Specimen Submission Manual 8th Edition
NSW Agriculture Veterinary Laboratory Services

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1. Personal
Rubber boots
Overalls
Gloves
- disposable
- postmortem gloves or gauntlets

Postmortem apron (optional)
Towel and soap
Wet weather gear

2. Animal Husbandry
Halter
Nose grips
Bleeding choke rope
Twitch
Pig handler
Drugs
- Rompun 2%
- Xylocaine 2% etc

3. Clinical
Stethoscope
Thermometers
Obstetrical gloves

4. Clinico-pathological
Test strips eg urine, blood and glucose
Nitrate and cyanide test

5. Clinical Specimens
Vacutainers – plain, heparin and EDTA
Vacutainer needle holders and needles (18G)
Sterile containers (100ml)
Sterile bottles – yellow top plastic 5, 25, 50ml
Swabs – packets sterile
Transport media

- Amies charcoal transport medium in bottles or commercial swab packs
- Phosphate buffered glycerol saline (PBGS) in bottles – supplied by labs

Microscope slides (and spreaders fro blood films)
Syringes (1-20ml) and needles (14-26G)
Scalpel handle and disposable blades
Scissors
Non-sterile faecal containers (50-100ml)
Vaginal mucus pipettes
Ethanol/iodine for skin asepsis
Biopsy instruments and small bottles of fixative

6. Euthanasia

Rifle and ammunition
Euthanasia solution and syringe/needle
Killing knife

7. Necropsy

Knives
- 20cm skinning 2.5cm wide straight blade
- 20cm skinning 2.5cm wide curved blade
- 15cm boning knife pointed straight

Steel
- 30cm Butcher's

Footrot secateurs
- 7.5cm blades – Wilkinson Sword

Handsaw 30cm blade
- Sandvik (Sweden) and replacement blade

Scissors
- Mayo straight 16cm
- Mayo straight 14cm
- Double sharp 11cm fine
- Pointed/1 rounded end and knob (for gut running)

Bone forceps
Toothed forceps
- 20cm
-18cm
- 13cm

Scalpel handles
- No. 4

Scalpel blades
- No. 24 and/or NO. 20

Rib Cutters
Meatsaw/hacksaw
Cleaver/hatchet
Buckets – plastic (2)
Trays
- plastic (large)
- plastic (small)

Sterile scissors and forceps for virological tissue samples

8. Pathological specimens
Sterile containers
- 50ml
- 25ml
- 5ml
Plastic bags 0.1mm thick
- large
- medium
- small
Rubber bands
Microscope slides and diamond pencils, or markable slides and pencil
Histopath jars with 10% neutral buffered formalin
- large 500ml
- medium 250ml
- small 125ml
Special fixatives (eg Bouins) if required
Ball of string

9. Decontamination/Disinfection
Container and 20 litres water
Disinfectant – litre Lysol or similar
Nail scrubbing brush (for cleaning instruments)
Long handled scrubbing brush (for cleaning boots)
Roll paper towel
Plastic garbage bags
Used beer can for contaminated "sharps" or disposable sharps container

10. Clerical
Clip board
Postmortem and laboratory submission forms
Specimen collection handbook
Pencil
Marking pens
Black biro
Adhesive labels
String-tie labels

11. Storage
Large metal esky with 1 blood vacutainer box and small foam esky inside
Frozen cold bricks, dry ice or portable car fridge
Serum storage plastic disposable tubes – 5ml

PRACTICAL SESSIONS - POSTMORTEM TECHNIQUES FOR RUMINANTS

J Seaman, Program Leader Flock Health, NSW Agriculture

To quote Dr HG Belschner "there is perhaps no way by which a veterinarian or stock owner can obtain more information about disease in animals than by a properly conducted postmortem examination".

Before starting an autopsy a thorough clinical history of the flock or herd is essential to get some idea of the diseases involved. Begin the autopsy with the intention of examining first the system which clinical signs suggest is the seat of the disease but always complete the full autopsy examining all organs in a logical and systematic order.

The ideal postmortem specimen is a freshly dead animal, preferably one that has been sacrificed while showing terminal clinical disease. Where possible the carcase should be placed on a plastic sheet or a clean grassy area to minimise dust and other contamination.

Before starting, it is essential to have all your equipment organised and readily accessible. Suggested requirements include:

- knives and sharpening steel
- secateurs
- scissors
- forceps
- butchers saw (for removing brains)
- large secateurs (for cutting ribs)
- water with disinfectant
- formalin container
- sterile jars
- string
- plastic bags
- trays
- a micro-cassette tape recorder or note paper for recording your findings
- scrubbing brush
- soap and towel

Protective clothing including overalls, rubber boot and gloves should be worn when doing the autopsy. It is a good idea to have water with antiseptic on hand to clean the instruments during the autopsy.

