Chapter 14

Biology and Diseases of Ruminants: Sheep, Goats, and Cattle

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I. INTRODUCTION

Since the first edition of this book, the use of ruminants as research subjects has changed dramatically. Formerly, large animals were primarily used for agricultural research or as models of human diseases. Over the past decade, ruminants have continued in their traditional agricultural research role but are now extensively used for studies in molecular biology, genetic engineering, and biotechnology for basic science, agricultural, and clinical applications. Concern and interest for the welfare for these species and improved understanding of their biology and behavior have continued during this time, and these are reflected in some respects in the changing husbandry and management. This chapter addresses the basic biology, husbandry, and more common and important diseases of three ruminant species—sheep, goats, and cattle—commonly used in the laboratory. One chapter is simply not adequate, however, to address

the many details and complexities of these species' biology, management, and diseases. References noted in the text offer more information to the interested reader.

A. Taxonomy

Sheep, goats, and cattle are ungulates, "hooved" animals that are members of the order Artiodactyla (even-toed ungulates, or animals with cloven hooves), suborder Ruminantia (ruminants, or cud-chewing animals) and family Bovidae. Members of the Bovidae group of mammals are distinguished by characteristics such as an even number of toes, a compartmentalized forestomach, and horns. These animals are obligate herbivores and, as adults, derive all their glucose from gluconeogenesis. The subfamily Caprinae includes sheep and goats. The genus and subgenus *Ovis* includes domestic sheep as well as wild Asian and European sheep species. Domestic sheep are *Ovis aries.* The subgenus *Pachyceros* includes the wild North American species as well as snow sheep (*O. nivicola*) of northeastern Siberia. *Capra hircus* is the domestic goat that originated from western Asian goats. *Capra pyrenaica* (Spanish goat), *C. ibex* (goats of the Red Sea and Caucasus area), and *C. falconiere* (wild goat of Afghanistan and Pakistan) are other members of the genus. The subfamily Bovinae and genus *Bos* include all domestic and wild cattle. The subgenus *taurus* contains all of today's domestic cattle. Common genus and species terminology for modern-day cattle includes *Bos taurus* and *B. indicus. Bos taurus* (domestic cattle), originally from the European continent, have no hump over the withers. *Bos indicus,* also known as Zebu cattle, have a hump over the withers and drooping ears. These cattle include breeds found in the tropics and are extremely heat tolerant, and some breeds are known for parasite resistance. *Bos taurus* and *B. indicus* have been crossed, and new breeds have been developed during this century (Briggs and Briggs, 1980; Walker *et al.,* 1983).

There are several hundred breeds of sheep worldwide that are distinguished as "meat," "wool" or "hair," or "dual-purpose." Some wool or hair breeds have varying coat colors. Some breeds are raised for milk (cheese) production. Common breeds of European origin that are raised for meat in the United States include the larger breeds such as Dorset, Columbia, Suffolk, and Hampshire. Slightly smaller breeds include Southdown and Border Cheviot. Wool breeds include Merino, Rambouillet, Lincoln, and Romney; wool breeds are subclassified according to the properties of the wool. The Barbados is known as a "hair" breed. Newer breeds that have been developed in the United States include Polypay and Targhee (Briggs and Briggs, 1980).

Goat breeds are numerous and are usually classified according to use as dairy, meat, fiber, or skin-type breeds. The major dairy breeds are the Alpine, Nubian, Toggenburg, La Mancha, Saanen, and Oberhaslie; all have origins on the European continent. The Nubian breed was developed from crossbreeding

British stock with Egyptian and Indian goats. This breed is relatively heat tolerant and produces milk with the highest butterfat (about 4–5%). Fiber breeds include the Angora and the Cashmere. The Angora, the source of mohair, originated in Turkey. The Cashmere breed is found primarily in mountainous areas of Central Asia. The La Mancha, a newer breed of dairy goat first registered in the United States in 1958, has rudimentary ears that are a genetically dominant distinguishing characteristic of the breed. The meat breeds include the Boer, Sapel, Ma Tou, Kambling, and Pygmy. The Pygmy goat is small and is sometimes used for both meat and milk. The Mubend of Uganda and the Red Sokoto of West Africa produce quality skins for fine leather (Smith and Sherman, 1994).

Most breeds of cattle are classified as "dairy" or "beef"; a few breeds are considered "dual-purpose." Common dairy breeds in the United States include Holstein–Friesian, Brown Swiss, Jersey, Ayrshire, Guernsey, and Milking Shorthorn. Holsteins have the largest body size, whereas Jerseys have the smallest. Of breeds in temperate regions, Jerseys have been considered to be the most heat tolerant, but Holsteins have been found to adapt to warmer climates. There are many beef breeds. The more common in the United States include Angus (also called Aberdeen-Angus), Hereford (both polled and horned), and Simmental (Briggs and Briggs, 1980; Schmidt *et al.,* 1988). Breeds indigenous to other continents, such as the Cape Buffalo, have been found to have unique innate immune characteristics that protect them from endemic trypanosomiasis (Muranjan *et al.,* 1997).

More detailed information regarding these and other ruminant breeds is available in Briggs and Briggs (1980). "Rare" or "minor" breeds of sheep, goats, and cattle are studied for their genetic and production characteristics. Discussions of these and efforts at conservation are described in detail elsewhere (National Research Council, 1993).

Several terms are unique to ruminants. In relation to sheep, a ewe is the female, and a ram is the adult intact male. A lamb is the young animal, and *ram lamb* and *ewe lamb* are commonly used terms. A wether is a castrated male. The birthing process is referred to as *lambing.* With respect to goats, a doe or nanny is the female. A buck or billy is the adult intact male. A kid or goatling is a young goat. A young male may be referred to as a buckling, and a young female may be referred to as a doeling. A castrated male in this species is also called a wether. The birthing process is called kidding. With respect to cattle, an adult female is a cow, and an adult male is a bull. A calf is a young animal. A heifer is a female who has not had her first calf. A steer is a castrated male. *Calving* refers to the act of giving birth.

B. Comments about and Examples of Use in Research

Ruminants have been used as research models since the inception of the land grant college system, first in production

agriculture and now also in basic and applied studies for the anatomic and physiologic sciences and in biomedical research for a variety of purposes. Healthy, normal young ruminants serve as models of cardiac transplantation and as preclinical models for evaluation of cardiac assist or prosthetic devices, such as vascular stents and cardiac valves (Salerno *et al.*, 1998). For many years, ruminants have been useful research subjects for reproductive research, such as research on embryo transfer, artificial insemination, and control of the reproductive cycle (Wall *et al.*, 1997). Several important milestones in gene transfer, cloning, nuclear transfer, and genetic engineering techniques have been developed or demonstrated using these species (Ebert *et al.*, 1994; Schnieke, 1997; Cibelli *et al.*, 1998a,b) (see Fig. 1). One of many proposed uses of genetically engineered ruminants is the production of proteins that will be secreted in the milk and later isolated (Ebert *et al.*, 1994; Memon and Ebert, 1992). Healthy sheep and goats are also often used for antibody production (Hanly *et al.*, 1995). Genome mapping developed rapidly during the 1990s; extensive information is available and is increasing for sheep and cattle (Broad *et al.*, 1998; Womack, 1998).

Sheep are often selected for studying areas such as ruminant physiology and nutrition. These animals provide obvious bene-

fits over the use of cattle in research from the standpoint of size, ease of handling, cost of maintenance, and docile behavior. Sheep are also widely used models for basic and applied fetal and reproductive research (Buttar, 1997; Rees *et al.*, 1998; Ross and Nijland, 1998). The species is used for investigating circadian rhythms related to day length (Lehman *et al.*, 1997), and the interaction between olfactory cues and behavior (Kendrick *et al.*, 1997). The number and diversity of natural- and induced-disease research models in sheep are great and increasing. Natural models include congenital hyperbilirubinemia/hepatic organic anion excretory defect (Dubin–Johnson syndrome) in the Corriedale breed, congenital hyperbilirubinemia/hepatic organic anion uptake defect (Gilbert syndrome) in the Southdown breed, glucose-6-phosphate dehydrogenase deficiency in the Dorset breed, GM_1 gangliosidosis in the Suffolk breed, and pulmonary adenomatosis (jaagsiekte) in many breeds (Hegreberg, 1981a). Induced models include arteriosclerosis, hemorrhagic shock, copper poisoning (Wilson's disease), and metabolic toxocosis (Hegreberg, 1981b).

Goats are used in a wide variety of agricultural and biomedical disciplines such as immunology, mastitis, nutrition, and parasitology research. Vascular researchers select the goat because of the large, readily accessible jugular veins. Goats with

Fig. 1. The production of cloned cattle reflects the changing use of ruminants in research.

inherited caprine myotonia congenita ("fainting goats") have been used as a model for human myotonia congenita (Thomsen's disease) (Kuhn, 1993). A line of inbred Nubians serves as models for the genetic disease β-mannosidosis and prenatal therapeutic cell transplantation strategies (Lovell et al., 1997). (These disorders are discussed in more detail in Section III,B,1.) Goats are used as a model for osteoporosis research (Welch et al., 1996).

Cattle are often used as a source of ruminal fluid for research, teaching, or treatment of other cattle, by placing a permanent fistula in the left abdominal wall to allow sampling of ruminal fluid (Dougherty, 1981). Cattle also serve as models of many infectious diseases, including zoonoses, and several inherited metabolic diseases. This species is useful for the basic and comparative research on the pathogenesis and immunology of inherited and infectious diseases. Bovine trichomoniasis, caused by Tritrichomonas (Trichomonas) fetus, has been identified as a useful model for the human infection by Trichomonas vaginalis (Corbeil, 1995). Inherited cardiomyopathies have been found in the Holstein–Friesian, Simmental–Red Holstein, Black Spotted Friesian, and Polled Hereford with woolly coat (Weil et al., 1997). Lipofuscinosis has been identified in Ayrshires and Friesians, and glycogenesis in Shorthorns and Brahmans. Metabolic diseases such as hereditary orotic aciduria and hereditary zinc deficiency have been characterized in Holstein–Friesian or Friesian cattle. Holstein cattle also serve as a model for leukocyte adhesion deficiency syndrome (AFIP, 1995).

C. Availability and Sources

Common breeds of normal, healthy ruminants are usually readily available, although seasonality may play a role, as noted below. Agricultural sources and reputable farms may be located through land-grant universities or agricultural schools, cooperative extension and 4-H networks, regional ruminant breeders' associations, and farm bureaus. Commercial sources of purpose-bred animals are found in technical publications and annual listings of research animal vendors. Breeds carrying genetic traits of interest, either as animal models or as valuable production characteristics, may be located through literature or Internet searches, animal science societies, breed or livestock conservation associations, and information resources such as the Armed Forces Institute of Pathology. Organizations such as the Institute for Laboratory Animal Research (ILAR), National Center for Research Resources (NCRR), or the Animal Welfare Information Center (AWIC) may also serve as information sources about the animals needed.

Purpose-bred research sheep and goats are available from commercial vendors and are usually maintained in registered facilities under federal standards that are also acceptable to research animal accrediting agencies. These commercial animals are frequently described as specific pathogen–free (SPF) and

housed as biosecure or closed flocks. Animal health programs are in place, and health reports or other quality assurance reports are usually available on request. Agricultural sources of either small ruminant may be acceptable, but specific research needs may not have been addressed or may not be understood. Lambs, kids, and milking goats may be difficult to locate in fall and winter months because most breeds of sheep and goats are seasonal breeders. Management practices exist, however, to extend the breeding and milking seasons.

Most cattle used as animal models in research in the United States are from one of the dairy breeds, usually Holstein, because this breed is now the most common. Purpose-bred, specific pathogen–free research cattle are not typically available. Because of selection and the management of dairy production units, calves and young stock are available year-round. Availability of young beef cattle is more seasonal, according to production cycles typically followed by that industry.

Auction barns or sales are not appropriate sources for research ruminants. Many of these animals are culls and will be poor-quality research subjects. They may be in poor body condition and stressed, may be sources of disease, and may contaminate other healthy animals, as well as the research facility.

Selection of the suppliers should be made only after research needs have been carefully considered. Consistently working with and buying directly from as few sources as possible are best. Certain types of research (i.e., agricultural nutrition studies) may better be served by selecting animals from local agricultural suppliers rather than commercial vendors located in a different geographical area.

The selection of sources for research ruminants includes scrutiny of flock or herd record keeping; health monitoring, vaccination, and preventive medicine programs (including hoof care); production standards and management practices consistent with the industry; management of the breeding flock or herd; sanitation and waste handling programs; vermin and insect control measures (especially for flies and other flying insects); rearing programs for and condition of young stock; the location, health, and condition of the other animals on the premises; intensity of housing; and animal housing facilities.

Preliminary and periodic visits to the source farms should be conducted. It is important to establish a good relationship with the local attending large-animal veterinarians, who will be valuable resources for current approved therapies and practices. They may need to be oriented on the specific requirements of animal research. Creative ways can be used to initiate and foster a good working relationship between the agricultural supplier and the research facility. Supplying the vaccines or dewormers required for flock health programs, providing services such as quarterly serological testing or fecal examinations for the herd or flock, and paying a premium (rather than market price) for animals that meet the quality criteria established for the research animals are often helpful.

A set of testing standards can be developed based on one

high-quality supplier, and then flocks or herds can be "qualified" based on those standards. Qualifying entails evaluations utilizing the facility and management aspects mentioned above and testing either a percentage of the herd or flock or the entire herd or flock for a number of infectious agents. The testing regimen itself should be carefully developed and evaluated.

Once qualified, each source farm should be reevaluated periodically to maintain its status. Slaughter checks may be appropriate; otherwise necropsy of sentinel animals may be required. Selected animals undergoing screening tests should be quarantined from the rest of flock or herd while awaiting test results. Vaccination and deworming regimens can be instituted during these quarantine periods. A second quarantine should occur when animals arrive at the research facility. The animal screening process also depends on the origin of the animal (state, country) and the scientific program. Federal and state regulations must be followed.

Socialization of the animals at the source facility should also be considered in terms of ease of handling and safety for personnel in the confinement of the research lab, barn, or farm. For example, frequently handled calves will be easier to manage, and adult dairy goats that have been acclimated to human contact are preferable.

Several texts provide information on industry standards for flock and herd management and preventive medicine strategies that can provide helpful orientation to those unfamiliar with these aspects. These references also provide information regarding vaccination products licensed for use in ruminants and typical herd and flock vaccination parasite control schedules ("Current Veterinary Therapy," 1986, 1993, 1999; "Council report," 1994; "Large Animal Internal Medicine," 1996; Smith and Sherman, 1994)

When designing a vaccination program during qualification of a source or at the research facility, it is important to evaluate the local disease incidence and the potential for exposure. Vaccination programs should be conducted with an awareness of duration of passive immunity and stresses in ruminants' lives (e.g., weaning, grouping, management changes, and shipping) that may impair immunity or increase susceptibility to infectious diseases. It is also prudent to evaluate the cost-effectiveness of vaccination; labor and vaccine expenses may be much higher than the potential animal morbidity or mortality for diseases in a particular locality. Not all of the vaccines mentioned subsequently will be necessary in all herds or flocks. Vaccination needs for research animals will also depend on the local disease history, intent of the research, the age of the animals needed for research, and the length of time the animals will be housed.

Typical health screening programs for sheep include Q fever (*Coxiella burnetii*); contagious ecthyma; caseous lymphadenitis (*Corynebacterium pseudotuberculosis*); Johne's disease (*Mycobacterium paratuberculosis*); ovine progressive pneumonia; internal parasitism such as nasal bots, lungworms, and intes-

tinal worms; and external parasitism such as sheep keds. Each supplier should be queried about vaccination programs for bluetongue, *Brucella ovis*, *Campylobacter* spp., *Chlamydia* (*enzootic abortion of ewes*), clostridial diseases, pneumonia complex (parainfluenza 3, *Pasteurella haemolytica*, and *P. multocida*), ovine ecthyma, rabies, *Dichelobacter (Bacteroides) nodosus*, *Arcanobacterium pseudotuberculosis*, *Bacillus anthracis*, and *Fusobacterium necrophorum*. Because of the limited number of biologics approved for small ruminants, products licensed for cattle have been used with success in sheep, and some licensed for sheep are used in goats ("Council report," JAVMA, 1994). In some cases, approved feed additives, such as coccidiostats, are fed to sheep.

The basic screening profile for goats should include Q fever (*Coxiella burnettii*), caprine arthritis encephalitis (CAE), brucellosis, tuberculosis, and Johne's disease (*Mycobacterium paratuberculosis*). Goats may also be tested for caseous lymphadenitis, contagious ecthyma, or *Mycoplasma* as needed. Herd vaccination programs may include immunizations against tetanus and other clostridial diseases, *Chlamydia*, *Campylobacter*, contagious ecthyma, caseous lymphadenitis, *Corynebacterium pseudotuberculosis*, and *Escherichia coli*.

Cattle herds should be screened for Johne's disease, brucellosis, tuberculosis, respiratory diseases, internal and external parasitism, and foot conditions such as hairy heel warts and foot rot. Determination of the status of the herd with respect to bovine leukemia virus (BLV) may be worthwhile. Herd programs may include essential or highly recommended vaccines against bovine viral diarrhea virus (BVDV), infectious bovine rhinotracheitis virus (IBRV), bovine respiratory syncytial virus (BRSV), parainfluenza 3 (PI-3), *Leptospira pomona*, *Tritrichomonas fetus*, rotavirus, coronavirus, *Campylobacter (Vibrio)*, *Pasteurella haemolytica* and *P. multocida*, and *Brucella abortus*. Other vaccination programs, dependent on herd status, endemic diseases, or geographic location, may include immunizations against the Clostridial diseases, *Moraxella bovis* (pinkeye), *Fusobacterium necrophorum* (foot rot), *Staphylococcus aureus* (mastitis), *Haemophilus somnus*, rabies, tetanus, *Bacillus anthracis*, enterotoxigenic *E. coli*, *Anaplasma*, and other *Leptospira* species. Some products considered to have limited efficacy include vaccines against *Salmonella dublin* and *S. typhimurium*. Some autogenous vaccines may be more effective than the commercially available products—for example, the bovine papillomavirus (warts) vaccines.

Rearing programs for dairy calves differ from those for the smaller ruminants, including the withdrawal of calves from their dams immediately or by 24 hours after birth. In the cattle industry, antibiotics, ionophores (antibiotics that control selected populations of ruminal organisms), coccidiostats, probiotics, and other approved additives may be part of the milk replacers, grain and concentrate formulations, and/or creep feeding regimens. Use varies by the segment of the industry, and regulations vary by country. Subcutaneous hormonal

implants (such as estradiol benzoate and progesterone combined, zeranol, or 17β-estradiol) are administered, especially to beef calves destined for market rather than breeding, to promote growth.

Transportation of the animals from the source to the research facility must be carefully planned, and all applicable livestock travel regulations followed. It is best to have the animals transported in vehicles regularly utilized by the source farm. If commercial haulers are used, then disinfecting trucks, trailers, and associated equipment, such as ramps and chutes, beforehand is particularly important. The loading, footing, and distribution of the animals in the trailers and trucks, as well as environmental conditions during shipping, are important to consider to minimize stress and injury to the animals. Sufficient time for acclimation to the facility, pens, handlers, feed, and water must be allowed once at the destination ("Livestock Handling and Transport," 1998).

D. Laboratory Management and Husbandry

Recent publications address many general considerations as well as specifics about the facilities, husbandry, space requirements, and standard practices for research and production ruminants. Institutions, private entities, researchers, and facility staff must also be aware of the recent adoption by the U.S. Department of Agriculture (USDA) of specific guidelines for regulation of farm animals, such as ruminants, that are used in biomedical and other nonagricultural research. The USDA Animal Care Policy 29 notes that the "Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching" and the "Guide for the Care and Use of Laboratory Animals" provide additional information to supplement the existing Animal Welfare Act regulations (CFR, 1985; FASS, 1999; Hays et al., 1998; NRC, 1996a; USDA, 2000).

In all cases, stress should be considered and minimized in the husbandry and handling of ruminants. Animals need to be provided adequate time to adapt to new surroundings. Stress decreases feed intake, and the resulting energy, vitamin, and mineral deficiencies will affect the growth and development in younger animals. Reproductive soundness and rumen function are affected by transport and similar stresses. Standard practices such as weaning, castration, dehorning, vaccinations, deworming and treatments for external parasites, shipping and the associated feed and water deprivation, introduction to a new housing environment and new personnel, and intercurrent disease are all stressors (Houpt, 1998). Animals should be acclimated to the use of halters and leads, temporary restraint devices, and other handling equipment associated with the research program. Personnel in the research facility who are unfamiliar with ruminants should be trained in appropriate handling techniques. Ap-

preciation for ruminant behaviors has grown in recent years, and refined ruminant handling techniques have been published (Houpt, 1998; Grandin, 1998).

When ruminants are confinement-housed, care should be taken to provide adequate but draft-free ventilation. Ammonia buildup and other waste gases may induce respiratory problems. In cold weather, if the ceiling, walls, or water pipes condense water, then the ventilation should be increased even at the expense of lower temperatures. Even adult goats and younger cattle are quite comfortable in cold, even subfreezing temperatures, if provided with adequate amounts of dry dust-free bedding and draft protection. Sheep, because of their wool, are remarkably tolerant to both hot and cold extremes. Newborn lambs and recently shorn adults are susceptible to hypothermia, hyperthermia, and sunburn. Therefore, in outside housing areas, sheep should be provided with shelters to minimize exposure to sun and inclement weather.

Animals housed under intensive confinement should be kept clean, and excreta should be removed from the pens or enclosures daily. Feed and water equipment should be maintained in sound, clean condition and should be constructed to prevent fecal contamination. Waterers should not create a muddy environment in paddocks or pens. There should be sufficient continuous-access waterers placed around the area to prevent competition or fighting. Feeders should be constructed to conform to species size and feeding characteristics and to prevent entrapment of head and limbs. Pens, other enclosures, passageways, chutes, and floors must be very sturdy to withstand such factors as the frequent cleaning; the strength, weight, and curiosity of all ages of animals; and the investigative and climbing behaviors of goats. Chain-link fences are dangerous because goats (as well as some breeds and ages of sheep) are curious and tend to stand on their hind legs against fencing or walls. Forelimbs may be caught easily in the mesh. Floors in any areas where animals will be housed, led, or herded must ensure secure footing at all times to prevent slipping injuries. All ruminants are social and herding animals. Therefore, they should be housed in groups or at least within eyesight and hearing of other animals. Singly housed animals should have regular human contact. Environmental enrichment should be governed by the experimental protocol or standard operating procedures, and durable play objects should be supplied to those animals that are housed in confinement. Calves, in particular, that must be singly housed or that have been recently weaned, need play objects (Morrow-Tesch, 1997).

Because sheep and goats are sensitive to changes in light cycle (especially reproductive parameters), photoperiod must be taken into account. Normally, sheep and goats should be maintained on a cycle comparable to natural conditions. Light intensity should be maintained at about 220 lux (ILAR, 1996; FASS, 1999). Light cycles can be manipulated for experimental reasons.

II. BIOLOGY

A. Unique Physiological Characteristics and Attributes, with Emphasis on Comparative Physiology

The development of the digestive system and the unique function of the rumen are among the most notable comparative anatomic and physiologic characteristics of ruminants. There is a three-compartment forestomach (rumen, reticulum, and omasum) and a true stomach (abomasum). The mature rumen functions as an anaerobic fermentation chamber in which the enzymes, such as cellulase, of the resident bacteria allow the animals to prosper as herbivores. Digestion is also aided by other microorganisms, such as protozoa (10^5-10^6/ml) and bacteria (10^9-10^{10}/ml), that contribute to rumen fermentation. The result is the production of volatile fatty acids (acetic, propionic, and butyric). Unlike in the monogastrics, fermentative digestion and volatile fatty acid absorption also occur in the large intestines. The main sources of energy for ruminants are volatile fatty acids (VFAs) rather than glucose. Glucose is formed from propionic acid (or from amino acids) for metabolism in the central nervous system (CNS), uterus, and mammary glands. Plasma glucose in ruminants is much lower than and is regulated differently from that in nonruminants. The rumen microorganisms also synthesize vitamins, such as B and K, and provide protein that is used by the animals' systems. Large amounts of fermentation gases such as CO_2 and methane, and small amounts of nitrogen, are naturally eructed (Hecker, 1983; Schimdt et al., 1988).

Intestinal immunoglobulin absorption by pinocytosis in the neonates is crucial to the success of passive transfer. This transfer mechanism is functional for approximately the first 36 hr after birth. Neonatal ruminants are immunocompetent, however, and this condition is used to advantage for vaccinations against some common diseases of the neonatal and later juvenile periods, such as infectious bovine rhinotracheitis (IBR) vaccine (using modified live virus vaccines) to calves when their dams' colostrum is lacking antibody against this virus.

Unlike hepatic lipogenesis in humans, lipogenesis in sheep primarily occurs in adipose tissue and the mammary gland (Hecker, 1983). In addition to normal lymph node chains, and as in other ruminants, sheep have small red "nodes" associated with blood vessels. Inadvertently named hemal "lymph nodes," they contain numerous red blood cells. Sheep have a relatively large pituitary gland, and accessory adrenal medullary tissue may be interspersed throughout the abdominal cavity.

Three major ovine histocompatability classes have been identified and designated as OVAR (*Ovis aries*) classes I, II, and III (Franz-Werner et al., 1996). Bovines are recognized as having several unique aspects involving their immune systems. The bovine lymphocyte antigen (BoLA) system ranks after the hu-

man (HLA) and murine (H-2) systems in terms of depth of knowledge (Lewin, 1996). Cattle are considered free of autoimmune diseases (Schook and Lamont, 1996).

The complexity of the immunobiology of the bovine mammary gland is being studied extensively because mastitis is the most prevalent disease in the dairy industry. Several innate immune mechanisms and cellular defenses, and their variation throughout lactation, have been described (Sordillo et al., 1997).

B. Normal Values: Growth, Longevity, Hematology, Clinical Chemistry

Hematology and clinical reference texts are available for the ruminant species and include overviews of normal values for age, sex, and breed-specific ranges, as well as discussions regarding the influences on the hemogram of many management, nutritional, geographic, metabolic, physiologic (including lactation), medication, and iatrogenic variables (Duncan and Prasse, 1986; Jain, 1986; Kaneko et al., 1997). These references should be consulted when preparing to include blood collection data in research protocols and when reviewing hematologic findings. In addition, most veterinary diagnostic laboratories have also developed databases for normal ranges for hematologic and clinical chemistry values based on subjects from their service areas, and these may be useful as local and breed references. Appropriate control groups must be incorporated into each research plan, however, to establish the normal values (see Table I) for the particular locale, diagnostic facilities, breed, age, sex, and research circumstances. Normal hematologic and clinical biochemistry data are presented in Tables II and III.

Some general statements apply to most ruminants. Most ruminants have fewer neutrophils than lymphocytes. The blood urea nitrogen (BUN) values cannot be used as an indicator of renal function because of the metabolism of urea nitrogen by rumen microflora. Because of the large volume of rumen water, ruminants can generally go several days without drinking before significant dehydration occurs. Erythrocytes may become more fragile during rehydration, resulting in some degree of hemolysis and hemoglobinuria. Severe dehydration can occur quickly, however, in animals that are ill. Urine pH is generally alkaline in adult ruminants.

Ruminant erythrocytes are smaller than those in other mammals, and hematocrits tend to be overestimated unless blood samples are centrifuged for longer amounts of time for packing of the cell pellet. Increased red-cell fragility is also associated with the smaller erythrocyte. Rouleau formation does not occur in cattle but does to a limited extent in sheep and goats. In addition to fetal hemoglobin, sheep are reported to have at least six different hemoglobins (Hecker, 1983). Blood coagulation in sheep is similar to that in humans.

Table 1

Normal Values for Sheep, Goats, and Cattle:
Vital Signs, Life Spans, and Weights[a]

Parameter and age	Sheep	Goats	Cattle
Chromosome number	54	60	60
Body temperature (° C)			
Young	39.5–40.5	39–40.5	39–40.5
Adult	39–40	38.5–39.5	38–39
Heart rate (beats/min)			
Young	140 (120–160)	140 (120–160)	120 (100–140)
Adult	75 (60–120)	85 (70–110)	60 (40–80)
Respiration rate (breaths/min)			
Young	50 (30–70)	50 (40–65)	48 (30–60)
Adult	36 (12–72)	28 (15–40)	24 (12–36)
Life span (years)	10–15	8–12	20–25
Body weights (lb)			
Birth	3–25		
1 month		25	
3 months		55	400
6 months	110	85	
9 months		110	
12 months		130	720
18 months		155	
24 months	300 (ram), 200 (ewe)	170	1100
36 months		205	
Deciduous dental formula	2(Di 0/3, Dc 0/1, Dp 3/3) = 20	2(Di 0/3, Dc 0/1, Dp 3/3) = 20	2(Di 0/3, Dc 0/1, Dp 3/3) = 20
Permanent dental formula	2(I 0/3, C 0/1, M 3/3) = 32	2(I 0/3, C 0/1, M 3/3) = 32	2(I 0/3, C 0/1, M 3/3) = 32

[a]Vital sign data for goats are from "Large Animal Internal Medicine" (1996). Sheep weight data represent weights of feeder lamb and adult dry ewe (Federation of Animal Science Societies [FASS], 1998). Goat weight data are for a large-breed male goat. Cattle weight data represent weights of female Holstein or Guernsey dairy cattle (FASS, 1998). Life span data for sheep and cattle are from Brooks *et al.* (1984).

Erythrocytes in Pygmy and Toggenburg goats tend to be more fragile than erythrocytes from other goat breeds. Normal caprine erythrocytes lack central pallor because they are flat and lack biconcavity. Normal caprine erythrocytes may exhibit poikilocytosis. At least five blood groups have been reported in goats: B, C, M, R-O, and X. Because transfusion reaction rates may be as high as 2–3%, cross-matching is advisable although not always practical (Smith and Sherman, 1994). Blood loss of up to 25% of the red cell mass at a single time point can be tolerated by healthy goats. Blood may safely be obtained in volumes of 10 ml/kg body weight and given in volumes of 10–20 ml/kg. In general, aspartate aminotransferase (AST) and lactate dehydrogenase (LDH) are not liver-specific in goats, and alanine aminotransferase (ALT; formally serum glutamic-pyruvic transaminase, or SGPT) cannot be used to evaluate hepatic disease in goats. γ-Glutamyltransferase (GGT) and alkaline phosphatase (AP) are associated with biliary stasis, and elevations in GGT are generally associated with hepatic damage.

C. Nutrition

The nutritional needs of ruminants vary considerably according to the species, breed type, different phases of development, the use of the animals, location, and different stresses in their lives. For example, mineral requirements and other nutritional requirements vary even among breeds of cattle. Several references are available that describe the varying requirements and are useful for determining the requirements of ruminants consistent with the parameters noted above and the type of feeds available (Jurgens, 1988; "Large Animal Clinical Nutrition," 1991; NRC, 1981, 1989, 1993, 1996b; "Large Animal Internal Medicine," 1996).

Preformulated commercial feeds, concentrates, and supplements are available specifically for the different species of ruminants. Some of these provide complete energy and protein requirements or may be used as supplements for what cannot be provided entirely by pasture, forage, hay, or silage. Concentrate mixtures contain salt, minerals, and other elements. Concentrates should contain a protein source such as soybean meal, cottonseed meal, or linseed meal. Computer programs are also

Table II

Normal Values for Sheep, Goats, and Cattle: Hematology

Parameter (units)	Sheep	Goats	Cattle
Packed cell volume (%)	27–45	22–38	24–46
Hemoglobin (g/dl)	9–15	8–12	8–15
Red blood cells (RBC) ($\times 10^6/\mu l$)	9–15	8–18	5–10
White blood cells (WBC) ($\times 10^3$)	4–12	4–13	4–12
Total protein (g/dl)	6.0–7.5	6–7.5	7–8.5
Mean corpuscular volume (fL)	28–40	16–25	40–60
Mean corpuscular hemoglobin (pg)	8–12	5.2–8	11–17
Mean corpuscular hemoglobin concentration (g/dl)	31–34	30–36	30–36
Reticulocytes (%)	0	0	0
RBC diameter (μm)	3.2–6	2.5–3.9	4.8
RBC life (days)	140–150	125	160
Myeloid: Erythroid ratio	0.77–1.68:10	0.69:10	0.31–1.85:10
Platelets ($\times 10^3/\mu l$)	250–750	300–600	100–800
Fibrinogen (mg/dl)	100–500	100–400	300–700
WBC differential: absolute count/μl (% of total)			
Stabs, bands	Rare	Rare	0–250 (0–2)
Segmented neutrophils	400–6000 (10–50)	1200–6250 (30–48)	600–5400 (15–45)
Lymphocytes	1600–9000 (40–75)	2000–9100 (50–70)	1800–9000 (45–75)
Monocytes	0–750 (0–6)	0–550 (0–4)	80–850 (2–7)
Eosinophils	0–1200 (0–10)	50–1050 (1–8)	80–2400 (2–20)
Basophils	0–350 (0–3)	0–150 (0–1)	0–250 (0–2)
Coagulation tests (sec)			
Prothrombin time	13.5–15.9	9.0–14.0	6.8–8.4
Partial thromboplastin time	27.9–40.7		11.0–17.4
Thrombin time	4.8–8.0	20.9–33.4	4.3–7.1

readily available for those who may need to formulate and balance rations. The palatability of feeds should be taken into account. Mineral deficiencies and supplementation have been shown to influence several physiologic parameters such as immune function. Introduction of young stock should include continuation of the feeding program of the source or gradual transition to appropriate feed for the animals available in the region of the research facility (NRC, 1996).

Good-quality pasture can support ruminants under certain circumstances. Lush spring pastures, especially pastures containing alfalfa, can induce bloat, diarrhea, grass tetany, or nitrate poisoning. Ruminants not acclimated to lush pasture should be fed good-quality hay and slowly introduced to pasture environments.

When ruminants have access to pasture, it is important to be aware of different eating habits. Sheep and cattle are grazers. Goats are browsers and will readily eat grasses, as well as seeds, nuts, fruit, and woody-stemmed plants. Goats, however, can also be selective eaters and will only eat the leafy, more nutritious parts of the plant. Therefore, goats have a tendency to "waste" hay. Other eating habits should also be considered. Finely ground concentrates are not tolerated well by goats; pelleted concentrates are preferred because the goat will pick out large particles in mixes. Generally, goats do not prefer "sweet" feeds that contain molasses and do not need supplemental concentrates if a good-quality pasture or hay is fed. When given access to a salt block, goats generally are self-regulating. Grass-fed goats and lactating goats may need supplementation with calcium and phosphorus, whereas alfalfa-fed goats do not (Bretzlaff et al., 1991). Horse and sheep feeds may be fed to goats provided that the feed does not contain much molasses (Bretzlaff et al., 1991). The copper content of horse feed is not excessive for goats, as it is for sheep. Pelleted horse feeds with 25–28% fiber and 12–14% protein are good goat rations. Goats will consume 5–8% of body weight in dry-matter intake (whereas cattle will usually consume only 4% of body weight). Goats enjoy human contact, and small alfalfa cubes make tasty treats for the goat.

Rations that have excessive calcium–phosphorus ratios or elevated magnesium levels may induce urinary calculi in male ruminants. These may also occur when forage grasses are high in silicates and oxalates.

To increase ovulation rate in does, some producers "flush" females by feeding 0.5–1 lb concentrate per head per day for several weeks before and after the initiation of the breeding season. Thin pregnant dairy goats should be fed 1 lb concentrate per

Table III

Normal Values for Sheep, Goats, and Cattle: Clinical Biochemistry[a]

Parameter (units)	Source	Sheep	Goat	Cattle
Alanine aminotransferase (ALT, SGPT; U/liter)	s, hp	30 ± 4	6–19	11–40 (27 ± 14)
Albumin (g/liter)		24–3.0 (27 ± 1.9)	27.0–39.0 (33.0 ± 3.3)	30.3–35.5 (32.9 ± 1.3)
Alkaline phosphatase (AP; U/liter)		68–387 (178 ± 102)	93–387 (219 ± 76)	0–488 (194 ± 126)
Aspartate aminotransferase (AST, SGOT; U/liter)	s, hp	60–280 (307 ± 43)	167–513	78–132 (105 ± 27)
Bicarbonate (HCO$_3$; mmol/liter)		20–25		17–29
Bilirubin				
Conjugated (mg/dl)	s, p, hp	0–0.27 (0.12)		0.04–0.44 (0.18)
Unconjugated (mg/dl)		0–0.12		0.03
Total (mg/dl)		0.1–0.5 (0.23 ± 0.01)	0.01	0.01–0.5 (0.2)
Blood urea nitrogen (BUN; mg/dl)	s, p, hp	8–20	10–20 (15 ± 2.0)	20–30
Calcium, total (mg/dl)	s, hp	11.5–12.8	8.9–11.7	9.7–12.4
Carbon dioxide, total (mmol/L)	s, hp	21–28 (26.2)	25.6–29.6 (27.4 ± 1.4)	21.2–32.2 (26.5)
Chloride (Cl; mmol/liter)	s, hp	95–103	99–110.3 (105.1 ± 2.9)	97–111 (104)
Creatine kinase (CK) U/liter	s, hp	8.1–12.9 (10.3 ± 1.6)	0.8–8.9 (4.5 ± 2.8)	4.8–12.1 (7.4 ± 2.4)
Creatinine (mg/dl)	s, p, hp	1.2–1.9	1.0–1.8	1.0–2.0
γ-Glutamyltransferase (GGT; U/liter)	s, p	20–52 (33.5 ± 4.3)	20–56 (38 ± 13)	6.1–17.4 (15.7 ± 4.0)
Globulin (g/liter)	s	35.0–57.0 (44.0 ± 5.3)	27.0–41.0 (36.0 ± 5.0)	30.0–34.8 (32.4 ± 2.4)
Glucose (mg/dl)	s, p, hp	50–80 (68.4 ± 6.0)	50–75 (62.8 ± 7.1)	45–75 (57.4 ± 6.8)
Lactate dehydrogenase (U/liter)	s, hp	238–440 (352 ± 59)		692–1445 (1061 ± 222)
Magnesium (mg/dl)	s	2.2–2.8	2.8–3.6	1.8–2.3
Phosphorus (P; mg/dl)	hp	5.0–7.3 (6.4 ± 0.2)	4.2–9.1 (6.5)	5.6–6.5
Potassium (K; mmol/L)	hp	3.9–5.4 (4.8)	3.5–6.7 (4.3 ± 0.5)	3.9–5.8 (4.8)
Sorbitol dehydrogenase (SDH; U/liter)	hp	5.8–27.9 (15.7 ± 7.5)	14.0–23.6 (19.4 ± 3.6)	4.3–15.3 (9.2 ± 3.1)
Sodium (Na; mmol/liter)	hp	139–152	142–155 (150 ± 3.1)	132–152 (142)
Total protein (TP, g/liter)	s	60.0–79.0 (72.0 ± 5.2)	64.0–70.0 (69.0 ± 4.8)	67.4–74.6 (71.0 ± 1.8)

[a]Data presented as ranges with mean and standard deviation in parentheses. s, Serum; p, plasma; hp, heparinized plasma. Clinical biochemistry data from Kaneko et al. (1997).

day, with the amount increasing to 1.5 lb per head per day during the last 6 weeks of gestation. Forage should be fed *ad libitum* during this time.

All newborn ruminants must receive passive immunity from colostrum, the first postpartum milk of a dam that contains concentrated protective maternal antibodies (most as IgG$_1$), functional leukocytes, cytokines, vitamins, minerals, and protein. Colostrum also has laxative properties. Trypsin inhibitors in the colostrum allow the passage of intact antibody molecules, by pinocytosis, through the neonate's gut wall and into the bloodstream during the first few days after birth. The quality of the colostrum is directly related to herd or flock management, vaccination programs, and the dam's overall condition and nutrition throughout gestation and at the time of parturition. Ensuring effective colostrum transfer is also dependent on the timing and amount taken by the neonate. Most neonatal ruminants can suckle well within 3 hr of birth. Those that do so have been shown to have significantly less diarrhea (Naylor, 1996). Neonates weakened by dystocia or hypothermia, for example, should be hand-fed or tube-fed colostrum. If necessary, the dam should be hand-milked and the newborn fed colostrum (for example, 20–40 ml for kids) every 2–4 hr for the first 1–2 days.

In typical management situations, dairy calves either are separated from their dams immediately after birth and bottle-fed colostrum, or they remain with their dams for only about 24 hr and suckle fresh colostrum during this time. Dairy producers then refrigerate and/or freeze the colostrum that cannot be consumed by the calf during that time and then feed this diluted 50:50 with warm water 3 times a day to the calves during the next 2–3 days. Extra frozen colostrum for emergencies may be obtained from dairy farmers; it is advantageous to obtain colostrum from well-managed herds and from the multiparous cows in the herd (not heifers) in the same geographic locale. Holstein calves, for example, should receive a minimum of 3– 5 liters within 12 hr of birth and then be fed about 10–15% of body weight in colostrum by 24 hr of age. After 3 days, calves are then placed on milk replacers.

Although young ruminants generally do well receiving their dams' milk, commercially available milk replacers are available and should generally be prepared and fed according to the manufacturer's recommendations. Containers used to prepare and feed these replacers should be sanitized daily. The fat content of both calf and lamb milk replacers is excessive; however, calf milk replacers can be used for kids if care is taken not to overfeed.

Young ruminants can be offered good-quality hay (such as second cutting) to nibble on by 1 week of age. Calves may be provided with calf starter, a commercially available concentrate with appropriate levels of energy and protein, fed according to the manufacturer's recommendations at 2–3 weeks of age. They can be weaned off milk replacer by 4–7 weeks of age. Young ruminants (4–12 months of age) need good-quality forage as well as grain and concentrate supplementation to promote development of the rumen. In farm management situations, forage can be silage, pasture, and hay. In a confinement situation like a research unit, good-quality hay, such as second cutting, is desirable. Animals should not be overfed and should be offered a mineral mix free-choice.

In contrast to dairy calves, beef calves remain with their mother cows until weaning at 7 months of age. Calves tend to suckle many times per day. As they mature, calves are creep-fed, with the energy and protein content of the ration determined by the milk production of the dams and by the available forage, such as pasture.

D. Reproduction

Several useful references addressing ruminant reproduction in detail are available ("Current Veterinary Therapy: Food Animal Practice," 1986, 1993, 1999; "Large Animal Internal Medicine," 1996; "Current Therapy in Large Animal Theriogenology," 1997; Hafez, 1987).

1. Reproductive Physiology

Sheep are seasonally polyestrous; most breeds will express estrus in the fall (Northern Hemisphere) and subsequently lamb in the spring. Some breeds of sheep may cycle in both the fall and the spring. Between seasonal periods of receptivity, the females undergo a long period of sexual quiescence called anestrus. In a research environment, ewes can be artificially stimulated to progress from anestrous to estrous cyclicity by maintaining the females in 8 hr of light and 16 hr of dark for 8–10 weeks. Puberty is reached at about 7–8 months (or earlier) in both rams and ewes; rams will typically reach puberty before their female counterparts. Ewes will display signs of estrus for about 24–30 hr and will ovulate spontaneously at the end of estrus. The estrous cycle length is 14–19 days, with an average of about 17 days. Following breeding, the average length of gestation is 147–150 days. Slightly longer gestations are observed in animals carrying single lambs (singlets), in animals carrying rams, and in certain breeds such as those derived from Merinos.

Prolificacy, or the number of lambs produced per gestation, tends to be dependent on the maturity of the dam (older dams tend to have multiple lambs) and on breed characteristics (some fine-wool breeds have fewer multiple births). The Finn and Dorset breeds are especially prolific. Lambs vary in size at birth

from about 3–4 lb up to 25 lb. Factors that affect birthweight include parental size, number of lambs in the litter (fewer lambs or singlets tend to be larger), age of the ewe (younger ewes have smaller lambs), lamb gender (males tend to be heavier), nutrition, and season or temperature (spring lambs tend to be larger than fall lambs).

Goats are seasonally polyestrous in temperate regions, so that young are born in favorable times of the year. They are short-day breeders, in that estrus (heat) is brought about by the decreasing light of shorter days. In temperate climates of the Northern Hemisphere, goats are normally anestrous during the summer and begin cycling in the fall. The actual length of the sexual cycle depends on day length, breed, and nutrition. Most dairy goats cycle between August and February or March. Nubians often have extended breeding cycles, and the sexual season of some breeds, including the Alpine, can be extended by artificial means. The caprine gestation length averages 150 days with a variation of 145–155 days. Does bear singletons, twins, and triplets, with slightly shorter gestation when the doe is carrying triplets.

Cows are polyestrous. Domestication of cattle has included selection against seasonality of the breeding season, particularly in dairy breeds but to some extent also in the beef breeds. In spite of this, cattle have been found to be still sensitive, in varying manifestations, to photoperiodicity. Reproductive physiology in cattle is influenced by many factors. The reproductive programs in source herds and at well-managed facilities will be production-related. Extensive coverage of both physiologic basics and specific industry-related criteria—for retention of a cow as a breeder, for example—are addressed in detail in texts and references oriented toward herd and production management ("Current Veterinary Therapy," 1986). Gestation in cattle is approximately 280 days, with a range of 270–292 days. The length of gestation in cattle is influenced by fetal sex; fetal numbers; age and parity of the cow; breed; genotype of cow, bull, or fetus; nutrition; and local environmental factors. As noted, these factors are also important in sheep and goats. Cows usually bear single calves, although twin births do occur. When twins are combinations of male and female calves, the female should be evaluated for freemartinism.

2. Detection of Estrus and Pregnancy

Ovine estrus detection is usually accomplished by the ram. Nonetheless, because artificial insemination is achievable in ewes, clinical signs of estrus are important. Typically, ewes in heat will show a mild enlargement of the vulva, with slight increases of mucus secretion. Ewes may isolate from the flock and appear anxious. It is often better and clearly more reliable to employ the help of a sterile ram to mark females when they are in standing heat. Two mating systems commonly employed include hand mating and group mating. With hand mating, ewes

are placed either singly or in small groups with the ram of choice. Ewes are removed as serviced. Group mating involves placement of a mature ram with approximately 50–60 ewes for the entire 6-week breeding season. In either mating system, it is best to attach a marking harness to the male so that individual ewes can be identified as serviced. This is important so that parturition dates can be calculated.

An easy, natural way to estimate pregnancy is by placing sterile teaser rams with the ewes at the end of the breeding season. Any animal marked by the ram probably has not conceived. Ultrasound scanners are also used for pregnancy detection. The ultrasound transducer is placed against the right abdomen; presence of a fetus is indicated on the machine. Claims of 98% accuracy at 6 weeks postbreeding have been made, although accuracy is generally best beyond 60 days of gestation. Interrectal Doppler ultrasound probes detect fetal pulses. Fetal heart rate is in the range of 130–160 beats per minute, whereas maternal heart rates tend to be 90–110 beats per minute. Accuracy is best beyond 60 days of pregnancy. Rectal–abdominal palpation is an inexpensive alternative. A plastic probe is introduced intrarectally into the ewe, which is restrained on her back in a cradle. The plastic probe is then manipulated toward the abdomen while palpating for the fetus with the opposite hand.

The age of the doe when she first expresses heat varies with breed. Some does will express signs of heat between 3 and 4 months old. However, does should be 7–10 months old or at least 80–90 lb in weight before being bred. The caprine estrous cycle lasts 18–24 days. The duration of estrus is 24–96 hr but averages about 40 hr. The estrous cycle can be more erratic in the beginning than in the end of the breeding season (Smith, 1997). "Standing heat" is usually 12–24 hr but can be as short as a few hours. Signs of estrus in goats include uneasiness, tail switching or "flagging," redness and swelling of the vulva, clear vaginal discharge that becomes white by the end of estrus, vocalization such as continuous bleating, and occasionally riding and standing with other does. A doe that is not in heat will not stand to back pressure or for attempts to hold her tail. Does can be induced to show signs of heat by buck exposure and will ovulate within 7–10 days after introduction of the buck. Goats ovulate during the later part of the estrous cycle, most between 24– 36 hr after the onset of estrus. Nevertheless, goats should be mated once signs of estrus are recognized and every 12 hr until the end of estrus.

Most goats kid only once a year, although some goats near the equator may kid twice. Once bred successfully, a goat will only rarely show signs of heat again. In fact, the first sign of pregnancy is usually a failure to return to heat, so animals should be carefully watched. Pregnancy can be affirmed by a variety of means. Goats will generally decrease milk production with pregnancy and should have at least a 6- to 8-week dry period for the udder to fully involute and prepare for the next milking period.

In cattle, age of first estrus is dependent on the breed, the season (with winter delaying), and the level of nutrition (with higher levels hastening puberty). In some cases, the presence of mature cycling cows influences heifer puberty. With adequate nutrition, dairy breeds will reach puberty at 10–12 months and beef breeds at 11–15 months, and estrous cycles will occur regularly after the pubertal (first) estrus. Maturing heifers will often have one or more ovulations before showing overt signs of estrus. Only one follicle usually ovulates per estrous cycle (Hafez, 1987) Estrus, or standing heat, in cattle averages 12– 16 hr in length, with a range of 6–24 hr ("Large Animal Internal Medicine," 1996). Detection of standing heat is important because it is closely related to the time of ovulation. Ovulation occurs approximately 25–32 hr after estrus. Detection of estrus is usually accomplished by visual observation of vaginal mucous discharge, mounting behavior by other females (i.e., the cow standing to be mounted is the individual in estrus), and receptivity to a bull (willingness to stand). Successful visual detection of standing heat is dependent on observation skills of handlers, knowledge of the herd, stresses (e.g., detection decreased in *Bos taurus* during heat stress), barn and yard surfaces (estrus detected better on dirt than on concrete), and maintaining a consistent observation schedule. Teaser animals outfitted with marking devices are also used. Other methods of detecting estrus include monitoring progesterone levels; glass slide and other evaluations of cervical mucus; change in vaginal pH; and body temperature changes (Hafez, 1987). Estrous cycles are usually 21 days in length, with a range of 17–25 days. It is recommended that a heifer deliver her first calf by 2 years of age.

After successful conception, progesterone levels in the cow remain elevated for most of the pregnancy, as the result of the corpus luteum of pregnancy, and they decline only during the final month. Conceptus implantation occurs beginning at about day 17. If the pregnancy fails before this time, the cow will begin to cycle again between days 18–24, but if the pregnancy ends after day 17, there may be a delayed return to estrus. Real-time ultrasonography can be used to determine pregnancy as early as 9 days after insemination, with embryos seen by days 26–29. Fetal gender can also be determined by experienced personnel by this method by about day 55. Detection of pregnancy can be successful by 25–40 days after conception by observation of failure to return to estrus or by palpation per rectum (detecting fetal membrane slip by days 30–35 and/or amniotic vesicle by days 28–35). Palpation of the fetus is possible by day 65 and placentomes by approximately days 100– 110. Palpation later in presumed pregnancy will provide information based on differences in size of the two uterine horns, changes in the uterine wall, and fremitus in the miduterine artery. Pregnancy can also be determined with reasonable success rates by determining if progesterone levels are elevated at days 20–24 after insemination. Levels of bovine pregnancy-specific protein B may also be measured; this is produced by trophoblastic cells and is detectable by days 15–24 and elevated throughout pregnancy.

Placentation in sheep, goats, and cattle is epitheliochorial and cotyledonary, in contrast to the diffuse or microcotyledonary placentas of horses and pigs. The placentomes, the infolded functional units of the placenta, are formed as the result of fusion of the villi of the fetal cotyledons projecting into the crypts of the maternal caruncles (specialized projections of uterine mucosa). Caruncles of sheep and goats are concave in shape, whereas those of cows are convex. The placentomes are distributed between the pregnant and nonpregnant horns of the uterus in sheep, and there are 90–100. In cattle, although the placentomes initially develop around the fetus, they will eventually be distributed to the limit of the chorioallantoic membrane even in the nongravid horn. The placentomes in the nongravid horn will be smaller than in the gravid horn. The total number will be 70–120.

3. Husbandry Needs

The best birthing preparation for all dams is to ensure a proper plane of nutrition (not overnutrition) and adequate exercise. If possible, the dam should be confined to a birthing pasture or sanitized maternity pen a few days prior to parturition. The birthing environment will be very important in the overall health of the dam and offspring; stress minimization and a clean environment will benefit the immune health of both in the short and long term. Outdoor parturition in a small birthing pasture has advantages. There is less stress and less intensity of pathogens. Indoor maternity pens should be clean, dry, warm, well bedded, well ventilated but draft-free, and well lighted. Adequate space per pen minimizes losses of neonates from being stepped and sat on by the dam. Management of these pens, especially if concentrated in an area, is important to minimize pathogens to which dam and young are exposed. Water troughs or buckets should be elevated or placed outside the pen, because lambs and kids have a tendency to fall or be pushed into them. Soiled bedding should be removed from the birthing pen between dams, the area sanitized and allowed to dry, and fresh bedding installed for the next occupant. Moving the female immediately before or during parturition may delay the birthing process. In goats, furthermore, *in utero* death may occur if parturition is unduly delayed. Dams should be monitored closely during parturition for dystocias; these may result in loss of young or in young severely weakened from the prolonged birthing process.

Prior to parturition, ewes should be sheared or crutched. *Crutching* refers to removing wool around the perineal and mammary areas; this minimizes fetal contamination during the birth process. Foot trimming can be done at this time as well. The tail and perineal area of the doe should be clipped and cleaned to improve postbirth sanitation. In general, the pregnant doe needs a 14 ft^2 (1.2 m × 1.2 m) area for the birthing process, and area needs to be increased after birthing to allow spacing for kids. Each cow should have a minimum pen area of 10 ft ×

10 ft. Evaluation of a cow's udder prior to breeding and especially as parturition approaches is important in order to assure adequate nutrition and success of passive transfer by the neonate. If the udder is edematous or if mastitis is present, for example, an alternate source of colostrum (such as frozen reserves) must made be available. Poor udder conformation may also be problematic; contingency plans should be made to ensure adequate support for the young if they cannot suckle from those udders. Inexperienced heifers may react indifferently or aggressively to their offspring and should be monitored more closely than older, multiparous cows with uneventful calving histories.

4. Parturition

Ewes approaching parturition generally isolate themselves from the flock, become restless, stamp their feet, blat, and periodically turn and look at their abdomen. The pelvic region will appear relaxed, and milk will be present in the udder. Once hard labor contractions begin, lambs will usually be born quickly. Animals that do not appear to be progressing correctly should be examined for dystocia. Most cases of fetal malpresentation or malpositioning can be corrected via vagino-uterine manipulation. Occasionally cesarean sections will be necessary. Sanitation, cleanliness, and adequate lubrication are of utmost importance when performing obstetrical procedures.

For about a week before parturition, rectal temperature of the doe will be above normal, or about 103°F depending on environmental temperatures. Approximately 24 hr prior to birth, rectal temperature will fall to slightly below normal. Many large dairy-goat facilities attempt to control the onset of parturition in order to assist birthing. The drug of choice to induce parturition in the goat is prostaglandin F$_{2\alpha}$ (PGF$_{2\alpha}$) (Ott, 1982). On day 144 of gestation, goats given PGF$_{2\alpha}$ (2.5–5 mg) will deliver kids within 28–57 hr. Most goats prefer to kid alone and do so unaided. Human interaction can actually interfere with normal birthing, especially in young or nervous does. Some does may reject kids if extensive human interference occurs. Does nearing parturition have an obviously swollen udder and a red, swollen vulva. Pelvic ligaments at the base of tail relax. The doe may circle to make a bed, get up and down, look at her tail or sides, push other goats away, and bleat softly. Signs of impending parturition include restlessness; vocalization (bleating softly); uneasiness, including getting up and down, pawing, and bedding; and a mucous discharge, leading to a moist tail. Eight to 12 hr prior to parturition, the cervix will dilate and the cervical mucous plug will be evident as a tan, smeared substance on the tail and perineum of the dam. Kids should present within 1–6 hr in either anterior or posterior position. A posterior presentation can be recognized by the presence of upward-pointing feet. Most does will rest between fetuses and are best left alone. However, if labor is prolonged more than 1 hr, a vaginal exam is indicated.

If the pregnant goat is housed with other goats, then herd-mates will express great interest in the dam. Unless moved prior to parturition, it is best to leave the dam with the group until after parturition, because removal may delay parturition. Goats are not prone to retained placenta. Normal kids will be quite active and will quickly attempt to stand and nurse. Weak kids should be towel-dried, warmed (via heat lamp, heat pad, or warm water bottle), and assisted to nurse or fed colostrum.

The goat is one of the few ungulate species that will exhibit "false pregnancy," or pseudopregnancy. This is a fairly common condition. Does may have characteristically distended abdomens and may develop hydrometra and "deliver" large volumes of cloudy fluid at expected due dates. Subsequent pregnancies can be normal. Goats should be tested for pregnancy by 40 days of age. Veterinary use of prostaglandins has been successful in treating this condition.

As in other species, parturition in cattle results from a combination of hormonal changes associated with the maturity of the fetus, notably ACTH (adrenocorticotropic hormone) and subsequent increases in fetal corticosteriods within 2 days of birth. Administration of ACTH to a fetus, or administration to the dam, results in premature birth. Pregnancy is extended if fetal pituitary or adrenal glands are removed surgically. The fetal cortisol probably affects placental steroid production, accounting for sharp increases in the estrogens and estrogen precursors. Coincident with this, maternal progesterone levels fall. The rising levels of estrogen cause release of maternal $PGF_{2\alpha}$ and induction of oxytocin receptors. Most cows will separate themselves from the rest of the herd. A cow will lift her tail and arch her back when she is within a few hours of delivering the calf, and most cows are recumbent when delivering the calf. Typically, the whole birthing process takes about 100 min. The length of labor of cows carrying larger calves also will be longer. Nervous heifers will take longer to deliver, and if they are disturbed, their labor may cease. All postparturient animals should be monitored for successful passage of these fetal membranes within 12 hr of birth. Veterinary intervention is required if not. Cows occasionally eat placentas, which may subsequently obstruct rumen outflow and require surgical correction. For cattle, it is now recommended practice to remove membranes that have passed, in order to prevent ingestion.

5. Early Development of the Newborn

Following lambing, it is critical that the newborns be "processed" so that they will have greatest survival chances. In a well-managed flock, many lambs and ewes will not need much assistance. When assistance is given, the newborn lamb's nose and mouth should be wiped free of secretions; gently swinging the lambs, head down, aids in removal of these fluids. The lamb should be dried off and stimulated through rubbing to aid its breathing. The lamb's navel should be dipped in an iodine solution to prevent subsequent navel infections. And the lamb should be identified by the application of an ear tag or ear notch. It is extremely important that the lamb be supplied with high-quality colostrum within the first 12 hr of birth. Lambs that are not nursing on their own should be tube-fed with colostrum that has been collected and saved previously (i.e., frozen in ice cube trays) or collected from the mother after parturition. Passive transfer can be assessed by measuring serum γ-glutamyltransferase (GGT) levels (Tessman et al., 1997). After the first few days, colostrum changes over to milk. Nursing lambs will ingest increasing amounts of milk as they grow. If the ewe cannot produce sufficient milk, the lamb should be "grafted" onto another ewe or fed artificially with a baby bottle. Powdered milk replacers are commercially available; the content of ewe milk is much different from that of cow's milk; thus lamb milk replacer should specifically be used. One report notes that 50–70% of lamb deaths occur during the first week of life and up to 90% occur within the first month. Good management of ewes during gestation, care of the lamb at parturition, application of an appropriate vaccination program, and observation and intervention within the first several weeks of a lamb's life will minimize losses (Ross, 1989).

Immediately after birth, the placenta and any birthing materials should be removed from the doe's pen. Kids do not usually need assistance. If kids are to be raised by the dam, they can be left alone; otherwise, kids should be towel-dried and removed from the dam. Kids are cold-sensitive and may require a heat lamp or other source of added warmth in cold weather. Navel cords should be dipped in tincture of iodine, and kids should be dehorned and castrated within the first several days of life.

To control caprine arthritis encephalitis (CAE), kids should be immediately removed from the dam and hand-fed heat-treated colostrum. Colostrum should be heat-treated for 1 hr at 131°F. The first feeding can be up to 125 ml of colostrum. Kids should receive a total of 250 ml colostrum within the first 36–48 hr of birth. After day 3, kids can be placed on milk replacer. Milk replacers should contain 16–24% fat and 20–28% milk-based protein. By 14 days of age, kids should be consuming approximately 1.1–1.4 liters of milk per day. Kids should be introduced to forages as soon as possible and may be weaned by 6–10 weeks or 18–25 lb body weight. Milk that is fed can be reduced by 4 weeks of age by decreasing either the volume fed or the number of feedings.

As with other dams, a cow is usually very attentive to her newborn calf, cleaning and softly vocalizing to the neonate. Calves typically are standing by 1 hr after birth and are suckling within 3 hr. As noted previously, dairy calves may be removed from the cow even before suckling, and the colostrum milked from the dam and given to the calf. Assistance may be required for nervous heifers, after dystocias and in extreme circumstances such as severe cold. Cleaning the newborn's nose and mouth, rubbing down the neonate, assuring that the calf does not get chilled, and assuring that it receives adequate colostrum are all important under any of these circumstances. A stressed calf's umbilical

may be treated with an iodine or chlorhexidine solution, although some authors note no benefit of navel treatment, specifying that successful transfer of passive immunity and sound sanitary management of birthing area are the most crucial factors in preventing omphalitis (navel ill) (House, 1996; Kersting, 1997; Kasari and Roussel, 1999). Because newborn calves can be deficient in vitamin A and iron, these may be injected to improve disease resistance (Wikse and Baker, 1996). In cases in which the dams' colostrum is known to be deficient in antibodies against common diseases, vaccinations may be administered at 1 day old and followed with boosters at regular intervals. Dehorning is performed when horn buds appear. Castration is performed between 2 and 9 weeks of age or later.

6. Sexing

Sexing the young in any of the ruminant species is straightforward. The vulva of the female young is located just ventral to the anus. The genitalia of the male include a penis, located along the ventral midline, and a scrotum, located in the inguinal region. The phenomenon of the freemartin, a genetic female born as a twin to a male, is the result of anastomoses between placental circulations of the twin fetuses; the mixing of blood-forming cells and germ cells results in the XX/XY chimeras. This occurs in 85–90% of phenotypic bovine females born as co-twins with males. The female will often have abnormal vulva and clitoris, and the vagina will be a blind end because of the lack of a cervix. Sometimes singleton freemartins are born if the male fetus is lost after 30 days' gestation. Multiple births are selected for and are common in sheep; the freemartin phenomenon is regarded as rare. Twinning is common in goats, and freemartinism occurs in about 6% of male–female pairs of twins. Intersexes are seen in some goat breeds and when polled goats are mated. Proof is usually based on evidence of abnormal genital development and reports of abnormal sexual behavior.

7. Weaning

Prior to weaning, it must be established that lambs can nutritionally survive without mother's milk. Thus, grain, and later roughage, should be offered to lambs well in advance of the day of weaning so that they can adjust to the feedstuff. To prevent the ewes from ingesting the lamb ration, a "creep" should be set up by building an area adjacent to the ewe–lamb pen and devising a slatted entry for the lambs to enter but not the ewes. Therefore, the lambs will be accustomed to the new ration through this creep-feeding process. If lambs and ewes will be pastured later in the spring, it is still beneficial to creep-feed lambs until pasture growth is adequate enough to fulfill the requirements of the growing lambs.

Lambs that are consuming 1.5–2 lb of creep feed per day may be weaned. Depending on the individual program, lambs may be weaned as early as 4 weeks of age, although 6–8 weeks of age is more common. If ewes are of a breed that will cycle twice a year, and if it is expected that they will be rebred, then the lambs must be weaned as early as possible so that lactational anestrus will resolve and ewes will recycle. Another factor is the cost of lactation rations for the ewes; if lamb grain is more economical than ewe grain, then lambs should be weaned. About 4–5 days prior to weaning, feeding of the lactation ration to the ewes should be discontinued, and only roughage fed. At weaning, the lambs should be removed in the creep, and the ewes removed to an area that is not within sight (and preferably sound) of the lambs. The ewes should be monitored for postweaning mastitis and treated as necessary. Ewes that have physical or disease problems or that have not been productive at lambing or feeding their lambs should be culled. The lambs should be monitored to assure that they continue to gain weight and are eating the new ration.

Kids should be introduced to forages within the first week of life because the natural curiosity of these animals will cause them to investigate sources of feed. Kids can be weaned by 6–10 weeks or 18–25 lb. Hand-fed milk should be reduced by 4 weeks of age by reducing the volume fed or by decreasing the number of feedings.

Dairy calves are now usually removed from their dams immediately after birth. It is less common now to allow the calves to remain with their dams for about 24 hr and suckle fresh colostrum during this time, because their intake will be inadequate. Dairy producers refrigerate and/or freeze the colostrum produced during the first 24 hr and feed this, diluted 50:50 with warm water, twice a day to the calves during the next 2–3 days. Holstein calves, for example, should receive a minimum of 3–5 liters within 12 hr of birth and then be fed about 10–15% of body weight in colostrum by 24 hr of age. After 3 days, calves are then placed on milk replacers, preformulated powders reconstituted with water that provide complete nutrition. Milk replacers are commercially available and should be fed according to manufacturer's recommendations

Vaccination programs for calves vary with the preventive medicine program for the overall herd. Passive immunity provided by colostrum from cows on sound management programs will last until a calf is about 6–7 months old; normally vaccinations are not necessary and are contraindicated during those first 6 months. The duration of passive immunity varies considerably among calves, however; some producers choose to begin vaccinating calves at 1–2 months of age and continue with monthly booster immunizations until the animals are 7 months old, when passive immunity is no longer a possibility.

8. Artificial Insemination

Artificial insemination (AI) in sheep is more difficult than in cattle because sheep are smaller and cannot be reproductively manipulated via the rectum and because the cervix of sheep is

more difficult to traverse with the insemination pipette. Breeding animals artificially with fresh semen produces pregnancy rates averaging 50% (not unlike that of cattle); artificial insemination with frozen semen is less successful. Several artificial insemination techniques have been used. Laparoscopic AI involves the surgical instillation of semen into the uterus through a small abdominal opening. The procedure is successful but is technically involved and costly. Cervical AI involves the transvaginal introduction of semen into the cervix. A modification of this technique (transcervical AI) allows for penetration through the cervix into the uterus. This method (called the Guelph system for transcervical AI) leads to successful penetration into the uterus in up to 75% of ewes when performed by an experienced inseminator.

Artificial insemination is now an integral part of dairy herding; natural insemination as a management practice is relatively rare. Technicians performing the AI technique are available through commercial enterprises. Dairy production employees are also trained. Information regarding the management of the donors and recipients, the storage and handling of the semen, and the skills and record keeping required is covered extensively elsewhere (Nebel, 1997).

9. Synchronization

Because sheep are hormonally similar to other ruminants, estrous synchronization techniques are comparable. Progesterone suppresses follicle-stimulating hormone (FSH) secretion, preventing animals from developing follicles and exhibiting estrus. Artificial or natural progesterone can be administered in the feed, through parenteral injection, subcuticular implants, and vaginal pessaries. The progesterone is withdrawn in about 12–14 days, after which the FSH secretion will initiate the process of follicle development (Trower, 1993). Estrus usually will occur in 36–60 hr (average is 48 hr). A natural method of synchronization, often applied to promote flock breeding within a short period of time (and thus parturition will be within a narrow window as well), is the introduction of sterile rams with the ewes before the beginning of the normal fall mating period. Pheromones released from males naturally stimulate the females to cycle and to synchronize their heats. It should be noted that introduction of a male during late anestrus will often stimulate ovulation in about 6 days; however, this cycle will generally be without clinical signs of estrus (silent heat). Vasectomy of rams is one method of producing sterile "teaser rams."

Introduction of the buck to a group of does will induce ovulation and may even synchronize does. Does that are kept separate from the buck will show signs of estrus, will ovulate within 6–10 days, and will have normal pregnancies when introduced to a buck. Bucks with horns and intact scent glands are better able to induce ovulation than dehorned bucks, whose scent glands often been removed.

Control of breeding in the goat has been studied mostly in dairy breeds in order to produce milk throughout the year and to reduce kidding labor. Goats in the luteal phase of the estrous cycle, days 4–16, are sensitive to $PGF_{2\alpha}$ (2.5–5 mg IM) and will show estrus in 36–60 hr postinjection (Bretzlaff, 1997). Dosing cycling animals twice 11 days apart will synchronize goats, and artificial insemination using this method has resulted in 40–60% conception rates (Bretzlaff, 1997; Greyling and Van Niekerk, 1986). Programs for timed breeding have been described and involve administering progestogens (Bretzlaff, 1997). Vaginal pessaries of fluorogestone acetate left in place for 21 days in the doe followed by an injection of pregnant mare serum gonadotropin (PMSG) at the time of pessary removal have proven successful. Also, when primed by $PGF_{2\alpha}$, an 11-day regimen of fluorogestone acetate with PMSG given on day 9 has been successful.

Synchronization of cattle estrous cycles and superovulation are used as management techniques in certain commercial cattle and dairy production settings where estrus synchronization or embryo transfer is advantageous to production and management. The methodology is also used in the research setting for coordinating donors and recipients of embryos or other genetically manipulated tissues for implantation. The options and dosing regimens are described in detail in veterinary clinical texts (Wenzel, 1997; Vanderboom et al., 1997). In synchronization, the principle is lysis of the existing corpus luteum. The more common practices involve the use of products approved for use in cattle such as $PGF_{2\alpha}$, one of its analogs, or products containing estradiol valerate. Progestogens are also used in conjunction with estradiol valerate. Other approaches, involving management techniques combined with pharmacologic interventions, are considered less successful. Superovulation regimens involve injections of FSH either alone or with $PGF_{2\alpha}$ at timed internals. Estrus is expected 48 hr after the final injection, and two inseminations are performed at 12 hr intervals after estrus detection. Preparation of recipients involves injection of $PGF_{2\alpha}$ or progestogens with gonadotropins such as PMSG. For greatest success as management tools, these must be combined with a consistent program that provides appropriate nutrition for all cattle involved. Synchronization of animals is also influenced by several other factors, however, such as time in the cycle when hormones are administered, response by each individual animal, whether the cow is a dairy or beef animal, parity and maturity of the cows, success of heat detection after the luteolysis, and accurate record keeping.

10. Embryo Transfer

Embryo transfer involves the removal of multiple embryos from a superovulated embryo donor and transferring them to synchronized recipients. This method maximizes the genetic potential of the donor animal. The donor animal is hormonally superovulated and inseminated. In sheep, about 1 week after breeding, the embryos are surgically removed from the donor's

uterus. In cattle, the procedure is nonsurgical. About 75% of expected embryos (determined by counting corpora lutea) can be recovered; successful recovery is affected by factors such as age of the donor, reproductive health, and experience of the surgeon or technician. Furthermore, not all collected embryos are of transferable quality. Recipients are hormonally synchronized with the donor animals. On the day of embryo collection, transferable embryos are implanted into the uterus of the recipient; laparoscopy has been used in the past and is now being replaced by nonsurgical methods. Pregnancy rates average about 70%. If recipients are not available, embryos, like sperm, can be frozen and kept for later transfer.

Embryo transfer is commonly practiced in cattle as a herd improvement technique and as a research technique for engineered embyros. Disease screening programs for all animals involved are important because several pathogens can be transmitted directly or indirectly, such as bovine viral diarrhea virus, bluetongue virus, infectious bovine rhinotracheitis virus, and mycoplasmal species.

11. Miscellaneous Management Considerations

a. Management of Male Animals

In sheep flocks and goat herds, as noted, male young are usually castrated by 1 month of age. The elastrator method is the more popular for animals less than 1 week of age. Other methods include the emasculatome (crushing) and surgical removal ("knife method"). The distress associated with castration and tail docking in lambs is the subject of debate and has been researched recently (Kent et al., 1995). As noted, male calves are usually castrated as early as possible and no later than 3 month of age. In some production situations, however, where maximum hormone responsive muscle development and grouping animals together for procedures dictate scheduling, the procedure may be performed on older males. Open and closed techniques are used, depending on the age of animals and on veterinary or farm practice.

Breeding and vasectomized rams and bucks are usually maintained by medium to large production farms. Smaller farms often borrow breeding males. Breeding males are typically selected by production record, pedigree, and/or breed. Vasectomized males are often retired breeders and should be tattooed or identified clearly to avoid any wasted breeding time. The vasectomy technique for both species is comparable (Smith and Sherman, 1994). Rams may be housed together for most of the year, whereas bucks are penned separately.

Because ewes will exhibit only a limited number of estrous cycles before becoming reproductively quiescent, it is critical that the male be capable of successfully breeding the female in an expeditious manner. Any defects in the external genitalia, reproductive diseases, or musculoskeletal abnormalities may prevent successful copulatory behaviors. Furthermore, it is impor-

tant to know the semen quality of the ram as one indicator of fertility. Semen can be collected via electroejaculation or by use of a teaser mount. Once semen is collected, it should be handled carefully and kept warm to prevent sperm death, leading to improper conclusions about the male. Typically, the characteristics usually evaluated as a determinate of sperm quality are volume (normal between 0.7 and 2.0 ml); motility (% of sperm moving in a forward wave; high quality is associated with motility of approximately 90%); concentration (sperm count per unit of volume as measured by a hemocytometer; high-quality semen should contain 1.8×10^9 sperm per ml); morphology (live versus dead cells, as determined by special stains and the percentage of abnormal-appearing sperm; neither the abnormalities nor the dead sperm should exceed 10% in high-quality semen).

The extensive use of artificial insemination in the dairy cattle industry has minimized the use of bulls on many farms, although a farm may maintain a few bulls for heat detection and for "cleanup" breeding. Breeding bulls are maintained in beef production establishments. Breeding bulls must be part of the herd vaccination program, with special attention to appropriate timing of immunizations for the commonly transmitted venereal diseases campylobacteriosis and trichomoniasis.

b. Cattle Tail Docking

Tail docking is a relatively recent development in dairy herd management and is practiced in the belief that it will minimize bacterial contamination of the udder and therefore the milk. Tails are typically docked to about 10 inches in length. The practice is more popular in certain regions in the United States. To date, there is no published study indicating that this technique provides any distinctive advantage over keeping the tail switch hair clipped short.

E. Behavior

Healthy ruminants have good appetites, chew cud, are alert and curious, have healthy intact coats, move without hindrance, and have clear, bright, clean eyes and cool dry noses. Even adult animals, when provided sufficient space, will play. Sheep and goats have tidy "pelleted" dark green feces. Cattle have pasty, moist, dark green-brown feces. Ruminants normally vocalize, and handlers will learn to recognize normal communication among the group or directed at caregivers in contrast to that when animals are stressed. Excessive, strained vocalizations are often a sign of stress in cattle. "Bruxism," or grinding of the teeth by a ruminant, is usually associated with discomfort or pain. Other signs of discomfort, stress, or illness include decreased time spent eating and cud chewing, restlessness, prolonged recumbency with outstretched neck and head, and hunched back when standing. Unhealthy ruminants may be thin,

may arch their backs or favor a limb, or may have external lumps or swollen joints, an unusual abdominal profile, or rough or dull coats.

All ruminants are herd animals to some extent and social individuals; therefore, every effort should be made to allow contact among animals, in terms either of direct contact or of sound, smell, or sight. Human contact and handling should be initiated promptly and maintained regularly and consistently throughout the animal's stay in the research facilities. Animals should be provided sufficient time to acclimate to handlers and research staff. Cattle and sheep can hear at higher frequencies than humans can and may react to sounds not perceived by handlers.

Knowledge of the peculiarities of sheep behavior will increase the ease of handling and decrease stress-related effects in research. Generally, fine-wooled breeds, such as Rambouillet, are the most gregarious and are best handled in groups. The meat, or "downs," breeds tend to be less gregarious, and the long-wooled breeds tend to be solitary (Ross, 1989; ASIA, 1996). Nonetheless, movement of animals is simplified by proper facility design. Sheep have a wide-angle visual field and are easily scared by activities that are taking place behind them. Sheep should be moved slowly and gently. To capture individuals within a flock, it is best to confine the flock to a smaller space and use a shepherd's crook or to gently catch the animal in front of the neck/thorax. Grabbing the wool can injure the animals, as well as damage the wool and the underlying tissues. Sheep move best in chutes that have solid walls, and individual animals will generally follow a lead animal. Any escape route will be challenged and, if successfully breached, will disrupt the entire flock movement. Sheep movement is also disrupted by contrasts such as light and shadows that impinge on a chute or corral. Finally, like most animals, sheep have a flight zone (minimum zone of comfort), the penetration of which will result in sheep scattering. This minimal flight distance can be modified by increasing handling of the animals and working at the edge of the zone, but it should always be considered when working with animals in chutes, pens, or other confined areas.

Goats exhibit behavioral characteristics that make them quite distinct from other ruminants. Their browsing activity makes them quite orally investigative. Goats will readily nibble or chew just about anything they come in contact with, so researchers should keep all paperwork and equipment out of reach. A herd of goats will readily chew through wood gates and fencing, especially when confined in areas without alternatives for chewing behavior. Goats are also inquisitive, restless, agile jumpers and climbers, and quite mischievous. If maintained in paddocks, strong high fences are essential, as are adequate spaces for exercise or boulders or rock piles for hoof maintenance and recreational climbing. Goats are more tolerant of isolation and are more easily acclimated to human contact than sheep are, but goats will confront unfamiliar intruders and make sneezing noises. Goats with horns will use them to advantage,

and horns may also become entangled in fencing. Although less strongly affected by flock behavior, goats are social animals. Most goats raised in close human contact are personable and cooperative and can easily be taught to stand for various procedures, including blood collection.

An understanding of breed behaviors, sources of stress in cattle, play behaviors, calf behaviors, and dominance determinants will contribute to prevention of injuries to handlers and better health and welfare of the animals. Ruminants of all ages, especially cattle of all ages, should be handled with an appreciation of the serious injury to human handlers that may result (Houpt, 1998). Cattle have a wide visual field, as sheep do, and a flight zone that varies in size, according to previous handling experiences (gentle handling and animal tameness make the flight zone smaller) and the circumstances of the moment (Grandin, 1993). Groups of cattle are moved effectively around a facility by utilizing chute systems, with sequences of gates, that minimize chances of animals turning around.

Dairy cattle have been bred and selected over centuries for their docile, tractable characters and production characteristics. In contrast, beef breeds have not been selected for docility and are generally more difficult to handle and restrain. Beef breeds, such as Angus, are known for their independent natures and protective maternal instincts. All cattle respond well to feed as a reward for desired behavior. Healthy cattle typically are very curious and watchful and are alert to sounds and smells. When not grazing or eating, they hold their heads up. When sleeping, the head and neck may be tucked back. Because of ruminant digestive and metabolic needs, much of the day is spent eating or cud chewing. Occasionally, adult cows sit upright like dogs. Cattle maintained inside tend to be more docile. In addition to forced isolation from other cattle, sources of stress include rough attitudes of handlers and unfamiliar visual patterns, routines, or environments. These stressors may exacerbate signs of systemic illnesses.

Calves are known for non-nutritive suckling, bar licking, and tongue rolling. Non-nutritive suckling behavior is greater in hungry calves and also right after a milk meal. It is best to provide nipples and other clean noninjurious materials for the animals to suck. Non-nutritive suckling can be detrimental in group-housed calves because it can result in disease transmission and hair ball formation. Environmental enrichment devices have been developed to cope with this behavior. The behavior diminishes as the animals are weaned onto solid food (Morrow-Tesch, 1997).

Play activity and vocalizations of calves mimic adult dominance behaviors. Play activity by young adult cattle is more common in males, can be quite rough, and is often triggered by a change in the environment. Dominance behaviors are dependent on direct physical contact among the cattle, and dominance hierarchies are established within a herd. Horns, age, and weight have been reported to be the most important determi-

nants. Aggressive behaviors in cattle may be triggered by newly introduced animals or unfamiliar visual patterns and by feeding when animals are very hungry. Aggression is more common among intact adult males.

III. DISEASES

This section focuses primarily on the more common diseases affecting sheep, goats, and cattle in the United States and elsewhere in North America and those that are reportable. For detailed information not included in this limited overview and for diseases of importance internationally, the authors recommend several excellent comprehensive and focused veterinary clinical texts and periodicals that address ruminant diseases, preventive medicine, and individual and flock or herd management. These are listed under "Major References" in the reference list at the end of this chapter.

Recommendations for current drug therapies, both approved and off-label use in ruminants, including withholding prior to slaughter, formularies, and related information can be found in the references noted above and in formularies (Hawk and Leary, 1995; Plumb, 1999). In addition, the Food Animal Residue Avoidance Databank (FARAD), accessible on the Internet <http://www.farad.org>, should be used as a resource. FARAD is a food safety project of the U.S. Department of Agriculture and is an information resource to prevent drug and pesticide residues in food animals and animal products.

A. Infectious Diseases

1. Bacterial, Mycoplasmal, and Rickettsial Diseases

a. Actinobacillosis ("Wooden Tongue")

Etiology. *Actinobacillus lignieresii* is an aerobic, nonmotile, non-spore-forming, gram-negative rod that is widespread in soil and manure and is found as normal flora of the respiratory, gastrointestinal, and reproductive tracts of ruminants. In sheep and cattle, *A. lignieresii* causes sporadic, noncontagious, and potentially chronic disease characterized by diffuse abscess and granuloma formation in tissues of the head and occasionally other body organs. This disease, called wooden tongue, has not been documented in goats.

Clinical signs. Skin lesions are common. Tongue lesions are more common in cattle than in sheep. Lip lesions are more common in sheep. Soft-tissue or lymph node swelling accompanied by draining tracts is observed in the head and neck regions, as well as other areas. Animals may have difficulty prehending

food; may be anorexic, weak, unthrifty and depressed; and may salivate excessively. Diagnosis is made based on clinical signs and is confirmed by culture.

Epizootiology and transmission. The organism penetrates wounds of the skin, mouth, nose, gastrointestinal tract, testicles, and mammary gland. Rough feed material and foreign bodies may play a role in causing abrasions. *Actino bacillus lignieresii* then enters into deeper tissues, where it causes chronic inflammation and abscess formation. Lymphatic spread may occur, leading to abscessation of lymph nodes or infection of other organs.

Necropsy findings. Purulent discharges of white-green exudate drain from the tracts that often extend from the area of colonization to the skin surface. Exudates will also contain characteristic small white-gray (sulfurlike) granules. The pus is usually nonodorous.

Differential diagnosis. Contagious ecthyma and caseous lymphadenitis are the primary differentials. Diseases or injuries causing oral pain and discomfort, such as dental infections, foreign bodies, and trauma, should be considered.

Treatment. Animals should be fed softer feeds. Antibiotics such as sulfonamides, tetracyclines, and ampicillin are effective, although high doses and long durations of therapy are required. Penicillin is not effective. Weekly systemic administration of sodium iodide for several weeks is not as effective as antibiotic therapy. Surgical excision and drainage are not recommended.

Prevention and control. Because the organism enters through tissue wounds, especially those associated with oral trauma, feedstuffs should be closely monitored for coarse material and foreign bodies.

b. Arcanobacterium Infection (Formerly actinomycosis, or "Lumpy Jaw")

Etiology. *Arcanobacterium* (formerly known as *Actinomyces* or *Corynebacterium*) *pyogenes* and *A. bovis* are anaerobic, nonmotile, non-spore-forming, gram-positive, pleomorphic rods to coccobacilli. *Arcanobacterium bovis* is a normal part of the ruminant oral microflora and is the organism associated with "lumpy jaw" in cattle; this syndrome is rarely seen in sheep and goats. This organism has also been associated with pharyngitis and mastitis in cattle.

Clinical signs and diagnosis. *Arcanobacterium bovis* causes mandibular lesions primarily. The mass will be firm, non-painful, and immovable. Draining tracts may develop over time.

If teeth roots become involved, painful eating and weight loss are evident. Radiographic studies are helpful for determining fistulas. Diagnosis is based on clinical signs, and culture is required to confirm *Arcanobacterium*. The prognosis is poor for lumpy jaw.

Epizootiology and transmission. These organisms are normal flora of the gastrointestinal tracts of ruminants and gain entrance into the tissues through abrasions and penetrating wounds.

Necropsy. Draining lesions with sulfurlike granules (as with actinobacillosis) are frequently observed.

Pathogenesis. *Arcanobacterium pyogenes* is known to produce an exotoxin, which may be involved in the pathogenesis.

Differential diagnosis. *Actinobacillus lignieresii and* caseous lymphadenitis are important differentials for draining tracts. A major differential for omphalophlebitis is an umbilical hernia, which will typically not be painful or infected. There are many differentials for septic joints and polyarthritis: *Chlamydia* spp., *Mycoplasma* spp., streptococci, coliforms, *Erysipelothrix rhusiopathiae*, *Fusobacterium necrophorum*, and *Salmonella* spp. Tumors, trauma to the affected area, such as the mandible, and dental disease or oral foreign body should also be considered.

Prevention and control. *Arcanobacterium bovis* lesions can be prevented or minimized by feeds without coarse or sharp materials.

Treatment. Penicillin or derivatives such as ampicillin or amoxicillin are treatments of choice. Sodium iodides (intravenous) and potassium iodides (orally) have been utilized also. Extended antibiotic therapy may be necessary. Surgical excision is an option. In addition to medications noted above, isoniazid is somewhat effective for *A. bovis* infections in nonpregnant cattle.

Research complications. The possibility of long-term infection and long therapy are factors that will diminish the value of affected research animals.

c. Actinomycosis

Omphalophlebitis, omphaloarteritis, omphalitis, and *navel ill* are terms referring to infection of the umbilicus in young animals.

Arcanobacterium pyogenes is the most common organism causing omphalophlebitis, an acute localized inflammation and infection of the external umbilicus. Most cases occur within the first 3 months of age, and animals are presented with a painful enlargement of the umbilicus. Animals may exhibit var-

ious degrees of depression and anorexia, and purulent discharges may be seen draining from the umbilicus. Involvement of the urachus is usually followed by cystitis and associated signs of dysuria, stranguria, hematuria, and so on. Severe sequelae may include septicemia, peritonitis, septic arthritis (joint ill), meningitis, osteomyelitis, and endocarditis.

Research complications. Young stock affected by omphalophlebitis may be inappropriate subjects because of growth setbacks and physiologic stresses from the infection. Affected adult animals will not thrive and, even with therapy, may not be appropriate research subjects.

d. Anthrax

Etiology. *Bacillus anthracis* is a nonmotile, capsulated, spore-forming, aerobic, gram-positive bacillus that is found in alkaline soil, contaminated feeds (such as bonemeal), and water. Common names for the disease anthrax include woolsorters' disease, splenic fever, charbon, and milzbrand.