For ruminants lie the animal on its right side. If the animal was found dead, note the position in which the animal was found, any signs of struggling, any discharge from external orifices and any evidence of jaundice, external wounds or injuries.

Open the carcase systematically by first removing the forelimb by severing the pectoral muscles and brachial plexis and laying the leg back followed by opening the hip joint of the hind limb by severing the teres ligament to lay the leg back. Incise the midline and reflect the skin followed by skinning the neck and head to give complete removal of the skin from the left side of the carcase. Next open the abdominal cavity along the lower flank and note any fluid which may be present. The abdominal organs can be observed in situ and need not be disturbed at this stage. The diaphragm is then observed and incised to confirm the negative pressure normally present in the pleural cavity. The rib cage is then removed using the large secateurs or rib cutters. The viscera of the left side of the carcase is now fully exposed. Note any evidence of oedema, subcutaneous congestion, haemorrhages, icterus, dehydration, emaciation or any other general body changes. With the carcase now opened the organ or systems indicated by the clinical disease may be examined followed by all other systems in the body.

The gastrointestinal tract involving the stomachs and intestines is removed as one by cutting the dorsal mesentery and then tying the oesophagus and cutting it as it passes through the diaphragm. These can all be placed on a tray for further examination later. Check the spleen on top of the rumen, particularly if in a recognised tick fever or Anthrax area.

The remaining abdominal organs are examined systematically and samples taken for laboratory examination where appropriate.

The liver should be examined for changes in colour, size, shape and any external abnormalities then incised to check texture and consistency. The size of the gall bladder and the nature of its bile contents should also be noted. If indicated a slice of liver no thicker than 2cm should be submitter to the laboratory for histopathology while a portion should also be submitted for bacterial culture if a bacterial disease is suspected.

The urogenital system should be examined by checking size, shape and colour of the kidneys, noting the thickness of the capsule and any external abnormalities of the renal cortex. Kidneys should be incised in a sagittal plane checking for deposits or other abnormalities in the renal pelvis. Specimens for laboratory examination should be taken where appropriate. The second kidney, the ureters, bladder and urethra should also be examined.

The thoracic organs are removed intact by cutting the vessels at the base of the heart and then tying the proximal trachea and following it down through the thoracic inlet and removing the heart and lungs as one. The lungs are examined for shape, colour, consistency, inflation and elasticity, then the trachea opened down into the bronchi to check for evidence of pneumonia or other abnormalities. The heart and pericardium are examined intact then opened to check for abnormalities in the external myocardium. The heart is opened in the direction of blood flow from posterior vena cava to aorta with heart valves being closely examined.

The oral cavity including the teeth and tongue should be examined then the mandibular symphysis split and the tongue, pharynx and larynx removed through the mandibular space for closer examination. The endocrine glands particularly the thyroids on the lateral surface of the trachea and adrenals anterior to the kidneys should also be examined. The musculo-skeletal system should be examined by incising muscles and opening joints where indicated.

Examination of the brain is essential for the diagnosis of central nervous system diseases. In the course of the autopsy, the skin will have been removed from the head, face and upper neck. Sever the head from the neck at the atlanto-occipital joint after first obtaining cerebrospinal fluid from this site, should it be required.

A meat saw is used to remove the cranial cap. First cut transversely across the skull at the level of the orbit. Next two lateral cuts from about the level of the inside orbit caudally and outwards then across to the occipital condyle on each side. The cranial cap is levered upwards from the back of the occipital condyles and the meninges cut to expose the brain free of its enclosing membranes. Tilt the skull backwards and allow the brain to drop out gently after cutting the optic chiasma and other cranial nerves. For histopathology the brain is immersed in 10% buffered formalin ensuring that the volume of fixative is at least ten times the volume of tissue. Check the base of the cranium for abnormalities.

Returning to the gastrointestinal tract the omental fat is cut off the rumen and the abomasum. The stomachs and intestine can then be separated and tied with string in two places then examined individually. The rumen should be opened along its greater curvature and the internal lining examined for mucosal sloughing erosions, abscesses or such. The rumen contents should be checked particularly when a poisoning is suspected. The reticulum and omasum are then incised and their internal linings examined. The abomasum should be incised and the mucous membrane checked for oedema, inflammation or erosions suggestive of parasitism or other irritations. Where parasitism is specifically suspected the abomasum and intestines should be submitted unopened direct to the laboratory or contents saved for worm counts in the field.

The intestines should be examined and the nature of the contents noted. The intestines may be opened at various places to check for inflammation of the mucosa or take smears from the wall. For histopathology small sections, preferably 2cm cylinders, should be taken with the ends nicked to cause outward curling of the mucosa when it contracts in the formalin. Alternatively, intestines can be opened and spread out on a thin cardboard to prevent twisting and curling.

Special note should be made of the mesenteric lymph nodes to check for enlargement or oedema suggestive of an inflammatory reaction.

On completion of the autopsy, specimens for the laboratory should be labelled, equipment disinfected and washed and the operator scrubbed down. Finally make sure you record the postmortem findings immediately whilst still at the site. Micro-cassette tape recorders are useful for making notes and a more detailed postmortem report can be written later.

PRACTICAL SESSIONS - POSTMORTEM TECHNIQUES WITH SPECIAL REFERENCE TO SHEEP

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Introduction

There is nothing "mystical" about conducting a postmortem examination, however for it to be instructive and useful requires a methodical, orderly and consistent approach. With experience, a definitive autopsy can usually be completed in 10-15 minutes. It is an exercise in observation and deduction, which normally allows definitive conclusions to be drawn. Most tissues can only respond in a limited and consistent way to a host of deleterious stimuli. Recognition of the altered state often permits a reasonable estimate as to its cause. Confirmation may come from more sophisticated laboratory back-up, but a provisional diagnosis is at least possible from gross postmortem findings.

Postmortem Equipment

General equipment

Comparatively little specialist equipment is required. Suitable protective clothing, including disposal gloves should be worn, both for personal protection and to reduce the chance of disseminating infection to other properties. Soap and water, and disinfectant are required for personal clean-up afterwards.

A good quality butcher's knife is a pre-requisite. While size and shape may be a matter of personal preference, it is imperative that the knife be sharp. A steel and a small oil-stone are needed to keep it so. Become adept at their use. Disposable scalpels are useful for detailed dissection, as are a pair of medium-sized scissors and forceps. String is useful for tying off portions of intestines, etc. Horticultural pruning shears can be used as rib cutters. Footrot shears are suitable as bone forceps, as in removing spinal cords in lambs and young sheep, but do not supply sufficient mechanical advantage for the removal of spinal cords from the vertebral columns of adult sheep. A small hand-saw can be used to remove the brain from the cranium. Where a brain or spinal cord is required, the head or vertebral column can usually be taken to a site (such as a veterinary laboratory) where powered-tools are available to facilitate removal and examination.

Ancillary Equipment

Useful information can be obtained from urinalysis by multitest "dipstick" urine tests. Similarly, "dipstick" pH indicators are available to measure abomasal and rumenal pH. Material to be transported over some distance or during hot weather should be kept chilled, and requires

proper packaging. Assorted sized plastic bags are useful and their contents need to be well labelled. Where specimens could leak in transit, double-packaging is advisable. Special transport media for microbiology is often required; use of sterile swabs and containers for routine microbiological sampling reduces the risk of chance contamination of samples.

Tissues harvested for histopathology, should be promptly preserved. Ten per cent formol-saline is the routine fixative (preservative) of choice. Abomasum and intestinal tract can also be fixed in Bouin's fixative. While Bouin's solution acts quickly, it penetrates tissues poorly and so is unsuitable for solid tissues. Hollow-tubed viscera such as intestines should be partly incised lengthwise to allow adequate penetration of fixative to the inner surface. Tissue samples from solid organs such as liver, kidney and spleen should not exceed 1cm thickness or 3cm along any other edge, for proper fixation. Long, thin sections (<3mm) often curl up on fixing, and are difficult to process.

Remember the golden rule:

Ten Volumes Of Fixative Are Required To Preserve One Volume Of Tissue

Preliminary Examination

The aim of any field investigation is to provide clients with useful information on which they can act. Before commencing any autopsies it is always highly instructive to place the disease episode under review in its proper perspective.

You need to be aware of the specific circumstances surrounding the cause for the present investigation. Many times, "having asked the right questions", a provisional diagnosis can readily be established even before a detailed postmortem examination is begun. The axiom, "common things occur commonly", should always remain uppermost in one's mind. It is important to know which common diseases are present in any locality, and their seasonality.

Preliminary information required relates to number, age and type of sheep involved, duration of the problem, duration of the clinical course, whether there are any particular feeding or management practices peculiar to the affected sheep, and what recent treatment, if any, has been given. Information on routine Clostridial disease vaccination and anthelmintic control programs is important.

Dead and sick sheep should be examined critically before detailed postmortem examination to assess their physical condition, whether they died quietly or after struggling, whether there are any discharge present, and the rate/extent of postmortem decomposition. Clinical blindness, weakness, ataxia, jaundice, diarrhoea and respiratory distress can provide valuable clues as to the ultimate cause of losses. Elevated rectal temperature may indicate acute infection. If possible collect clotted and

unclotted blood samples (use EDTA anticoagulant for preference) from affected live sheep and unaffected flockmates. Follow-up clinical pathology at a diagnostic laboratory provides potentially valuable information on the circulatory system, general nutrition status, trace element-mineral or vitamin-abnormalities and, from enzyme or metabolite assays, the functional status of liver, kidney, musculo-skeletal system, etc.