Clinical signs and diagnosis. Anthrax is a sporadic but very serious infectious disease of cattle, sheep, and goats characterized by septicemia, hyperthermia, anorexia, depression, listlessness, depression, and tremors. Subacute and chronic cases may occur also and are characterized by swelling around the shoulders, ventral neck, and thorax. The incubation period is 1 day to 2 weeks. Bloody secretions such as hematuria and bloody diarrhea often occur. Abortion and blood-tinged milk may also be noted. The disease is usually fatal, especially in sheep and goats, after 1–3 days. Death is the result of shock, renal failure, and anoxia.

Diagnosis is based on the clinical signs of peracute deaths and hemorrhage. Stained blood smears may show short, single to chained bacilli. Blood may be collected from a superficial vein and submitted for culture.

Epizootiology and transmission. Cattle and sheep tend to be affected more commonly than goats, because of grazing habits. Older animals are more vulnerable than younger, and bulls are more vulnerable than cows. Although the disease occurs worldwide, and even in cold climates, most cases in the United States occur in the central and western states, and outbreaks usually occur as the result of spore release after abrupt climatic changes such as heavy rainfall after droughts or during warmer, dryer months. Spores survive very well in the environment. The anthrax organisms (primarily spores) are generally ingested, sporulate, and replicate in the local tissues. Abrasive forages may play a role in infection. Transmission via insect bites or through skin abrasions rarely occurs.

Necropsy. Necropsies should not be done around animal pens or pastures, and definitive diagnoses may be made without

opening the animals. Incomplete rigor mortis, rapid putrefaction, and dark, uncoagulated blood exuding from all body orifices are common findings. Blood collected carefully and promptly from peripheral veins of freshly dead animals can be used diagnostically. Splenomegaly, cyanosis, epicardial and subcutaneous hemorrhages, and lymphadenopathy are characterisitic of the disease.

Pathogenesis. The rapidly multiplying organisms enter the lymphatics and bloodstream and result in a severe septicemia and neurotoxicosis. Encapsulation protects the organisms from phagocytosis. Liberated toxins cause local edema.

Differential diagnosis. Although anthrax should always be considered when an animal healthy the previous day dies acutely, other causes of acute death in ruminants should be considered, e.g., bloat, poisoning, enterotoxemia, malignant edema, blackleg, and black disease.

Prevention and control. Outbreaks must be reported to state officials. Anthrax is of particular concern as a bioterrorism agent. Any vaccination programs should also be reviewed with regulatory personnel. Herds in endemic areas and along waterways are usually vaccinated routinely with the Sterne-strain spore vaccine (virulent, nonencapsulated, live). Careful hygiene and quarantine practices are crucial during outbreaks. Dead animals and contaminated materials should be incinerated or buried deeply. Biting insects should be controlled. The disease is zoonotic and a serious public health risk.

Treatment. Treatment of animals in early stages with penicillin and anthrax antitoxin (hyperimmune serum, if available) may be helpful. Amoxicillin, erythromycin, oxytetracycline, gentamicin, and fluoroquinolones are also good therapeutic agents. During epidemics, animals should be vaccinated with the Sterne vaccine.

Research complications. Natural and experimental anthrax infections are a risk to research personnel; the pathogen may be present in many body fluids and can penetrate intact skin. The organism sporulates when exposed to air, and spores may be inhaled during postmortem examinations.

e. Brucellosis

Etiology. *Brucella* is a nonmotile, non-spore-forming, nonencapsulated, gram-negative coccobacillus. *Brucella abortus* is one of several *Brucella* species that infects domestic animals but cross-species infections occur rarely. *Brucella abortus* or *B. melitensis* may cause brucellosis in sheep, cattle, and goats. *Brucella melitensis* (biovar 1, 2, or 3) is the primary cause of sheep disease (Garin-Bastuji *et al.,* 1998). *Brucella ovis* is more

commonly associated with ovine epididymitis or orchitis than abortion. In the United States, clusters of brucellosis are still found in western areas contiguous to Yellowstone National Park. *Bang's disease* is the common name given to the disease in ruminants.

Clinical signs and diagnosis. *Brucella melitensis* in the adult ewe is generally asymptomatic and self-limiting within about 3 months. However, because the organism may enter and cause necrosis of the chorionic villi and fetal organs, abortion or stillbirths may occur. Abortion usually occurs in the third trimester, after which the ewe will appear to recover. It has been reported that up to 20% of infected ewes may abort more than once. Rams will also be infected and may develop orchitis or pneumonia. The disease caused by *B. ovis* is manifested by clinical or subclinical infection of the epididymis, leading to epididymal enlargement and testicular atrophy. *Brucella ovis* causes decreased fertility. *Brucella melitensis* is the more common cause of brucellosis in goats. *Brucella abortus* has been shown to infect goats in natural and experimental infections, and *B. ovis* has also been shown to infect goats experimentally. Does infected with *B. melitensis* will also abort during the third trimester. Infections with *B. abortus* in cattle produce few clinical signs. There may be a brief septicemia during which organisms are phagocytosed by neutrophils and fixed macrophages in lymph nodes. In cows, the organism localizes in supramammary lymph nodes and udders and in the endometrium and placenta of pregnant cows. Infection may cause abortions after the fifth month, with resulting retained placentas. Permanent infection of the udder is common and results in shedding of organisms in milk. In bulls, the organism may cause unilateral orchitis and epidydimitis and involvement of the secondary sex organs. Organisms may be in the semen. In infected herds, lameness may also be a clinical sign.

Diagnosis of brucellosis can be made by bacterial isolation of the *Brucella* organism from necropsy samples (especially the fetal stomach contents), as well as by supportive serological evidence. Many serological tests are available, such as the tube and plate agglutination tests, the card or rose bengal test, the rivanol precipitation test, complement fixation, enzyme-linked immunosorbent assay (ELISA), polymerase chain reaction (PCR), and others. Test selection is often dependent on state requirements in the United States.

Epizootiology and transmission. The primary route of transmission of *B. abortus* is ingestion of the organism from infected tissues and fluids (milk, vaginal and uterine discharges) during and for a few weeks after abortion or parturition; contaminated semen is considered to be a minor source of infection. Exposure to the organism may occur via the gastrointestinal tract (contaminated feed or water), the respiratory tract (droplet infection), or the reproductive tract (contaminated semen) and

through other mucous membranes such as the conjunctiva. *Brucella ovis* is transmitted in the semen, as well as orally or nasally through contaminated feed and bedding.

Necropsy findings. A sheep fetus aborted due to *Brucella* will exhibit generalized edema. The liver and spleen will be swollen, and serosal surfaces will be covered with petecchial hemorrhages. Peritoneal and pleural cavities often contain serofibrinous exudates. The placenta will be leathery.

Pathogenesis. Ruminants are considered especially susceptible to *Brucella* infection, because of higher levels of erythritol (a sugar alcohol), which is a growth stimulant for the organism. *Brucella* utilizes erythritol preferentially over glucose as an energy source. Placentas and male genitalia also contain high levels of erythritol. *Brucella* organisms also evade lysis when phagocytosed by macrophages and neutrophils and survive intracellularly in phagosomes. Abortion is the result of placentitis, typically during the third trimester of gestation. *Brucella ovis* enters the host through the mucous membranes, then passes into the lymphatics, causes hyperplasia of reticuloendothelial cells, and is spread to various organs via the blood. The organism localizes in the epididymides, the seminal vesicles, the bulbourethral glands, and the ampullae. Orchitis may be a sequelae of the disease. Epididymitis can be diagnosed by identifying gross lesions by palpation of the epididymides, by serological evidence of antibodies to *B. ovis,* and by semen cultures.

Differential diagnosis. Differential diagnoses include all other abortion-causing diseases. Many other agents, such as *Actinobacillus* spp., *Arcanobacterium (Actinomyces) pyogenes, Eschericia coli, Pseudomonas* spp., *Proteus mirabilis, Chlamydia, Mycoplasma,* and others may be associated with ovine epididymitis and orchitis. A clinically and pathologically similar agent, *Actinobacillus seminis,* has been isolated from virgin rams. This organism has morphological and staining characteristics similar to those of *B. ovis* and complicates the diagnosis (Genetzky, 1995).

Prevention and control. The Rev 1 vaccine has been recommended for vaccination of ewe lambs in endemic areas, but this vaccine is not used in the United States. Separating young rams from potentially infected older males, sanitizing facilities, and vaccinating them with *B. ovis* bacterin can prevent the disease. Over the past 20 years, aggressive federal and state regulatory and cattle herd health programs in the United States have provided control and prevention mechanisms for this pathogen through a combination of serological monitoring of herds, slaughter of diseased animals, herd management, vaccination programs, and monitoring of transported animals. Most states are considered brucellosis-free in the cattle populations; thus, procurement of ruminants that have been exposed to this infectious agent will be unlikely. Cattle vaccination programs can be

very successful when conducted on a herd basis to reduce likelihood of exposure. Strain 19 and the recently validated attentuated strain RB51 are live vaccines and can be used in healthy heifer calves 4–12 months old. Vaccination for older animals may be done under certain circumstances. Vaccination of bull calves is not recommended, because of low likelihood of spread through semen and possibility of vaccination-induced orchitis. The strain 19 vaccine induces long-term cell-mediated immunity, protects a herd from abortions, and protects the majority of a herd from reactors during a screening and culling program. The vaccine will not, however, protect the animals from becoming infected with *B. abortus.*

Strain 19 vaccine induces an antibody response in cattle. The RB51 vaccine does not result in antibody titers and therefore is advantageous because infection with *Brucella* can be determined serologically. The RB51 vaccine has been designated as the official calfhood bovine brucellosis vaccine in the United States by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) (Stevens *et al.,* 1997).

Brucella vaccine should be administered to unstressed, healthy cattle, with attention to particular side effects of the vaccination material and to prevention of compounding stresses associated with weaning, regrouping, other management changes, and shipping. The RB51 is regarded as less pathogenic and abortigenic in cattle.

Treatment. Definite confirmation of *Brucella* infection is important from the standpoint of public and herd health. Culling is considered the treatment of choice in cattle herds. Rams infected with *B. ovis* should be isolated and treated with tetracyclines.

Research complications. Brucellosis represents a research complication as a cause of abortions and of infections in male ruminants. Impairment of the infected host's immune system, especially alteration of phagocytic cells where the bacteria stay in membrane-bound vesicles, should be considered. The potential complications of needle sticks by large-animal veterinarians with the strain 19 vaccine and the public health risks (undulant fever) are well known. Less is known presently regarding the RB51 vaccine effects in humans. Epidemiologic and diagnostic methodologies are being developed to track and monitor these cases. There is also a risk of human infection from handling infected materials during a dystocia or postmortem. Worldwide, *B. melitensis* is the leading cause of human brucellosis.

f. Campylobacteriosis (Vibriosis)

i. Campylobacter fetus subsp. intestinalis; C. jejuni infection (ovine vibriosis)

Etiology. Campylobacter (Vibrio) fetus subsp. *intestinalis,* a pleomorphic curved to coccoid, motile, non-spore-forming,

gram-negative bacterium, causes campylobacteriosis, the most important cause of ovine abortion in the United States. There are few reports of campylobacteriosis in goats in the United States. *Vibriosis* is derived from the name formerly given to the genus; the term is still frequently used.

Clinical signs and diagnosis. Ovine vibriosis is a contagious disease that causes abortion, stillbirths, and weak lambs. The organism inhabits the intestines and gallbladder in subclinical carriers. Abortion generally occurs in the last trimester, and abortion storms may occur as more susceptible animals, such as maiden ewes, become exposed to the infectious tissues. It is reported that 20–25% of the flock may become infected and up to 5% of the ewes will die (Jensen and Swift, 1982). Some lambs may be born alive but will be weak, and dams will not be able to produce milk.

Diagnosis is achieved by microscopic identification or isolation of the organism from placenta, fetal abomasal contents, and maternal vaginal discharges. Tentative identification of the organism can be made by observing curved ("gull-wing") rods in Giemsa-stained or Ziehl–Neelsen–stained smears from fetal stomach contents, placentomes, or maternal uterine fluids.

Epizootiology and transmission. Campylobacteriosis occurs worldwide. *Campylobacter* spp., such as *C. jejuni,* normally inhabit ovine gastrointestinal tracts. Transmission of the disease occurs through the gastrointestinal tract, followed by shedding, especially associated with aborted tissues and fluids. In abortion storms, considerable contamination of the environment will occur due to placenta, fetuses, and uterine fluids. Ewes may have active *Campylobacter* organisms in uterine discharges for several months after abortion. The bacteria will also be shed in feces, and feed and water contamination serve as another source. There is no venereal transmission in the ovine.

Necropsy. Aborted fetuses will be edematous, with accumulation of serosanguinous fluids within the subcutis and muscle tissue fascia. The liver may contain 2–3 cm pale foci. Placental tissues will be thickened and edematous and will contain serous fluids similar to those of the fetus. The placental cotyledons may appear gray.

Pathogenesis. The organism enters the bloodstream and causes a short-term bacteremia (1–2 weeks) prior to the localizing of the bacteria in the chorionic epithelial cells and finally passing into the fetus.

Differential diagnosis. *Toxoplasma, Chlamydia,* and *Listeria* should be considered in late gestation ovine abortions.

Prevention and control. A bacterin is available to prevent the disease. Carrier states have been cleared by treating with a combination of antibiotics, including penicillin and oral chlortetra-cycline. Aborting ewes should be isolated immediately from the rest of the flock. After an outbreak, ewes will develop immunity lasting 2–3 years.

Treatment. Infected animals should be isolated and provided with supportive therapy. Prompt decontamination of the area and disposal of the aborted tissues and discharges are important.

Research complications. Losses from abortion may be considerable. *Campylobacter* ssp. are zoonotic agents, and *C. fetus* subsp. *intestinalis* may be the cause of "shepherd's scours."

ii. Campylobacter fetus subsp. venerealis infection (bovine vibriosis)
Etiology. *Campylobacter fetus* subsp. *venerealis* is the main cause of bovine campylobacteriosis abortions. It does not cause disease in other ruminant species.

Clinical signs and diagnosis. Preliminary signs of a problem in the herd will be a high percentage of cows returning to estrus after breeding and temporary infertility. This will be particularly apparent in virgin heifers that may return to estrus by 40 days after breeding. Long interestrous intervals also serve an indication of a problem. Spontaneous abortions will occur in some cases, typically during the fourth to eighth months of gestation. Severe endometritis may lead to salpingitis and permanent infertility.

Demonstration or isolation of the organism, a curved rod with corkscrew motility, is the basis for diagnosis. The vaginal mucous agglutination test is used to survey herds for campylobacteriosis. Serology will not be worthwhile, because the infection does not trigger a sufficient antibody response. Culture from breeding animals may be difficult because *Campylobacter* will be overgrown by faster-growing species also present in the specimens.

Epizootiology and transmission. The bacteria is an obligate, ubiquitous organism of the genital tract. Transmission is from infected bulls to heifers. Older cows develop effective immunity.

Necropsy findings. Necrotizing placentitis, dehydration, and fibrinous serositis will be found grossly. In addition, bronchopneumonia and hepatitis will be seen histologically.

Pathogenesis. *Campylobacter* organisms grow readily in the genital tract, and infection is established within days of exposure. The resulting endometritis prevents conception or causes embyronic death.

Differential diagnosis. The primary differential diagnosis for campylobacteriosis is trichomoniasis. Other venereal diseases

should be considered when infertility problems are noted in a herd. These include brucellosis, mycoplasmosis, ureaplasmosis, infectious bovine rhinotracheitis–infectious pustular vulvovaginitis (IBR-IPV), and bovine virus diarrhea (BVD). Leptospirosis should also be considered. In addition, management factors such as nutrition and age of heifers at introduction to the herd should be considered.

Prevention and control.   Killed bacterin vaccines are available, either as oil adjuvant or as aluminum hydroxide adsorbed. The former is preferred because of duration of immunity but causes granulomas. That vaccine also has specific recommendations regarding administration several months before the breeding season. The latter product is administered closer to the breeding season, and the duration of immunity is not as prolonged. In both cases, boosters should be given after the initial immunization and as part of the regular prebreeding regimen. Only one bacterin product is approved for use in bulls. Many combination vaccine products contain only the aluminum hydroxide adsorbed product. Artificial insemination (AI) is particularly useful at controlling the disease, but bulls used for AI must be part of a screening program for this and other venereal diseases such as trichomoniasis.

Treatment.   Cows will usually recover from the infection, and treatment with antibiotics such as penicillin, administered as an intrauterine infusion, improve the chances of returning to breeding condition.

g.   Caprine Staphylococcal Dermatitis

Etiology.   The most common caprine bacterial skin infection is caused by *Staphylococcus intermedius* or *S. aureus* and is known as staphylococcal dermatitis (Smith and Sherman, 1994). The *Staphylococcus* organisms are cocci and are categorized as primary pathogens or ubiquitous skin commensals of humans and animals. *Staphylococcus aureus* and *S. intermedius* are classified as primary pathogens and produce coagulase, a virulence factor.

Clinical signs and diagnosis.   Small pustular lesions, caused by bacterial infection and inflammation of the hair follicle, occur around the teats and perineum. Occasionally, the infection may involve the flanks, underbelly, axilla, inner thigh, and neck. Staphylococcal dermatitis may occur secondary to other skin lesions. Diagnosis is based on lesions. Culture will distinguish *S. aureus*.

Pathogenesis.   Simple boredom may cause rubbing, followed by staphylococcal infection of damaged epidermis.

Differential diagnosis.   The presence of scabs makes contagious ecthyma a differential diagnosis, along with fungal skin infections and nutritional causes of skin disease.

Treatment.   Severe infections should be treated with antibiotics based on culture and sensitivity. Severe lesions and lesions localized to the underbelly, thighs, and udder benefit by periodic cleaning with an iodophor shampoo and spraying with an antibiotic and an astringent (Smith and Sherman, 1994).

h.   Clostridial Diseases

i.   Clostridium perfringens type C infection (enterotoxemia and struck)

Etiology.   *Clostridium perfringens* is an anaerobic, grampositive, nonmotile, spore-forming bacterium that lives in the soil, in contaminated feed, and in gastrointestinal tracts of ruminants. The bacteria is categorized by toxin production. Toxins include alpha (hemolytic), beta (necrotizing), delta (cytotoxic and hemoltyic), epsilon, and iota. Types of *C. perfingens* are A, B, C, D, and E. This is a common and economically significant disease of sheep, goats, and cattle.

Clinical signs and diagnosis.   The beta toxin associated with overgrowth of this bacterium results in a fatal hemorrhagic enterocolitis within the first 72 hr of a young ruminant's life. Many animals may be found dead, with no clinical presentation. Affected animals are acutely anemic, dehydrated, anorexic, restless, and depressed and may display tremors or convulsions as well as abdominal pain. Feces may range from loose gray-brown to dark red and malodorous. Morbidity and mortality may be nearly 100%.

A similar noncontagious but acutely fatal form of enterotoxemia in adult sheep, called struck, occurs in yearlings and adults. Struck is rare in the United States. The disease is also caused by the beta toxin of *C. perfringens* type C and is often associated with rapid dietary changes or shearing stresses in sheep. Although affected animals are usually found dead, clinical signs include uneasiness, depression, and convulsions. Mortality is usually less than 15%.

Diagnosis is usually based on necropsy findings, although confirmation can be made by culture of the organism. Identification of the beta toxin in intestinal contents may be difficult because of instability of the toxin.

Epizootiology and transmission.   Clostridial organisms are ubiquitous in the environment as well as in the gastrointestinal tract and contaminated feeds. Confinement and poor sanitation predisposes to infection with *C. perfringens*. Transmission is by ingestion of contaminated material.

Necropsy findings.   Necropsy findings include a milk-filled abomasum, and hemorrhage in the distal small intestine and throughout the large intestine. Petechial hemorrhages of the serosal surfaces of many organs, especially the thymus, heart, and gastrointestinal tract, will be visible. Hydropericardium, hydroperitoneum, and hemorrhagic mesenteric lymph nodes will also be present. Pulmonary and brain edema may also be

seen. Histologically, the gram-positive *C. perfringens* organisms may be visible in excess numbers along the mucosal surface of the swollen, congested, necrotic intestines.

In cases of struck, necropsy findings include congestion and erosions of the mucosa of the gastrointestinal tract, serosal hemorrhages, and serous peritoneal and pericardial fluids. In late stages of the disease and especially if prompt necropsy is not performed, the organism will infiltrate the muscle fascial layers and produce serohemorrhagic and gaseous infiltration of perimysial and epimysial spaces.

Pathogenesis. Hemorrhagic enterotoxemia is an acute, sporadic disease caused by the beta toxin of *Clostridium perfringens* type C. Neonates ingest the organism, which then proliferates and attaches to the gastrointestinal microvilli and elaborates primarily the beta toxins. The trypsin inhibitors present in colostrum prevent inactivation of the beta toxin. The toxins injure intestinal epithelial cells and then enter the blood, leading to acute toxemia. The intestinal injury may result in diarrhea, with small amounts of hemorrhage. Associated electrolyte and water loss result in dehydration, acidosis, and shock.

Differential diagnosis. Differential diagnoses include other clostridial diseases such as blackleg and black disease, as well as coccidiosis, salmonellosis, anthrax, and acute poisoning.

Prevention and control. A commercial toxoid is available and should be administered to the pregnant animals prior to parturition. An alternative includes administration of an antitoxin to the newborn lambs. The disease may become endemic once it is on the premises.

Treatment. Treatment is difficult and usually unsuccessful. Antitoxin may be useful in milder cases, and the antitoxin and toxoid can also be administered during an outbreak.

Research complications. This disease can be costly in losses of neonates and younger animals.

ii. Clostridium perfringens type D infection (pulpy kidney disease)

Etiology. *Clostridium perfringens* type D releases epsilon toxin that is proteolytically activated by trypsin. This disease caused by *C. perfringens* tends to be associated with sheep and is of less importance in goats and cattle.

Clinical signs. The peracute condition in younger animals is characterized by sudden deaths, which are occasionally preceded by neurological signs such as incoordination, opisthotonus, and convulsions. Because the disease progresses so rapidly to death (within 1–2 hr), clinical signs are rarely observed. Hypersalivation, rapid respirations, hyperthermia, convulsions, and opisthotonus have been noted. In acute cases, hyperglycemia and glucosuria are considered almost pathognomonic.

Clinical signs in chronic cases in older animals, such as adult goats, include soft stools, weight loss, anorexia, depression, and severe diarrhea, sometimes with mucus and blood. Mature affected sheep may be blind and anorectic and may head-press.

Necropsy findings. Necropsy findings are similar to those seen with *C. perfringens* type C. Additionally, extremely necrotic, soft kidneys ("pulpy kidneys") are usually observed immediately following death. (This phenomenon is in contrast to what is normally associated with later stages of postmortem autolysis.) Focal encephalomalacia, and petechial hemorrhages on serosal surfaces of the brain, diaphragm, gastrointestinal tract, and heart are common findings. Diagnosis can be made from the typical clinical signs and necropsy findings as well as the observation of glucose in the urine at necropsy.

Pathogenesis. The epsilon toxin causes neuronal death and shock, probably through vascular damage. The noncontagious, peracute form of enterotoxemia occurs in suckling, fast-growing animals, either nursing from their dams or on high-protein, high-energy concentrates. The largest, fastest-growing animals generally are predisposed to this condition; for example, lambs, fat ewe lambs, and usually singleton lambs tend to be most susceptible. The hyperglycemia and glucosuria seen in acute cases are due to epsilon toxin effects on liver glycogen metabolism.

Differential diagnosis. Tetanus, enterotoxigenic *E. coli*, botulism, polioencephalomalacia, grain overload, and listeriosis are differentials.

Prevention and control. Vaccination prevents the disease. Maternal antibodies last approximately 5 weeks postpartum; thus young animals should be vaccinated at about this time. Feeding regimens to young, fast-growing animals and feeding of concentrates to adults should be evaluated carefully.

Treatment. Treatment consists of support (fluids, warmth), antitoxin administration, oral antibiotics, and diet adjustment.

iii. Clostridium tetani infection (tetanus, lockjaw)

Etiology. *Clostridium tetani* is a strictly anaerobic, motile, spore-forming, gram-positive rod that persists in soils and manure and within the gastrointestinal tract. At least 10 serotypes of *C. tetani* exist.

Clinical signs. Infection by *C. tetani* is characterized by a sporadic, acute, and fatal neuropathy. After an incubation period of 4 days to 3 weeks, the animal exhibits bloat; muscular spasticity; prolapse of the third eyelid; rigidity and extension of the limbs, leading to a stiff gate; an inability to chew; and hyperthermia. Erect or drooped ears, retracted lips, drooling, hypersensitivity to external stimuli, and a "sawhorse" stance are frequent signs. The animal may convulse. Death occurs within 3–10 days, and mortality is nearly 100%, primarily from

respiratory failure. Diagnosis is based on clinical signs. Muscle-related serum enzymes such as aspartate aminotransferase (AST), creatinine kinase (CK), and lactate dehydrogenase (LDH) might be elevated. (Jensen and Swift, 1982). Serum cortisol may also be elevated, and stress hyperglycemia may be evident. Permanent lameness may result in survivors.

Epizootiology and transmission. *Clostridium tetani* is a soil contaminant and is often found as part of the gut microflora of herbivores. The organisms sporulate and persist in the environment. All species of livestock are susceptible, but sheep and goats are more susceptible than cattle. Individual cases may occur, or herd outbreaks may follow castration, tail docking, ear tagging, or dehorning. Mouth wounds may also be sites of entry.

Pathogenesis. Tetanus, or lockjaw, is caused by the toxins of *C. tetani.* All serovars produce the same exotoxin, which is a multiunit protein composed of tetanospasmin, which is neurotoxic, and tetanolysin, which is hemolytic. A nonspasmogenic toxin is also produced. Contamination of wounds results in anaerobic proliferation of the bacterium and liberation of the tetanospasmin, which diffuses through motor neurons in a retrograde direction to the spinal cord. The toxin inhibits the release of glycine and γ-aminobutyric acid from Renshaw cells; this results in hypertonia and muscular spasms. Proliferation of *C. tetani* in the gut of affected animals may also serve as a source and may produce clinical signs. The uterus is the most common site of infection in postparturient dairy cattle with retained placentas.

Differential diagnoses. Early in the course of the infection, differential diagnoses include bloat, rabies, hypomagnesemic tetany, polioencephalomalacia, white muscle disease, enterotoxemia in lambs, and lead poisoning. Polyarthritis of cattle is a differential for the gait changes in that species.

Necropsy findings. Findings are nonspecific except for the inflammatory reaction associated with the wound. Because of the low number of organisms necessary to cause neurotoxicosis, isolation of *C. tetani* from the wound may be difficult.

Treatment. Treatment consists of cleaning the infected wound; administering tetanus antitoxin (e.g., at least 500 IU in an adult sheep or goat); vaccinating with tetanus toxoid; administering of antibiotics (penicillin, both parenterally [potassium penicillin intravenously and procaine penicillin intramuscularly] and flushed into the cleaned wound), a sedative or tranquilizer (e.g., acepromazine or chlorpromazine) and a muscle relaxant; and keeping the animal in a dark, quiet environment. Supportive fluids and glucose must be administered until the animal is capable of feeding. If the animal survives, revaccination should be done 14 days after the previous dose.

Prevention and control. Like other ubiquitous clostridial diseases, tetanus is impossible to eradicate. The disease can be controlled and prevented by following good sanitation measures, aseptic surgical procedures, and vaccination programs. Tetanus toxoid vaccine is available and very effective for stimulating long-term immunity. Tetanus antitoxin can be administered (200 IU in lambs) as a preventive or in the face of disease as an adjunct to therapy. Both the toxoid and the antitoxin can be administered to an animal at the same time, but they should not be mixed in the syringe, and each should be administered at different sites, with a second toxoid dose administered 4 weeks later. Animals should be vaccinated 2 or 3 times during the first year of life. Does and ewes should receive booster vaccinations within 2 months of parturition to ensure colostral antibodies.

Research complications. Unprotected, younger ruminants may be affected following routine flock or herd management procedures. Contaminated or inadequately managed open wounds or lesions in older animals may provide anaerobic incubation sites.

iv. Clostridium novyi infection (bighead; black disease; bacillary hemoglobinuria, or red water) and C. chauvoei infection (blackleg)

Etiology. *Clostridium novyi,* an anaerobic, motile, spore-forming, gram-positive bacteria, is the agent of bighead and black disease. *Clostridium novyi* type D (*C. hemolyticum*) is the cause of bacillary hemoglobinuria, or "red water." *Clostridium chauvoei* is the causative agent of blackleg.

Clinical signs. Bighead is a disease of rams characterized by edema of the head and neck. The edema may migrate to ventral regions such as the throat. Additional clinical signs include swelling of the eyelids and nostrils. Most animals will die within 48–72 hours. Black disease, or infectious necrotic hepatitis, is a peracute, fatal disease associated with *C. novyi.* It is more common in cattle and sheep but may be seen in goats. The clinical course is 1–2 days in cattle and slightly shorter in sheep. Otherwise healthy-appearing adult animals are often affected. Clinical signs are rarely seen, because of the peracute nature of the disease. Occasionally, hyperthermia, tachypnea, inability to keep up with other animals, and recumbency are observed prior to death. Bacillary hemoglobinuria is an acute disease seen primarily in cattle and characterized by fever and anorexia, in addition to the hemoglobinemia and hemoglobinuria indicated by the name. Animals that survive a few days will develop icterus. Mortality may be high.

Blackleg, a disease similar to bighead, causes necrosis and emphysema of muscle masses, serohemorrhagic fluid accumulation around the infected area, and edema (Jackson *et al.,* 1995). Blackleg is more common in cattle than in sheep. The incubation period is 2–5 days and is followed by hyperthermia,

muscular stiffness and pain, anorexia, and gangrenous myositis. The clinical course is short, 24–48 hr, and untreated animals invariably die. Blackleg in cattle can be associated with subcutaneous edema or crepitation; these do not usually occur in sheep. Most lesions are associated with muscles of the face, neck, perineum, thigh, and back.

Epizootiology and transmission. Bighead is caused by the toxins of *C. novyi*, which enters through wounds often associated with horn injuries during fighting. The *C. novyi* type B organisms produce alpha and beta toxins, and the alpha toxins are mostly responsible for toxemia, tissue necrosis, and subsequent death. *Clostridium novyi* type D is endemic in the western United States. It is hypothesized that the *C. chauvoei* organisms enter through the gastrointestinal tract. Black disease and bacillary hemoglobinuria are associated with concurrent liver disease, often associated with *Fasciola* infections (liver flukes); it is sometimes seen as a sequela to liver biopsies. The diseases are more common in summer months, and fecal contamination of pastures, flooding, and infected carcasses are sources of the organism. Birds and wild animals may be vectors of the pathogen. Ingested spores are believed to develop in hepatic tissue damaged and anoxic from the fluke migrations.

Necropsy. Diagnosis of black disease is usually based on postmortem lesions. Subcutaneous vessels will be engorged with blood, resulting in dried skin with a dark appearance. Carcasses putrefy quickly. In addition, hepatomegaly and endocardial hemorrhages are common, and hepatic damage from flukes may be so severe that diagnosis is difficult. Blood coagulates slowly in affected animals.

Pathogenesis. The propagation of the clostridial organisms is self-promoted by the damage caused by the toxins and the increased local anaerobic environment created. *Clostridium novyi* proliferates in the soft tissues of the head and neck, and the resultant clostridial toxin causes increased capillary permeability and the liberation of serous fluids into the tissues. Mixed infections with related clostridial organisms may lead to increasing hemorrhage and necrosis in the affected tissues. Diagnosis is based on clinical signs. In black disease and bacillary hemoglobinuria disease, the ingested clostridial spores are absorbed, enter the liver, and cause hepatic necrosis. Associated toxemia causes subcutaneous vascular dilatation; increased pericardial, pleural, and peritoneal fluid; and endocardial hemorrhages. The toxins produced by *C. novyi*, identified as beta, eta, and theta, and each having enzymatic or lytic properties or both, also contribute to the hemolytic disease. *Clostridium chauvoei* spores proliferate in traumatized muscle areas damaged by transportation, rough handling, or injury.

Differential diagnosis. Differential diagnoses include other clostridial diseases as well as photosensitization. Hemolytic diseases such as babesiosis, leptospirosis, and hemobartonellosis should be included as differentials.

Treatment. For *C. chauvoei* infection (blackleg), early treatment with penicillin or tetracycline may be helpful. Treatment for black disease is not rewarding even if the animal is found before death. Carcasses from bacillary hemoglobinuria losses should be burned, buried deeply, or removed from the premises.

Prevention and control. Vaccinating animals with multivalent clostridial vaccines can prevent these diseases. Subcutaneous administration of vaccine material is recommended over intramuscular. Vaccinations may be useful in an outbreak. Careful handling of ruminants during shipping and transfers will contribute to fewer muscular injuries. For bighead, mature rams penned together should be monitored for lesions, especially during breeding season. Control of fascioliasis is very important in prevention and control of black disease and in the optimal timing of vaccinations.

v. Clostridium septicum infection (malignant edema)
Etiology. *Clostridium septicum* is the species usually associated with malignant edema, but mixed infections involving other clostridial species such as *C. chauvoei, C. novyi, C. sordellii,* and *C. perfringens* may occur. *Clostridium* spp. are motile (*C. chauvoei, C. septicum*) or nonmotile, anaerobic, spore-forming, gram-positive rods.

Clinicial signs. Malignant edema, or gas gangrene, is an acute and often fatal bacterial disease caused by *Clostridium* spp. The incubation period is approximately 2–4 days. The affected area will be warm and will contain gaseous accumulations that can be palpated as crepitation of the subcutaneous tissue around the infected area. Regional lymphadenopathy and fever may occur. The animal becomes anorexic, severely depressed, and possibly hyperthermic. Edema and crepitation may be noted around the wound; death occurs within 12 hr to 2 days.

Epizootiology and transmission. The organisms are ubiquitous in the environment and may survive in the soil for years. The disease is especially prevalent in animals that have had recent wounds such as those that have undergone castration, docking, ear notching, shearing, or dystocia.

Necropsy findings. The tissue necrosis and hemorrhagic serous fluid accumulations resemble those of other clostridial diseases.

Pathogenesis. In most cases, the clostridial organisms cause a spreading infection through the fascial planes around the area of the injury; vegetative organisms then produce potent exotoxins, which result in necrosis (alpha toxin) and/or hemolysis (beta toxin). Furthermore, the toxins enter the bloodstream and

central nervous system, resulting in systemic collapse and high mortality.

Necropsy. Spreading, crepitant lesions around wounds are suggestive of malignant edema. Affected tissues are inflamed and necrotic. Gas and serosanguineous fluids with foul odors infiltrate the tissue planes. Large rod-shaped bacteria may be observed on histopathology; confirmation is made through culture and identification. Intramuscular inoculation of guinea pigs causes a necrotizing myositis and death. Organisms can be cultured from guinea pig tissues.

Treatment. Infected animals can be treated with large doses of penicillin and fenestration of the wound is recommended.

Prevention and control. Proper preparation of surgical sites, correct sanitation of instruments and the housing environment, and attention to postoperative wounds will help prevent this disease. Multivalent clostridial vaccines are available.

Research complications. Morbidity or loss of animals from lack of or unsuccessful vaccination and from contaminated surgical sites or wounds may be consequences of this disease.

i. Colibacillosis

Etiology. *Escherichia coli* is a motile, aerobic, gram-negative, non-spore-forming coccobacillus commonly found in the environment and gastrointestinal tracts of ruminants. *Escherichia coli* organisms have three areas of surface antigenic complexes (O, somatic; K, envelope or pili; and H, flagellar), which are used to "group" or classify the serotypes. *Colibacillosis* is the common term for infections in younger animals caused by this bacteria.

Clinical signs. Presentation of *E. coli* infections vary with the animal's age and the type of *E. coli* involved. Enterotoxigenic *E. coli* infection causes gastroenteritis and/or septicemia in lambs and calves. Colibacillosis generally develops within the first 72 hr of life when newborn animals are exposed to the organism. The enteric infection causes a semifluid, yellow to gray diarrhea. Occasionally blood streaking of the feces may be observed. The animal may demonstrate abdominal pain, evidenced by arching of the back and extension of the tail, classically described as "tucked up." Hyperthermia is rare. Severe acidosis, depression, and recumbancy ensue, and mortality may be as high as 75%. The septicemic form generally occurs between 2 and 6 weeks of age. Animals display an elevated body temperature and show signs suggestive of nervous system involvement such as incoordination, head pressing, circling, and the appearance of blindness. Opisthotonos, depression, and death follow. Occasionally, swollen, painful joints may be observed with septicemic colibacillosis. Blood cultures may be helpful in identifying the septicemic form.

In ruminants, *E. coli* is is a less common cause of cystitis and pyelonephritis. The cystitis is characterized by dysuria and pollakiuria; gross hematuria and pyuria may be present. The infection may or may not be restricted to the bladder; in the later presentation, and in cases of pyelonephritis, a cow will be acutely depressed, have a fever and ruminal stasis, and be anorexic. In chronic cases, animals will be polyuric and undergo weight loss. *Escherichia coli* may also cause *in utero* disease in cattle, resulting in abortion or weakened offspring.

Epizootiology and transmission. *Escherichia coli* is one of the most common gram-negative pathogens isolated from ruminant neonates. Zeman *et al.* (1989) classify *E. coli* infections into four groups: enterotoxigenic, enterohemorrhagic, enteropathogenic, and enteroinvasive. Enterotoxigenic *E. coli* (ETEC) attach to the enterocytes via pili, produce enterotoxins, and are the primary cause of colibacillosis in animals and humans. Fimbrial (pili) antigens associated with ovine disease include K99 and F41. Enterohemorrhagic *E. coli* (EHEC) attach and efface the microvillus, produce verotoxins, and occasionally cause disease in humans and animals. Enteropathogenic *E. coli* (EPEC) colonize and efface the microvillus but do not produce verotoxins. EPEC are associated with disease in humans and rabbits and cause a secretory diarrhea. Enteroinvasive *E. coli* (EIEC) invade the enterocytes of humans and cause a shigella-like disease.

Overcrowding and poor sanitation contribute significantly to the development of this disease in young animals. The organism will be endemic in a contaminated environment and present on dams' udders. The bacteria rapidly proliferate in the neonates' small intestines. The bacteria and associated toxins cause a secretory diarrhea, resulting in the loss of water and electrolytes. If the bacteria infiltrate the intestinal barrier and enter the blood, septicemia results.

Diagnosis of the enteric form can be made by observation of clinical signs, including diarrhea and staining of the tail and wool.

Necropsy findings. Swollen, yellow to gray, fluid-filled small and large intestines, swollen and hemorrhagic mesenteric lymph nodes, and generalized tissue dehydration are common. Septicemic lambs may have serofibrinous fluid in the peritoneal, thoracic, and pericardial cavities; enlarged joints containing fibrinopurulent exudates; and congested and inflamed meninges. Isolation and serotyping of *E. coli* confirm the diagnosis. ELISA and latex agglutination tests are available diagnostic tools.

Differential diagnosis. Differential diagnoses include the enterotoxemias caused by *C. perfringens* type A, B, or C; *Campylobacter jejuni; Coccidia,* rotavirus, coronavirus, *Salmonella,* and *Cryptosporidia.* Other contributing causes of abomasal tympany in young ruminants, such as dietary changes, copper deficiency, excessive intervals between feedings of milk replacer, or feeding large volumes should be considered.

Prevention and control. The best preventive measures are maintenance of proper housing conditions, limiting overcrowding, and frequently sanitizing lambing areas. Attention to colostrum feeding techniques and colostral quality are important means of preventing disease. Treatment must include intravenous fluid hydration and reestablishment of acid–base and electrolyte abnormalities.

Treatment. Antibiotics such as trimethoprim-sulfadiazine, enrofloxacin, cephalothin, amikacin, and apramycin may be helpful; oral antibiotics are not recommended. Vaccines are available for prevention of colibacillosis in cattle.

j. Corynebacterium pseudotuberculosis Infection (Caseous Lymphadenitis)

Etiology. *Corynebacterium pseudotuberculosis* (previously *C. ovis*) are nonmotile, non-spore-forming, aerobic, short and curved, gram-positive coccobacilli. Caseous lymphadenitis (CLA) is such a common, chronic contagious disease of sheep and goats that any presentation of abscessing and draining lymph nodes should be presumed to be this disease until proven otherwise. The disease has been reported occasionally in cattle.

Clinical signs and diagnosis. Abscessation of superficial lymph nodes, such as the superficial cervical, retropharyngeal, subiliacs (prefemoral), mammary, superficial inguinals, and popliteal nodes, and of deep nodes, such as mediastinal and mesenteric lymph nodes, is typical. Radiographs may be helpful in identifying affected central nodes. Peripheral lymph nodes may erode and drain caseous, "cheesy," yellow-green-tan secretions. The incubation period may be weeks to months. Over time, an infected animal may become exercise-intolerant, anorexic, and debilitated. Fever, increased respiratory rates, and pneumonia may also be common signs. Exotoxin-induced hemolytic crises may occur occasionally. Morbidity up to 15% is common, and morbid animals will often eventually succumb to the disease.

Diagnosis is based on clinical lesions; ELISA serological testing is also available. Smears of the exudate or lymph nodes aspirates can be Gram-stained. Lymph node aspirates may also be sent for culturing.

Epizootiology and transmission. The organism can survive for 6 months or more in the environment and enters via skin wounds, shearing, fighting, castration, and docking. Ingestion and aerosolization (leading to pulmonary abscesses) have been reported as alternative routes of entry.

Necropsy findings. Disseminated superficial abscesses as well as lesions of the mediastinal and mesenteric lymph nodes will be identified. Cut surfaces of the affected lymph nodes may appear lamellated. Lungs, liver, spleen, and kidneys may also be affected. Cranioventral lung consolidation with hemorrhage, fibrin, and edema are seen histologically.

Pathogenesis. *Corynebacterium pseudotuberculosis* produces an exotoxin (phospholipase D) that damages endothelial and blood cell membranes. This process enhances the organisms' ability to withstand phagocytosis. The infection spreads through the lymphatics to local lymph nodes. The necrotic lymph nodes seed local capillaries and hematogenously and lymphatically spread the organisms to other areas, especially the lungs.

Differential diagnosis. Differentials include pathogens causing lymphadenopathy and abscessation.

Treatment. Antibiotic therapy is not usually helpful. Abscesses can be surgically lanced and flushed with iodine-containing and/or hydrogen peroxide solutions. Abscessing lymph nodes can be removed entirely from valuable animals. During warmer months, an insect repellent should be applied to and around healing lesions. All materials used to treat animals should be disposed of properly. Because of the contagious nature of the disease, animals with draining and lanced lesions should be isolated from CLA-negative animals at least until healed. Commercial vaccines are available (Piontkowski and Shivvers, 1998).

Prevention and control. Minimizing contamination of the environment, using proper sanitation methods for facilities and instruments, segregating affected animals, and taking precautions to prevent injuries are all important.

Research complications. This pathogen is a risk for animals undergoing routine management procedures or invasive research procedures, because of its persistence in the environment, its long clinical incubation period, and its poor response to antibiotics.

k. Corynebacterium renale, C. cystitidis, and C. pilosum Infections (Pyelonephritis; Posthitis and Ulcerative Vulvovaginitis)

Etiology. *Corynebacterium renale, C. cystitidis,* and *C. pilosum* are sometimes referred to as the *C. renale* group. These are piliated and nonmotile gram-positive rods and are distinguished biochemically. *Corynebacterium renale* causes pyelonephritis in cattle, and *C. pilosum* and *C. cystitidis* cause posthitis, also known as pizzle rot or sheath rot, in sheep and goats. In many references, all these clinical presentations are attributed to *C. renale.*

Clinical signs and diagnosis. Acute pyelonephritis is characterized by fever, anorexia, polyuria, hematuria, pyuria, and arched back posture. Untreated infections usually become

chronic, with weight loss, anorexia, and loss of production in dairy animals. Relapses are common, and some infections are severe and fatal. Diagnosis of pyelonephritis is based on urinalysis (proteinuria and hematuria) and rectal or vaginal palpation (assessing ureteral enlargement). Urine culturing may not be productive. In chronic cases, *E. coli* and other gram-negatives may be present.

Posthitis and vulvovaginitis are characteriazed by ulcers, crusting, swelling and pain. The area may have a distinct malodor. Necrosis and scarring may be sequelae of more severe infections. Fly-strike may also be a complication. Diagnosis is based on clinical signs and on investigation of feeding regimens.

Epizootiology and transmission.   Ascending urinary tract infections with cystitis, ureteritis, and pyelonephritis are widespread problems, but incidence is relatively low. The vaginitis and posthitis contribute to the venereal transmission, but indirect transmission is possible because the organisms are stable in the environment and present on the wool or scabs shed from affected animals. Posthitis occurs in intact and castrated sheep and goats.

Necropsy findings.   Pyelonephritis, multifocal kidney abscessation, dilated and thickened ureters, cystitis, and purulent exudate in many sections of the urinary tract are common finding at gross necropsy.

Pathogenesis.   *Corynebacterium renale* is a normal inhabitant of bovine genitourinary tracts. The pilus mediates colonization. Conditions such as trauma, urinary tract obstruction, and anatomic anomalies may predispose to infection. In addition, more basic pH urine levels may block some immune defenses. Infections ascend through the urinary tract. The bacteria are urease-positive when tested *in vitro,* and the ammonia produced *in vivo* during an infection damages mucosal linings, with subsequent inflammation.

Corynebacterium cystitidis and *C. pilosum* are normally found around the prepuce of sheep and goats. High-protein diets, resulting in higher urea excretion and more basic urine, are contributing factors. Posthitis and vulvovaginitis may develop within a week of change to the more concentrated or richer diet, such as pasture or the addition of high-protein forage. The ammonia produced irritates the preputial and vulvar skin, increasing the vulnerability to infection.

Differential diagnosis.   Urolithiasis is a primary consideration for these diseases. Contagious ecthyma should be considered for the crusting that is seen with posthitis and vulvovaginitis, although the lesions of contagious ecthyma are more likely to develop around the mouth. Ovine viral ulcerative dermatosis is also a differential for the lesions of posthitis and vulvovaginitis.

Prevention and treatment.   Because high-protein feed is often associated with posthitis and vulvovaginitis, feeding prac-

tices must be reconsidered. Clipping long wool and hair also is helpful.

Treatment.   Long-term (3 weeks) penicillin treatment is effective for pyelonephritis. Reduction of dietary protein, clipping and cleaning skin lesions, treating for or preventing fly-strike, and topical antibacterial treatments are effective for posthitis and vulvovaginitis; systemic therapy may be necessary for severe cases. Surgical debridement or correction of scarring may also be indicated in severe cases.

l.   Erysipelas

Etiology.   *Erysipelothrix rhusiopathiae* is a nonmotile, non-spore-forming, gram-positive rod that resides in alkaline soils.

Clinical signs.   *Erysipelothrix* causes sporadic but chronic polyarthritis in lambs less than 3 months of age. In older goats, erysipelas has been associated with joint infections.

Epizootiology and transmission.   The disease may follow wound inoculation associated with castration, docking, or improper disinfection of the umbilicus. Following wound contamination and a 1- to 5-day incubation period, the lamb exhibits a fever and stiffness and lameness in one or more limbs. Joints, especially the stifle, hock, elbow, and carpus, are tender but not greatly enlarged.

Necropsy findings.   Thickened articular capsules, mild increases in normal-appearing joint fluid and erosions of the articular cartilage are usually found. The joint capsule is infiltrated with mononuclear cells, but bacteria are difficult to find. Diagnosis is based on clinical signs of polyarthritis, and confirmation is made by culturing the organism from the joints.

Differential diagnosis.   Differential diagnoses include polyarthritis caused by chlamydia or other bacteria and stiffness caused by white muscle disease. Other bacteria causing septic joints include *Areanobacterium pyogenes* and *Fusobacterium necrophorum.* Caprine arthritis encephalitis (CAE) should also be considered.

Prevention and control.   Proper sanitation and prevention of wound contamination are important in preventing the infection in lambs. Screening of goat herds for CAE is recommended.

Treatment.   Erysipelas is sensitive to penicillin antibiotic therapy.

m.   Dermatophilosis (Cutaneous Streptothricosis, Lumpy Wool, Strawberry Foot Rot)

Etiology.   *Dermatophilus congolensis* is an aerobic, gram-positive, filamentous bacterium with branching hyphae. Dermatophilosis is a chronic bacterial skin disease characterized by

crustiness and exudates accumulating at the base of the hair or wool fibers (Scanlan *et al.,* 1984).

Clinical signs. Animals will be painful but will not be pruritic. Two forms of the disease exist in sheep: mycotic dermatitis (also known as lumpy wool) and strawberry foot rot. Mycotic dermatitis is characterized by crusts and wool matting, with exudates over the back and sides of adult animals and about the face of lambs. Strawberry foot rot is rare in the United States but is characterized by crusts and inflammation between the carpi and/or tarsi and the coronary bands. Animals will be lame. In goats and cattle, similar clinical signs of crusty, suppurative dermatitis are seen; the disease is often referred to as cutaneous streptothricosis in these species. Lesions in younger goats are seen along the tips of the ears and under the tail.

Diagnosis is based on clinical signs as well as the typical microscopic appearance on stained skin scrapings, cultures, and serology.

Epizootiology and transmission. The disease occurs worldwide, and the *Dermatophilus* organism is believed to be a saprophyte. Transmission occurs by direct or indirect contact and is aggravated by prolonged wet wool or hair associated with inclement weather. Biting insects may aid in transmission.

Necropsy findings. Lymphadenopathy as well as liver and splenic changes may be observed. Histopathologically, superficial epidermal layers are necrotic and crusted with serum, white blood cells, and wool or hair. Dermal layers are hyperemic and edematous and may be infiltrated with mononuclear cells.

Pathogenesis. Lesions typically begin around the muzzle and hooves and the dorsal midline.

Prevention and control. Potash alum and aluminum sulfate have been used as wool dusts in sheep to prevent dermatophilosis. Minimizing moist conditions is helpful in controlling and preventing the disease. In addition, controlling external parasites or other factors that cause skin lesions is important. Lesions will resolve during dry periods.

Treatment. Animals can be treated with antibiotics such as penicillin and oxytetracycline. Treating the animals with povidone-iodine shampoos or chlorhexidine solutions is also useful in clearing the disease.

n.   *Dichelobacter (Bacteroides) nodosus and Fuso-
bacterium necrophorum Infection (Virulent Foot Rot;
Contagious Foot Rot of Sheep and Goats; Foot Scald)*

Etiology. Two bacteria, *Dichelobacter (Bacteroides) nodosus* and *Fusobacterium necrophorum,* work synergistically in causing contagious foot rot in sheep and goats. Other organisms may be involved as secondary invaders. Both *Dichelobacter* and *Fusobacterium* are nonmotile, non-spore-forming, anaerobic, gram-negative bacilli. Foot rot is a contagious, acute or chronic dermatitis involving the hoof and underlying tissues (Bulgin, 1986). It is the leading cause of lameness in sheep. At least 20 serotypes of *Dichelobacter* are known. *Arcanobacterium pyogenes* may also contribute to the pathogenicity or to foot abscesses in goats. Foot scald, an interdigital dermatitis, is caused primarily by *D. nodosus* alone.

Clinical signs. Varying degrees of lameness are observed in all ages of animals within 2–3 weeks of exposure to the organisms. Severely infected animals will show generalized signs of weight loss, decreased productivity, and anorexia associated with an inability to move. The interdigital skin and hooves will be moist, with a distinct necrotic odor. Morbidity may reach 70% in susceptible animals. Diagnosis is based on clinical signs. Smears and cultures confirm the definitive agents. Clinical signs of the milder disease, foot scald, include mild lameness, redness and swelling, and little to no odor.

Epizootiology and transmission. *Fusobacterium necrophorum* is ubiquitous in soil and manure, in the gastrointestinal tract, and on the skin and hooves of domestic animals. In contrast, *Dichelobacter* contaminates the soil and manure but rarely remains in the environment for more than about 2 weeks. Some animals may be chronic carriers. Overcrowded, warm, and moist environments are key elements in transmission. Outbreaks are likely in the spring season. Shipping trailers and contaminated pens or yards should be considered also as likely sources of the bacteria.

Pathogenesis. Both organisms are transmitted to the susceptible animal by direct or indirect contact. The organisms enter the hoof through injuries or through sites where *Strongyloides papillosus* larvae have penetrated. *Fusobacterium necrophorum* initiates the colonization and is followed by *D. nodosus.* The latter attaches and releases proteases; these cause necrosis of the epidermal layers and separation of the hoof from the underlying dermis. The pathogenicity of the serotypes of *D. nodosus* is correlated with the production of these proteases and numbers of pili. Additionally, *F. necrophorum* causes a severe, damaging inflammatory reaction.

Differential diagnosis. Foot abscesses, tetanus, selenium/vitamin E deficiencies, copper deficiency, strawberry foot rot, bluetongue virus infection (manifested with myopathy and coronitis), and trauma are among the many differentials that must be considered.

Treatment. Affected animals are best treated by manually trimming the necrotic debris from the hooves, followed by application of local antibiotics and foot wraps. Systemic antibiotics

such as penicillin, oxytetracycline, and erythromycin may be used. Goats have improved dramatically when given a single dose of penicillin (40,000 U/kg) (Smith and Sherman, 1994). Footbaths containing 10% zinc sulfate, 20% copper sulfate, or 10% formalin (not legal in all states) can be used for treatment as well as for prevention of the disease. Affected animals should be separated from the flock. Vaccination has been shown to be effective as part of the treatment regimen. Some breeds of sheep and some breeds and lines of goats are resistant to infection. Individual sheep may recover without treatment or are resistant to infection.

Prevention and control.   Prevention and control programs involve scrutiny of herd and flock management; quarantine of incoming animals; vaccination; segregation of affected animals; careful and regular hoof trimming; discarding trimmings from known or suspected infected hooves; maintaining animals in good body condition; avoiding muddy pens and holding areas; and culling individuals with chronic and nonresponsive infections. *Dichelobacter nodosus* bacterins are commercially available; cross protection between serotypes varies. Biannual vaccinination in wet areas may be essential. Some breeds may develop vaccination site lumps. Footbaths of 10% zinc sulfate, 10% formalin (where allowed by state regulations), or 10% copper sulfate are also considered very effective preventive measures. Goats are less sensitive than sheep to the copper in the footbaths.

Research complications.   Treating and controlling foot rot is costly in terms of time, initial handling and treatments and their follow-up, housing space, and medications.

o.   *Fusobacterium necrophorum and Bacteroides melaninogenicus Infection (Foot Rot of Cattle, Interdigital Necrobacillosis of Cattle)*

Etiology.   Interdigital necrobacillosis of cattle is caused by the synergistic infection of traumatized interdigital tissues by *Fusobacterium necrophorum* and *Bacteroides melaninogenicus.* Like *F. necrophorum, B. melaninogenicus* is a nonmotile, anaerobic, gram-negative bacterium. *Dichelobacter nodosus,* the agent of interdigital dermatitis, may be present in some cases. This is a common cause of lameness in cattle.

Clinical signs.   Clinical signs include mild to moderate lameness of sudden onset. Hindlimbs are more commonly affected, and cattle will often flex the pastern and bear weight only on the toe. The interdigital space will be swollen, as will be the coronet and bulb areas. Characteristic malodors will be noted, but there will be little purulent discharge. In more severe cases, animals will have elevated body temperature and loss of appetite. The lesions progress to fissures with necrosis until healing occurs. The diagnosis is by the odor and appearance. Anaerobic culturing confirms the organisms involved.

Epizootiology and transmission.   Cases may be sporadic, or epizootics may occur. *Bos taurus* dairy breeds and animals with wide interdigital spaces are more commonly affected. The factors here are comparable to those present in foot rot of smaller ruminants.

Necropsy findings.   Findings at necropsy include dermatitis and necrosis of the skin and subcutaneous tissues. Although necropsy would rarely be performed, secondary osteomyelitis may be noted in severe cases by sectioning limbs.

Pathogenesis.   The bacteria enter through the skin of the interdigital area after trauma to the interdigital skin, from hardened mud, or from softening of the skin due to, for example, constant wet conditions in pens. Colonization leads to cellulitis. In addition, *F. necrophorum* releases a leukocidal exotoxin that reduces phagocytosis and causes the necrosis, whereas the tissues and tendons are damaged by the proteases and collagenases produced by *B. melaninogenicus.* Zinc deficiency may play a role in the pathogenesis in some situations.

Differential diagnoses.   The most common differentials for sudden lameness include hairy heel warts and subsolar abcesses. Bluetongue virus should also be considered. Grain engorgement and secondary infection from cracks caused by selenium toxicosis should also be considered. The exotic foot-and-mouth disease virus would be considered in areas where that pathogen is found.

Prevention and control.   As with foot rot in smaller ruminants, management of the area and herd are important. Paddocks and pens should be kept dry, well drained, and free of material that will damage feet. Footbaths and chlortetracycline in the feed have been shown to control incidence. Affected animals should be segregated during treatment. Chronically affected or severely lame animals should be culled. New cattle should be quarantined and evaluated.

Treatment.   Successful treatment regimens that result in healing within a week include cleaning the feet and trimming necrotic tissue; parenteral antimicrobials, such as oxytetracycline or procaine penicillin, or sulfonomethazine in the drinking water or tetracyclines in feed; and footbaths (such as 10% zinc sulfate, 2.5% formalin, or 5% copper sulfate) twice a day. In severe cases, more aggressive therapy such as bandaging the feet or wiring the digits together may be needed. Animals can recover without treatment but will be lame for several weeks. Acquired immunity is reported to be poor.

Research complications.   Research complications are comparable to those noted for foot rot in smaller ruminants.

p. Fusobacterium necrophorum infection (Foot Abscesses)

Fusobacterium necrophorum is also associated with foot abscesses, the infection of the deeper structures of the foot, in sheep and goats. Only one claw of the affected hoof may be involved. The animals will be three-legged lame, and the affected hoof will be hot. Pockets of purulent material may be in the heel or toe.

q. Heel Warts (Bovine Digital Dermatitis, Interdigital Papillomatosis, Papillomatous Digital Dermatitis, Foot Warts, Heel Warts, Hairy Foot Warts, Mortellaro's Disease)

Etiology. Bacteria such as *Fusobacterium* spp., *Bacteroides* spp., and *Dichelobacter nodosus* have been isolated from bovine heel lesions. Spirochete-like organisms have also been shown in the lesions of cows with papillomatous digital dermatitis (PDD), in the United States and Europe; these have culturing requirements similar to those of *Treponema* species.

Clinical signs. All lesions occur on the haired, digital skin. One or all feet may be affected. Most lesions occur on the plantar surface of the hindfoot (near the heel bulbs and/or extending from the interdigital space), but the palmar and dorsal aspect of the interdigital spaces may also be involved. Progression of lesions, typically over 2–3 weeks, includes erect hairs, loss of hair, and thickening skin. Moist plaques begin as red and remain red or turn gray or black. Exudate or blood may be present on the plaque. Plaques enlarge and "hairs" protrude from the roughened surface. Lesioned areas are painful when touched. The lesions may or may not be malodorous.

Epizootiology and transmission. Facility conditions and herd management are considered contributing factors. The following have been examined as contributing factors: nutrition, particularly zinc deficiency; poorly drained, low-oxygen, organic material underfoot; poor ventilation; rough flooring; damp and dirty bedding areas; and overcrowding. These interdigital lesions occur commonly in young stock and in dairy facilities throughout the world. The disease is seen only in cattle.

Pathogenesis. The organisms noted above, combined with poor facility and herd management, are critical in the pathogenesis.

Differential diagnosis. Differentials for lameness will include sole abscesses, laminitis, and trauma.

Prevention and control. Each facility and management condition noted above should be addressed in conjunction with appropriate antibiotic and/or antiseptic treatment regimens. All equipment used for hoof trimming must be cleaned and disinfected after every use. Trucks and trailers should also be sanitized between groups of animals.

Treatment. Antibiotic and antiseptic regimens have been used successfully for this problem. Antibiotics include parenteral cephalosporins and pencillins, as well as topical tetracyclines with bandaging. Antiseptic or antibiotic solutions in footbaths include tetracyclines, zinc sulfate, lincomycin, spectinomycin, copper sulfate, and formalin. The footbaths must be well maintained, minimizing contamination by feces and other materials. Tandem arrangements, such as the cleaning footbaths and then the medicated footbaths, and preventing dilution from precipitation are useful. Other treatments such as surgical debridement, cryotherapy, and caustic topical solutions have been successful.

Research complications. Infectious, contagious PPD is one of the major causes of lameness among heifers and dairy cattle and is a costly problem to treat. The outbreaks are generally worse in younger animals in chronically infected herds. The immune response is not well understood, and it may be temporary in older animals.

r. Haemophilus somnus infection (Thromboembolic Meningoencephalitis)

Etiology. *Haemophilus somnus* is a pleomorphic, nonencapsulated, gram-negative bacterium. Diseases caused by this organism include thromboembolic meningoencephalitis (TEME), septicemia, arthritis, and reproductive failures due to genital tract infections in males and females. *Haemophilus somnus* is a also major contributor to the bovine respiratory disease complex. *Haemophilus* spp. have been associated with respiratory disease in sheep and goats.

Clinical signs. The neurologic presentation may be preceded by 1–2 weeks of dry, harsh coughing. Neurologic signs include depression, ataxia, falling, conscious proprioceptive deficits; signs such as head tilt from otitis interna or otitis media, opisthotonus, and convulsions may be seen as the brain stem is affected. High fever, extreme morbidity, and death within 36 hr may occur. Respiratory tract infections are usually part of the complex with infectious bovine rhinotracheitis virus, bovine respiratory syncytial virus, bovine viral diarrhea virus, parainfluenza 3, *Mycoplasma*, and *Pasteurella*, and the synergism among these contributes to the signs of bovine respiratory disease complex (BRDC). In acute neurologic as well as chronic pneumonic infections, polyarthritis may develop. Abortion, vulvitis, vaginitis, endometritis, placentitis, and failure to conceive are manifestations of reproductive tract disease. In all cases, asymptomatic infections may also occur.

Diagnosis based on culture findings is difficult because *H. somnus* is part of the normal nasopharyngeal flora. Paired serum samples are recommended; single titers in some animals seem to be high because of passive immunity, previous vaccination, or previous exposure. In cases of abortion, other causes should be eliminated from consideration.

Epizootiology and transmission. Because the organism is considered part of the normal flora of cattle and can be isolated from numerous tissues, the distinction between the normal flora and the status of chronic carrier is not clear. Outbreaks are associated with younger cattle in feedlots in western United States, but stresses of travel and coinfection with other respiratory pathogens are involved in some cases. Adult cattle have also been affected. Vaccination for viral respiratory pathogens may increase susceptibility. Transmission is by respiratory and genital tract secretions. The organism does not persist in the environment.

Necropsy findings. Pathognomonic central nervous system lesions include multifocal red-brown foci of necrosis and inflammation on and within the brain and the meninges. Many thrombi with bacterial colonies will be seen in these affected areas. Ocular lesions may also be seen, including conjunctivitis, retinal hemorrhages, and edema. Usually animals with neurological disease will not have respiratory tract lesions. The respiratory tract lesions include bronchopneumonia and suppurative pleuritis. When combined with *Pasteurella* infection, the pathology becomes more severe. Aborted fetuses will not show lesions, but necrotizing placentitis will be evident histologically. Pure cultures of *H. somnus* may be possible from these tissues.

Pathogenesis. Inhalation of contaminated respiratory secretions from carrier animals is the primary means of transmission. The anatomical location of bacterial residence within the carriers has not been identified. After gaining access by way of the respiratory tract, the bacteria proliferate, and a bacteremia develops. The bacteria are phagocytosed by neutrophils but are not killed. The thrombosis formation is due to the adherence by the nonphagocytosed organisms to vascular endothelial cells, degeneration and desquamation of these cells, and exposure of subendothelial collagen, with subsequent initiation of the intrinsic coagulation pathway. Antigen–antibody complex formation, resulting in vasculitis, is also correlated with high levels of agglutinating antibodies.

Differential diagnosis. Differentials in all ruminants include other pathogens associated with neurological disease and respiratory disease such as *Pasteurella hemolytica, P. multocida,* and *P. aeruginosa.* In smaller ruminants, *Corynebacterium pseudotuberculosis* should be considered.

Prevention and control. Stressed animals or those exposed to known carriers can be treated prophylactically with tetracycline administered parenterally or orally (in the feed or water). The late-stage polyarthritis is resistant to antibiotic therapy, because of failure of the antibiotic to reach the site of infection. Planning vaccination programs carefully will decrease chances of outbreaks. For example, avoiding vaccinating animals for infectious bovine rhinotrachetitis and bovine viral diarrhea during

times of stress to the cattle is worthwhile. Killed whole-cell bacterins are commercially available; these have been shown to be effective in controlling the respiratory disease presentation. Control of other clinical aspects of the *H. somnus* disease by these bacterins has not been well described.

Treatment. Rapid treatment at the first signs of neurologic disease is important in an outbreak. *Haemophilus somnus* is susceptible to several antibiotics, such as oxytetracycline and penicillin, and these are often used in sequence until the cattle are recovered.

s. Leptospirosis

Etiology. Seven different species of the spirochete genus *Leptospira* are now recognized, and pathogenic serovars exist within each species; previously pathogenic leptospires were all classified as members of the species *L. interrogans.* The serovars *pomona, icterohaemorrhagiae, grippotyphosa, interrogans,* and *hardjo* are recognized pathogens. *Leptospira hardjo* and *L. pomona* are the serovars most commonly diagnosed in cattle, with *L. hardjo* causing endemic infection. *Leptospira hardjo* is also the major sheep serovar. Goats are susceptible to several serovars.

Clinical signs. Leptospirosis is a contagious but uncommon disease in sheep and goats. The disease may cause abortion, anemia, hemoglobinuria, and icterus and is often associated with a concurrent fever. After a 4- to 10-day incubation period, the organism enters the bloodstream and causes bacteremia, fever, and red-cell hemolysis. Leptospiremia may last up to 7 days. Immune stimulation is apparently rapid, and antibodies are detectable at the end of the first week of infection; cross-serovar protection does not occur. During active bacteremia, hemolysis may result in hemoglobin levels of 50% below normal. Hyperthermia, hemoglobinuria, icterus, and anemia may be observed during this phase, and ewes in late gestation may abort. Abortion usually occurs only once. Mortality rates of above 50% have been reported in infected ewes and lambs (Jensen and Swift, 1982). Subclinical infection is more common in nonpregnant and nonlactating animals. Sheep infected with leptospirosis may display a hemolytic crisis associated with IgM acting as a cold-reacting hemagglutinin.

Acute and chronic infections in cattle are more common than infections in sheep and goats. Acute forms in cattle display signs similar to those in sheep. Acute infection in calves may progress to meningitis and death. Lactating cows will have severe drops in production. Chronic cases may lead to abortion, with retained placenta, and weakened calves or animals that carry the infection. Infertility may also be a sequela.

Epizootiology and transmission. Leptospires are a large genus, and leptospirosis is a complicated disease to prevent,

treat, and control. The organism survives well in the environment, especially in moist, warm, stagnant water. Cattle, swine, and other domestic and wild animals are potential carriers of serovars common to particular regions. Wild animals often serve as maintenance hosts, but domestic livestock may be reservoirs also. Organisms are shed in urine, in uterine discharges, and through milk. Animals become carriers when they are infected with a host-adapted serovar; sporadic clinical disease is more commonly associated with exposure to a non-host-adapted serovar (Heath and Johnson, 1994). Infection may occur via oral ingestion of contaminated feed and water, via placental fluids, or through the mucous membranes of the susceptible animal. Placental or venereal transmission may occur. As the organisms are cleared from the bloodstream, they chronically infect the renal convoluted tubules and the reproductive tract (and occasionally the cerebrospinal fluid or vitreous humor). Chronically infected animals may shed the organism in the urine for 60 days or longer.

Necropsy. Diagnosis is confirmed by identification of leptospires in fetal tissues. The leptospires are visible in silver- or fluorescent antibody-stained sections of liver or kidney. Leptospires may also be seen under dark-field or phase-contrast microscopy of fetal stomach contents. Fetal and maternal serology, and diagnostic tests such as the microscopic agglutination test, are useful; interpretation is complicated because of cross reaction of antibodies to many serovars.

Differential diagnosis. More than one serovar may cause infection in one animal, and each serovar should be considered as a separate pathogen. Because of the associated anemia, differential diagnoses should include copper toxicity and parasites, in addition to other abortifacient diseases.

Prevention and control. Polyvalent vaccines, tailored to common serovars regionally, are available and effective for preventing leptospirosis in cattle. Immunity is serovar specific. Because serological titers tend to diminish rapidly (40–50 days in sheep [Jensen and Swift, 1982]), frequent vaccination may be necessary. Other prevention measures such as species-specific housing, control of wild rodents, and proper sanitation should be instituted.

Treatment. Antibiotic treatment is aimed at treating ill animals and trying to clear the carrier state. Treatment methods for acute leptospirosis include oxytetracycline for 3–6 days. Addition of oxytetracycline or chlortetracycline to the feed for 1 week may be helpful. These antibiotics are considered best for removal of the carrier state of some serovars. Vaccination and antibiotic therapy can be combined in an outbreak.

Research complications. Leptospirosis is zoonotic and may be associated with flulike symptoms, meningitis, or hepatorenal failure in humans.

t. Listeria (Circling Disease, Silage Disease)

Etiology. *Listeria monocytogenes* is a pleomorphic, motile, non-spore-forming, β-hemolytic, gram-positive bacillus that inhabits the soil for long periods of time and has been often found in fermented feedstuffs such as spoiled silage. Of the 16 known serovars, several produce clinical signs in ruminants. *Listeria ivanovii* (associated with abortions in sheep) is serovar 5.

Clinical signs. Listeriosis is an acute, sporadic, noncontagious disease associated with neurological signs or abortions in sheep and other ruminants. The overall case rate is low. The disease may present as an isolated case or with multiple animals affected. Three forms of disease are described: encephalitis, placentitis with abortion, and septicemia with hepatitis and pneumonia. The encephalitic form is most common in sheep; septicemic forms may occur in neonatal lambs (Scarratt, 1987). Clinically, the encephalitic form begins with depression, anorexia, and mild hyperthermia after an incubation period of 2–3 weeks. As the disease progresses, animals exhibit nasal discharges and conjunctivitis and begin to walk in circles, as if disoriented. Facial paralytic lesions, including drooping of an ear or eyelid, dilation of a nostril, or strabismus occur unilaterally on the affected side as the result of dysfunction of some or all the cranial nerves V–XII. The neck will by flexed away from the affected side. Facial muscle twitching, protrusion of the tongue, dysphagia, hypersalivation, and nasal discharges may be noted. The hypersalivation may lead to metabolic acidosis in advanced cases in cattle. Anorexia, prostration, coma, and death follow. The placental form usually results in last-trimester abortions in ewes and does, which typically survive this form of the disease. The affected females may be asymptomatic or may show severe clinical signs such as fever and depression, with subsequent retained placenta or endometritis. Abortion usually occurs within 2 weeks of *Listeria* infection. In cattle, abortion occurs during the last 2 months of gestation and has been induced experimentally 6–8 days after exposure. Cows present with the range of clinical signs seen in smaller-ruminant dams. There is no long-term effect on the fertility of affected dams.

Epizootiology and transmission. The organism is transmitted by oral ingestion of contaminated feeds and water or possibly by inhalation. By the oral route, the organism enters through breaks in the oral cavity and ascends to the brain stem by way of nerves. When severe outbreaks occur, feedstuffs should be assessed for spoilage. *Listeria* organisms can be shed by asymptomatic carriers, especially at the end of pregnancy and at lambing.

Diagnosis and necropsy findings. Diagnosis is usually made from clinical signs. Culture confirms the diagnosis (cold enrichment at 20°C is preferable but not essential for isolation). Impression smears will show the pleomorphic gram-positive

characterisitics of the pathogen. Tissue fluorescent antibody techniques may also be utilized. Gross lesions are not observed with the encephalitic form. Microscopic lesions include thrombosis, neutrophilic or mononuclear foci in areas of inflammation, and neuritis. The pons, medulla, and anterior spinal cord are primarily affected in the encephalitic form. Microabscesses of the midbrain are characteristic of *Listeria* encephalitis in sheep. Aborted fetuses that are intact may show fibrinous polyserositis, with excessive serous fluids; small, necrotic foci of the liver; and small abomasal erosions. Necrotic lesions of the fetal spleen and lungs may also be seen. In goats, *Listeria*-induced neurological lesions occur only in the brain stem. Placentitis, focal bronchopneumonia, hepatitis, splenitis, and nephritis may be seen with other forms.

Pathogenesis. With the encephalitic form, the organism penetrates mucosal abrasions and enters the trigeminal or hypoglossal nerves. The *Listeria* organisms then migrate along the nerves and associated lymphatics to the brain stem (medulla and pons). In the septicemic form, the organism penetrates tissues of the gastrointestinal tract and enters the bloodstream, to be distributed to the liver, spleen, lungs, kidneys, and placenta. After infection, organisms are shed in all body secretions (infected milk is an important risk factor for zoonosis). A toxin produced by *Listeria monocytogenes* is correlated with pathogenicity, but the mechanism of the pathogenesis of this molecule has not been elucidated.

Differential diagnoses. Rabies, bacterial meningitis, brain abscess, lead toxicity, and otitis media must be considered as differentials. In sheep, the differentials include organisms that cause abortion, and neurological signs, such as enterotoxemia due to *Clostridium perfringens* type D. In goats, the major differentials include caprine arthritis encephalitis viral infection and chlamydial and mycoplasmal infections. In both species, scrapie is a differential. In cattle, aberrant parasite migration or *Hemophilus somnus* infection must also be considered.

Prevention and control. Affected dams should be segregated and treated. Other animals in the group may be treated with oxytetracycline as needed. Aborted tissues should be removed immediately. Proper storage of fermented feeds minimizes this source of contamination. When silage spoils, the pH increases, producing a suitable growth environment for the organism. Commercial vaccines are not available in the United States.

Treatment. Affected animals can be treated aggressively with penicillin, ampicillin, oxytetracycline, or erythromycin. Exceptionally high levels of penicillin are required for treating affected cattle. Severely affected animals should receive appropriate fluid support and other nursing care. Treatment is less

successful, and mortality is especially high in sheep. Recovered animals tend to resist reinfection.

Research complications. In addition to the loss of fetal animals, stress to the dams, and risks to other animals, any aborted tissue by a ruminant should be regarded as a potential zoonotic risk. *Listeria* can cause mild to severe flulike symptoms in humans and may be a particular risk for pregnant women and for older or immune-compromised individuals. Listeriosis in humans is a reportable disease.

u. Lyme Disease (Borrelia burgdorferi Infection, Borreliosis)

Etiology. Lyme disease is caused by the spirochete *Borrelia burgdorferi.*

Clinical signs and diagnosis. Reports in ruminants indicate seroconversion to *B. burgdorferi*, but there are few definitive correlations to the arthritis that is present. Diagnosis requires culturing from the affected joints and diagnostic elimination of other causes of lameness and arthritis.

Epizootiology and transmission. The organism is present throughout much of the Northern Hemisphere and has been reported in many mammals and also in birds. Ticks of the *Ixodes ricinus* complex are the major vectors of the spirochete and must be attached for 24 hr for successful transmission.

Pathogenesis. The *Ixodes* ticks have three life stages: larval, nymphal, and adult. Feeding occurs once during each stage, and wild animals are the source of blood meals. The larval stages feed from rodents, such as the white-footed deer mouse, *Peromyscus leucopus*, from which they acquire the spirochete. The nymphal stage is that which usually infects other animals. The adult ticks are usually found on deer.

Differential diagnosis. Seroconversion to *B. burgdorferi* does not necessarily confirm the cause of arthritis. Other causes of arthritis and lameness in ruminants include trauma, caprine arthritis encephalitis virus, *Mycoplasma* spp., *Chlamydia psittaci, Erysipelothrix* spp., *Arcanobacterium pyogenes, Brucella* spp., and rickets.

Prevention and control. Control of the tick vector is the most important factor in preventing the possibility of exposure or disease.

Treatment. Antibiotic therapy, with tetracycline, penicillin, amoxicillin, and cephalosporins, is used for diagnosed or suspected Lyme arthritis.

Research complications. Lyme disease is zoonotic, and the *Ixodes* ticks transmit the disease to humans.

v. Mastitis

i. Ovine mastitis Mastitis in ewes may be acute, subclinical, or chronic. Acute mastitis often results in anorexia, fever, abnormal milk, and swelling of the mammary gland. *Pasteurella haemolytica* is the most common cause of acute mastitis. Additional isolates may include, in order of prevalence, *Staphylococcus aureus, Actinomyces (Corynebacterium)* spp., and *Histophilus ovis. Escherichia coli* and *Pseudomonas aeruginosa* have also been found to cause acute mastitis. As many as six serotypes of *Pasteurella haemolytica* have been isolated from the mammary glands of mastitic ewes. Furthermore, intramammary inoculation of these organisms isolated from ovine and bovine pulmonary lesions has resulted in clinical mastitis in ewes (Watkins and Jones, 1992).

Subclinical mastitis is detected only indirectly, by counting somatic cells. The most common isolate from ewes with subclinical mastitis is coagulase-negative staphylococci. Other isolates include *Actinomyces bovis, Streptococcus uberis, S. dysgalactiae, Micrococcus* spp., *Bacillus* spp., and fecal streptococci. Most of these organisms are commonly found in the environment.

Diffuse chronic mastitis, or hardbag, results from interstitial accumulations of lymphocytes in the udder. Both glands are usually affected, but no inflammation is present. Serological evidence suggests that diffuse chronic mastitis is caused by the retrovirus that causes ovine progressive pneumonia (OPP or maedi/visna virus). Other bacterial agents or *Mycoplasma* have not usually been isolated from udders with this type of mastitis.

Acute mastitis occurs in approximately 5% of lactating ewes annually, and it usually occurs either soon after lambing or when lambs are 3–4 months old (Lasgard and Vaabenoe, 1993). Subclinical mastitis occurs in 4–50% of lactating ewes (Kirk and Glenn, 1996). Subclinical mastitis is more common in ewes from high-milk-producing breeds. Skin or teat lesions and dermatitis increase the prevalence of disease. Acute mastitis can be diagnosed in ewes with associated systemic signs of disease by physical examination of the udder and inspection of the milk. Subclinical mastitis is often suggested by somatic cell counts elevated above 1×10^6 cells/ml. When high somatic cell counts are identified, subclinical mastitis can be diagnosed by milk culture. The California mastitis test may also be helpful as an indicator of mastitis. Manual palpation of a hard, indurated udder as well as serological testing for the maedi/visna virus is helpful in confirming the diagnosis of diffuse chronic mastitis. Treatment for acute bacterial mastitis should include aggressive application of broad-spectrum antibiotics (intramammary and systemic) and supportive therapy such as fluids and anti-inflammatory drugs. It is may be helpful to milk out the infected udder frequently; oxytocin injections preceding milking will improve gland evacuation. Because somatic cell counting is often not routinely performed, treatment of subclinical mastitis is seldom done. There is currently no treatment available for diffuse chronic mastitis.

ii. Caprine mastitis Lactating goats are subject to inflammation of mammary gland, or mastitis. The primary causative organisms are *Staphylococcus epidermidis* and other coagulase-negative *Staphylococcus* spp. Clinical signs of mastitis include abnormal coloration or composition of milk, mammary gland redness, heat and pain, enlargement of the mammary gland, discoloration of the mammary gland, and systemic signs of septicemia. Large abscesses may be present in the affected gland. *Staphylococcus aureus* is also associated with caprine mastitis, and toxemia may be part of the clinical picture. This organism produces a necrotizing alpha toxin that can result in gangrenous mastitis. Caprine mastitis may be clinical or subclinical, and the first indication of mastitis may be weak, depressed, or thin kids. Diagnosis is based on careful culture of mastitic milk. Treatment includes frequent stripping, intramammary antibiotics, and nonsteroidal anti-inflammatory drugs. Oxytocin (5–10 U) may help milk letdown for frequent strippings. Bovine mastitis products can be used in the goat; however, care should be taken not to insert the mastitis tube tip fully, because damage to the protective keratin layer lining the teat canal may occur. In severe acute systemic cases, steroids, fluids, and systemic antibiotics may be necessary.

Other less common causes of mastitis in goats include *Streptococcus* spp. (*S. agalactiae, S. dysgalactiae, S. uberis,* and *zooepidemicus*). Gram-negative causes of caprine mastitis include *Escherichia coli, Klebsiella pneumoniae, Pasteurella* spp., *Pseudomonas,* and *Proteus mirabilis. Corynebacterium pseudotuberculosis* can cause mammary gland abscessation, whereas *Mycoplasma mycoides* may cause agalactia and systemic disease. "Hard udder" can be caused by caprine arthritis encephalitis virus (CAEV). Brucellosis and listeriosis can cause a subclinical interstitial mastitis (Smith and Sherman, 1994).

iii. Bovine mastitis Mastitis is the disease of greatest economic importance for the dairy cattle industry. The majority of the impact will be on the production and overall health of the cows, but low-incidence herds also diminish the risk of calves' ingesting or being exposed to pathogens. The most common bovine mastitis pathogens include *Staphylococcus aureus* and *Streptococcus agalactiae, S. dysgalactiae,* and *S. uberis;* coliform agents such as *Escherichia coli, Enterobacter aerogenes, Serratia marcescens,* and *Klebsiella pneumoniae;* mycoplasmal species such as *Mycoplasma bovis, M. bovigenitalium, M. californicum, M. canadensis,* and *M. alkalescens;* and *Salmonella* spp. such as *S. typhimurium, S. newport, S. enteritidis, S. dublin,* and *S. muenster.* Many of these agents such as *Staphylococcus*

spp., *Salmonella* spp., and the coliforms can cause both acute and chronic mastitis, as well as severe systemic disease, including fever and anorexia. These must be regarded as herd and environmental pathogens in terms of treatment and prevention. The pathogenesis of staphylococcal infections is comparable to that in goats. *Staphylococcus agalactiae* can be cleared from udders because it does not invade other tissues, is an obligate resident of the glands, and is susceptible to penicillin. In contrast, *S. uberis* and *S. dysgalactiae* are environmental organisms and can be highly resistant to pencillin. *Mycoplasma bovis* is the more common of the mycoplasmal pathogens and can cause severe infections. Transmission of the mycoplasmas is not well defined but may be related to their presence in other organ systems. Treatments for mycoplasmal mastitis are not successful; culling is recommended.

There are many interrelated factors associated with prevention and control of mastitis in a herd, including herd health and dry cow management, order of animals milked, milking procedures, milking equipment, condition of the teats, and the condition of the environment. Management of the overall herd includes aspects such as vaccination programs, nutrition, isolation of incoming animals, and quarantine and treatment of or culling diseased individuals. Culturing or testing newly freshened cows and monitoring the bulk milk tank serve as indicators of subclinical mastitis. Herd management will diminish teat lesions. Bacterin vaccines are available for preventing and controlling coliform mastitis and *S. aureus* mastitis. At the time of dry-off, all cows must be treated by intramammary route. Some infections can be successfully cleared during this time. Younger, disease-free animals should be milked first; any animals with diagnosed problems should be milked after the rest of the herd and/or segregated during treatment. Milkers' hands easily serve as a means of pathogen transmission, and wearing rubber gloves is recommended. Teat and udder cleaning practices include washing and drying with single-service paper or cloth towels or pre- and postmilking dipping. Milking equipment must be maintained to provide proper vacuum levels and pumping rates, and liners should be the appropriate size. Facilities that provide clean and dry areas for the animals to rest, feed, and move will diminish teat injuries and reduce exposures to mastitis pathogens. In that regard, inorganic bedding such as clean sand harbors few pathogens in contrast to shavings and sawdust.

w. Moraxella bovis Infection (Infectious Bovine Keratoconjunctivitis, Pinkeye)

Etiology.   *Moraxella bovis,* a gram-negative coccobacillus, is the most common cause of infectious bovine keratoconjunctivitis (IBK) in cattle. This organism is not a cause of keratoconjunctivitis in sheep and goats. The disease includes conjunctivitis and ulcerative keratitis. The pathogenic *M. bovis* strain is piliated, and at least seven serotypes exist.

Clinical signs.   Lacrimation, photophobia, and blepharospasm are seen initially. Conjunctival injection and chemosis develop within a day of exposure, and then keratitis with corneal edema and ulcers. Anterior uveitis may be a sequela within a few days, and thicker mucopurulent ocular discharge may be seen. Corneal vascularization begins by 10 days after onset. Reepithelialization of the corneal ulcers occurs by 2–3 weeks after onset. Diagnosis is usually based on clinical signs, but culturing is helpful and fluoroscein staining is useful for demonstrating corneal ulceration.

Epizootiology and transmission.   The disease is more severe in younger cattle. The clinical signs of IBK tend to be more severe in cattle that are also infected with infectious bovine rhinotracheitis (IBR) virus or those that have been vaccinated recently with modified live IBR vaccine. The bacteria are shed in nasal secretions and cattle with no clinical symptoms may be carriers. Transmission is by fomites, flies, aerosols, and direct contact. Incidence in winter months is very low. Nonhemolytic strains are associated with the winter epidemics, and hemolytic strains are associated with summer epidemics.

Necropsy findings.   Necropsy is not typically performed on these cases. Corneal edema, ulceration, hypopyon, and uveitis would be noted, depending on the stage of infection.

Pathogenesis.   The pili of *M. bovis* bind to receptors of corneal epithelium. The virulent strains of the bacteria then release the enzymes that damage the corneal epithelial cells. Other factors contributing to infection include ultraviolet light and trauma from dust and plant materials.

Differential diagnoses.   Infectious bovine rhinotrachetitis virus causes conjunctivitis, but the central corneal ulceration that is characteristic of IBK is not seen with *M. bovis* infections. *Mycoplasma, Listeria, Branhamella (Neisseria),* and adenovirus may be cultured from affected bovine eyes but none has been shown to produce the corneal lesions when inoculated into susceptible animals.

Prevention and control.   Cattle should not be immunized intranasally with modified live infectious bovine rhinotracheitis vaccine during IBK outbreaks; this will likely exacerbate the infection. New animals should be quarantined and treated prophylactically before introduction to herds. The available vaccines, containing. *M. bovis* pili or killed *M. bovis,* help decrease incidence and severity of disease; these preparations are not completely effective, because the *M. bovis* strain may not be homologous to that used for the vaccine preparation. Other preventive measures include 10% permethrin-impregnated bilateral ear tags, pour-on avermectins, or dust bags or face rubbers containing insecticide (such as 5% coumaphos) to control flies throughout the season and premises; mowing of high pasture

grass to minimize ocular trauma; provision of shade; control of dust and sources of other mechanical trauma; and segregation of animals by age.