Preliminary studies show that in many ways anterior chamber fluid from the eyes reflect serum values of some enzymes, metabolites and electrolytes. Postmortem blood coagulation and haemolysis rapidly invalidate many serum assays, however anterior chamber fluid values reflect antemortem blood values for some time (hours) after death, and can provide useful diagnostic information (unpublished data).

Guidelines for Dissecting Sheep

Conventionally, sheep are autopsied in left lateral recumbency (ie left side down). The rumen then lies underneath rather than over other abdominal viscera. In left lateral recumbency the spleen is however virtually inaccessible. For systemic virus infections, where uncontaminated splenic tissue may be of paramount importance for virology, it is best to ignore convention, and autopsy the sheep in right lateral recumbency!

The right handed operator faces the abdomen of the sheep when it is in left lateral recumbency. Reflect the upper front and hind leg, disarticulating the hind limb at the coxo-femoral joint. Reflect the skin on the right side of the body, and on both the right and left sides of the neck and face. Cut the right side abdominal muscles, following the line of the ribs, the lumbar muscles and continuing to the anterior midline attachment at the pubis of the pelvis. The muscle mass is hinged in the midline.

It can either be reflected or removed entirely. There is less likelihood of puncturing abdominal viscera if the abdominal muscles are removed in this way, rather than by commencing with a ventral midline incision.

The tongue, oesophagus and trachea are dissected and reflected to the thoracic inlet. Expose and examine the thyroids, attached to the proximal trachea. The right side of the diaphragm is cut away from the ribs. (That side of the lungs will deflate unless the trachea has been plugged or clamped). The right half of the rib cage is removed by cutting through the ribs at the costo-chondral junction near the sternum, and close to their insertion in the vertebral column. Horticultural pruning shears make good rib cutters for sheep. Check for pliability and fragility of the ribs. Bone quality here is reasonably representative of bone quality in the remainder of the skeleton. The symphysis of the mandibles is cut and the jaws retracted laterally to expose the molars and hard and soft palate. The head can now be disarticulated and severed at the

altanto-occipital joint before the brain is removed. Hock and knee joints at least should be inspected as well as any other grossly abnormal joints. Reflect the skin before opening the joint. Open the pericardial sac and check for excessive pericardial fluid.

At this stage, major dissection has been completed and most internal organs are accessible for detailed inspection. Before commencing this systematic examination, it is important to overview the visible organs in situ, noting any abnormality of size, shape, colour and position. Provided adequate care has been taken, any extraneous or excessive body fluids present can be related to an abnormality in the animal, rather than as a contribution from the operator.

It is a matter of judgement as to when specific tissues are harvested fro further processing, however tissues and fluids for microbiology should be collected as soon as practicable to minimise extraneous contamination.

The carcase is now systematically eviscerated. As they become available, hollow viscera should be opened to allow inspection of the inner surfaces. This applies particularly to trachea, bronchi, heart and major vessels, alimentary tract, bladder and reproductive organs.

The oesophagus is dissected free and the heart, lungs and trachea are removed and inspected. The abomasum is transected where it emerges from the reticulo-rumen and at the pyloric junction with the small intestine. The large intestine is transected at the rectum. The viscera should be transected between 2 ties or clamps to prevent spillage of gut contents. The abomasum is removed by careful traction and blunt dissection; the small and large intestines are removed in their entirety, by careful dissection from the liver and by cutting the roots of their mesenteries. The pancreas is embedded in the small intestinal mesentery.

The intestinal tract should be stripped from its mesentery. Abomasum and intestines can now be examined in detail and processed for a total worm count if desired (see separate section). The oesophagus and forestomachs can now be removed. The spleen normally remains attached to the lateral wall of the rumen.

Remaining internal organs can now be examined, including urinary bladder, kidneys, reproductive organs, adrenals and liver. Muscle masses of limbs and back should be incised and inspected.

While the above is not a detailed anatomical dissection guide it does provide a simple, systematic approach to autopsy of the sheep, with the technique generally applicable to non-avian domestic animals. (Conventionally, non-ruminants are autopsied in right lateral recumbency, rather than left lateral recumbency). Judging the normality of various organ systems is a matter of experience. Detailed descriptions of gross alterations associated with various disease states are recorded elsewhere in this publication.

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Index

B

C

D

E

F

G

H

I

J

K

L

M

N

O

P

Q

R

S

U

V

W

X

Y

Z

Follow Up Notes

Course: Date:

Flashes of light regarding cases at clinic or hospital:

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New equipment I should purchase:

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Page Ref

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Page Ref

Additional Notes:

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Page Ref

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Page Ref