Treatment. Cattle can recover without treatment, but younger animals should be treated as soon as the infection is detected. Antibiotic treatments include topical, subconjunctival administration and intramuscular dosing. Several standard topical antibiotics have been shown to be effective, including oxytetracycline, gentamicin, and triple antibiotic combinations. These should be administered twice per day. Subconjunctival injections of antibiotics, such as penicillin G, provide higher corneal levels of drug; these are typically administered only once or twice in severe cases. Intramuscular doses of long-acting oxytetracycline, given on alternate days, are effective in larger herds, and 2 doses 72 hr apart eliminate carriers. Third-eyelid flaps, temporary tarsorrhaphy, or eye patches may be useful in certain cases.

Research complications. This pathogen does present a complication due to the carrier status of some animals, the likelihood of herd outbreaks, the severity of disease in younger animals, and the morbidity, possible progression to uveitis, and time and treatment costs associated with infections. The overall condition of the cattle will be affected for several weeks, and permanent visual impairment or loss, as well as ocular disfigurement, may occur.

x. Mycobacterial Diseases

Mycobacterium bovis Infection (Tuberculosis)

Etiology. Mycobacteria are aerobic, nonmotile, non-spore-forming, acid-fast pleomorphic bacteria. Most cases of tuberculosis in sheep are related to *Mycobacterium bovis* or *M. avium*. Cases in goats have been attributed to *M. bovis, M. avium*, or *M. tuberculosis. Mycobacterium bovis*, or the bovine tubercle bacillus, is the cause in cattle but has been isolated from many domestic and wild mammals. Other agents of mammalian tuberculosis include *M. microti* and *M. africanum*.

Clinical signs. Tuberculosis is a sporadic, chronic, contagious disease of ruminants and is zoonotic. The infection is often asymptomatic later in the illness, and it may be diagnosed only at necropsy. The respiratory system (*M. bovis*) or the digestive system (*M. avium*) is the primary site of infection; other tissues such as mammary tissue and reproductive tract may be infrequently involved. Locations of the characteristic tubercles will determine whether clinical signs are seen. Respiratory signs may include dyspnea, coughing, and pneumonia. Digestive tract signs include diarrhea, bloat, or constipation; diarrhea is most common. Lymphadenopathy occurs in advanced cases. Fever and generalized disease may be seen after calving. Infected goats lose weight and develop a persistent cough.

Epizootiology and transmission. Although *M. bovis* can be killed by sunlight, it otherwise survives a long time in the environment and in cattle feces. Animals acquire the infection from the environment or from other animals via aerosols, from contaminated feed and water, and from secretions such as milk, semen, genital discharges, urine, and feces. Clinically normal animals may serve as carriers. The bacilli stimulate an initial neutrophilic tissue response. Neutrophils become necrotic and are phagocytosed by macrophages, forming giant epithelioid cells called Langhans' giant cells. An outer lymphocytic zone is formed, and fibrotic encapsulation creates the classical caseous nodules. Vascular erosion and hematogenous migration of the organisms may lead to lesions throughout the body.

Necropsy findings. Yellow primary tubercles (granulomas) with central areas of caseous necrosis and calcification are present in the lungs. Caseous nodules are also associated with gastrointestinal organs and mesenteric lymph nodes.

Prevention and control. Significant progress has been made in eradication programs in the United States during the past several decades, but during the 1990s, infected animals continued to be found in domestic cattle herds and particularly in captive deer herds in hunting preserves. The intradermal tuberculin test, using purified protein derivative (PPD), is usually used as a diagnostic indicator in live animals. This test should be performed annually on bovine and caprine dairy herds (and bison herds); the official tests are the caudal fold, comparative cervical, and single cervical tests. Notification to state officials is required following identification of intradermal-positive animals. Great care must be exercised in any handling of tissue or necropsies of reactors, and state animal health officials should be consulted regarding disposal of materials and cleaning of premises following depopulation of positive animals.

Treatment. No treatment is recommended, and treatment is usually not allowed, because of the zoonotic potential, chronicity of the disease, and the treatment costs. Slaughter is preferred, to prevent potential transmission to humans.

Research complications. The pathogen is zoonotic.

Paratuberculosis, or Johne's disease (Mycobacterium paratuberculosis)

Etiology. Mycobacterium paratuberculosis, the causative agent of Johne's disease, is a fastidious, non-spore-forming, acid-fast, gram-positive rod. The organism is actually a subspecies of *M. avium*, but *M. paratuberculosis* does not produce the siderophore mycobactin (an iron-binding molecule) of *M. avium*.

Clinical signs and diagnosis. Johne's disease is a chronic, contagious, granulomatous disease of adult ruminants and is

characterized by unthriftiness, weight loss, and intermittent diarrhea. In sheep and goats, chronic wasting is usually seen, occasionally with pasty feces or diarrhea. In cattle, chronic diarrhea and rapid weight loss are the most common clinical signs of the disease. Usually older adult animals are infected, but over time in an infected herd, younger animals will become infected when sufficient doses of organisms are ingested. Although clinical signs are nonspecific, Johne's disease should be considered if the affected diarrheic animals have a good appetite and are on a good anthelmintic program.

The disease is diagnosed based on clinical signs and laboratory analyses, although none of the tests is more than 50% sensitive. In addition, the sensitivity of the serological tests differs between species. The standard is the fecal culture that takes 8–12 weeks. The enzyme-linked immunosorbent assay (ELISA) is now considered the most reliable serological test, but false negatives do occur. Other serological tests such as agar gel immunodiffusion (AGID) and complement fixation are useful. Herd screening may be done using the AGID or ELISA serological tests. Identification of the organism on culture, or the presence of acid-fast organisms on mucosal or mesenteric lymph node smears or from rectal biopsies, helps confirm the diagnosis. Some animals serologically negative for Johne's disease, however, have been found to be positive on fecal culture. Commercial AGID tests approved for use in cattle may be useful in diagnosing Johne's disease in sheep (Dubash et al., 1996). Serological tests cross-react with other species of Mycobacterium, especially M. avium.

Epizootiology and transmission. The organism is prevalent in the environment and is transmitted to young animals by direct or indirect contact. Although vertical transmission has been reported, the organism more commonly enters the gastrointestinal tract and penetrates the mucosa of the distal small intestine, primarily the ileum. Chronic carriers may intermittently shed the organisms.

Pathogenesis. Mycobacterium paratuberculosis is an obligate parasite that grows only in macrophages of infected animals. Nursing infected dams are a primary source of infection of neonates. If the organism is not cleared, it proliferates slowly in the tissue, leading to inflammatory reactions that progress through neutrophilic to mononuclear stages. The organism may penetrate the lymphatics and proliferate in mesenteric lymph nodes. After an incubation period of a year or more, some of the carriers will progress to clinical disease manifested by fibrotic and hyperplastic changes in the ileum, leading to the classic thickening in the region. Gut changes result in intermittent diarrhea, with subsequent dehydration, electrolyte imbalances, and malnutrition, although this clinical sign is more common in cattle than in sheep or goats.

Necropsy and diagnosis. The ileum from infected cattle is grossly thickened; this is not seen in sheep and goats. Ileal and ileocecal lymph nodes provide the best samples for histology and acid-fast staining.

Differential diagnosis. Diseases causing chronic wasting and poor coat and body condition of all ruminants should be considered. These include chronic salmonellosis, peritonitis, severe parasitism, winter dysentery, and pyelonephritis. Deer can be infected, and the lesions can be confused with those of tuberculosis.

Treatment. Treatment is not worthwhile.

Prevention and control. Prevention is the most effective method to manage this pathogen. Efforts should be focused on eliminating the disease through test and slaughter. Neonates should not be reared by infected dams. Some states have Johne's disease eradication programs. Facilities and pastures where animals testing positive for Johne' disease were maintained should be thoroughly cleaned and kept vacant for a year after culling.

Other considerations. Mycobacterium paratuberculosis is being investigated as a factor in the development of Crohn's disease in humans.

y. Navel Ill (Omphalitis, Omphalophlebitis, Omphaloarteritis, Joint Ill)

Etiology. The most common organism causing infection of the umbilicus is Arcanobacterium (formerly Actinomyces, Corynebacterium) pyogenes; other bacteria may be present. Arcanobacterium spp. are anaerobic, nonmotile, non-spore-forming, gram-positive, pleomorphic rods to coccobacilli. Other environmental contaminants are also associated with this disease, such as Escherichia coli, Enterococcus spp., Proteus, Streptococcus spp., and Staplylococcus spp.

Clinical signs and diagnosis. Navel ill is an acute localized inflammation and infection of the external umbilicus. Animals present with fever and painful enlargement of the umbilicus. Animals may exhibit various degrees of depression and anorexia, and purulent discharges may be seen draining from the umbilicus. Involvement of the urachus is usually followed by cystitis and associated signs of dysuria, stranguria, and hematuria. Other common severe sequelae include septicemia, pneumonia, peritonitis, septic arthritis (joint ill), meningitis, osteomyelitis, uveitis, endocarditis, and diarrhea.

Epizootiology and transmission. Many cases occur in neonates, and most cases occur within the first 3 months of age. Cleanliness of the birthing and housing environment and successful transfer of passive immunity are important factors in the occurrence of the disease. Dystocia resulting in weak neonates can be a factor predisposing to the development of the disease.

Navel ill is diagnosed by typical clinical signs. The presence

of microabscesses and palpation of the umbilical area for firm intra-abdominal structures extending from the umbilicus are abnormal. Assessment of colostral immunoglobulin transfer may contribute to determination of the prognosis. Navel ill should always be considered for young ruminants with fever of unknown origin during the first week of life and for slightly older lambs, kids, or calves that are not thriving. Arthrocentesis of affected joints and culture of the fluid for identification of the pathogen are also diagnostic options and essential for effective antimicrobial selection.

Differential diagnosis. The major differential is an umbilical hernia, which will typically not be painful or infected and can often be reduced. Mycoplasmal arthritis is a differential in kids. In the past, *Erysipelothrix rhusopathiae* was a common navel ill pathogen in sheep.

Treatment. Omphalitis can be treated with a 10 to 14 day course of broad-spectrum antibiotics such as ampicillin, amoxicillin, penicillin, ceftiofur, florfenicol, and erythromycin. If an isolated abscess is palpable, it should be surgically opened and repeatedly flushed with iodine solutions. Surgical reduction of the infected umbilicus is indicated if intra-abdominal structures are involved. The prognosis for recovery is good if systemic involvement has not occurred.

Prevention and control. The disease is best prevented and controlled by providing clean birthing environments, ensuring adequate colostral immunity, thoroughly dipping the umbilicus of newborns in tincture of iodine or strong iodine solution (Lugol's), monitoring for dystocias, and maintaining young growing animals in noncontaminated environments.

Research complications. The disease can be costly to treat, and the toll taken on young animals due to the consequences of systemic infection may detract from their research value.

z. Pasteurellosis (Shipping Fever, Hemorrhagic Septicemia, Enzootic Pneumonia)

Etiology. *Pasteurella hemolytica* and *P. multocida* are aerobic, nonmotile, non-spore-forming, bipolar, gram-negative rods. Biotype A serotypes are associated with pneumonia and septicemia in all ruminants (Ellis, 1984). Serotype 1 of *P. hemolytica* is considered a major cause of pulmonary lesions of bovine bronchopneumonia and fibrinous bronchopneumonia.

Clinical signs. Pasteurellosis is an acute bacterial disease characterized by bronchopneumonia, septicemia, and sudden death. The organism invades the mucosa of the gastrointestinal tract or respiratory tract and causes localized areas of necrosis, hemorrhage, and thrombosis. The lungs and liver are frequent areas of formation of microabscesses. Acute rhinitis or pharyngitis often precedes the respiratory form. The organism also

may invade the bloodstream, causing disseminated septicemia. Clinically, the lambs may exhibit nasal discharge of mucopurulent to hemorrhagic exudate, hyperthermia, coughing, dyspnea, anorexia, and depression. With the respiratory form, auscultation of the thorax suggests dullness and consolidation of anteroventral lobes; this will be confirmed by radiographs. The disease is diagnosed by clinical signs, blood cultures from septicemic animals, blood smears showing bipolar organisms, and history of predisposing stressors. In cultures, *P. hemolytica* is distinguished from *P. multocida* by hemolysis on blood agar; only *P. multocida* produces indole.

Epizootiology and transmission. The organism is ubiquitous in the environment and in the respiratory tracts of these animals. Younger ruminants, between 2 and 12 months of age, are especially prone to infection during times of stress, such as weaning, transportation, dietary changes, weather changes, and overcrowding. The pneumonic form appears as a complex associated with concurrent infections such as parainfluenza 3, adenovirus type 6, respiratory syncytial virus, mycoplasmas, chlamydia, *Pasteurella multocida* and *Bordetella parapertussis* (Martin, 1996; Brogden *et al.,* 1998). The organism is transmitted between animals by direct and indirect contact, through inhalation or ingestion.

Necropsy findings. Necropsy lesions include areas of necrosis and hemorrhage in the small intestines and multifocal 1 mm lesions distributed on the surfaces of the lungs and liver. With the pneumonic form, serofibrinous exudates fill the alveoli; ventral lung lobes are consolidated and are congested and purple-gray in color. Fibrinous pleuritis, pericarditis, and hematogenously induced arthritis also may be evident.

Pathogenesis. A leukotoxin is considered to be a key factor in the pathogenesis of the *P. hemolytica* infection. Macrophages and neutrophils are lysed by the toxin as they arrive at the lung, and the enzymes released by the neutrophils cause additional damage to the tissue.

Treatment. Treatment may include the use of antibiotics such as penicillin, ampicillin, tylosin, sulfonamides, or oxytetracycline. Newer antibiotics, such as ceftiofur, tilmicosin, spectinomycin, and florfenicol, are very effective and approved for use in cattle. In outbreaks, cultures from fresh necropsies are helpful for determining sensitivities useful for the remaining group.

Prevention and control. The incidence of disease can be decreased by minimizing the degree of stress; by improving management, such as nutrition and control of parasitism; and, in cattle and sheep, by vaccinating for viral respiratory infections such as parainfluenza. Early *Pasteurella hemolytica* bacterin vaccines for use in cattle are not considered effective, but newer products based on immunizing against the leukotoxin and some bacterial capsule surface antigens are effective. *Pasteurella*

multocida bacterins and live streptomycin-dependent mutant vaccines are available. In young animals, passive immunity is protective. Preventive measures also include maintaining good ventilation in enclosures and barns. New animals to the flock or herds should be quarantined for at least 2 weeks before introduction.

aa. Salmonellosis

Etiology. *Salmonella typhimurium* is a motile, aerobic to facultatively anaerobic, non-spore-forming, gram-negative bacillus and is the organism associated with enteric disease and some abortions in ruminants. It is a common inhabitant of the gastrointestinal tract of ruminants. Current nomenclature categorizes *S. typhimurium* as a serovar within the species *S. enteritidis* (the other two species are *S. typhi* and *S. choleraesuis*). *Salmonella typhimurium*, *S. dublin*, and *S. newport* are the common species seen in bovine cases. *Salmonella typhimurium*, *S. dublin*, *S. anatum*, and *S. montevideo* are seen in ovine and caprine cases, although a host-adapted species has not been identified in the goat. Ovine abortions due to various *Salmonella* species are not reported in the United States but are enzootic in other countries. *Salmonella* serotypes have been associated with aborted fetuses in all ruminant species.

Clinical signs and diagnosis. Salmonellosis causes acute gastroenteritis, dysentery, and septicemia (Anderson and Blanchard, 1989). Clinically, the animals become anorexic and hyperthermic. Diarrhea or dysentery develops; feces may contain mucus and/or blood and have a putrid odor. Animals become severely depressed and weak, losing a high percentage of their body weight. Animals may die in 1–5 days because of dehydration associated with dysenteric fluid loss, septicemia, shock, and acidosis. Morbidity may be 25%, and mortality may be high. Septicemia may result in subsequent meningitis, polyarthritis, and pneumonia. Chronically infected animals may have intermittent diarrhea.

In goats, salmonellosis may be recognized as diarrhea and septicemia in neonates, as enteritis in preweaned kids and mature goats, and, rarely, as abortion. Adult cases may be sporadic, with intermittent bouts of diarrhea, subacute or even chronic. Morbidity and mortality will be highest in neonates, and some may simply be found dead. The older animals generally tend to fare better during the disease. Abdominal distension with profuse yellow feces is common. Kids become severely depressed, anorexic, febrile (with temperatures as high as 106°–107°F), dehydrated, acidotic, recumbent, and comatose.

Salmonella abortions may occur throughout gestation. There may not be any other clinical signs, or abortion may be seen with diarrhea, fever, and vulvar discharges. Hemorrhage, placental necrosis, and edema will be present. Metritis and placental retention may occur. Some mortality of dams may occur.

Diagnosis is based on clinical signs and can be confirmed by culturing fresh feces or at necropsy. Because of intermittent shedding of organisms, culture may be difficult; repeated cultures are recommended. Leukopenia and a degenerative shift to the left are not uncommon hematological findings.

Epizootiology and transmission. Stresses associated with recent shipping, overcrowding, and inclement weather may predispose the animal to enteric infection. Birds and rodents may be natural reservoirs of *Salmonella* in external housing environments. Transmission is fecal–oral. After ingestion, the organisms may proliferate throughout the gastrointestinal tract and may penetrate the mucosa of the intestines, invade the Peyer's patches and lymphatics, and migrate to the spleen, liver, and other organs. Animals that survive may become chronic carriers and shedders of the organisms, and this has been demonstrated experimentally (Arora, 1983). Fecal–oral transmission is also associated with *Salmonella* abortion; veneral transmission has not been reported.

Necropsy findings and diagnosis. Animals will have noticeable perineal staining. Intestines (particularly the ileum, cecum, and colon) may contain mucoid feces with or without hemorrhages. Petechial hemorrhages and areas of necrosis may be noticed on the surface of the liver, heart, and mesenteric lymph nodes. The wall of the intestines, gallbladder, and mesenteric lymph nodes will be edematous, and a pseudodiphtheritic membrane lining the distal small intestines and colon may be observed. This membrane is not normally seen in the goat (Smith and Sherman, 1994). Splenomegaly may be present. Aborted fetuses will often be autolysed. Placentitis, placental necrosis, and hemorrhage are commonly seen. Serologic evidence of recent infection can be demonstrated in the dam. *Salmonella* can be isolated from the aborted tissues.

Pathogenesis. After ingestion, the organism proliferates in the intestine. Damage to the intestines and the resulting diarrhea are due to the bacterial production of cytoxin and endotoxin. Although the *Salmonella* organisms will be taken up by phagocytic cells involved in the inflammatory response, they survive and multiply further. Septicemia is a common sequela, with the bacteria localizing throughout the body. In latently infected animals, it is often shed from the gallbladder and mesenteric lymph nodes. Younger animals may be susceptible because of immature immunity and intestinal flora and higher intestinal pH. Carriers may develop clinical disease when stressed.

Differential diagnoses. In young animals, differentials include other enteropathogens: *Escherichia coli*, rotavirus and coronavirus, clostridia, cryptosporidia, and other coccidial forms. These pathogens may also be present in the affected animals. Differentials in adults include bovine viral diarrheas and winter dysentery in cattle and parasitemia and enterotoxemia in all ruminants.

Prevention and control. Affected animals should be isolated during herd outbreaks. Samples for culture should include herd-mates, water and feed sources, recently arrived livestock (other species), and area wildlife, including birds and rodents. Repeated cultures, culling of animals, intensive cleaning, and disinfection of facilities are all important during outbreaks. The bacteria survive for about a week in moist cow manure. Vaccination using the commercially available killed bacterin or autologous bacterins may be useful in outbreaks involving pregnant cattle, although the J-5 bacterin is now considered better.

Treatment. Nursing care includes rehydration and correction of acid–base abnormalities. Antibiotic therapy may be useful in cases with septicemia, but it is controversial because it may induce carrier animals. Gentamicin, trimethoprim-sulfadiazine, ampicillin, enrofloxacin, and amikacin antibiotics may be successful.

Research complications. Salmonellosis is zoonotic, and some serotypes of the organism have caused fatalities even in immunocompetent humans. Attempts should be made to identify and cull carrier animals.

bb. Spirochete-Associated Abortion in Cattle (Epizootic Foothill Abortion)

Etiology. Spirochete-like organisms are associated with this disease; it is now recognized that the agent is not a chlamydial organism. The disease has been reported only in the foothills bordering the central valley of California.

Clinical signs. Cows that become infected with the causative agent before 6 months of gestation abort or give birth to weak calves without any clinical sign of infection. Cows infected after 6 months of gestation give birth to normal calves. Affected cows rarely abort in subsequent pregnancies.

Epizootiology and transmission. The tick vector is *Ornithodorus coriaceus.*

Necropsy. Fetuses show several pathological changes, including enlargement of the cervical lymph nodes, spleen, and liver. The calf's thymus will be small, and histologically there will be losses of thymic cortical lymphocytes. Histologic changes in lymph nodes and spleen include vasculitis, necrosis, and histiocytosis.

Treatment. Chlortetracycline treatment has been effective in controlling this disease.

cc. Tularemia

Etiology. Tularemia is caused by *Pasteurella (Francisella) tularensis* a nonmotile, non-spore-forming, aerobic, gram-negative, rod-shaped bacterium. Type A is more virulent than type B.

Clinical Signs. Although tularemia is a disease of livestock, pets, and wild animals, sheep are most commonly affected. The disease is characterized by hyperthermia, muscular stiffness, and lymphadenopathy. Infected animals move stiffly, are depressed, and are hyperthermic. Anemia and diarrhea may develop, and infected lymph nodes enlarge and may ulcerate. Mortality may reach 40%. Animals that recover will have immunity of long duration.

Epizootiology and transmission. The disease is most commonly transmitted by ticks or biting flies. The wood tick, *Dermacentor andersoni,* is an important vector in transmitting the disease in the western United States, and, as natural hosts, wild rodents and rabbits tend to be reservoirs of the pathogen.

Pathogenesis. The organisms, entering the tick bite wound, move via lymphatics to lymph nodes and subsequently to the bloodstream, where they cause septicemia. The organisms can also be transmitted orally through contaminated water.

Necropsy findings. Ticks may also be present on the carcasses. Suppurative, necrotic lymph nodes are typical. Lungs will be congested and edematous. Diagnosis is confirmed by prompt culturing of the organism from lymph nodes, spleen, or liver where granulomatous lesions form; *P. tularensis* does not survive for long periods in carcasses. Serological findings may also be helpful.

Treatment. Infected animals can be treated with oxytetracycline, aminoglycosides, or cephalosporins.

Differential diagnosis. When tick infestations are heavy, *P. tularensis* should be suspected. *Pasteurella haemolytica* (sheep), *Haemophilus somnus* (cattle), and *Mycoplasma mycoides* (goats), and anthrax (all ruminant species) should be considered as differentials.

Control and prevention. Eliminating the tick vectors can prevent tularemia. Animals should be provided with fresh water frequently. The organism can survive in freezing conditions and in water and mud for long periods of time. Caretakers, veterinarians, and researchers should take special precautions before handling the tissues of infected sheep, because this is a method of zoonotic spread.

Research complications. The disease is zoonotic, and transmission to people may result from tick bites or from handling contaminated tissues. Although not a major disease of concern in sheep, researchers using potentially infected animals from western range states of the United States should be aware of it. The organism is antigenically related to *Brucella* spp.

dd. Yersinia

Etiology. Yersiniosis is caused by infections with *Yersinia enterocolitica*, a gram-negative, aerobic, and facultative anaerobe of the family Enterobacteriaceae. There are 50 serotypes reported for *Y. enterocolitica. Yersinia pseudotuberculosis* infections have also been seen in ruminants. Enteric infections predominate in the diseases caused by these bacteria.

Clinical signs and diagnosis. Clinical disease may be seen rarely in many groups of ruminants. Goats of 1–6 months old suffer from the enteric form of the disease, which is characterized by sudden death or the acute onset of watery diarrhea lasting 1 or more days. Spontaneous abortions and weak neonates are also clinical manifestations of infection. Lactating does may have mastitis that becomes chronically hemorrhagic. Bacteremia results in internal abscesses, abortion, and acute deaths. *Yersinia pseudotuberculosis* has been associated with laboratory goat epizootics (Obwolo, 1976). Diarrhea in pastured sheep, stressed by other factors, has also been reported. Diagnosis is based on culture and serology.

Epizootiology and transmission. The bacteria are carried by wild birds and rodents, and transmission is by ingestion of contaminated feed and water.

Necropsy findings. Edema of mesenteric lymph nodes is the most common postmortem finding. Liver abscesses, microabsecesses in the intestines, and granuloma formation have also been reported. Placentas are white, with opaque white foci found on cotyledons. Histologically, suppurative placentitis and suppurative pneumonia are found in the fetal tissue.

Pathogenesis. After ingestion, the bacteria cause an enteric infection, and bacteremia follows.

Differential diagnoses. Other causes of abortions, including abortion storms, acute deaths, enteritis, neonatal deaths, and white foci on cotyledons, should be considered. In young animals, differentials include coccidiosis and nematode parasitism. *Corynebacterium pseudotuberculosis* and tuberculosis are differentials for the internal abscesses.

Prevention and control. Control measure are not well defined, because the epidemiology of the disease is poorly understood (Smith and Sherman, 1994). Tissues from affected goats must be handled and disposed of properly. Areas housing affected goats must be thoroughly sanitized.

Treatment. In case of an abortion storm, treatment of goats with tetracycline has been useful. Other broad-spectrum antibiotics may also be useful.

Research complications. *Yersinia* is zoonotic. The risk of severe enteric disease is considered particularly great for immunocompromised persons.

ee. Mycoplasmal Diseases

i. Mycoplasma bovigenitalium and M. bovis infections

Etiology. *Mycoplasma bovigenitalium* and *M. bovis* are associated sporadically with bovine infertility and abortions. This pathogen has also been reported associated with similar clinical signs in sheep and goats.

Clinical signs and diagnosis. Infertility is more commonly caused by *M. bovigenitalium* infections, and granular vulvovaginitis and endometritis will be present. Granular vulvovaginitis is characterized by raised papules on the mucous membranes and mucopurulent exudate. Abortions and mastitis are associated with *M. bovis* infections. Calves that are born may be weak.

It is rare to have a definitive diagnosis of an abortion due to *Mycoplasma.* After consideration of other causes of abortion and evaluation of tissues for placentitis or fetal inflammation, diagnosis is confirmed by isolation of *Mycoplasma* from the genital tract or aborted tissues.

Epidemiology and transmission. Mycoplasmal species are considered ubiquitous, are carried in the genital tracts of males and females, and are transmitted during natural breeding or through contaminated insemination materials. Aerosols also serve as a means of transmission. In addition, transmission occurs by passage through the birth canal, by direct contact, and by contamination from urine of infected animals.

Pathophysiology. Experimental infections of *M. bovis* have resulted in placentitis and fetal pneumonia.

Differential diagnoses. *Acholeplasma, Ureaplasma,* and *Haemophilus somnus* are differentials for granular vulvovaginitis.

Treatment. Fluoroquinolone antibiotics may be useful for treating *Mycoplasma*-induced reproductive diseases.

ii. Mycoplasma ovipneumoniae (ovine mycoplasmal pneumonia)

Etiology. *Mycoplasma ovipneumoniae* causes acute or chronic pneumonia in lambs.

Clinical signs. Mycoplasmas induce serious diseases in sheep, causing pneumonia, conjunctivitis, and genitourinary disease. The disease may be coincidental with pasteurellosis. Respiratory distress, coughing, and nasal discharge are ob-

served in infected animals. Bronchoalveolar lavage followed by culture is the best method for diagnosis (mycoplasmas are fastidious organisms requiring special handling techniques). Mycoplasmas are isolated from the genitourinary tract of sheep. Vulvovaginitis and reproductive problems are associated conditions.

Treatment. Tylosin, quinolones, oxytetracycline, and gentamicin are good choices for therapy.

Prevention. No vaccine is available.

iii. Mycoplasma mycoides biotype F38 (contagious caprine pleuropneumonia, caprine pneumonia, pleuritis, and pleuropneumonia)

Etiology. Mycoplasma mycoides biotype F38 is the agent of contagious caprine pleuropneumonia and is found worldwide. In the United States, caprine pneumonia is also caused by *M. ovipneumoniae, M. mycoides* subsp. *capri,* and *M. mycoides* subsp. *mycoides* (large colony type).

Clinical signs. Contagious caprine pleuropneumonia is characterized by severe dyspnea, nasal discharge, cough, and fever (McMartin *et al.,* 1980). Infections with other *Mycoplasma* species also have similar clinical signs. Septicemia without respiratory involvement may also be a presentation.

Epizootiology and transmission. This disease is highly contagious, with high morbidity and mortality. Transmission is by aerosols. *Mycoplasma mycoides* subsp. *mycoides* has become a serious cause of morbidity and mortality of goat kids in the United States.

Necropsy. Large amounts of pale straw-colored fluid and fibrinous pneumonia and pleurisy are typical. Some lung consolidation may be present. Meningitis, fibrinous pericarditis, and fibrinopurulent arthritis may also be found. Diagnosis is usually made at necropsy by culture of the organism from lungs and other internal organs.

Differential dagnosis. In the United States, the principal differential for *M. mycoides* subsp. *mycoides* is caprine arthritis encephalitis.

Treatment. Tylosin and oxytetracycline are effective. Some infections are slow to resolve.

Prevention and control. Vaccines are available in some areas. Infected herds are quarantined. New goats should be quarantined before introduction to the herd.

Research complications. The worldwide distribution of the F38 biotype, as well as the aerosol transmission and high mor-

bidity and mortality characteristics of mycoplasmal infectious, make these infections economically important diseases. Considerable attention is presently given to this genus as a source of morbidity and mortality in goats.

iv. Mycoplasma conjunctivae (mycoplasmal keratoconjunctivitis)

Etiology. Mycoplasma conjunctivae causes infectious conjunctivitis, or pinkeye, in sheep and goats with associated hyperemia, edema, lacrimation, and corneal lesions. *Mycoplasma mycoides* subsp. *mycoides, M. agalactiae, M. arginini,* and *Acholeplasma oculusi* have also been associated with keratoconjunctivitis in these species. Respiratory disease and other infections, such as mastitis, may also be observed.

Clinical signs and diagnosis. All ages of animals may be affected. Initially, lacrimation, conjunctival vessel injection, and then keratitis and neovascularization are seen. Sometimes uveitis is evident. Although the presentation is usually unilateral, bilateral involvement is possible. Recurring infections are common. Culturing provides the better diagnostic information, and cultures will be positive even after clinical signs have diminished.

Epizootiology and transmission. The infection is passed easily between animals by direct contact. Animals can become reinfected, and carrier animals may be a factor in outbreaks.

Necropsy. It is unlikely that animals would die or be euthanized and undergo necropsy for this problem. Conjunctival scrapings would include neutrophils during earlier stages and lymphocytes during later stages. Epithelial cell cytoplasm should be examined for organisms.

Differential diagnosis. The primary differential in sheep and goats is *Chlamydia,* as well as *Branhamella, Rickettsia (Colesiota) conjunctivae,* and infectious bovine rhinotracheitis in goats only. It is important to consider these differentials if arthritis, pneumonia, or mastitis is present in the group or the individual.

Treatment. Animals do recover spontaneously within about 10 weeks. Tetracycline ointments and powders are also used. Third-eyelid flaps may be necessary if corneal ulceration develops.

Prevention and control. New animals should be quarantined and, if necessary treated, before introduction to the flock or herd.

ff. Rickettsial Diseases

i. Eperythrozoonosis (Eperythrozoon, Haemobartonella)
Etiology. Eperythrozoonosis is a rare, sporadic, noncontagious,

blood-borne disease in ruminants worldwide caused by the rickettsial agent *Eperythrozoon.* Host-specific species of importance are *E. ovis,* the causative species in sheep and goats, and *E. wenyoni, E. tegnodes,* and *E. tuomii,* the causative agents in cattle. Although the disease is of minor importance, it can cause severe anemia and debilitation in affected animals. *Haemobartonella bovis* is also rare, and is usually found only in association with other rickettsial diseases.

Clinical signs and diagnosis. The disease is more severe in sheep. Following an incubation period of 1–3 weeks, infected animals exhibit episodic hyperthermia, weakness, and anemia. Losses may be greater in younger lambs. Cattle are usually latently infected but may have swollen and tender teats and legs. Fever, anemia, and depression will be present if the cattle are stressed by another systemic disease. Diagnosis is based on clinical evidence of anemia and is confirmed by observing the rickettsiae on the surface of red blood cells in a blood smear.

Epizootiology and transmission. The rickettsial organisms are transmitted typically to young sheep by biting insects, ticks, contaminated needles or blood-contaminated surgical instruments.

Necropsy findings. Necropsy findings include splenic enlargement and tissue icterus.

Pathogenesis. The organism invades and destroys red blood cells. It is believed that intravascular hemolysis and erythrophagocytosis contribute to the macrocytic anemia. As with other red blood cell parasites, splenectomy aggravates the disease.

Differential diagnosis. Clontridium novyi type D, babesiosis, and leptospirosis are the primary differentials.

Prevention and control. Following strict sanitation practices for surgical procedures and controlling external parasites prevent the disease.

Treatment. Treatment is not usually recommended, but oxytetracycline has been used. Sheep will develop immunity if supported nutritionally during the disease.

Research complications. Splenectomized animals are the experimental models used to study these diseases.

ii. Q fever, or query fever (Coxiella burnetii)

Etiology. Coxiella burnetii is a small, gram-negative, obligate intracellular rickettsial organism that causes query fever and is regarded as a major cause of late abortion in sheep.

Clinical signs. Infection of ruminants with *C. burnetii* is usually asymptomatic. Experimental inoculation in other mammals has resulted in transient hyperthermia, mild respiratory disease, and mastitis. Abortions, stillbirths, and births of weak lambs are also seen.

Epizootiology and transmission. Coxiella burnetii is extremely resistant to environmental changes as well as to disinfectants; persistence in the environment for a year or longer is possible. The organism is associated with either a free-living or an arthropod-borne cycle. *Coxiella burnetii* is found in a variety of tick species, such as ixodid or argasid, where it replicates and is excreted in the feces. Once introduced into a mammal, *Coxiella* may be maintained without a tick intermediate. The organism is especially concentrated in placental tissues, replicates in trophoblasts, and will be in reproductive fluids. Additionally, the organism is shed in milk, urine, feces, and oronasal secretions.

Necropsy findings. No specific lesion will be seen in aborted or stillborn fetuses, but necrotizing placentitis will be a finding in cases of abortion. The placenta will contain white chalky plaques and a red-brown exudate. The disease can be diagnosed by identifying the rickettsial organisms in smears of placental secretions. The organism has been found in the placentas of clinically normal animals. The organism stains red with modified Ziehl–Neelsen and Macchiavello stains and purple with Giemsa stain.

Differential diagnosis. Because of the organisms' similarity to *Chlamydia,* confirmation must be made by culture techniques, immunofluorescent procedures, ELISA, and complement fixation tests.

Treatment. Coxiella can be treated with oxytetracyclines. A vaccine is not commercially available.

Prevention and control. Any aborting animals should be segregated from other animals, and other pregnant animals should be treated prophylactically with tetracycline. Serologic screening of ruminant sources should be performed routinely. Barrier housing, a review of ventilation exhaust, and defined handling procedures are often required. All placentas and all aborted tissues should be handled and disposed of carefully. Q fever has been reported in many mammalian species, including cats.

Research complications. Coxiella burnetii-free animals are particularly important in studies involving fetuses and placentation. Because of its zoonotic potential, *C. burnetii* presents a unique problem in the animal research facility environment. A single organism has been shown to cause disease. Some of the greatest concerns are the risk to immunocompromised individuals, pregnant women, and other animals, and the presence of carrier animals or those that may shed the organism in placentas, for example.

2. Viral Diseases

a. Adenovirus Infections

Etiology. The ruminant adenoviruses are DNA viruses that cause respiratory and reproductive tract diseases. Nine antigenic types of the bovine adenovirus have been identified, with type 3 associated with respiratory disease. Two of the ovine and two of the caprine antigenic types have been identified.

Clinical Signs. Signs of infection range from subclinical to severe, including pneumonia, enteritis, conjunctivitis, keratoconjunctivitis, weak calf syndrome, and abortion. Respiratory tract and intestinal tract diseases may be concurrent. Infections caused by this virus are often found associated with other viral and bacterial infections.

Epizootiology and transmission. The virus is believed to be widespread, but prevalence and characteristics of infection have not been characterized. Transmission of adenoviruses in other species (e.g., canine) is by aerosols or fecal–oral routes.

Necropsy findings. Lesions found after experimental infections include atelectasis, edema, and consolidation of the lungs.

b. Bluetongue Virus Infection (Reoviridae)

Etiology. The bluetongue virus is an RNA virus in the *Orbivirus* genus and Reoviridae family. Five serotypes (2, 10, 11, 13, and 17) have been identified in the United States, where it is seen mostly in western states. Bluetongue is an acute arthropod-borne viral disease of ruminants, characterized by stomatitis, depression, coronary band lesions, and congenital abnormalities (Bulgin, 1986).

Clinical signs and diagnosis. Sheep are the most likely to show clinical signs. Clinical disease is less common in goats and cattle. Early in the infection, animals will spike a fever and will develop hyperemia and congestion of tissues of the mouth, lips, and ears. The virus name, bluetongue, is associated with the typical cyanotic membranes. The fever may subside, but tissue lesions erode, causing ulcers. Increased salivary discharges and anorexia are often related to ulcers of the dental pad, lips, gums, and tongue, although salivation and lacrimation may precede apparent ulceration. Chorioretinitis and conjunctivitis are also common signs in cattle and sheep. Lameness may be observed associated with coronitis and is evident in the rear legs. Skin lesions such as drying and cracking of the nose, alopecia, and mammary glands are also observed. Secondary bacterial pneumonia may also occur. Animals may also develop severe diarrhea and become recumbent. Sudden deaths due to cardiomyopathy may occur at any time during the disease. Hematologically, animals will be leukopenic. The course of the disease is about 2 weeks, and mortality may reach 80%.

If animals are pregnant, the virus crosses the placenta and causes central nervous system lesions. Abortions may occur at any stage of gestation in cattle. Prolonged gestation may result from cerebellar hypoplasia and lack of normal sequence to induce parturition. Cerebellar hypoplasia will also be present in young born of the infected dams, as well as hydrocephalus, cataracts, gingival hyperplasia, or arthrogryposis.

Diagnosis is suspected with the characteristic clinical signs and exposure to viral vectors. Virus isolation is the best diagnostic approach if blood is collected during the febrile stage of the disease or brains from aborted fetuses. Fluorescent antibody tests, ELISA, virus neutralization tests, PCR, and agar gel immunodiffusion (AGID) tests are also used to confirm the diagnosis.

Epizootiology and transmission. Severe outbreaks have occurred in other countries during this century. Screening for this disease has limited the strains present in the United States. The disease is most common in outdoor-housed animals primarily in the western United States. The virus is primarily transmitted by biting midges, *Culicoides*. *Culicoides variipennis* is the most common vector in the United States. A combination of factors associated with viral strain, available and susceptible hosts, environmental conditions (such as damp areas where flies breed), and vector presence are factors in the severity of outbreaks. The disease is rarely transmitted by animal-to-animal contact or by infected animal products. Virus-contaminated semen, transplacental transfer, and carriage on transferred embyros are other possible means of transmission.

Necropsy findings. At necropsy, erosive lesions may be observed around the mouth, tongue, palate, esophagus, and pillars of the rumen. Ulceration or hyperemia of the coronary bands may also be seen. Many of the internal organs will contain petechial and ecchymotic hemorrhages of the surfaces, and hemorrhage may be seen at the base of the pulmonary artery.

Pathogenesis. The virus multiplies in the hemocoel and salivary glands of the fly and is excreted in transmissible form in the insect's saliva. After entering the host, the virus causes prolonged viremia. The incubation period is 6–14 days. The virus migrates to and attacks the vascular endothelium. The resulting vasculitis accounts for the lesions of the skin, mouth, tongue, esophagus, and rumen and the edema often found in many tissues. Ballooning degeneration of affected tissues, followed by necrosis and ulceration, occurs. The effects on fetuses appear to be due to generalized infections of developing organs.

Differential diagnosis. Differentials include other infectious vesicular diseases such as foot-and-mouth disease, contagious ecthyma, bovine viral diarrhea virus–mucosal disease, infectious bovine rhinotracheitis, bovine papular stomatitis, and malignant catarrhal fever. Rinderpest is a differential in countries

where it is endemic. Photosensitization should be considered. Foot rot is a differential for the lameness and coronitis. Differentials for the manifestations such as arthrogryposis include border disease virus and genetic predispositions of some breeds such as Charolais cattle and Merino sheep.

Prevention and control.   Cellular and humoral immunity are necessary for protection from infection. The bluetongue virus is insidious because the genome is capable of reassortment, and some vaccines will not have the antigenic components represented in the local infection. In addition, there is little to no cross protection between strains. Modified live vaccines are available in some parts of the United States but should not be used in pregnant animals. Vaccinating lambs and rams in an outbreak is worthwhile, for example, but vaccinating late-gestation ewes may cause birth defects or abortions. Congenital defects are more common from vaccine use than from naturally occurring infection. Minimizing exposure to the vector in endemic areas will decrease the incidence of the disease.

Treatment.   Supportive care and nursing care are helpful, including gruels or softer feeds, easily accessed water, and shaded resting places. Nonsteroidal anti-inflammatory drugs are often administered. For the cases of secondary bacterial pneumonia and some cases of bluetongue conjunctivitis, antibiotics may be administered.

Research complications.   This is a reportable disease because clinical signs resemble foot-and-mouth disease and other exotic vesicular diseases.

c.   *Bovine Lymphosarcoma (Bovine Leukemia Virus Infection, Bovine Leukosis)*

Etiology.   Bovine lymphosarcoma refers to lymphoproliferative diseases in young cattle that are not associated with bovine leukemia virus (BLV) infection, and those in older cattle that are associated with BLV. BLV is a B lymphocyte–associated retrovirus (Johnson and Kaneene, 1993a,b,c).

Clinical signs.   Forms of bovine lymphosarcoma that are not associated with BLV infection are calf, or juvenile; thymic, or adolescent (animals 6 months to 2 years old); and cutaneous (any age). The calf form is rare and characterized by generalized lymphadenopathy. Onset may be sudden, and the disease is usually fatal within a few weeks. Signs include lymphadenopathy, anemia, weight loss, and weakness. Some animals may be paralyzed because of spinal cord compression from subperiosteal infiltration of neoplastic cells. The adolescent form is also rare, the course rapid, and the prognosis poor. The disease is seen most often in beef breeds such as Hereford cattle and is characterized by space-occupying masses in the neck or thorax. These masses are also often present in the brisket. Secondary

effects of the masses are loss of condition, dysphagia, rumen tympany, and fatal bloat. The cutaneous presentation has a longer course and may wax and wane. The masses are found at the anus, vulva, escutcheon, shoulder, and flank; they are painful when palpated, raised, and often ulcerated. The animals are anemic, and neoplastic involvement may affect cardiac function. Generalized or limited lymphadenopathy may be apparent.

Only the adult, or enzootic, form of bovine lymphosarcoma is associated with BLV infection. Many animals do not develop any malignancies or clinical signs of infection and simply remain permanently infected. Some cows manifest disease only during the periparturient period. Malignant lymphoma is the more common, whereas leukosis, due to B-lymphocyte proliferation, is rare. Clinical signs are loss of condition and a drop in production of dairy cattle, anorexia, diarrhea, ataxia, paresis, and other signs dependent on the location of the neoplastic tissue. Tumors are associated with lymphoid tissues. Common sites also include the abomasum, spinal canal, and uterus. Cardiac tumors develop at the right atrial or left ventricular myocardium, and associated beat and rate abnormalities may be auscultated. The common ocular manifestation of the disease is exophthalmos due to retrobulbar masses. Many internal organs may be involved, and tumors may be palpable per rectum. Secondary infections will be due to immunosuppression and the weakened state of the animal.

Sheep have acquired BLV infection naturally and have been used as experimental models; in both situations, this species is susceptible to tumor and leukemia development. Goats seroconvert but do not develop the clinical syndromes.

Diagnosis is based on the animal's age, clinical signs, serology, hematology findings according to the form, aspirates or biopsies of masses, and necropsy findings. Kits are available for running AGID, for which the BLV antigens gp-51 and gp-24 are used; antibodies may be detected within weeks after exposure and may also help in predicting disease in clinically normal cattle. ELISA and PCR diagnostic aids will also be helpful.

Epizootiology and transmission.   This disease is present worldwide. It is estimated that at least 50% of the cattle in the United States are infected with BLV. As few as 1% of these animals develop lymphosarcoma, but the adult form of the disease described here is the most common bovine neoplastic disease in the United States. Larger herds tend to have higher rates. Genetic predisposition may be involved; in addition to the presence of BLV, the type of bovine lymphocyte antigen (BoLA) may be correlated to resistance or susceptibility and to the course of the disease. Transmission is believed to be by inhalation of BLV in secretions; in colostrum; horizontally by contaminated equipment not sanitized between cattle; and by rectum (e.g., mucosal irritation during per-rectum exams or procedures). Natural-service bulls may transmit the infection to cows. Cows infected with BLV may transmit the infection to

their calves *in utero*. Tabanid and other flies also serve as vectors, but these represent a minor means of transmission.

Necropsy findings. Neoplastic infiltration of many organs and tissues are found in the calf form and the cutaneous forms. Tumors may be local or widely distributed in the enzootic form. Definitive diagnosis of neoplastic tissue specimens is by histology.

Pathogenesis. As with other retroviruses, the BLV integrates viral DNA into host target cell DNA by means of the reverse transcriptase enzyme, creating a provirus.

Prevention and control. There is no vaccine for this disease. Development and maintenance of a BLV-free herd, or controlling infection within a herd, requires financial and programmatic commitments: BLV-positive and BLV-negative animals maintained separately; serologic testing (such as at least every 6 months) and separating positive animals; and washing and then disinfecting instruments, needles (or using sterile single-use products), and equipment for ear tagging and dehorning and other such equipment between animals. A fresh rectal exam sleeve and lubricant should be used for each animal examined. Otherwise serologically positive cows may have undetectable antibodies during the periparturient period. Embryo transfer recipients should be negative, and the virus will not be transferred by the embryonic stage. Calves should be fed colostrum from serologically negative cows.

Treatment. Treatment regimens of corticosteroids and cancer chemotherapeutic agents provide only short-term improvement. In cases where ova, embryos, or semen need to be collected, supportive care for the affected animals is essential.

Research complications. The United States and several countries, some in Europe, have official programs for eradication of enzootic bovine leukosis.

d. Bovine Herpes Mammillitis (Bovine Herpesvirus 2 Bovine Ulcerative Mammillitis)

Etiology. Bovine herpesvirus 2 causes bovine herpes mammillitis, a widespread disease characterized by teat and udder lesions, as well as oral and skin lesions.

Clinical signs and diagnosis. Lesions begin suddenly with teat swelling; the tissue will be edematous and tender when touched. The udder lesions may extend to the perineum. The lesions progress to vesicles, then to ulcers; these may take 10 weeks to heal. Lesions rarely may also develop focally around the mouth and generally on the skin of the udder. Secondary mastitis may occur, because of bacteria associated with the scabs. Diagnosis is by clinical signs and serologically.

Epizootiology and transmission. The virus is reported to be widespread. Occurrence is often seasonal, and biting insects may be vectors. Transmission with successful infection requires deep penetration of the skin. Transmission may be by contaminated milkers' hands, contaminated equipment, and other fomites.

Differential diagnosis. Differential diagnoses include other diseases that cause lesions on teats such as pseudocowpox, papillomatosis, and vesicular stomatitis. Other vesicular diseases may be considered, but other more severe clinical signs might be associated with those.

Prevention and control. Established milking hygiene practices are important control measures: having milkers wash their hands with germicidal solutions or wear gloves, cleaning equipment between animals, and separating affected animals.

Treatment. There is no treatment, and affected animals should be separated from the herd and milked last. Lesions can be cleaned and treated with topical antibacterials.

e. Bovine Viral Diarrhea Virus

Etiology. The bovine viral diarrhea virus (BVDV) is a pestivirus of the Flaviviridae family. The Flaviviridae include hog cholera virus and border disease virus of sheep. The virus contains a single strand of positive-sense RNA. A broad range of disease and immune effects is produced by BVDV only in cattle. In addition, this virus is important in the etiology of bovine pneumonias. Bovine viral diarrhea/mucosal disease (BVD/MD) is one of the most important viral diseases and one of the most complex diseases of cattle. Strains of BVDV are characterized as cytopathic (CP) and noncytopathic (NCP), based on cell-culture growth characteristics. The virus has also been categorized as type 1 and type 2 isolates. Heterologous strains exist that may confound even sound vaccination programs.

Clinical signs and diagnosis. Signs of BVDV infections may be subclinical but also include abortions, congenital abnormalities, reduced fertility, persistent infection (PI) with gradual debilitation, and acute and fatal disease. The presence of antibodies, whether from passive transfer or immunizations, does not necessarily guarantee protection from the various forms of the disease.

An acute form of the disease, caused by type 2 BVDV, occurs in cattle without sufficient immunity. After an incubation period of 5–7 days, clinical signs include fever, anorexia, oculonasal discharge, oral erosions (including on the hard palate), diarrhea, and decreased milk production. The disease course may be shorter with hemorrhagic syndrome and death within 2 days. Clinical signs of BVDV in calves also include severe enteritis and pneumonia.

When susceptible cows are infected *in utero* from gestational days 50–100, or gestational cows are vaccinated with a modified live vaccine, abortion or stillbirth result. Congenital defects caused by BVDV during gestational days 90–170 include impaired immunity (thymic atrophy), cerebellar hypoplasia, ocular defects, alopecia or hypotrichosis, dysmyelinogenesis, hydranencephaly, hydrocephalus, and intrauterine growth retardation. Typical signs of cerebellar dysfunction will be evident in calves, such as wide-based stance, weakness, opisthotonus, hyperflexion, hypermetria, nystagmus, or strabismus. Some severely affected calves will not be able to stand. Ophthalmic effects include retinal degeneration and microphthalmia.

Fetuses can also be infected *in utero,* normal at birth, immunotolerant to the virus, and persistently infected (PI). The term *mucosal disease* is commonly associated with this form of the infection. Many PI animals do not survive to maturity, however, and many have weakened immune systems. The PI animals are important because they shed virus and will probably show the clinical signs of mucosal disease (MD) caused by a CP BVDV strain derived from an NCP BVDV strain. These MD clinical signs include fever, anorexia, and profuse diarrhea that may include blood and fibrin casts, and oral and pharyngeal erosions, as well as erosion at the interdigital spaces and on the teats and vulva. Many other associated clinical signs include anemia, bloat, lameness, or corneal opacities and discharges. Secondary effects of hemorrhage and dehydration also contribute to the morbidity and mortality. Animals that do not succumb to the disease will be chronically unthrifty, debilitated, and infection-prone.

Diagnosis in affected calves is based on herd health history, clinical signs, and antibodies to BVDV in precolostral serum. Viral culturing from blood may be useful. In older animals, oral lesions, serology, detection of viral antigen, and virus isolation contribute to the diagnosis. Leukopenia, and especially lymphopenia, are seen. Serology must be interpreted with the awareness of the possibility of PI immunotolerant animals.

Vaccination against the disease carries its own set of side effects and potential problems, especially when using modified live vaccines, whether against CP or NCP strains. The condition of the animals is also a variable.

Epizootiology and transmission.   BVDV is present throughout the world. Transmission occurs easily by direct contact between cattle, from feed contaminated with secretions or feces, and by aborted fetuses and placentas. PI females transmit the virus to their fetuses. Semen also is a source of virus.

Necropsy findings.   In affected calves, histopathologic findings include necrosis of external germinal cells, focal hemorrhages, and folial edema. Later in the disease, large cavities develop in the cerebellum, and atrophy of the cerebellar folia and thin neuropil are evident. Older calves may have areas of intestinal necrosis. In cases where oral erosions occur, erosions will be found extending throughout the gastrointestinal tract to the cecum. The respiratory tract lesions will often be complicated by secondary bacterial pneumonia. When the hemorrhagic syndrome develops, petechiation and mucosal bleeding will be present.

Pathogenesis.   The CP and NCP strains are thought to be related mutations of the BVDV; the CP short-lived isolates are believed to arise from the NCP strains. The NCP strains are those present in the PI animals, and the strains are maintained in cattle populations. CP and NCP isolates vary in virulence, and classification of these types is based on viral surface proteins. Considerable antigenic variation also exists between strains and types. Other viral infections, such as bovine respiratory syncytial virus and infectious bovine rhinotracheitis, may also be present in the same animals.

The pathology caused by BVDV is due to its ability to infect epithelial cells and impair the functioning of immune cell populations through out the bovine system. In type 2 BVDV hemorrhagic syndrome, death results from viral-induced thrombocytopenia. In fetuses, the virus infects developing germinal cells of the cerebellum. The Purkinje's cells in the granular layer are killed, and necrosis and inflammation follow. The immune effects are the result of the virus's interfering with neutrophil and macrophage functions and of lymphocyte blastogenesis. All of these predispose the affected animals to bacterial infections with *Pasteurella haemolytica.* BVDV damages dividing cells in fetal organ systems, resulting in abortions and congenital effects.

Differential diagnosis.   Many differentials must be considered for the clinical manifestations of BVDV infections. Differentials for enteritis of calves include viral infections, *Cryptosporidia, Escherichia coli, Salmonella,* and *Coccidia. Salmonella,* winter dysentery, Johne's disease, intestinal parasites, malignant catarrhal fever (MCF), and copper deficiency are differentials for the diarrhea seen in the disease in adult animals. Respiratory tract pathogens such as bovine respiratory syncytial virus, *Pasteurella, Haemophilus,* and *Mycoplasma* must be considered for the respiratory tract manifestations. Oral lesions are also produced by MCF, vesicular stomatitis, bluetongue, and papular stomatitis. Infectious bovine herpesvirus 1, leptospirosis, brucellosis, trichomoniasis, and mycosis should be considered in cases of abortion.

Prevention and control.   Combined with sound management in a typical cattle herd, vaccination is the best way to prevent BVDV and should be integrated into the herd health program, timed appropriately preceding breeding, gestation, or stressful events. Vaccine preparations for BVDV are modified live virus (MLV) or killed virus. Each has advantages and disadvantages. The former induces rapid immunity (within 1 week) after a single dose, provides longer duration of immunity against sev-

eral strains, and induces serum neutralizing antibodies. MLV vaccines are not recommended for use in pregnant cattle, may induce mucosal disease, and may be immunosuppressive at the time of vaccination. The immunosuppression is detrimental if cattle are concurrently exposed to field-strain virus because it will facilitate infection and possible clinical disease. The MLV strains may cross the placenta, resulting in fetal infections. The killed vaccines are safer in pregnant animals but require booster doses after the initial immunization, may need to be given 2–3 times per year, and do not induce cell-mediated immunity.

Passive immunity may protect most calves for up to 6–8 months of age. Subsequent vaccination with MLV may provide lifelong immunity, but this is not guaranteed. Annual boosters are recommended to protect against vaccine breaks.

The virus persists in the environment for 2 weeks and is susceptible to the disfectants chlorhexidine, hypochlorite, iodophors, and aldehydes.

Maintenance of a closed herd to prevent any possibility of the introduction of the virus is difficult. Isolation of new animals, avoidance of the purchase of pregnant cows, scrutiny of records from source farms, use of semen tested bulls, minimization of stress, testing of embryo-recipient cows, and maintainenance of populations of ruminants (smaller or wild species) separately on the premises will minimize viral exposure. Other management strategies may require a program for testing and culling PI cattle. This can be expensive but may be a worthwhile investment to remove the virus shedders from a herd.

Treatment. No specific treatment is available. Supportive care and treatment with antibiotics to prevent secondary infection are recommended. Animals that survive the infection should be evaluated a month after recovery to determine their status as PI or virus-free.

f. Cache Valley Virus

Etiology. Cache Valley virus (CVV), of the *arbovirus* genus of the Bunyaviridae family, is a cause of congenital defects in lambs.

Clinical signs and diagnosis. Teratogenic effects of *in utero* CVV infection in fetal and newborn lambs include arthrogryposis, microencephaly, hydranencephaly, porencephaly, cerebellar hypoplasia, and micromyelia. Stillbirths and mummified fetuses are seen. Lambs will be born weak and will act abnormally.

Diagnosis is by evidence of seroconversion in precolostral blood samples or fetal fluids, as the result of *in utero* infection.

Epizootiology and transmission. The virus is present in the western United States, although it has been isolated in a few Midwestern states. Although considered a disease of sheep, virus has been isolated from cattle and from wild ruminants

and antibodies found in white-tailed deer. Transmission is by arthropods during the first trimester of pregnancy.

g. Caprine Arthritis Encephalitis Virus

Etiology. Caprine arthritis encephalitis virus (CAEV) occurs worldwide, with a high prevalence in the United States. Caprine arthritis encephalitis (CAE) is considered the most important viral disease of goats. The CAEV is in the *Lentivirus* genus of the Retroviridae family. It causes chronic arthritis in adults and encephalitis in young. CAEV is in the same viral genus as the ovine progressive pneumonia virus (OPPV).

Clinical signs and diagnosis. The most common presentation in goats is an insidious, progressive arthritis in animals 6 months of age and older. Animals become stiff, have difficulty getting up, and may be clinically lame in one or both forelimbs. Carpal joints are so swollen and painful that the animal prefers to eat, drink, and walk on its "knees." In dairy goats, milk production decreases, and udders may become firmer.

This retrovirus also causes neurological clinical signs in young kids 2–6 months old. Kids may be bright and alert, afebrile, and able to eat normally even when recumbent. Some kids may initially show unilateral weakness in a rear limb, which progresses to hemiplegia or tetraplegia. Mild to severe lower motor neuron deficits may be noted, but spinal reflexes are intact. Clinical signs may also include head tilt, blindness, ataxia, and facial nerve paralysis.

Older animals in the group may experience interstitial pneumonia or chronic arthritis. The pneumonia is similar to the pneumonia in sheep caused by OPPV; the course is gradual but progressive, and animals will eventually lose weight and have respiratory distress. Some animals in a herd may not develop any clinical signs.

Diagnosis is based on clinical signs, postmortem lesions, and positive serology for viral antibodies to CAEV. An agar gel immunodiffusion (AGID) test identifies antibodies to the virus and is used for diagnosis. Kids acquire an anti-CAEV antibody in colostrum, and this passive immunity may be interpreted as indicative of infection with the virus. The antibody does not prevent viral transmission.

Epizootiology and transmission. The virus is prevalent in most industrialized countries. The common means of transmission, from adults to kids, is in the colostrum and milk in spite of the presence of anti-CAEV antibody in the colostrum. Transmission may occur among adult goats by contact. Intrauterine transmission is believed to be rare. Transmission to sheep has occurred only experimentally; there is no documented case of natural transmission.

Necropsy findings. Necropsy and histopathology reveal a striking synovial hyperplasia of the joints with infiltrates of

lymphocytes, macrophages, and plasma cells. Other histologic lesions include demyelination in the brain and spinal cord, with multifocal invasion of lymphocytes, macrophages, and plasma cells. In severe cases of mastitis, the udder may appear to be composed of lymphoid tissue.

Pathogenesis. The virus infects cells of the mononuclear system, resulting in the formation of non-neutralizing antibody to viral core proteins and envelope proteins. Immune complex formation in synovial, mammary gland, and neurological tissue is thought to result in the clinical changes observed. Most commonly, the carpal joint is affected, followed by the stifle, hock, and hip. The infection is lifelong.

Differential diagnosis. The differential diagnosis for the neurologic form of CAEV should include copper deficiency, enzootic pneumonia, white muscle disease, listeriosis, and spinal cord disease or injury. The differential diagnosis for CAEV arthritis should include chlamydia and mycoplasma.

Prevention and control. Herds can be screened for CAE by testing serologically, using an AGID or an enzyme-linked immunosorbent assay (ELISA) test. The ELISA is purported to be more sensitive, whereas the AGID is more specific. Individual animals show great variation in development of antibody. Because CAE is highly prevalent in the United States, and because seronegative animals can shed organisms in the milk, retesting herds at least annually may be necessary. Recently, an immunoprecipitation test for CAE has been developed that has high sensitivity and specificity.

Control measures include management practices such as test and cull, prevention of milk transmission, and isolation of affected animals. Parturition must be monitored, and kids must be removed immediately and fed heat-treated colostrum (56°C for 1 hr). CAEV-negative goats should be separated from CAEV-positive goats.

Treatment. There is no treatment for CAEV.

h. Infectious Bovine Rhinotracheitis Virus (Infectious Bovine Rhinotracheitis–Infectious Pustular Vulvovaginitis)

Etiology. The infectious bovine rhinotracheitis virus (IBRV) is also referred to as bovine herpesvirus 1 (BHV-1) and is an alphaherpesvirus. IBRV causes or contributes to several bovine syndromes, including respiratory and reproductive tract diseases. It is one of the primary pathogens in the bovine respiratory disease complex. Strains include BHV-1.1 (associated with respiratory disease), BHV 1.2 (associated with respiratory and genital diseases), and BHV 1.4 (associated with neurological diseases), which has been reclassified as bovine herpesvirus 5.

Clinical signs and diagnosis. Diseases caused by the virus include conjunctivitis, rhinotracheitis, pustular vulvovaginitis, balanoposthitis, abortion, encephalomyelitis, and mastitis. The respiratory form is known as infectious bovine rhinotracheitis, and clinical signs may range from mild to severe, the latter particularly when there are additional respiratory viral infections or secondary bacterial infections. The mortality rate in more mature cattle is low, however, unless there is secondary bacterial pneumonia. Fever, anorexia, restlessness, hyperemia of the muzzle, gray pustules on the muzzle (that later form plaques), nasal discharge (that may progress from serous to mucopurulent), hyperpnea, coughing, salivation, conjunctivitis with excessive epiphora, and decreased production in dairy animals are typical signs. Open-mouth breathing may be seen if the larynx or nasopharygneal areas are blocked by mucopurulent discharges. Neonatal calves may develop respiratory as well as general systemic disease. In these cases, in addition to the symptoms already noted, the soft palate may become necrotic, and gastrointestinal tract ulceration occurs. Young calves are most susceptible to the encephalitic form; signs include dull attitude, head pressing, vocalizations, nystagmus, head tilt, blindness, convulsions, and coma, as well as some signs, such as discharges, seen with respiratory tract presentations. This form is usually fatal within 5 days. Abortion may occur simultaneously with the conjunctival or respiratory tract diseases, when the respiratory infection appears to be mild, or may be delayed by as much as 3 months after the respiratory tract disease signs. Infectious pustular vulvovaginitis is most commonly seen in dairy cows, and clinical signs may be mild and not noticed. Otherwise, signs are fever, depression, anorexia, swelling of the vulvar labia, vulvar discharge, and vestibular mucosa reddened by pustules. The cow will often carry her tail elevated away from these lesions. These soon coalesce, and a fibrous membrane covers the ulcerated area. If uncomplicated, the infection lasts about 4–5 days, and lesions heal in 2 weeks. Younger infected bulls may develop balanoposthitis with edema, swelling, and pain such that the animals will not service cows.

Epizootiology and transmission. IBRV is widely distributed throughout the world, and adult animals are the reservoirs of infection. The disease is more common in intensive calf-rearing situations and in grouped or stressed cattle. Transmission is primarily by secretions, such as nasal, during and after clinical signs of disease. Modified live vaccines are capable of causing latent infections.

Necropsy findings. Fibrinonecrotic rhinotracheitis is considered pathognomic for IBRV respiratory tract infections. There will be adherent necrotic lesions in the respiratory, ocular, and reproductive mucosa. When there are secondary bacterial infections, such as *Pasteurella* bronchopneumonia, findings will include congested tracheal mucosa and petechial and ecchymotic

hemorrhages in that tissue. Lesions from the encephalitic form include lymphocytic meningoencephalitis and will be found throughout the gray matter (neuronal degeneration, perivascular cuffing) and white matter (myelitis, demyelination). Intranuclear inclusion bodies are not a common finding with this herpesvirus.

Pathogenesis. In the encephalitic form, the virus first grows in nasal mucosa and produces plaques. These resolve within 11 days, and the encephalitis develops after the virus spreads centripetally to the brain stem by the trigeminal nerve dendrites. Latent infections are also established in neural tissue.

Differential diagnosis. The severe oral erosions seen with BVDV infections are rare with infectious bovine rhinotracheitis—infectious pustular vulvovaginitis (IBR-IPV). The conjunctivitis of IBR may initially be mistaken for that of a *Moraxella bovis* (pinkeye) infection; the IBR will be peripheral, and there will not be corneal ulceration. Bovine viral diarrhea virus and IBRV are the most common viral causes of bovine abortion. Differentials for balanoposthitis include trauma from service.

Prevention and control. Vaccination options include inactivated, attenuated, modified live, and genetically altered preparations. Some are in combination with parainfluenza 3 (PI-3) virus. The MLV preparations are administered intranasally; these are advantageous in calves for inducing mucosal immunity even when serologic passive immunity is already present and adequate. Some newer vaccines, with gene deletion, allow for serologic differentiation between antibody responses from infection or immunization. Bulls with the venereal form of the infection will transmit the virus in semen; intranasal vaccine may be used to provide some immunity.

Treatment. Uncomplicated mild infections will resolve over a few weeks; palliative treatments, such as cleaning ocular discharges and supplying softened food, are helpful in recovery. Antibiotics are usually administered because of the high likelihood of secondary bacterial pneumonia. The encephalitic animals may need to be treated with anticonvulsants.

i. Parainfluenza 3 (PI-3)

Etiology. Parainfluenza 3, an RNA virus of the family Paramyxoviridae, causes mild respiratory disease of ruminants when it is the sole pathogen. The viral infection often predisposes the respiratory system to severe disease associated with concurrent viral or bacterial pathogens. Viral strains are reported to vary in virulence. Serotypes seen in the smaller ruminants are distinct from those isolated from cattle.

Clinical signs and diagnosis. Infections ranging from asymptomatic to mild signs of upper respiratory tract disease are associated with this virus by itself; infections are almost never fatal. Clinical signs include ocular and nasal discharges, cough, fever, and increased respiratory rate and breath sounds. In pregnant animals, exposure to PI-3 can result in abortions. Clinical signs become apparent or more severe when additional viral pathogens are present, such as bovine viral diarrhea virus, or a secondary bacterial infection, such as *Pasteurella haemolytica* infection, is involved. Greater morbidity and mortality will be sequelae of the bacterial infections. Viral isolation or direct immunofluorescence antibody (IFA) from nasal swabs can be used for definitive diagnosis.

Epizootiology and transmission. The virus is considered ubiquitous in cattle and is a common infection in sheep. Presently it is assumed that the virus is widespread in goats, but firm evidence is lacking.

Necropsy findings. For an infection of PI-3 only, findings will be negligible. Some congestion of respiratory mucosa, swelling of respiratory tract–associated lymph nodes, and mild pneumonitis may be noted grossly and histologically. Intranuclear and intracytoplasmic inclusion bodies may be present in the mucosal epithelial cells. Findings will be similar but not as severe as those caused by bovine respiratory syncytial virus. Immunohistochemistry may also be used.

Pathogenesis. PI-3 infects the epithelial mucosa of the respiratory tract; however, the disease is often asymptomatic when uncomplicated.

Differential diagnosis. Differentials, particularly in cattle, include infections with other respiratory tract viruses of ruminants: IBRV, BVDV, bovine respiratory syncytial virus, and type 3 bovine adenovirus.

Prevention and control. Immunization, management, and nutrition are important for this respiratory pathogen, as for others. In cattle, modified live vaccines for intramuscular (IM), subcutaneous (SC), or intranasal (IN) administration are available. The IM and SC routes provide immune protection within 1 week after administration but will not provide protection in the presence of passively acquired antibodies. It is contraindicated for pregnant animals because it will cause abortion. The IN route immunizes in the presence of passively acquired antibodies, provides immunity within 3 days of administration, and stimulates the production of interferon. Other vaccine formulations, about which less information is reported, include inactivated or chemically altered live-virus preparations; both are administered IM, and followup immunizations are needed

within 4 weeks. Booster vaccinations are recommended for all preparations within 2–6 months after the initial immunization. All presently marketed vaccine products come in combination with other bovine respiratory viruses as multivaccine products. The humoral immunity protects against PI-3 abortions.

There is no approved PI-3 vaccine for sheep and goats. The use of the cattle formulation in these smaller ruminants is not recommended.

Sound management of housing, sanitation, nutrition, and preventive medicine programs are all equally important components in prevention and control.

Treatment.   Uncomplicated disease is not treated.

j.   Respiratory Syncytial Viruses of Ruminants

Etiology.   The respiratory syncytial viruses are pneumoviruses of the Paramyxoviridae family and are common causes of severe disease in ruminants, especially calves and yearling cattle. Two serotypes of the bovine respiratory syncytial virus (BRSV) have been described for cattle; these may be similar or identical to the virus seen in sheep and goats.

Clinical findings and diagnosis.   Infections may be subclinical or develop into severe illness. Clinical signs include fever, hyperpnea, spontaneous or easily induced cough, nasal discharge, and conjunctivitis. Interstitial pneumonia usually develops, and harsh respiratory sounds are evident on auscultation. Development of emphysema indicates a poor prognosis, and death may occur in the severe cases of the viral infection. Secondary bacterial pneumonia, especially with *Pasteurella haemolytica*, with morbidity and mortality, is also a common sequela. Abortions have been assciated with BRSV outbreaks.

Diagnosis is based on virus isolation and serology (acute and convalescent). Nasal swabs for virus isolation should be taken when animals have fever and before onset of respiratory disease.

Epizootiology and transmission.   These viruses are considered ubiquitous in domestic cattle and are transmitted by aerosols.

Necropsy findings.   Gross lesions include consolidation of anteroventral lung lobes. Edema and emphysema are present. As the name indicates, syncytia, which may have inclusions, form in areas of the lungs infected with the virus. Necrotizing bronchiolitis, bronchiolitis obliterans, and hyaline membrane formation will be evident microscopically.

Pathogenesis.   The severe form of the disease, which often follows a mild preliminary infection, is thought to be caused by immune-mediated factors during the process of infection in the lung. Virulence may vary greatly among viral strains.

Differential diagnosis.   Differentials should include other ruminant respiratory tract viruses.

Prevention and control.   Vaccination should be part of the standard health program, and all animals should be vaccinated regularly. Vaccinations should be administered within 1–2 months of stressful events, such as weaning, shipping, and introduction to new surroundings. Currently available vaccines include an inactivated preparation and a modified live virus preparation administered intramuscularly or subcutaneously; immunity develops well in yearling animals, and colostral antibodies develop when cows are vaccinated during late gestation. Passive immunity from colostrum provides at least partial protection to calves in herds where disease is prevalent. But this immunity suppresses the mucosal IgA response and serum antibody responses. The basis for successful immune protection is the mucosal memory IgA, but this is difficult to achieve with present vaccine formulations. The virus is easily inactivated in the environment.

Preventive measures in preweaning animals should include preconditioning to minimize weaning stress.

Treatment.   Recovery can be spontaneous; however, antibiotics and supportive therapy are useful to prevent or control secondary bacterial pneumonia. In severe cases, antihistamines and corticosteriods may also be necessary. Use of vaccine during natural infection is not productive and may result in severe disease.

k.   Ulcerative Dermatosis (Ovine Venereal Disease, Balanoposthitis)

Etiology.   Ulcerative dermatosis is a contagious disease of sheep only. It is caused by a poxvirus similar to but distinct from the causative agent of contagious ecthyma ("Current Veterinary Therapy," 1993).

Clinical signs and diagnosis.   Lesions include ulcers and crusts associated with the skin and mucous membranes of the genitalia, face, and feet (Bulgin, 1986). Genital lesions are much more common than the facial or coronal lesions. Discomfort may be associated with the lesions. Paraphimosis occasionally occurs. These lesions are painful; during breeding season, animals will avoid coitus. Morbidity is low to moderate, and mortality negligible if the flock is otherwise healthy. Diagnosis is based on clinical signs.

Epizootiology and transmission.   Endemic to the western United States, ulcerative dermatosis is transmitted through direct contact with abraded skin of the prepuce, vulva, face, and feet.

Necropsy findings.   Necropsy would rarely be necessary to diagnose an outbreak in a healthy flock. Findings will be similar to those described for contagious ecthyma.

Pathogenesis.   Following an incubation period of 2–5 days, the virus replicates in the epidermal cells and leads to necrosis and pustule formation. Pustules rapidly break, forming weeping ulcers. The ulcers scab over and eventually form a fibrotic scar. The disease usually resolves in 2–6 weeks. Rarely, the disease will persist for many months to more than a year.

Differential diagnosis.   The main differential is contagious ecthyma, which is grossly and histopathologically associated with epithelial hyperplasia. This is also a feature of ulcerative dermatosis.

Prevention and control.   No vaccine is available. Affected animals, especially males, should not be used for breeding.

Treatment.   Affected animals should be separated from the rest of the flock. Treatment is supportive, including antiseptic ointments and astringents.

Research complications.   Breeding and maintenance of the flocks' condition, because of the pain associated with eating, will be compromised during an outbreak.

l.   Border Disease

Etiology.   Border disease, also known as hairy shaker disease (or "fuzzies" in the southwestern United States), is a disease of sheep caused by a virus closely related to the bovine viral diarrhea virus (BVDV), a pestivirus of the Togaviridae family. Goats are also affected. The virus causes few pathogenic effects in cattle.

Clinical signs and diagnosis.   Border disease in ewes causes early embryonic death, abortion of macerated or mummified fetuses, or birth of lambs with developmental abnormalities. Lambs infected *in utero* that survive until parturition may be born weak and often exhibit a number of congenital defects such as tremor, hirsutism (sometimes darkly pigmented over the shoulders and head), hypothyroidism, central nervous system defects, and joint abnormalities, including arthrogryposis. Later, survivors may be more susceptible to diseases and may develop persistent, sometimes fatal, diarrhea. The virus infection produces similar clinical manifestations in goats, except that the hair changes are not seen.

Diagnosis includes the typical signs described above, as well as serological evidence of viral infection. Virus isolation confirms the diagnosis.

Epizootiology and transmission.   The virus is present worldwide, and reports of disease are sporadic. Disease has occurred when no contact with cattle has occurred. Persistently infected animals, such as lambs, are shedding reservoirs of the virus in urine, feces, and saliva throughout their lives.

Necropsy findings.   Lesions include placentitis, and characteristic joint and hair-coat changes in the fetus. Histologically, axonal swelling, neuronal vacuolation, dysmyelination, and focal microgliosis are observed in central nervous system structures.

Pathogenesis.   The virus entering the ewe via the gastrointestinal or respiratory tracts penetrates the mucous membranes and causes maternal and fetal viremia. Infection during the first 45 days of gestation causes embryonic death. In lambs infected between 45 and 80 days, the virus activates follicular development, diminishes the myelination of neurons, and causes dysfunction of the thyroid gland. Infection after 80 days of gestation results in lambs that are born persistently infected. Infected lambs have high perinatal mortality; survivors have diminished signs over time but, as noted, continue to shed the virus.

Prevention and control.   Border disease can be prevented by vaccinating breeding ewes with killed-BVDV vaccine. Congenitally affected lambs should be maintained separately and disposed of as soon as humanely possible. New animals to the flock should be screened serologically. If cattle are housed nearby, vaccination programs for BVDV should be maintained.

Treatment.   There is no treatment other than supportive care for affected animals.

m.   Contagious Ecthyma (Contagious Pustular Dermatitis, Sore Mouth, Orf)

Etiology.   Contagious ecthyma, also known as contagious pustular dermatitis, sore mouth, or orf, is an acute dermatitis of sheep and goats caused by a parapoxvirus. This disease occurs worldwide and is zoonotic. Naturally occurring disease has also been reported in other species such as musk ox and reindeer. Other parapoxviruses infect the mucous membranes and skin of cattle, causing the diseases bovine pustular dermatitis and pseudocowpox.

Clinical signs and diagnosis.   The disease is characterized by the presence of papules, vesicles, or pustules and subsequently scabs of the skin of the face, genitals of both sexes, and coronary bands of the feet. Lesions develop most frequently at mucocutaneous junctions and are found most commonly at the commissures of the mouth. Orf is usually found in young animals less than 1 year of age. Younger lambs and kids will have difficulty nursing and become weak. Lesions may also develop on udders of nursing dams, which may resist suckling by offspring to nurse, leading to secondary mastitis. The scabs may appear nodular and raised above the surface of the surrounding

skin. Morbidity in a susceptible group of animals may exceed 90%. Mortality is low, but the course of the disease may last up to 6 weeks.

Diagnosis is based on characteristic lesions. Biopsies may reveal eosinophilic cytoplasmic inclusions and proliferative lesions under the skin. Electron microscopy will reveal the virus itself. Disease is confirmed by virus isolation.

Epizootiology and transmission. All ages of sheep and goats are susceptible. Seasonal occurrences immediately after lambing and after entry into a feedlot are common; stress likely plays a role in susceptibility to this viral disease. Older animals develop immunity that usually prevents reinfection for at least 1 or more years. Resistant animals may be present in some flocks or herds. The virus is very resistant to environmental conditions and may contaminate small-ruminant facilities, pens, feedlots, and the like for many years as the result of scabs that have been shed from infected animals. Transmission occurs through superficial lesions such as punctures from grass awns, scrapes, shearing, and other common injuries.

Necropsy findings. Necropsy findings include ballooning degeneration of epidermal and dermal layers, edema, granulomatous inflammation, vesiculation, and cellular hyperplasia. Secondary bacterial infection may also be evident.

Pathogenesis. The virus is typical of the Poxviridae, resembling sheep poxvirus (not found in the United States) and vaccinia virus and replicating in the cytoplasm of epithelial cells. Following an incubation period of 2–14 days, papules and vesicles develop around the margins of the lips, nostrils, eyelids, gums, tongue, or teats; skin of the genitalia; or coronary band of the feet. The vesicles form pustules that rupture and finally scab over.

Differential diagnosis. Ulcerative dermatosis and bluetongue virus should be considered in both sheep and goats. An important differential in goats is staphylococcal dermatitis.

Prevention and control. Individuals handling infected animals should be advised of precautions beforehand, should wear gloves, and should separate work clothing and other personal protective equipment. Clippers, ear tagging devices, and other similar equipment should always be cleaned and disinfected after each use. Colostral antibodies may not be protective. Vaccinating lambs and kids with commercial vaccine best prevents the disease. Dried scabs from previous outbreaks may also be used by rubbing the material into scarified skin on the inner thigh or axilla. Animals newly introduced to infected premises should be vaccinated upon arrival. Precautions must be taken when vaccinating animals, because the vaccine may induce orf in the animal handlers; it is not recommended to vaccinate

animals in flocks already free of the disease. Affected dairy goats should be milked last, using disposable towels for cleaning teat ends.

Treatment. Affected animals should be isolated and provided supportive care, especially tube feeding for young animals whose mouths are too sore to nurse. Treatment should also address secondary bacterial infections of the orf lesions, including systemic antibiotics for more severe infections. Treatment for myiasis may also be necessary. The viral infection is self-limiting, with recovery in about 4 weeks.

Research complications. Carrier animals may be a factor in flock or herd outbreaks. Contagious ecthyma is a zoonotic disease, and human-to-human transmission can also occur. The virus typically enters through abrasions on the hands and results in a large (several centimeters) nodule that is described as being extremely painful and lasting for as many as 6 weeks. Lesions heal without scarring.

n. Foot-and-Mouth Disease

Etiology. Foot-and-mouth disease (FMD) is caused by the foot-and-mouth disease virus, a picornavirus in the *Aphthovirus* genus. The disease is also referred to as aftosa or aphthous fever. Seven immunologically distinct types of the virus have been identified, with 60 subtypes within those 7. Epidemics of the disease have occurred worldwide. North and Central America have been free of the virus since the mid-1950s. This is a reportable disease in the United States; clinical signs are very similar to other vesicular diseases. Cattle (and swine) are primarily affected, but disease can occur in sheep and is usually subclinical in goats.

Clinical signs and diagnosis. In addition to vesicle formation around and in the mouth, hooves, and teats, fever, anorexia, weakness, and salivation occur. Vesicles may be as large as 10 cm, rupture after 2 days, and subsequently erode. Secondary bacterial infections often occur at the erosions. Anorexia is likely due to the pain associated with the oral lesions. High morbidity and low mortality, except for the high mortality in young cattle, are typical.

Diagnosis must be based on ELISA, virus neutralization, fluorescent antibody tests, and complement fixation.

Epizootiology and transmission. Domestic and wild ruminants and several other species, such as swine, rats, bears, and llamas are hosts. Asymptomatic goats can serve as virus reservoirs for more susceptible cohoused species such as cattle. Greater mortality occurs in younger animals. The United States, Great Britain, Canada, Japan, New Zealand, and Australia are FMD-free, whereas the disease is endemic in most of South

America, parts of Europe, and throughout Asia and Africa. The virus is very contagious and is spread primarily by the inhalation of aerosols, which can be carried over long distances. Transmission may also occur by fomites, such as shoes, clothing, and equipment. Human hands, soiled bedding, and animal products such as frozen or partially cooked meat and meat products, hides, semen, and pasteurized milk also serve as sources of virus.

Necropsy findings. Vesicles, erosions, and ulcers are present in the oral cavity as well as on the rumen pillars and mammary alveolar epithelium. Myocardial and skeletal muscle degeneration (Zenker's) is most common (and accounts for the greater mortality) in younger animals. Histological findings include lack of inclusion bodies. Vesicular lesions include intracellular and extracellular edema, cellular degeneration, and separation of the basal epithelium.

Pathogenesis. The incubation period is 2–8 days. The virus replicates in the pharynx and digestive tract in the cells of the stratum spinosum, and viremia and spread of virus to many tissues occur before clinical signs develop. Virus shedding begins about 24 hr before clinical signs are apparent. Vesicles result from the separation of the superficial epithelium from the basal epithelium. Fluid fills the basal epithelium, and erosions develop when the epithelium sloughs. Persistent infection also occurs, and virus can be found for months or years in the pharnyx; the mechanisms for the persistence are not known.

Differential diagnosis. Vesicular stomatitis is the principal differential. Other differentials include contagious ecthyma (orf), rinderpest, bluetongue, malignant catarrhal fever, bovine papular stomatitis, bovine herpes mammillitis, and infectious bovine rhinotracheitis virus infection.

Prevention and control. Movement of animals and animal products from endemic areas is regulated. Quarantine and slaughter are practiced in outbreaks in endemic areas. Quarantine and vaccination are also used in endemic areas, but vaccines must be type-specific and repeated 2 or 3 times per year to be effective and will provide only partial protection. Autogenous vaccines are best in an outbreak. Passive immunity protects calves for up to 5 months after birth. The virus is inactivated by extremes of pH, sunlight, high temperatures, sodium hydroxide, sodium carbonate, and acetic acid.

Treatment. Nursing care and antibiotic therapy to minimize secondary reactions help with recovery. Humoral immunity is considered the more important immune mechanism, with cell-mediated immunity of less importance.

Research complications. Rare cases in humans have been reported. Importation into the United States of animal products from endemic areas is prohibited.

o. Malignant Catarrhal Fever

Etiology. Malignant catarrhal fever (MCF) is a severe disease primarily of cattle. The agents of MCF are viruses of the Gammaherpesvirinae subfamily. Alcelaphine herpesvirus 1 and 2 and ovine herpesvirus 2 are known strains. The alcelaphine strains are seen in Africa. The ovine strain is seen in North America. The alcelaphine and ovine strains differ in incubation times and duration of illness. Disease may occur sporadically or as outbreaks.

Clinical signs and diagnosis. Signs range from subclinical to recrudescing latent infections to the lethal disease seen in susceptible species, such as cattle. Sudden death may also occur in cattle. Presentations of the disease may be categorized as alimentary, encephalitis, or skin forms; all three may occur in an animal. Corneal edema starting at the limbus and progressing centripetally is a nearly pathognomonic sign; photophobia, severe keratoconjunctivitis, and ocular involvement may follow. Other signs include prolonged fever, oral mucosal erosions, salivation, lacrimation, purulent nasal discharge, encephalitis, and pronounced lymphadenopathy. As the disease progresses, cattle may shed horns and hooves. In North America, cattle will also have severe diarrhea. The course of the disease may extend to 1 week. Recovery is usually prolonged, and some permanent debilitation may occur. The disease is fatal in severely affected individuals.

History of exposure, as well as the clinical signs and lesions, contributes to the diagnosis. Serology, PCR-based assays, viral isolation, and cell-culture assays, such as cytopathic effects on thyroid cell cultures, are also used. Because of the susceptibility of rabbits, inoculation of this species may be used. In less severe outbreaks or individual animal disease, definitive diagnosis may never be made.

Epizootiology and transmission. Most ruminant species are susceptible to MCF. Sheep are sources of infection for cattle, which are dead-end hosts. Other ruminants, including goats, may harbor the virus. Both the African and North American strains are transmissible to rabbits; these animals develop a fatal lymphoproliferative disease. The virus is shed from the nasopharynx. Infection of lambs is horizontal from direct contact. Other sources of the virus include water troughs, placental tissues, contaminated fomites, aerosols, birds, and caretakers.

Necropsy. Gross findings at necropsy include necrotic and ulcerated nasal and oral mucosa; thickened, edematous, ulcerated, and hemorrhagic areas of the intestinal tract; swollen, friable, and hemorrhagic lymph nodes and other lymphatic tissues; and erosion of affected mucosal surfaces. Lymph nodes should be submitted for histological examination. Histological findings include nonsuppurative vasculitis and encephalitis;

large numbers of lymphocytes and lymphoblasts will be present without evidence of virus.

Pathogenesis. The incubation period may be up to 3 months. Vascular endothelium and all epithelial surfaces will be affected. The virus is believed to cause proliferation of cytotoxic T lymphocytes with natural killer cell activities, and the resulting lesions are due to an autoimmune type of phenomenon.

Differential diagnoses. The differentials for this disease are bovine viral diarrhea/mucosal disease, bovine respiratory disease complex, infectious bovine rhinotracheitis, bluetongue, vesicular stomatitis, and foot-and-mouth disease. Causes of encephalitis, such as bovine spongiform encephalopathy and rabies, should be considered. In Africa, rinderpest is also a differential. Other differentials are arsenic toxicity and chlorinated naphthalene toxicity.

Prevention and control. No vaccine is available at this time. In North America, sheep, as well as cattle that have been either exposed or that have survived the disease, are reservoirs for outbreaks in other cattle. If there is concern regarding presence of the virus, animals should be screened serologically; once an animal has been infected, it remains infected indefinitely. Lambs can be free of the infection if removed from the flock at weaning. The virus is very fragile outside of host's cells and will not survive in the environment for more than a few hours.

Treatment. Affected and any exposed animals should be isolated from healthy animals. There is no specific treatment for MCF; supportive treatment may improve recovery rates. Corticosteroids may be useful.

p. Ovine Progressive Pneumonia (Maedi/Visna)

Etiology. An RNA virus in the lentivirus group of the Retroviridae family causes ovine progressive pneumonia (OPP), or maedi/visna. *Maedi* refers to the progressive pneumonia presentation of the disease; *visna* refers to the central nervous system disease, which is reported predominantly in Iceland. Visna has been reported in goats but may have been due to caprine arthritis encephalitis infection.

Clinical signs and diagnosis. OPP is a viral disease of adult sheep characterized by weakness, unthriftiness, weight loss, and pneumonia (Pepin et al., 1998; de la Concha Bermejillo, 1997). Clinically, animals exhibit signs of progressive pulmonary disease after an extremely long incubation period of up to 2 years. Respiratory rate and dyspnea gradually increase as the disease progresses. The animal continues to eat throughout the disease; however, animals progressively lose weight and become weak. Additionally, mastitis is a common clinical feature. Thoracic auscultation reveals consolidation of ventral lung

lobes; and hematological findings indicate anemia and leukocytosis. The rare neurological signs include flexion of fetlock and pastern joints, tremors of facial muscles, progressive paresis and paralysis, depression, and prostration. Death occurs in weeks to months.

The disease can be serologically diagnosed with agar gel immunodiffusion (AGID) tests, virus isolation, serum neutralization, complement fixation, and enzyme-linked immunosorbent assay (ELISA) tests.

Epizootiology and transmission. Sixty-eight percent of sheep in some states have been infected with the virus (Radostits et al., 1994). It is transmitted horizontally via inhalation of aerosolized virus particles and vertically between the infected dam and fetus. In addition, transmission through the milk or colostrum is considered common (Knowles, 1997).

Necropsy findings. Lesions are observed in lungs, mammary glands, joints, and the brain. Pulmonary adhesions, ventral lung lobe consolidation, bronchial lymph node enlargement, mastitis, and degenerative arthritis are visualized grossly. Meningeal edema, thickening of the choroid plexus, and foci of leukoencephalomalacia are seen in the central nervous system (CNS). Histologically, interalveolar septal thickening, lymphoid hyperplasia, histiocyte and fibrocyte proliferation, and squamous epithelial changes are seen in the lungs. Meningitis, lymphoid hyperplasia, demyelination, and glial fibrosis are seen in the CNS.

Pathogenesis. The virus has a predilection for the lungs, mediastinal lymph nodes, udder, spleen, joints, and rarely the brain. After initial infection, the virus integrates into the DNA of mature monocytes and persists as a provirus. Later in the animal's life, infected monocytes mature as lung (and other tissue) macrophages and establish active infection. The virus induces lymphoproliferative disease, histiocyte and fibrocyte proliferation in the alveolar septa, and squamous metaplasia. Pulmonary alveolar and vascular changes impinge on oxygen and carbon dioxide exchange and lead to serious hypoxia and pulmonary hypertension. Secondary bacterial pneumonia may contribute to the animal's death.

Differential diagnosis. Pulmonary adenomatosis is the differential diagnosis.

Prevention and control. Isolating or removing infected animals can prevent the disease. Facilities and equipment should also be disinfected.

Treatment. Treatment is unsuccessful.

q. Poxviruses of Ruminants

i. Ovine viral dermatosis. Ovine viral dermatosis is a venereal disease of sheep caused by a parapoxvirus distinct from

contagious ecthyma. The disease resolves within 2 weeks in healthy animals, but lesions are painful and resemble those of *Corynebacterium renale* posthitis/vulvovaginitis. Symptomatic treatment may be necessary in some cases. There is no vaccine. Animals should not be used for breeding while clinical signs are present.

ii. Proliferative stomatitis (bovine papular stomatitis)

Etiology. A parapoxvirus is the causative agent of bovine papular stomatitis. This virus is considered to be closely related to the parapoxvirus that causes contagious ecthyma and pseudocowpox. It is also a zoonotic disease. The disease is not considered of major consequence, but high morbidity and mortality may be seen in severe outbreaks. In addition, lesions are comparable in appearance to those seen with vesicular stomatitis, bovine viral diarrhea virus, and foot-and-mouth disease. The disease occurs worldwide.

Clinical signs and diagnosis. Raised red papules or erosions or shallow ulcers on the muzzle, nose, oral mucosa (including the hard palate), esophagus, and rumen of younger cattle are the most common findings. In some outbreaks, the papules will be associated with ulcerative esophagitis, salivation, diarrhea, and subsequent weight loss. Lesions persist or may come and go over a span of several months. Morbidity among herds may be 100%. Mortalities are rare. Bovine papular stomatitis is associated with "rat tail" in feedlot cattle. Animals continue to eat and usually do not show a fever. No lesion is seen on the feet. The infection may also be asymptomatic.

Diagnosis is based on clinical signs, histological findings, and viral isolation.

Epizootiology and transmission. Cattle less than 1 year of age are most commonly affected, and disease is rare in older cattle. Transmission is by animal-to-animal contact.

Necropsy findings. Raised papules may be found around the muzzle and mouth and involve the mucosa of the esophagus and rumen. Histologically, epithelial cells will show hydropic degeneration and hyperplasia of the lamina propria. Eosinophilic inclusions will be in the cytoplasm of infected epithelial cells.

Pathogenesis. Following exposure to the virus, erythematous macules most commonly appear on the nares, followed by the mouth. These become raised papules within a day, regressing after days to weeks; the lesions that remain will be persistent yellow, red, or brown spots. Some infections may recur or persist, with animals showing lesions intermittently or continuously over several months.

Differential diagnosis. Pseudocowpox, vesicular stomatitis, foot-and-mouth disease, and bovine viral diarrhea virus infection are the differentials for this disease. The differential for the "rat tail" clinical sign is *Sarcocystis* infection.

Prevention and control. There is no vaccine available for bovine papular stomatitis. Because of the similarity of this virus to the parapoxvirus of contagious ecthyma, it is important to be aware of the persistence in the environment and susceptibility of younger cattle. Vaccination using the local strain, and the skin scarification technique for orf, have been protective. Handlers should wear gloves and protective clothing.

Treatment. Cattle usually will not require extensive nursing care, but lesions with secondary bacterial infections should be treated with antibiotics.

Research complications. Handlers may develop lesions on their hands at sites of contact with lesions of cattle.

iii. Pseudocowpox

Etiology. Pseudocowpox is a worldwide cattle disease caused by a parapoxvirus related to the causative agents of contagious ecthyma and bovine papular stomatitis (see Sections III,A,2,m and III,A,2,q,ii). Lesions are confined to the teats. This is also a zoonotic disease.

Clinical signs and diagnosis. Minor lesions are usually confined to the teats. These are distinctive because of the ring- or horseshoe-shaped scab that develops after 10 days. Additional lesions sometimes develop on the udder, the medial aspect of the thighs, and the scrotum. The teat lesions may predispose to mastitis.

Pathogenesis. The virus is spread by contaminated hands, equipment, and fomites.

Differential diagnosis. Differentials include bovine herpes mammillitis and papillomatosis.

Prevention and control. Milking hygiene is helpful in control.

Treatment. Lesions should be treated symptomatically, and affected animals milked last.

Research complications. Like other related poxviruses, this virus causes nodular lesions on humans.

r. Pulmonary Adenomatosis (Jaagsiekte)

Etiology. Pulmonary adenomatosis is a rare but progressive wasting disease of sheep, with worldwide distribution. Pulmonary adenomatosis is caused by a type D retrovirus antigenically related to the Mason–Pfizer monkey virus. *Jaagsiekte* was the designation when the disease was described originally in South Africa.

Clinical signs and diagnosis. Typical clinical signs include progressive respiratory signs such as dyspnea, rapid respiration,

and wasting. The disease is diagnosed by these chronic clinical signs and histology.

Epizootiology and transmission.   The disease is transmitted by aerosols. Body fluids of viremic animals, such as milk, blood, saliva, tears, semen, and bronchial secretions, will contain the virus or cells carrying the virus.

Necropsy.   The adenomas and adenocarcinomas will be small firm lesions distributed throughout the lungs. The adenocarcinomas metastasize to regional lymph nodes.

Pathogenesis.   As with ovine progressive pneumonia (OPP), the incubation period is up to 2 years long. Adenocarcinomatous lesions arising from type II alveolar epithelial cells may be discrete or confluent and involve all lung lobes.

Differential diagnosis.   This disease occurs coincidentally with or is a differential diagnosis for OPP.

Treatment.   No treatment is effective.

s.   Papillomatosis (Warts, Verrucae)

Etiology.   Cutaneous papillomatosis is a very common disease in cattle and is much less common among sheep and goats. The disease is a viral-induced proliferation of the epithelium of the neck, face, back, and legs. These tumors are caused by a papillomavirus (DNA virus) of the Papovaviridae family, and the viruses are host-specific and often body site–specific. Most are benign, although some forms in cattle and one form in goats can become malignant. In cattle, the site specificity of the papillomavirus strains are particularly well recognized. Designations of the currently recognized bovine papillomavirus (BPV) types are BPV-1 through BPV-5.

Clinical signs and diagnosis.   The papillomas may last up to 12 months and are seen more frequently in younger animals. Lesions have typical wart appearances and may be single or multiple, small (1 mm) or very large (500 mm). The infections will generally be benign, but pain will be evident when warts develop on occlusal surfaces or within the gastrointestinal tract. In addition, when infections are severe, weight loss may occur. When warts occur on teats, secondary mastitis may develop.

In cattle, BPV-1 and BPV-2 cause fibropapillomas on teats and penises or on head, neck, and dewlap, respectively. BPV-3 causes flat warts that occur in all body locations, BPV-4 causes warts in the gastrointestinal tract, and BPV-5 causes small white warts (called rice-grain warts) on teats. Warts caused by BPV-3 and BPV-5 do not regress spontaneously. Prognosis in cattle is poor only when papillomatosis involves more than 20% of the body surface.

In sheep, warts are the verrucous type. The disease is of little consequence unless the warts develop in an area that causes dis-

comfort or incapacitation such as between the digits, on the lips, or over the joints. In adult sheep, warts may transform to squamous cell carcinoma. In goats, the disease is rare, and the warts are also of the verrucous type and occasionally may develop into squamous cell carcinoma. Warts on goat udders tend to be persistent.

Diagnosis is made by observing the typical proliferative lesions.

Epizootiology and transmission.   Older animals are less sensitive to papillomatosis than young animals, although immunosuppressed animals of any age may develop warts as the result of harbored latent infections. The virus is transmitted by direct and indirect (fomite) contact, entering through surface wounds and sites such as tattoos.

Pathogenesis.   The incubation period ranges from 1 to 6 months. The virus induces epidermal and fibrous tissue proliferation, often described as cauliflower-like skin tumors. The disease is generally self-limiting.

Differential diagnosis.   In sheep and goats, differentials include contagious ecthyma, ulcerative dermatosis, strawberry foot rot, and sheep and goat pox.

Prevention and control.   Commercial vaccines (available only for cattle) or autogenous vaccines must be used with a recognition that papovavirus strains are host-specific and that immunity from infection or vaccination is viral-type–specific. Autogenous vaccines are generally considered more effective. Some vaccine preparations are effective at prevention but not treatment of outbreaks. Viricidal products are recommended for disinfection of contaminated environments. Minimizing cutaneous injuries and sanitizing equipment (tattoo devices, dehorners, ear taggers, etc.) in a virucidal solution between uses are also recommended preventive and control measures. Halters, brushes, and other items may also be sources of virus.

Treatment.   Warts will often spontaneously resolve as immunity develops. In severe cases or with flockwide or herdwide problems, affected animals should be isolated from nonaffected animals, and premises disinfected. Warts can be surgically excised and autogenous vaccines can be made and administered to help prevent disease spread. Cryosurgery with liquid nitrogen or dry ice has also proven to be successful for wart removal. Topical agents such as podophyllin (various formulations) and dimethyl sulfoxide may be applied to individual lesions once daily until regression.

t.   Pseudorabies (Mad Itch, Aujeszky's Disease)

Etiology.   Pseudorabies is an acute encephalitic disease caused by a neurotropic alphaherpesvirus, the porcine herpesvirus 1. One serotype is recognized, but strain differences exist. The disease has worldwide distribution. It is a primarily a clinical dis-

ease of cattle, with less frequent reports (but no less severe clinical manifestations) in sheep and goats.

Clinical signs and diagnosis. A range of clinical signs is seen during the rapid course of this usually fatal disease. At the site of virus inoculation or in other locations, abrasions, swelling, intense pruritus, and alopecia are seen. Pruritus will not be asymmetric. Animals will also become hyperthermic and will vocalize frantically. Other neurological signs range from hoof stamping, kicking at the pruritic area, salivation, tongue chewing, head pressing and circling, to paresthesia or hyperesthesia, ataxia, and conscious proprioceptive deficits. Nystagmus and strabismus are also seen. Animals will be fearful or depressed, and aggression is sometimes seen. Recumbency and coma precede death.

Diagnostic evidence includes clinical findings; virus isolation from nasal or pharyngeal secretions or postmortem tissues; and histological findings at necropsy. Serology of affected animals is not productive, because of the rapid course. If swine are housed nearby, or if swine were transported in the same vehicles as affected animals, serological evaluations are worthwhile from those animals.

Epizootiology and transmission. Swine are the primary hosts for pseudorabies virus, but they are usually asymptomatic and serve as reservoirs for the virus. The infection can remain latent in the trigeminal ganglion of pigs and recrudesce during stressful conditions. Other animals are dead-end hosts. The unprotected virus will survive only a few weeks in the environment but may remain viable in meat (including carcasses) or saliva and will survive outside the host, in favorable conditions, in the summer for several weeks and the winter for several months. Transmission is by oral, intranasal, intradermal, or subcutaneous introduction of the virus. When the virus is inhaled, the clinical signs of pruritus are less likely to be seen. Transmission can also be by inadvertent exposure (e.g., contaminated syringes) of ruminants to the modified live vaccines developed for use in swine. Spread between infected ruminants is a less likely means of transmission, because of the relatively short period of virus shedding. Transport vehicles used for swine may also be sources of the virus. Raccoons are believed to be vectors of the virus. Horses are resistant to infection.

Necropsy findings. There is no pathognomonic gross lesion. Definitive histologic findings include severe, focal, nonsuppurative encephalitis and myelitis. Eosinophilic intranuclear inclusion bodies (Cowdry type A) may be present in some affected neurons. Methods such as immunofluorescence and immunoperoxidase staining can be used to show presence of the porcine herpesvirus 1.

Pathogenesis. The incubation period is 90–156 hr and duration of the illness is 8–72 hr. The longest duration is seen in animals with pruritus around the head.

Differential diagnoses. Differentials for the neurologic signs of pseudorabies infection include rabies, polioencephalomalacia, salt poisoning, meningitis, lead poisoning, hypomagnesemia, and enterotoxemia. Those for the intense pruritus include psoroptic mange and scrapie in sheep, sarcoptic mange, and pediculosis.

Prevention and control. Pseudorabies is a reportable disease in the United States, where a nationwide eradication program exists; states are rated regarding status. Effective disinfectants include sodium hypochlorite (10% solution), formalin, peracetic acid, tamed iodines, and quaternary ammonium compounds. Five minutes of contact time is required, and then surfaces must be rinsed. Other disinfectant methods for viral killing include 6 hr of formaldehyde fumigation, or 360 min of ultraviolet light. Transport vehicles should be cleaned and disinfected between species. Serological screening for pseudorabies of swine housed near ruminants is essential.

Treatment. There is no treatment, and most affected animals die.

Research complications. Swine housed close to research ruminants should be serologically screened prior to purchase, and all transport vehicles should be cleaned and disinfected between loads of large animals. Humans have been reported to seroconvert. The porcine herpesvirus 1 shares antigens with the infectious bovine rhinotracheitis virus.

u. Rabies (Hydrophobia)

Etiology. Rabies is a sporadic but fatal, acute viral disease affecting the central nervous system. The rabies virus is a neurotropic RNA virus of the *Lyssavirus* genus and the Rhabdoviridae family. Sheep, goats, and cattle are susceptible. The zoonotic potential of this virus must be kept in mind at all times when handling moribund animals with neurological signs characteristic of the disease. Rabies is endemic in many areas of the world and within areas of the Unites States. This is a reportable disease in North America.

Clinical findings and diagnosis. Animals generally progress through three phases: prodromal, excitatory, and paralytic. Many signs in the different species during these stages are nonspecific, and forms of the disease are also referred to as dumb or furious. During the short prodromal phase, animals are hyperthermic and apprehensive. Animals progress to the excitatory phase, during which they refuse to eat or drink and are active and aggressive. Repeated vocalizations, tenesmus, sexual excitement, and salivation occur during this phase. The final paralytic stage, with recumbency and death, occurs over several hours to days. This paralytic stage is common in cattle, and animals may simply be found dead. The clinical course is usually 1–4 days.

Diagnosis is based on clinical signs, with a progressive and fatal course. Confirmation presently is made with the fluorescent antibody technique on brain tissue.

Epizootiology and transmission. The rabies virus is transmitted via a bite wound inflicted by a rabid animal. Cats, dogs, raccoons, skunks, foxes, wild canids, and bats are the common disease vectors in North America. Virus is also transmitted in milk and aerosols.

Necropsy findings. Few lesions are seen at necropsy. Many secondary lesions from manic behaviors during the course of disease may be evident. Histological findings will include nonsuppurative encephalitis. Negri bodies in the cytoplasm of neurons of the hippocampus and in Purkinje's cells are pathognomonic histologic findings.

Pathogenesis. After exposure, the incubation period is variable, from 2 weeks to several months, depending on the distance that the virus has to travel to reach the central nervous system. The rabies virus proliferates locally, gains access to neurons by attaching to acetylcholine receptors, via a viral surface glycoprotein, migrates along sensory nerves to the spinal cord and brain, and then descends via cranial nerves (trigeminal, facial, olfactory, glossopharyngeal) to oral and nasal cavity structures (i.e., salivary glands). The fatal outcome is currently believed to be multifactorial, related to anorexia, respiratory paralysis, and effects on the pituitary.

Differential diagnosis. Rabies should be included on the differential list when clinical signs of neurologic disease are evident. Other differentials for ruminants include herpesvirus encephalitis, thromboembobolic meningoencephalitis, nervous ketosis, grass tetany, and nervous cocciodiosis.

Prevention and control. Vaccines approved for use cattle and sheep are commercially available and contain inactivated virus; there is not one available in the United States for goats. Ruminants in endemic areas, such as the East Coast of the United States, should be routinely vaccinated. Any animals housed outside that may be exposed to rabid animals should be vaccinated. Vaccination programs generally begin at 3 months of age, with a booster at 1 year of age and then annual or triennial boosters. Awareness of the current rabies case reports for the region and wildlife reservoirs, however, is important. Monitoring for and exclusion of wildlife from large-animal facilities are worthwhile preventive measures. The virus is fragile and unstable outside of a host animal.

Research complications. Aerosolized virus is infective. Personal protective equipment, including gloves, face mask, and eye shields, must be worn by individuals handling animals that are manifesting neurological disease signs.

v. Transmissible Spongiform Encephalopathies

i. Bovine spongiform encephalopathy (mad cow disease). Bovine spongiform encephalopathy, a transmissible spongiform encephalopathy (TSE), is not known to occur in the United States, where since 1989 it has been listed as a reportable disease. The profound impact of this disease on the cattle industry in Great Britain during the past two decades is well known. The disease may be caused by a scrapielike (prion) agent. It is believed that the source of infection for cattle was feedstuff derived from sheep meat and bonemeal that had been inadequately treated during processing. The incubation period of years, the lack of detectable host immune response, the debilitating and progressive neurological illness, and the pathology localized to the central nervous system are characteristics of the disease, and are is comparable to the characteristics of other TSE diseases such as scrapie, which affects sheep and goats. In addition, the infectious agent is extremely resistant to dessication and disinfectants. Confirmation of disease is by histological examination of brain tissue collected at necropsy; the vacuolation that occurs during the disease will be symmetrical and in the gray matter of the brain stem. Molecular biology techniques, such as Western blots and immunohistochemistry, may also be used to identify the presence of the prion protein. Differentials include many infectious or toxic agents that affect the bovine nervous and musculoskeletal systems, such as rabies, listeriosis, and lead poisoning. Metabolic disorders such as ketosis, milk fever, and grass tetany are also differentials. There is no vaccine or treatment. Prevention focuses on import regulations and not feeding ruminant protein to ruminants; recent USDA regulations prohibit feeding any mammalian proteins to ruminants.

ii. Scrapie

Etiology. Scrapie is a sporadic, slow, neurodegenerative disease caused by a prion. Scrapie is a reportable disease. It is much more common in sheep than in goats. The disease is similar to transmissible mink encephalopathy, kuru, Creutzfeldt–Jakob disease, and bovine spongiform encephalopathy (mad cow disease). Prions are nonantigenic, replicating protein agents.

Clinical signs and diagnosis. During early clinical stages, animals are excitable and hard to control. Tremors of head and neck muscles, as well as uncoordinated movements and unusual "bunny-hopping" gaits are observed. In advanced stages of the disease, animals experience severe pruritus and will self-mutilate while rubbing on fences, trees, and other objects. Blindness and abortion may also be seen. Morbidity may reach 50% within a flock. Most animals invariably die within 4–6 weeks; some animals may survive 6 months. In goats, the disease is also fatal. Pruritus is generally less severe but may be localized. A wide range of clinical signs have also been noted in goats, including listlessness, stiffness or restlessness, or behavioral changes such as irritability, hunched posture, twitching, and

erect tail and ears. As with sheep, the disease gradually progresses to anorexia and debilitation.

Diagnosis can be made by clinical signs and histopathological lesions. A newer diagnostic test in live animals is based on sampling from the third eyelid. Tests for genetic resistance or susceptibility require a tube of EDTA blood and are reasonably priced.

Epizootiology and transmission. The Suffolk breed of sheep tends to be especially susceptible. Scrapie has also been reported in several other breeds, including Cheviot, Dorset, Hampshire, Corriedale, Shropshire, Merino, and Rambouillet. It is believed that there is hereditary susceptibility in these breeds. Targhees tend to be resistant. Genomic research indicates there are two chromosomsal sites governing this trait; these sites are referred to codons 171 (Q, R, or H genes can be present) and 136 (A or V genes can be present). Of the five genes, R genes appear to confer immunity to clinical scrapie in Suffolks in the United States. Affected Suffolks in the United States that have been tested have been AA QQ. The disease is also enzootic is many other countries. The disease tends to affect newborns and young animals; however, because the incubation period tends to range from 2 to 5 years, adult animals display signs of the disease. Scrapie is transmitted horizontally by direct or indirect contact; nasal secretions or placentas serve as sources of the infectious agent. Vertical transmission is questioned, and transplacental transmission is considered unlikely.

Necropsy findings. At necropsy, no gross lesion is observed. Histopathologically, neuronal vacuolization, astrogliosis, and spongiform degeneration are visualized in the brain stem, the spinal cord, and especially the thalamus. Inflammatory lesions are not seen.

Pathogenesis. Replication of the prions probably occurs first in lymphoid tissues throughout the host's body and then progresses to neural tissue.

Differential diagnosis. In sheep and goats, depending on the speed of onset, differentials for the pruritus include ectoparasites, pseudorabies, and photosensitization.

Prevention and control. If the disease diagnosed in a flock, quarantine and slaughter, followed by strict sanitation, are usually required. The U.S. Department of Agriculture has approved the use of 2% sodium hydroxide as the only disinfectant for sanitation of scrapie-infected premises. Prions are highly resistant to physicochemical means of disinfection. Artificial insemination or embryo transfer has been shown to decrease the spread of scrapie (Linnabary *et al.*, 1991).

Treatment. No vaccine or treatment is available.

Research complications. As noted, this is a reportable disease. Stringent regulations exist in the United States regarding importation of small ruminants from scrapie-infected countries.

w. Vesicular Stomatitis Virus

Etiology. Vesicular stomatitis (VS) is caused by the vesicular stomatitis virus (VSV), a member of the Rhabdoviridae. Three serotypes are recognized: New Jersey, Indiana, and Isfahan. The New Jersey and Indiana strains cause sporadic disease in cattle in the United States. The disease is rare in sheep.

Clinical signs and diagnosis. Adult cattle are most likely to develop VS. Fever and development of vesicles on the oral mucous membranes are the initial clinical signs. Lesions on the teats and interdigital spaces also develop. The vesicles progress quickly to ulcers and erosions. The animal's tongue may be severely involved. Anorexia and salivation are common. Weight loss and decreased milk production are noticeable. Morbidity will be high in an outbreak, but mortality will be low to nonexistent.

Diagnostic work should be initiated as soon as possible to distinguish this from foot-and-mouth disease. Diagnosis is based on analysis of fluid, serum, or membranes associated with the vesicles. Virus isolation, enzyme-linked immunosorbent assay (ELISA), competitive ELISA (CELISA), complement fixation, and serum neutralization are used for diagnosis.

Epizootiology and transmission. This disease occurs in several other mammalian species, including swine, horses, and wild ruminants. VSV is an enveloped virus and survives well in different environmental conditions, including in soil, extremes of pH, and low temperatures. Outbreaks of VS occur sporadically in the United States, but it is not understood how or in what species the virus survives between these outbreaks. Incidence of disease decreases during colder seasons. Equipment, such as milking machines, contaminated by secretions is a mechanical vector, as are human hands. Transmission may also be from contaminated water and feed. Transmission is also believed to occur by insects (blackflies, sand flies, and *Culicoides*) that may simply be mechanical vectors. It is believed that carrier animals do not occur in this disease.

Necropsy. It is rare for animals to be necropsied as the result of this disease. Typical vesicular lesion histology is seen, with ballooning degeneration and edema. There is no inclusion body formation.

Pathogenesis. Lesions often begin within 24 hr after exposure. The virus invades oral epithelium. Injuries or trauma in any area typically affected, such as mouth, teats, or interdigital areas, will increase the likelihood of lesions developing there. Animals will develop a long-term immunity; this immunity can be overwhelmed, however, by a large dose of the virus.

Differential diagnosis. Foot-and-mouth disease lesions are identical to VS lesions. Other differentials in cattle include bovine viral diarrhea, malignant catarrhal fever, contagious ecthyma, photosensitization, trauma, and caustic agents.

Prevention and control. Quarantine and restrictions on shipping infected animals or animals from the premises housing affected animals are required in an outbreak. Vaccines are available for use in outbreaks and have decreased the severity of lesions. Phenolics, quaternaries, and halogens are effective for inactivating and disinfecting equipment and facilities.

Treatment. Affected animals should be segregated from the rest of the herd and provided with separate water and softened feed. These animals should be cared for after unaffected animals. Any feed or water contaminated by these animals should not be used for other animals; contaminated equipment should be disinfected. Topical or systemic antibiotics control secondary bacterial infections. Cases of mastitis secondary to teat lesions must be treated as necessary. Any abrasive materials that could cause further trauma to the animals should be removed.

Research complications. Animals developing vesicular lesions must be reported promptly to eliminate the possibility of an outbreak of foot-and-mouth disease. Personal protective equipment, especially gloves, should be worn when handling any animals with vesicular lesions. VSV causes a flulike illness in humans.

x. Viral Diarrhea Diseases

i. Ovine. Rotavirus, of the family Reoviridae, induces an acute, transient diarrhea in lambs within the first few weeks of life. Four antigenic groups (A–D) have been identified by differences in capsid antigens VP3 and VP7. Primarily group A, but also groups B and C, have been isolated from sheep. The disease is characterized by yellow, semifluid to watery diarrhea occurring 1–4 days after infection. The disease can progress to dehydration, anorexia and weight loss, acidosis, depression, and occasionally death. The virus is ingested with contaminated feed and water and selectively infects and destroys the enterocytes at the tips of the small intestinal villi. The villi are replaced with immature cells that lack sufficient digestive enzymes; osmotic diarrhea results. Virus may remain in the environment for several months. The disease is diagnosed by virus isolation, electron microscopy of feces, fecal fluorescent antibody, fecal ELISA tests (marketed tests generally detect group A rotavirus), and fecal latex agglutination tests. Rotavirus diarrhea is treated by supportive therapy, including maintaining hydration, electrolyte, and acid–base balance. A rotavirus vaccine is available for cattle; because of cross-species immunity, oral administration of high-quality bovine colostrum from vaccinated cows to infected sheep may be helpful ("Current Veterinary Therapy," 1993).

Coronavirus, of the family Coronaviridae, produces a more severe, long-lasting disease when compared with rotavirus. Clinical signs are similar to above, although the incubation period tends to be shorter (20–36 hr), and animals exhibit less anorexia than those with rotavirus. Additionally, mild respiratory disease may be noted (Janke, 1989). Like rotavirus, coronavirus also destroys enterocytes of the villus tips. The virus can be visualized with electron microscopy. Treatment is supportive; close consideration of hydration and acid–base status is essential. Bovine vaccines are available.

ii. Caprine. Rotavirus, coronavirus, and adenoviruses affect neonatal goats; however, little has been documented on the pathology and significance of these agents in this age group. It appears that bacteria play a more important role in neonatal kid diarrheal diseases then in neonatal calf diarrheas.

iii. Bovine. Rotaviruses, coronaviruses, parvoviruses, and bovine viral diarrhea virus (BVDV) are associated with diarrheal disease in calves. Each pathogen multiplies within and destroys the intestinal epithelial cells, resulting in villous atrophy and clinical signs of diarrhea (soft to watery feces), dehydration, and abdominal pain. These viral infections may be complicated by parasitic infections (e.g., *Cryptosporidium, Eimeria*) or bacterial infections (e.g., *Escherichia coli, Salmonella, Campylobacter*). Treatment is aimed at correcting dehydration, electrolyte imbalances, and acidosis; cessation of milk replacers and administration of fluid therapy intravenously and by stomach tube may be necessary, depending on the presence of suckle reflex and the condition of the animals. Diagnosis is by immunoassays available for some viruses, viral culture, exclusion or identification of presence of other pathogens (by culture or fecal exams), and microscopic examination of necropsy specimens. Prevention focuses on calves suckling good-quality colostrum; other recommendations for calf care are in Section II,B,5. Combination vaccine products are available for immunizing dams against rotavirus, coronavirus, and enterotoxigenic *E. coli*. Additional supportive care for calves includes providing calves with sufficient energy and vitamins until milk intake can resume.

Rotaviruses of serogroup A are the most common type in neonatal calves; 4- to 14-day old calves are typically affected, but younger and older animals may also be affected. The small intestine is the site of infection. Antirotavirus antibody is present in colostrum, and onset of rotavirus diarrhea coincides with the decline of this local protection. Transmission is likely from other affected calves and asymptomatic adult carriers. The diarrhea is typically a distinctive yellow. Colitis with tenesmus, mucus, and blood may be seen. This virus may be zoonotic.

Coronaviruses are commonly associated with disease in calves during the first month of life, and they infect small- and large-intestinal epithelial cells. The virus infection may extend to mild pneumonia. Transmission is by infected calves and also by asymptomatic adult cattle, including dams excreting virus at

the time of parturition. Calves that appear to have recovered continue to shed virus for several weeks.

Parvovirus infections are usually associated with neonatal calves. BVDV infections also are seen in neonates and also affect many systems and produce other clinical signs and syndromes that are described in Section III,A,2,e.

iv. Winter Dysentery. Winter dysentery is an acute, winter-seasonal, epizootic diarrheal disease of adult cattle, although it has been reported in 4-month-old calves. The etiology has not yet been defined, but a viral pathogen is suspected. Corona-virus-like viral particles have been isolated from cattle feces, either the same as or similar to the coronavirus of calf diarrhea. Outbreaks typically last a few weeks, and first-lactation or younger cattle are affected first, with waves of illness moving through a herd. Individual cows are ill for only a few days. The incubation period is estimated at 2–8 days. The outbreaks of disease are often seen in herds throughout the local area. Clinical signs include explosive diarrhea, anorexia, depression, and decreased production. The diarrhea has a distinctive musty, sweet odor and is light brown and bubbly, but some blood streaks or clots may be mixed in with the feces. Animals will become dehydrated quickly but are thirsty. Respiratory symptoms such as nasolacrimal discharges and coughing may develop. Recovery is generally spontaneous. Mortalities are rare. Diagnosis is based on characteristic patterns of clinical signs, and elimination of diarrheas caused by parasites such as coccidia, bacterial organisms such as *Salmonella* or *Mycobacterium paratuberculosis,* and viruses such as BVDV. Pathology is present in the colonic mucosa, and necrosis is present in the crypts.

3. Chlamydial Diseases

a. Enzootic Abortion of Ewes (Chlamydial Abortion)

Etiology. *Chlamydia psittaci* is a nonmotile, obligate, intracytoplasmic, gram-negative bacterium.

Clinical signs. Enzootic abortion in sheep and goats is a contagious disease characterized by hyperthermia and late abortion or by birth of stillborn or weak lambs or kids (Rodolakis *et al.,* 1998). The only presenting clinical sign may be serosanguineous vulvar discharges. Other animals may present with arthritis or pneumonia. Infection of animals prior to about 120 days of gestation results in abortion, stillbirths, or birth of weak lambs. Infection after 120 days results in potentially normal births, but the dams or offspring may be latently infected. Latently infected animals that were infected during their dry period may abort during the next pregnancy. Ewes or does generally only abort once, and thus recovered animals will be immune to future infections.

Epizootiology and transmission. *Chlamydia* possess group and specific antigens associated with the cell surface. The group

antigen is common among all *Chlamydia;* the specific antigen is common to related subgroups. Two subgroups are recognized, one that causes EAE and one that causes polyarthritis and conjunctivitis. The disease is transmitted by direct contact with infectious secretions such as placental, fetal, and uterine fluids or by indirect contact with contaminated feed and water.

Necropsy. Placental lesions include intercotyledonary plaques and necrosis and cotyledonary hemorrhages. Histopathological evidence of leukocytic infiltration, edema, and necrosis is found throughout the placentome. Fetal lesions include giant-cell accumulation in mesenteric lymph nodes and lymphohistiocytic proliferations around the blood vessels within the liver. Diagnosis is based on clinical signs and laboratory (serological or histopathological) identification of the organism. Impression smears in placental tissues stained with Giemsa, Gimenez, or modified Ziehl–Neelsen can provide preliminary indications of the causative agent. Immunofluorescence, enzyme-linked immunosorbent assay (ELISA), and polymerase chain reaction (PCR) methods also aid in diagnosis.

Differential diagnosis. Q fever will be the major differential for late-term abortion and necrotizing placentitis. *Campylobacter* and *Toxoplasma* should also be considered for late-term abortion.

Treatment. Animals may respond to treatment with oxytetracycline. Abortions are prevented through administration of a commercial vaccine, but the vaccine will not eliminate infections. This is a sheep vaccine and should be administered before breeding and annually to at least the young females entering the breeding herd or flock.

Research complications. In addition to losses or compromise of research animals, pregnant women should not handle aborted tissues.

b. Chlamydial Polyarthritis of Sheep

Etiology. *Chlamydia psittaci* is a nonmotile, obligate intracellular, gram-negative bacterium. Chlamydial polyarthritis is an acute, contagious disease characterized by fever, lameness (Bulgin, 1986), and conjunctivitis (see Section III,A,3,c) in growing and nursing lambs.

Clinical signs. Clinically, animals will appear lame on one or all legs and in major joints, including the scapulohumeral, humeroradioulnar, coxofemoral, femorotibial, and tibiotarsal joints. Lambs may be anorexic and febrile. Animals frequently also exhibit concurrent conjunctivitis. The disease usually resolves in approximately 4 weeks. Joint inflammation usually resolves without causing chronic articular changes.

Epizootiology and transmission. The disease is transmitted to susceptible animals by direct contact as well as by contaminated

feed and water. The organism penetrates the gastrointestinal tract and migrates to joints and synovial membranes as well as to the conjunctiva. The organism causes acute inflammation and associated fibrinopurulent exudates.

Necropsy findings. Lesions are found in joints, tendon sheaths, conjunctiva, and lungs. Pathological sites will be edematous and hyperemic, with fibrinous exudates but without articular changes. Lesions will be infiltrated with mononuclear cells. Lung lesions include atelectasis and alveolar inspissation. Diagnosis is based on clinical signs. Synovial taps and subsequent smears may allow the identification of chlamydial inclusion bodies.

Treatment. Animals respond to treatment with parenteral oxytetracycline.

c. Chlamydial Conjunctivitis (Infectious Keratoconjunctivitis, Pinkeye)

Etiology. *Chlamydia psittaci,* a nonmotile, obligate intracellular, gram-negative bacterium, is the most common cause of infectious keratoconjunctivitis in sheep. *Chlamydia* and *Mycoplasma* are considered to be the most common causes of this disease in goats. Chlamydial conjunctivitis is not a disease of cattle.

Clinical signs. Infectious keratoconjunctivitis is an acute, contagious disease characterized in earlier stages by conjunctival hyperemia, epiphora, and edema and in later stages by, corneal edema, ulceration, and opacity. Perforation may result from the ulceration. Animals will be photophobic. In less severe cases, corneal healing associated with fibrosis and neovascularization occurs in 3–4 days. Lymphoid tissues associated with the conjunctiva and nictitating membrane may enlarge and prolapse the eyelids. Morbidity may reach 80–90%. Bilateral and symmetrical infections characterize most outbreaks. Relapses may occur. Other concurrent systemic infections may be seen, such as polyarthritis or abortion in sheep and polyarthritis, mastitis, and uterine infections in goats.

Epizootiology and transmission. Direct contact, and mechanical vectors such as flies easily spread the organism.

Necropsy. If the chlamydial or mycoplasmal agents are suspected, diagnostic laboratories should be contacted for recommendations regarding sampling. Conjunctival smears are also useful.

Pathogenesis. The pathogen penetrates the conjunctival epithelium and replicates in the cytoplasm by forming initial and elementary bodies. The infection moves from cell to cell and causes an acute inflammation and resultant purulent exudate.

The chlamydial organism may penetrate the bloodstream and migrate to the opposite eye or joints, leading to arthritis. Diagnosis is suggested by the clinical signs. Cytoplasmic inclusions observed on conjunctival scrapings and immunofluorescent techniques help confirm the diagnosis.

Differential diagnosis. Nonchlamydial keratoconjunctivitis also occurs in sheep and goats. The primary agents involved include *Mycoplasma conjunctiva, M. agalactiae* in goats, and *Branhamella (Neisseria) ovis.* A less common differential for sheep and cattle is *Listeria monocytogenes.* Other differentials include eye worms, trauma, and foreign bodies such as windblown materials (pollen, dust) and poor-quality hay; these latter irritants and stress may predispose the animals' eyes to the infectious agents.

Prevention and control. Source of mechanical irritation should be minimized whenever possible. Quarantine of new animals and treatment, if necessary, before introduction into the flock or herd are important measures. Shade should be provided for all animals.

Treatment. The infections can be self-limiting in 2–3 weeks without treatment. Treatment consists of topical application of tetracycline ophthalmic ointments. Systemic or oral oxytetracycline treatments have been used with the topical treatment. Atropine may be added to the treatment regimen when uveitis is present. Shade should be provided.

4. Parasitic Diseases

a. Protozoa

i. Anaplasmosis

Etiology. Anaplasmosis is an infectious, hemolytic, noncontagious, transmissible disease of cattle caused by the protozoan *Anaplasma marginale. Anaplasma* is a member of the Anaplasmatacae family within the order Rickettsiales. In sheep and goats, the disease is caused by *A. ovis* and is an uncommon cause of hemolytic disease. Anaplasmosis has not been reported in goats in the United States. Some controversy exists regarding the classification. Most recently it is classified as a protozoal disease because of similarities to babesiosis. It has also been classified as a rickettsial pathogen. This summary addresses the disease in cattle with limited reference to *A. ovis* infections, but there are many similarities to the disease in cattle.

Clinical signs and diagnosis. Acute anemia is the predominant sign in anaplasmosis, and fever coincides with parasitemia. Weakness, pallor, lethargy, dehydration, and anorexia are the result of the anemia. Four disease stages—incubation, developmental, convalescent, and carrier—are recognized. The incubation stage may be long, 3–8 weeks, and is characterized by a rise in body temperature as the infection moves to the next

stage. Most clinical signs occur during the 4- to 9-day developmental stage, with hemolytic anemia being common. Death is most likely to occur at this stage or at the beginning of the convalescent stage. Death may also occur from anoxia, because of the animal's inability to handle any exertion or stress, especially if treatment is initiated when severe anemia exists. Reticulocytosis characterizes the convalescent stage, which may continue for many weeks. Morbidity is high, and mortality is low. The carrier stage is defined as the time in the convalescent stage when the animal host becomes a reservoir of the disease, and *Anaplasma* organisms and any parasitemia are not discernible.

Common serologic tests are the complement fixation test and the rapid card test. These become positive after the incubation phase and do not distinguish between the later three stages of disease. Definitive diagnosis is made by clinical and necropsy findings. Staining of thin blood smears with Wright's or Giemsa stain allows detection of basophilic, spherical *A. marginale* bodies near the red blood cell peripheries. Evidence will most likely be found before a hemolytic episode. A negative finding should not eliminate the pathogen from consideration.

Epizootiology and transmission. The disease is common in cattle in the southern and western United States. *Anaplasma* organisms are spread biologically or mechanically. Mechanical transmission occurs when infected red blood cells are passed from one host to another on the mouthparts of seasonal biting flies. Sometimes mosquitoes or instruments such as dehorners or hypodermic needles may facilitate transfer of infected red cells from one animal to another. Biological transmission occurs when the tick stage of the organism is passed by *Dermacentor andersoni* and *D. occidentalis* ticks. The carrier stage covers the time when discernible *Anaplasma* organisms can be found on host blood smears. Recovered animals serve as immune carriers and disease reservoirs.

Necropsy. Pale tissues and watery, thin blood are typical findings. Splenomegaly, hepatomegaly, and gallbladder distension are common findings.

Pathogenesis. The parasites infect the host's red blood cells, and acute hemolysis occurs during the parasites' developmental stage. The four stages of the parasite's life cycle are described above because these are closely linked to the clinical stages.

Differential diagnosis. The clinical disease closely resembles the protozoal disease babesiosis.

Prevention and control. Offspring of immune carriers resist infection up to 6 months of age because of passive immunity. Vector control and attention to hygiene are essential, such as between-animal rinsing in disinfectant of mechanical vectors such as dehorners. There is no entirely effective means, however, to prevent and control the disease. Vaccination (killed

whole organism) programs are not entirely effective, and vaccine should not be administered to pregnant cows. Neonatal isoerythrolysis may occur because of the antierythrocyte antibodies stimulated by one vaccine product. Vaccinated animals can still become infected and become carriers. The cattle vaccine has shown no efficacy in smaller ruminants, and there is no *A. ovis* vaccine. Identifying carriers serologically and treating with tetracycline during and/or after vector seasons may be an option. Removing carriers to a separate herd is also an approach. Interstate movement of infected animals is regulated.

Treatment. Oxytetracycline, administered once, helps reduce the severity of the infection during the developmental stage. Other tetracycline treatment programs have been described to help control carriers.

ii. Babesiosis (red water, Texas cattle fever, cattle tick fever) *Etiology.* *Babesia bovis* and *Ba. bigemina* are protozoa that cause subclinical infections or disease in cattle. These are intraerythrocytic parasites. *Babesia bovis* is regarded as the more virulent of the two organisms. This disease is not seen in the smaller ruminants in the United States.

Clinical signs and diagnosis. The more common presentation is liver and kidney failure due to hemolysis with icterus, hemoglobinuria, and fever. Hemoglobinuria indicates a poor prognosis. Acute encephalitis is a less common presentation and begins acutely with fever, ataxia, depression, deficits in conscious proprioception, mania, convulsions, and coma. The encephalitic form generally also has a poor prognosis. Sudden death may occur.

Thin blood smears stained with Giemsa will show *Babesia* trophozoites at some stages of the disease, but lack of these cannot be interpreted as a negative. The trophozoites occur in a variety of shapes, such as piriform, round, or rod. Complement fixation, immunofluorescent antibody, and enzyme immunoassay are the most favored of the available serologic tests.

Epizootiology and transmission. Babesiosis is present on several continents, including the Americas. In addition to domestic cattle, some wild ruminants, such as white-tailed deer and American buffalo, are also susceptible. *Bos indicus* breeds have resistance to the disease and the tick vectors. Innate resistance factors have been found in all calves. If infected, these animals will not show many signs of disease during the first year of life and will become carriers. Stress can cause disease development.

Necropsy findings. Signs of acute hemolytic crisis are the most common findings, including hepatomegaly, splenomegaly, dark and distended gallbladder, pale tissues, thin blood, scattered hemorrhages, and petechiation. Animals dying after a longer course of disease will be emaciated and icteric, with thin blood, pale kidneys, and enlarged liver.

Pathogenesis. The protozoon is transmitted by the cattle fever ticks *Boophilus annulatus, B. microplus,* and *B. decoloratus;* these one-host ticks acquire the protozoon from infected animals. It is passed transovarially, and both nymph and adult ticks may transmit to other cattle. Only *B. ovis* is transmitted by the larval stage. Clinical signs develop about 2 weeks after tick infestations or mechanical transmission but may develop sooner with the mechanical transmission. Hemolysis is due to intracellular reproduction of the parasites and occurs intra- and extravascularly. In addition to the release of merozoites, proteolytic enzymes are also released, and these contribute to the clinical metabolic acidosis and anoxia. The development of the encephalitis form is believed to be the result of direct invasion of the central nervous system, disseminated intravascular coagulation, capillary thrombosis by the parasites and infarction, and/or tissue anoxia.

Differential diagnosis. In addition to anaplasmosis, other differentials for the hemolytic form of the disease are leptospirosis, chronic copper toxicity, and bacillary hemoglobinuria. Several differentials in the United States for the encephalitic presentation include rabies, nervous system coccidiosis, polioencephalomalacia, lead poisoning, infectious bovine rhinotracheitis, salt poisoning, and chlorinated hydrocarbon toxicity.

Prevention and control. Control or eradication of ticks and cleaning of equipment to prevent mechanical transmission, as noted in Section III,A,3,a,i, are important preventive measures. Some vaccination approaches have been effective, but a commercial product is not available.

Treatment. Supportive care is indicated, including blood transfusions, fluids, and antibiotics. Medications such as diminazene diaceturate, phenamidine diisethionate, imidocarb diprionate, or amicarbalide diisethionate are most commonly used. Treatment outcomes will be either elimination of the parasite or development of a chronic carrier state immune to further disease.

Research complications. This is a reportable disease in the United States.

iii. Coccidiosis

Etiology. Coccidiosis is an important acute and chronic protozoal disease of ruminants. In young ruminants, it is characterized primarily by hemorrhagic diarrhea. Adult ruminants may carry and shed the protozoa, but they rarely display clinical signs. Intensive rearing and housing conditions and stress increase the severity of the disease in all age groups.

Coccidia are protozoal organisms of the phylum Apicomplexa, members of which are obligatory intracellular parasites. There are at least 11 reported species of coccidia in sheep, of which several are considered pathogenic: *Eimeria ashata, E. crandallis,* and *E. ovinoidalis* (Schillhorn van Veen, 1986). At

least 9 species of *Eimeria* have been recognized in the goat (Foreyt, 1990). *Eimeria ninakohlyakimovae, E. arloingi,* and *E. christenseni* are regarded as the most pathogenic. *Eimeria bovis* and *E. zuernii* (highly pathogenic), and *E. auburnensis* and *E. alabamensis* (moderately pathogenic), are among the 13 species known to infect cattle. *Eimeria zuernii* is more commonly seen in older cattle and is the agent of "winter coccidiosis."

Clinical signs and diagnosis. Hemorrhagic diarrhea develops 10 days to 3 weeks after infection. Fecal staining of the tail and perineum will be present. Animals will frequently display tenesmus; rectal prolapses may also develop. Anorexia, weight loss, dehydration, anemia, fever (infrequently), depression, and weakness may also be seen in all ruminants. The diarrhea is watery and malodorous and will contain variable amounts of blood and fibrinous, necrotic tissues. The intestinal hemorrhage may subsequently lead to anemia and hypoproteinemia. Depending on the predilection of the coccidial species for small and/or large intestines, malabsorption of nutrients or water may occur, and electrolyte imbalances may be severe. Concurrent disease with other enteropathogens may also be part of the clinical picture.

In sheep, secondary bacterial infection with organisms such as *Fusobacterium necrophorum* may ensue. Young goats may die peracutely or suffer severe anemia from blood loss into the bowel. Older goats may lose the pelleted form of feces. Cattle may have explosive diarrhea and develop anal paralysis.

The disease is usually diagnosed by history and clinical signs. Numerous oocysts will frequently be observed in fresh fecal flotation (salt or sugar solution) samples as the diarrhea begins. Laboratory results are usually reported as number of oocysts per gram of feces. Coccidia seen on routine fecal evaluations reflect shedding, possibly of nonpathogenic species, without necessarily being indicative of impending or resolving mild disease.

Epizootiology and transmission. As noted, coccidiosis is a common disease in young ruminants. In goats, young animals aged 3 weeks to 5 months are primarily affected, but isolated outbreaks in adults may occur after stressful conditions such as transportation or diet changes. Coccidia are host-specific and also host cell–specific. The disease is transmitted via ingestion of sporulated oocysts. Coccidial oocysts remain viable for long periods of time when in moist, shady conditions.

Necropsy. Necropsies provide information on specific locations and severity of lesions that correlate with the species involved. Ileitis, typhlitis, and colitis with associated necrosis and hemorrhage will be observed. Mucosal scrapings will frequently yield oocysts. Various coccidial stages associated with schizogony or gametogony may be observed in histopathological sections of the intestines. Fibrin and cellular infiltrates will be found in the lamina propria.

Pathogenesis. This parasite has a complex life cycle in which sexual and asexual reproduction occurs in gastrointestinal enterocytes (Speer, 1996). The severity of the disease is correlated primarily with the number of ingested oocysts. Specifics of life cycles vary with the species, and those characteristics contribute to the pathogenicity. In most cases, the disease is well established by the time clinical signs are seen. Oocysts must undergo sporulation over a 3- to 10-day period in the environment. After ingestion of the sporulated oocysts, sporozoites are released and penetrate the intestinal mucosa and form schizonts. Schizonts initially undergo replication by fission to form merozoites and eventually undergo sexual reproduction, forming new oocysts. The organisms cause edema and hyperemia; penetration into the lamina propria may lead to necrosis of capillaries and hemorrhage.

Differential diagnosis. Differential diagnoses include the many enteropathogens associated with acute diarrhea in young ruminants: cryptosporidia, colibacilli, salmonella, enterotoxins, *Yersinia,* viruses, and other intestinal parasites such as helminths. In cattle, for example, bovine viral diarrhea virus and helminthiasis caused by *Ostergia* must be considered. Management factors, such as dietary-induced diarrheas, are also differentials. In older animals, differentials in addition to stress are malnutrition, grain engorgement, and other intestinal parasitisms.

Prevention and control. Good management practices will help prevent the disease. Oocysts are resistant to disinfectants but are susceptible to dry or freezing conditions. Proper sanitation of animal housing and minimizing overcrowding are essential. Coccidiostats added to the feed and water are helpful in preventing the disease in areas of high exposure.

Treatment. Affected animals should be isolated. On an individual basis, treatment should also include provision of a dry, warm environment, fluids, electrolytes (orally or intravenously), antibiotics (to prevent bacterial invasion and septicemia), and administration of coccidiostats. Coccidiostats are preferred to coccidiocidals because the former allow immunity to develop. Although many coccidial infections tend to be self-limiting, sulfonamides and amprolium may be used to aid in the treatment of disease. Other anticoccidial drugs include decoquinate, lasalocid, and monensin; labels should be checked for specific approval in a species or specific indications. Animals treated with amprolium should be monitored for development of secondary polioencephalomalacia. Pen mates of affected animals should be considered exposed and should be treated to control early stages of infection.

Mechanisms of immunity have not been well defined but appear to be correlated with the particular coccidial species and their characteristics (for example, the extent of intracellular penetration). Immunity may result when low numbers are ingested and there is only mild disease. Immunity also may develop after more severe infections.

iv. Cryptosporidiosis

Etiology. *Cryptosporidium* organisms are a very common cause of diarrhea in young ruminants. Four *Cryptosporidium* species have been described in vertebrates: *C. baileyi* and *C. meleagridis* in birds and *C. parvum* and *C. muris* in mammals. *Cryptosporidium parvum* is the species affecting sheep (Rings and Rings, 1996). Debate continues regarding whether there are definite host-specific variants.

Clinical signs and diagnosis. Cryptosporidiosis is characterized by protracted, watery diarrhea and debilitation. The diarrhea may last only 6–10 days or may be persistent and fatal. The diarrhea is watery and yellow, and blood, mucus, bile, and undigested milk may also be present. Infected animals will display tenesmus, anorexia and weight loss, dehydration, and depression. In relapsing cases, animals become cachectic. Overall, morbidity will be high, and mortality variable.

Mucosal scrapings or fixed stained tissue sections may be useful in diagnosis. The disease is also diagnosed by detecting the oocysts in iodine-stained feces or in tissues stained with periodic acid–Schiff stain or methenamine silver. *Cryptosporidium* also stains red on acid-fast stains such as Kinyoun or Ziehl-Neelsen. Fecal flotations should be performed without sugar solutions or with sugar solutions at specific gravity of 1.27 (Foryet, 1990). Fecal immunofluorescent antibody (IFA) techniques have also been described.

Epizootiology and transmission. Younger ruminants are commonly affected: lambs, kids (especially kids between the ages of 5 and 10 days old), and calves less than 30 days old. Like other coccidians, *Cryptosporidium* is transmitted via the fecal–oral route. In addition to local contamination, water supplies have also been sources of the infecting oocysts. The oocysts are extremely resistant to desiccation in the environment and may survive in the soil and manure for many months.

Necropsy findings. The lesions caused by *Cryptosporidium* are nonspecific. Animals will be emaciated. Moderate enteritis and hyperplasia of the crypt epithelial cells with villous atrophy as well as villous fusion, primarily in the lower small intestines, will be present. Cecal and colonic mucosae may sometimes be involved. Gastrointestinal smears may be made at necropsy and stained as described above.

Pathogenesis. Although *Cryptosporidium* infections are clinically similar to *Eimeria* infections (Moore, 1989), *Cryptosporidium,* in contrast to *Eimeria,* invades just under the surface but does not invade the cytoplasm of enterocytes. There is no intermediate host. The oocysts are half the size of *Eimeria* oocysts and are shed sporulated; they are, therefore, immediately infective. Within 2–7 days of exposure, diarrhea and oocyst shedding occur. The diarrhea is the result of malabsorption and, in younger animals, intraluminal milk fermentation. Autoinfection within the lumen of the intestines may also occur and result

in persistent infections. In addition, several other pathogens may be involved, such as concurrent coronavirus and rotavirus infections in calves. Environmental stressors such as cold weather increase mortality. Intensive housing arrangements increase morbidity and mortality.

Differential diagnosis. Other causes of diarrhea in younger ruminants include rotavirus, coronavirus, and other enteric viral infections; enterotoxigenic *Escherichia coli; Clostridium;* other coccidial pathogens; and dietary causes (inappropriate use of milk replacers). In addition, these other agents may also be causing illness in the affected animals and may complicate the diagnosis and the treatment picture. *Eimeria* is more likely to cause diarrhea in calves and lambs at 3-4 weeks of age. *Giardia* organisms may be seen in fecal preparations from young ruminants but are not considered to play a significant role in enteric disease.

Prevention and control. Precautions should be taken when handling infected animals. Affected animals must be removed and isolated as soon as possible. Animal housing areas should be disinfected with undiluted commercial bleach or 5% ammonia. Formalin (10%) fumigation has proven successful (Foryet, 1990). After being cleaned, areas should be allowed to dry thoroughly and should remain unpopulated for a period of time. Because enteric disease often is multifactorial, other pathogens should also be considered, and management and husbandry should be examined.

Treatment. No known drug treatment is available. The disease is generally self-limiting, so symptomatic, supportive therapy aimed at rehydrating, correcting electrolyte and acid-base balance, and providing energy is often effective. Supplementation with vitamin A may be helpful. Age resistance begins to develop when the animals are about 1 month old.

Research complications. Cryptosporidiosis is a zoonotic disease. It is easily spread from calves to humans, for example, even as the result of simply handling clothing soiled by calf diarrhea. Adult immunocompetent humans are reported to experience watery diarrhea, cramping, flatulence, and headache. The disease can be life-threatening in immunocompromised individuals.

v. Giardiasis

Etiology. *Giardia lamblia* (also called *G. intestinalis* and *G. duodenalis*) is a flagellate protozoon. Giardiasis is a worldwide protozoal-induced diarrheal disease of mammals and some birds (Kirkpatrick, 1989), but it not considered to be a significant pathogen in ruminants.

Clinical signs and diagnosis. Diarrhea may be continuous or intermittent, is pasty to watery, is yellow, and may contain

blood. Animals exhibit fever, dehydration, and depression. Chronic cases may result in a "poor doer" syndrome with weight loss and unthriftiness.

Giardia can be diagnosed by identifying the motile piriform trophozoites in fresh fecal mounts. Oval cysts can be floated with zinc sulfate solution (33%). Standard solutions tend to be too hyperosmotic and to distort the cysts. Newer enzyme-linked immunosorbent assay (ELISA) and IFA tests are sensitive and specific.

Epizootiology and transmission. *Giardia* infection may occur at any age, but young animals are predisposed. Chronic oocyst shedding is common. Transmission of the cyst stage is fecal-oral. Wild animals may serve as reservoirs.

Necropsy findings. Gross lesions may not be evident. Villous atrophy and cuboidal enterocytes may be evident histologically.

Pathogenesis. Following ingestion, each *Giardia* cyst releases four trophozoites, which attach to the enterocytes of the duodenum and proximal jejunum and subsequently divide by binary fission or encyst. The organism causes little intestinal pathology, and the cause of diarrhea is unknown but is thought to be related to disruption of digestive enzyme function, leading to malabsorption. Disturbances in intestinal motility may also occur (Rings and Rings, 1996).

Prevention and control. Intensive housing and warm environments should be minimized. Cysts can survive in the environment for long periods of time but are susceptible to desiccation. Effective disinfectants include quaternary ammonium compounds, bleach-water solution (1:16 or 1:32), steam, or boiling water. After cleaning, areas should be left empty and allowed to dry completely.

Treatment. *Giardia* has been successfully treated with oral metronidazole. Benzimidazole anthelmintics are also effective, but these are not approved for use in animals for this purpose.

Research complications. *Giardia* is zoonotic. Precautions should be taken when handling infected animals.

vi. Neosporosis

Etiology. Neosporosis is a common, worldwide cause of bovine abortion caused by the protozoal species *Neospora caninum.* Abortions have also been reported in sheep and goats. Neonatal disease is seen in lambs, kids, and calves. Until 1988, these infections were misdiagnosed as caused by *Toxoplasma gondii.* Some similarities exist between the life cycles and pathogeneses of both organisms.

Clinical signs and diagnosis. Abortion is the only clinical sign seen in adult cattle and occurs sporadically, endemically, or as abortion storms. Bovine abortions occur between the third

and seventh month of gestation; fetal age at abortion correlates with the parity of the dam as well as with pattern of abortion in the herd. Although cows that abort tend to be culled after the first or second abortion, repeated *N. caninum*-caused abortions will occur progressively later in gestation (up to about 6 months) and within a shorter time frame in the same cow (Thurmond and Hietala, 1997). Although infections in adults are asymptomatic other than the abortions, decreased milk production has been noted in congenitally infected cows.

Many *Neospora*-infected calves will be born asymptomatic. Weakness will be evident in some infected calves, but this resolves. Rare clinical signs include exophthalmos or asymmetric eyes, weight loss, ataxia, hyperflexion or hyperextension of all limbs, decreased patellar reflexes, and loss of conscious proprioception. Some fetal deaths will occur, and resorption, mummification, autolysis, or stillbirth will follow.

Immunohistochemistry and histopathology of fetal tissue are the most efficient and reliable means of establishing a postmortem diagnosis. Serology (IFA and ELISA) is useful, including precolostral levels in weak neonates, but this indicates only exposure. Titers of dams will not be elevated at the time of abortion; fetal serology is influenced by the stage of gestation and course of infection. Earlier and rapid infections are less likely to yield antibodies against *Neospora*. None of the currently available tests is predictive of disease.

Epizootiology and transmission. The parasite is now acknowledged to be widespread in dairy and cattle herds. The life cycle of *N. caninum* is complex, and many aspects remain to be clarified. The definitive host is the dog (McAllister *et al.*, 1998). Placental or aborted tissues are the most likely sources of infection for the definitive host and play a minor role in transmission to the intermediate hosts. The many intermediate hosts include ruminants, deer, and horses. Transplacental transmission is the major mode of transmission in dairy cattle and is the means by which a herd's infection is perpetuated. A less significant mode of transmission is by ingestion of oocysts, which sporulate in the environment or in the intermediate host's body. Reactivation in a chronically infected animal's body is the result of rupture of tissue cysts in neural tissue. Seropositive immunity does not protect a cow from future abortions. Many seropositive cows and calves will never abort or show clinical signs, respectively. Some immunological cross-reactivity may exist among *Neospora, Cryptosporidia,* and *Coccidium.*

Necropsy findings. Aborted fetuses will usually be autolysed. In those from which tissue can be recovered, tissue cysts are most commonly found in the brain. Spinal cord is also useful. Histological lesions include mild to moderate gliosis, nonsuppurative encephalitis, and perivascular infiltration by mixed mononuclear cells.

Pathogenesis. As with *Toxoplasma,* cell death is the result of intracellular multiplication of *Neospora* tachyzoites. *Neospora*

undergoes sexual replication in the dog's intestinal tract, and oocysts are shed in the feces. The intermediate hosts develop nonclinical systemic infections, with tachyzoites in several organs, and parasites then localize and become encysted in particular tissues, especially the brain. Infections of this type are latent and lifelong. Except when immunocompromised, most cattle do not usually develop clinical signs and do not have fetal loss. Fetuses become infected, leading to fetal death, mid-gestation abortions, or live calves with latent infections or congenital brain disease. It usually takes 2–4 weeks for a fetus to die and to be expelled. Many aspects of the role of the maternal immune response and pregnancy-associated immunodeficiency in the patterns of *Neospora* abortions remain to be elucidated.

Differential diagnosis. Even when there is a herd history of confirmed *Neospora* abortions, leptospirosis, bovine viral diarrhea virus (BVDV), infectious bovine rhinotracheitis virus (IBRV), salmonellosis, and campylobacteriosis should be considered. BVDV in particular should be considered for abortion storms. Differentials for weak calves are BVDV, perinatal hypoxia following dystocia (immediate postpartum time), bluetongue virus, *Toxoplasma,* exposure to teratogens, or congenital defects.

Prevention and control. The primary preventive measure is preventing contact with contaminated feces. Oocysts will not survive dry environments or extremes of temperature. Dog populations should be controlled, and dogs and other canids should not have access to placentas or aborted fetuses. Dogs should also be restricted from feed bunks and other feed storage areas. Preventive culling is not economically practical for most producers. A vaccine recently became available. If embryo transfer is practiced, recipients should be screened serologically before use.

Treatment. There is no known treatment or immunoprophylaxis.

vii. Sarcocystosis

Etiology. Sarcocystosis is the disease caused by the cyst-forming sporozoon *Sarcocystis. Sarcocystis capricanus, S. ovicanus,* and *S. tenella* are the species that infect sheep and goats. *Sarcocystis cruzi, S. hirsuta,* and *S. hominis* are the species that infect cattle. Definitive hosts are carnivores, and all ruminant species are intermediate hosts.

Clinical signs and diagnosis. Clinical signs of sarcocystosis infection are seen in cattle during the stage when the parasite encysts in soft tissues. Often the infections are asymptomatic. Fever, anemia, ataxia, symmetric lameness, tremors, tail-switch hair loss, excessive salivation, diarrhea, and weight loss are clinical signs. Abortions in cattle occur during the second

trimester and in smaller ruminants 28 days after ingestion of the sporulated oocysts.

Definitive diagnosis is based on finding merozoites and meronts in neural tissue lesions. Clinical hematology results include decreased hematocrit, decreased serum protein, and prolonged prothrombin times. *Sarcocystis*-specific IgG will increase dramatically by 5–6 weeks after infection. There is no cross-reaction between *Sarcocystis* and *Toxoplasma*.

Epizootiology and transmission. Infection rates among cattle in the United States are estimated to be very high. Transmission is by ingestion of feed and water contaminated by feces of the definitive hosts. Dogs are the definitive hosts for the species that infect the smaller ruminants. Cats, dogs, and primates (including humans when *S. hominis* is involved) are the definitive hosts for the species that infect cattle.

Necropsy. Aborted fetuses may be autolysed. Lesions in neural tissues, including meningoencephalomyelitis, focal malacia, perivascular cuffing, neuronal degeneration, and gliosis, are most marked in the cerebellum and midbrain. Lesions may be found in other tissues, such as lymphadenopathy, and hemorrhages may be found in muscles and on serous surfaces. Cysts in cardiac and skeletal muscles are common incidental findings during necropsies.

Pathogenesis. Ingestion of muscle flesh from an infected ruminant results in *Sarcocystis* cysts' being broken down in the carnivore's digestive system, release of bradyzoites, infection of intestinal mucosal cells by the bradyzoites, differentiation into sexual stages, fusion of the male and female gametes to form oocysts, and shedding as sporocysts by the definitive hosts. The sporocysts are eaten by the ruminant and penetrate the bowel walls; several stages of development occur in endothelial cells of arteries. Merozoites are the form that enters soft tissues, such as muscle, and subsequently encysts.

Prevention and control. Feed supplies of ruminants must be protected from fecal contamination by domestic and wild carnivores. These animals should be controlled and must also not have access to carcasses. In larger production situations, monensin may be fed as a prophylactic measure.

Treatment. Monensin fed during incubation is prophylactic, but the efficacy in clinically affected cattle is not known.

viii. Toxoplasmosis

Etiology. Toxoplasmosis is caused by the obligate intracellular protozoon *Toxoplasma gondii,* a coccidial parasite of the family Eimeridae. Cats are the only definitive hosts, and several warm-blooded animals, including ruminants, have been shown to be intermediate hosts. The disease is a major cause of abortion in sheep and goats and less common in cattle.

Clinical signs and diagnosis. Clinical signs depend on the organ or tissue parasitized. Toxoplasmosis is typically associated with placentitis, abortion, stillbirths, or birth of weak young (Underwood and Rook, 1992; Buxton, 1998). It has also been shown to cause pneumonia and nonsuppurative encephalitis. The enteritis at the early stage of infection may be fatal in some hosts. Hydrocephalus does not occur in animals as it does in human fetal *Toxoplasma* infections. Rare clinical presentations in ruminants include retinitis and chorioretinitis; these are usually asymptomatic.

Infection of the ewe during the first trimester usually leads to fetal resorption, during the second trimester leads to abortion, and during the third trimester leads to birth of weak to normal lambs with subsequent high perinatal mortality. Congenitally infected lambs may display encephalitic signs of circling, incoordination, muscular paresis, and prostration. In sheep, weak young will develop normally if they survive the first week after birth. Infected adult sheep show no systemic illness. Infected adult goats, however, may die.

Diagnosis may be difficult, and biological, serological, and histological methods are helpful. Serological tests are the most readily available. Complement fixation and the Sabin–Feldman antibody test may assist in diagnosis. Antibodies found in fetuses are indicative of congenital infection and are typically detectable 35 days after infection; fetal thoracic fluid is especially useful in demonstrating serological evidence of exposure. Biological methods, such as tissue culture or inoculation of mice with maternal body fluids, or with postmortem or necropsy tissues, are more time-consuming and expensive.

Epizootiology and transmission. This protozoon is considered ubiquitous. Fifty percent (50%) of adult western sheep and 20% of feedlot lambs have positive hemagglutination titers (1:64 or higher) (Jensen and Swift, 1982). Transmission among the definitive host is by ingestion of tissue cysts.

Necropsy findings. At necropsy, placental cotyledons contain multiple small white areas that are sites of necrosis, edema, and calcification. Fetal brains may show nonspecific lesions such as coagulative necrosis, nonsuppurative encephalomyelitis, pneumonia, myocarditis, and hepatitis. Histologically, granulomas with *Toxoplasma* organisms may be seen in the retina, myocardium, liver, kidney, brain, and other tissues. Impression smears of these tissues, stained appropriately (e.g., with Giemsa), provide a rapid means of diagnosis. Identification of the organism in tissue sections (especially of the heart and the brain) also confirms the findings. *Toxoplasma gondii* is crescent-shaped, with a clearly visible nuclei, and will be found within macrophages.

Pathogenesis. The protozoon has three infectious stages: the tachyzoite, the bradyzoite, and the sporozoite within the oocyst. The definitive hosts, felids, become infected by ingesting cyst

stages in mammalian tissues, by ingesting oocysts in feces, and by transplacental transfer. Ingested zoites invade epithelial cells and eventually undergo sexual reproduction, resulting in new oocysts, which the cats will shed in the feces. Cats rarely show clinical signs of infection. One cat can shed millions of oocysts in 1 gm of feces, but the asymptomatic shedding takes place for only a few weeks in its life. Oocysts sporulate in cat feces after 1 day. Ruminants are intermediate hosts of toxoplasmosis and become infected by ingesting sporulated oocyst-contaminated water or feed. As in the definitive host, the ingested sporozoite invades epithelial cells within the intestine but also further invades the bloodstream and is transported throughout the host. The organism migrates to tissues such as the brain, liver, muscles, and placenta. Placental infection develops about 14 days after ingestion of the oocysts. The damage caused by an infection is due to multiplication within cells. *Toxoplasma* does not produce any toxin.

Differential diagnosis. Differentials for abortion include *Campylobacter, Chlamydia,* and Q fever.

Prevention and control. Feline populations on source farms should be controlled. Eliminating contamination of feed and water with cat feces is the best preventive measure. Sporulated oocysts can survive in soil and other places for long periods of time and are resistant to desiccation and freezing. Vaccines for abortion prevention in sheep are available in New Zealand and Europe.

Treatment. Toxoplasmosis treatment is ineffective, although feeding monensin during pregnancy may be helpful (Underwood and Rook, 1992). (Monensin is not approved for this use in the Unites States.) Weak lambs that survive the first week after birth will mature normally and will not deliver *Toxoplasma*-infected young.

Research complications. Because toxoplasmosis is zoonotic, precautions must be taken when handling tissues from any abortions or neurological cases. Infections in immunocompromised humans have been fatal.

ix. Trichomoniasis

Etiology. Trichomoniasis is an insidious venereal disease of cattle caused by *Tritrichomonas* (also referred to as *Trichomonas) fetus,* a large, pear-shaped, flagellated protozoon. The organism is an obligate parasite of the reproductive tract, and it requires a microaerophilic environment to establish chronic infections. In the United States, it is now primarily a disease seen in western beef herds. There are many similarities between trichomoniasis and campylobacteriosis; both diseases cause herd infertility problems.

Clinical signs and diagnosis. Clinical signs include infertility manifested by high nonpregnancy rates as well as periodic py-

ometras and abortions during the first half of gestation. Often the problem is not recognized until herd pregnancy checks indicate many "open," delayed-estrus, late-bred cows, or cows with postcoital pyometras. The abortion rate varies from 5% to 30%, and placentas will be expelled or retained. *Tritrichomonas fetus* also causes mild salpingitis but this does not result in permanent damage. Other than these manifestations, infection with *T. fetus* causes no systemic signs.

Diagnosis is based on patterns of infertility and pyometras. For example, pyometras in postcoital heifers or cows are suggestive of this pathogen. Diagnostic methods include identifying or culturing the trichomonads from preputial smegma, cervicovaginal mucus, uterine exudates, placental fluids, or abomasal contents of aborted fetuses. Other nonpathogenic protozoa from fecal contamination may be present in the sample. The trichomonad has three anterior flagellae, one posterior flagella, and an undulating membrane; it travels in fluids with a characteristic jerky movement. Culturing must be done on specific media, such as Diamond's or modified Pastridge.

Epizootiology and transmission. All transmission is by venereal exposure from breeding bulls or cows or, in some cases, contaminated breeding equipment.

Necropsy findings. Nonspecific lesions, such as pyogranulomatous bronchopneumonia of fetuses and placentitis, may be seen in aborted material; some cases will have no gross lesions. Histologically, trichomonads may be visible in the fetal lung lesions and the placenta; those tissues are also the most useful for culturing.

Pathogenesis. *Tritrichomonas fetus* colonizes the female reproductive tract, and subsequent clinical manifestations may be related to the size of the initial infecting dose. *Tritrichomonas fetus* does not interfere with conception. Embryonic death occurs within the first 2 months of infection. Affected cows will clear the infection over a span of months and maintain immunity for about 6 months. Infections in younger bulls are transient; apparently organisms are cleared by the bulls' immune systems and are dependent on exposure to infected females. Older bulls become chronic carriers, probably because of the ability of *T. fetus* to colonize deeper epithelial crypts of the prepuce and penis.

Differential diagnosis. Campylobacteriosis is the other primary differential for reduced reproductive efficiency of a herd. Other venereal diseases should be considered when infertility problems are noted in a herd: brucellosis, mycoplasmosis, ureaplasmosis, and infectious pustular vulvovaginitis. In addition, management factors such as nutrition and age of heifers at introduction to the herd should be considered.

Prevention and control. A bacterin vaccine is available. Heifers, cows, and breeding bulls are vaccinated subcutaneously

twice at 2 to 4 week intervals, with the booster dose adminis-
tered 4 weeks before breeding season starts. Similar timing is
recommended for administration of the annual booster; a long,
anamnestic response does not occur. Bulls used for artificial in-
semination (AI) are screened routinely for *T. fetus* (and *Campy-
lobacter*). AI reduces but does not eliminate the disease. The
use of younger, vaccinated bulls is recommended in all circum-
stances. New animals should be tested before introduction to
the herd. Control measures also include culling affected cows or
else removing them from the breeding herd for 3 months to rest
and clear the infection. Culling chronically infected bulls is
strongly recommended.

Treatment. Imidazole compounds have been effective, but the
use of these is not permitted in food animals in the United
States. Therapeutic immunizations are worthwhile when a pos-
itive diagnosis has been made. These will not curtail fetal losses
but will shorten the convalescence of the affected cows and im-
prove immunity of breeding bulls.

Research complications. Trichomoniasis should be consid-
ered whenever natural service is used and fertility problems are
encountered.

b. Nematodes

Nematodes are important ruminant pathogens that cause
acute, chronic, subclinical, and clinical disease in adults and
adolescents. The major helminths may cause gastroenteritis as-
sociated with intestinal hemorrhage and malnutrition. Nemato-
diasis is associated with grazing exposure to infective larvae;
animals procured for research may have had exposure to these
helminths. Mixed infections of these parasites are common.
Generally, older animals develop resistance to some of the spe-
cies; thus, animals between about 2 months and 2 years of age
are most susceptible to infection. Because of the parasites' ef-
fects on the animals' physiology, infection in these younger an-
imals is a major contributor to a cycle of poor nutrition and di-
gestion, compromised immune responses, and impaired growth
and development. Diagnosis is primarily based on fecal flota-
tion techniques; however, because many of these nematodes
have similar-appearing ova, hatching the ova and identifying
the larvae are often required (Baermann technique). A number
of anthelmintics can be used to interrupt nematode life cycles.
See Zajac and Moore (1993) and Pugh *et al.* (1998) for com-
prehensive reviews of treatment and control of nematodiasis.

*i. Haemonchus contortus, H. placei (barber's pole worm,
large stomach worm).* *Haemonchus contortus* is the most im-
portant internal parasite of sheep and goats, and the brief de-
scription here focuses on the disease in the smaller ruminants.
Haemonchus contortus and *H. placei* infections do occur in
younger cattle and are similar to the disease in sheep. *Hae-
monchus* is extremely pathogenic, and the adults feed by suck-
ing blood from the mucosa of the abomasum. Severe anemia
may lead to death. Weight loss, decreased milk production, poor
wool growth, and intermandibular and cervical edema due to
hypoproteinemia ("bottle jaw") are also common clinical signs.
Diarrhea is not seen in all cases but may sometimes be severe or
chronic. The life cycle is direct. Under optimal conditions, a
complete life cycle, from ingestion of larvae to eggs passed in
the feces, occurs in 3 weeks. Embryonated eggs may develop
into infective larvae within a week. Hypobiotic (arrested) larvae
may exist for several months in animal tissues, serving as a
reservoir for future pasture contamination. Periparturient in-
creases in egg shedding by ewes contribute to large numbers of
eggs spread on spring pastures ("spring rise"). Resistance to
common anthelmintics has developed; currently ivermectin or
benzimidazole products are used, with a minimum of 2 dosings
given 2–3 weeks apart. Levamisole is also used. In severe cases,
animals may benefit from blood transfusions and iron supple-
mentation. Because animals may easily acquire infective larvae
from ingestion of contaminated feed and from contaminated
pastures, general facility sanitation and pasture management
and rotation are important preventive and control measures.
Haemonchus contortus is susceptible to destruction by freezing
temperatures and dry conditions.

*ii. Ostertagia (Teladorsagia) circumcincta (medium stomach
worm).* *Ostertagia circumcincta* is also highly pathogenic for
sheep and goats and, like *Haemonchus,* attaches to the abomasal
mucosa and ingests blood. The life cycle is comparable to that
of *Haemonchus,* including the phenomenon of hypobiosis. Lar-
vae are especially resistant to cool temperatures, however, and
will overwinter on pastures. Larvae-induced hyperplasia of abo-
masal epithelial glands results in a change of gastric pH from
about 2.0 to near 7.0, leading to decreased digestive enzyme ac-
tivity and malnutrition. Clinical syndromes are categorized as
type 1 or type 2. The former type is associated with infections
acquired in fall or spring and is seen in younger animals. The
latter type is associated with emergence of the arrested larvae
during spring or fall. Clinical signs include anemia, weight loss,
decreased milk production, and unthriftiness. Diarrhea is usu-
ally seen in type 1 only; the symptoms of type 2 are comparable
to those of *Haemonchus* infections. Anthelmintic drug therapy
is comparable to that for *Haemonchus,* and drug resistance is
also a problem with *Ostertagia.*

iii. Ostertagia ostertagi (cattle stomach worm). *Ostertagia
ostertagi* is the most pathogenic and most costly of the cattle ne-
matodes. *Ostertagia leptospicularis* and *O. bisonis* also cause
disease. The life cycle is direct, and egg shedding by the cattle
may occur within 3–4 weeks of ingestion of infective larvae.
Hypobiosis is also a characteristic of *O. ostertagi.* In the initial

steps of infection, the normal processes of the abomasum are profoundly disrupted and cells are destroyed as the larvae develop within and emerge from the glands. *Moroccan leather appearance* is the term to describe the result of cellular hyperplasia and loss of cell differentiation. Cycles of infection and morbidity depend on geographic location, climate, and production cycles. Type 1 cattle ostertagiasis is associated with ingestion of large numbers of infective larvae, occurs in animals less than 2 years old, and causes diarrhea and anorexia. Type 2 ostertagiasis occurs in cattle 2–4 years old and older adults, is the result of the emergence and development of hypobiotic larvae, and in addition to signs seen with type 1, hypoproteinemia with development of submandibular edema, fever, and anemia is a clinical sign. Treatment options include ivermectin, fenbendazole, and levamisole; all are effective against the arrested larvae. *Ostertagia* is susceptible to desiccation but is resistant to freezing.

iv. Trichostrongylus vitrinus, T. axei, T. colubriformis (hair worms). *Trichostrongylus* species favor cooler conditions, and some larvae may overwinter. Although the different species may affect different segments of the gastrointestinal tract, the nematode attaches to the mucosa and affects secretion and/or absorption. *Trichostrongylus vitrinus* and *T. colubriformis* infect the small intestine of sheep and goats. *Trichostrongylus axei* infects the abomasum of cattle, sheep, and goats and causes increases in abomasal pH similar to those seen with *Ostertagia*. Mucosal hyperplasia is not seen. The prepatent period is about 3 weeks. Affected animals display unthriftiness, anorexia, decreased milk production, weight loss, diarrhea, and dehydration. These worms show intermediate resistance to freezing temperatures and dry conditions.

v. Nematodirus spathiger, N. battus (thread-necked worms). *Nematodirus* has lower pathogenicity compared with other gastrointestinal nematodes. The larvae cause small-intestinal necrosis and inflammation. The larvae are especially resistant to desiccation and freezing. Clinical signs include depression, weight loss, anorexia, and diarrhea.

vi. Cooperia (small intestinal worms). *Cooperia* primarily affects younger animals less than 1 year of age. *Cooperia curticei* infects the small intestine of sheep and goats; *C. punctata* and *C. oncophora* infect the small intestines of cattle, sheep, and goats. *Cooperia pectinata* infects the stomach of cattle. Large numbers lead to clinical infection, and the prepatent period is about 3 weeks. *Cooperia* and *Osteragia* infections, like infections of some other nematode species, may act synergistically. Because these nematodes suck blood, clinical signs include anemia, gastrointestinal hemorrhage, and malnutrition. Animals exhibit weight loss, diarrhea, and depression. *Cooperia* species are intermediate to resistant to the effects of cold temperatures.

vii. Strongyloides papillosus. *Strongyloides papillosus* is a small-intestinal parasite of sheep and cattle. *Strongyloides* has a different life cycle from that of many nematodes. The eggs, expelled in the feces, are larvated, and when they hatch, they form both free-living males and females or parasitic females only. The parasitic females may enter the gastrointestinal tract through oral ingestion, such as in milk during nursing, or through direct penetration of the skin. Penetrating larvae enter the bloodstream and are transported to the lungs, where they penetrate the alveoli, are coughed up, and then swallowed to ultimately enter the gastrointestinal tract. Adult females may reproduce in the small intestines by parthenogenesis. Clinical signs associated with *Strongyloides* include weight loss, diarrhea, unthriftiness, and dermatitis in cases where large numbers migrate through the skin. The current broad-spectrum anthelmintics are effective against *Strongyloides*.

viii. Bunostomum trigonocephalum (hookworm). *Bunostomum trigonocephalum* is a hookworm that occasionally infects sheep in locales in the southwestern United States. Like *Strongyloides*, *Bunostomum* infection may involve oral ingestion or direct penetration of the skin (followed by tracheal migration and swallowing). The larvae mature in the small intestines and suck blood. Larvae are susceptible to desiccation and freezing. Heavy infection with *Bunostomum* may result in anemia, diarrhea, intestinal hemorrhage, edema, and weight loss.

ix. Oesophagostomum columbianum, O. venulosum (nodule worms). *Oesophagostomum* spp. primarily infect the large intestine and occasionally the distal small intestine, causing nodule worm disease, or simply gut. *Oesophagostomum columbianum* and *O. venulosum* infect sheep and cattle. These nematodes may affect sheep from 3 months to 2 years of age, and the prepatent period is about 6 weeks. Larvae are highly sensitive to freezing and desiccation and rarely overwinter. Larvae penetrate the large-intestinal mucosa but occasionally move into the deeper areas of the intestinal wall near the serosa. The resultant inflammatory reaction may lead to the formation of a caseous nodule that may mineralize over time. Intestinal lesions may accelerate peristalsis, leading to diarrhea, or may inhibit peristalsis (later stages), resulting in constipation. Clinical signs include weakness, unthriftiness, alternating episodes of diarrhea and constipation, and severe weight loss. Nodular lesions are typical at necropsy.

x. Chabertia ovis (large-mouth bowel worm). *Chabertia ovis* is a minor colon parasite of sheep, goats, and cattle and is seen primarily in sheep. Signs of infection are not usually seen in cattle. Prepatent periods are up to 50 days. Heavy infection, which may result from as few as 100 worms located at the proximal end of the colon, may lead to hemorrhagic mucoid diarrhea, weight loss, weakness, colitis, and mild anemia.

xi. Trichuris (whipworms). *Trichuris* spp. are mildly patho-genic nematodes and are usually attached to the cecal mucosa. *Trichuris* has a rather long prepatent period, extending from 1 to 3 months. The oval eggs are double-operculated and survive well in pasture environmental extremes. The adult worms also have a characterisitic morphology, with one thicker end appear-ing as a whip handle. The nematodes cause a minor cecitis and will feed on blood. Clinical infection is rare and results in diar-rhea with mucus and blood. Treatment and prevention methods are similar to those for other nematodes.

xii. Dictyocaulus (lungworms). *Dictyocaulus* spp., or lung-worms, are nematodes that cause varying clinical signs in rumi-nants. In sheep, *Dictyocaulus filaria, Protostrongylus rufes-cens,* and *Muellerius capillaris* cause disease; *Dictyocaulus* is the most pathogenic. Goats are infected by the same species as sheep, but infections are uncommon. *Dictyocaulus viviparus* is the only lungworm found in cattle, causing "fog fever." Infec-tions with these parasites in the United States tend to be associ-ated with cooler, moister climates. Lungworms induce a severe parasitic bronchitis (known as husk, or verminous pneumonia) in sheep between approximately 2 and 18 months of age. Sheep infected with any of the lungworm species may display cough-ing, dyspnea, nasal discharge, weight loss, unthriftiness, and occasionally fever. Coughing and dyspnea are symptoms in goats. Diagnosis is suggested by persistent coughing and nasal discharge and is confirmed by identifying larvae in the feces or adults in pathological samples. The Baermann technique, in-volving prompt examination of room-temperature feces, is usu-ally used; zinc sulfate flotation is also used.

Dictyocaulus has a direct life cycle. The adult worms reside in the large bronchi. *Dictyocaulus* produces embryonated eggs that are coughed up and swallowed; the eggs then hatch in the intestines, and larvae are expelled in the feces. The expelled lar-vae are infectious in about 7–10 days and, after ingestion, pen-etrate the intestinal mucosa and move through the lymphatics and blood into the lungs, where they develop into adults in about 5 weeks. *Dictyocaulus filaria* causes an especially severe bron-chitis in sheep. *Protostrongylus* inhabits smaller bronchioles. *Muellerius* is of minor pathogenicity. *Protostrongylus* and *Muellerius* require the snail or slug as an intermediate host. In-fection occurs through ingestion of infected snails; infections are less likely than those caused by the direct ingestion of *Dic-tyocaulus* larvae. Immunity wanes over a year. Viral and bacte-rial respiratory tract infections may be associated with the par-asitic infection.

Dictyocaulus viviparus causes the obvious signs in cattle. More severe illness is seen after infections with *Cooperia* and *Ostertagia,* because of a synergism between the nematodes even if the cattle are not currently infected with those parasites. Hypobiosis (arrested development of immature worms in lung tissue) is associated with *Dictyocaulus* infections; cattle will be silent carriers, showing no clinical signs and serving as a means for the infection to survive over winter or a dry season. Pastures can be heavily contaminated during the next grazing season.

Necropsy lesions include bronchiolitis and bronchitis, atelec-tasis, and hyperplasia of peribronchiolar lymphoid tissue. Ne-matodes frequently reside in the bronchi of the diaphragmatic lung lobes and are frequently enmeshed with frothy exudate.

Prevention and control of the disease involve appropriate pas-ture management. Elimination of intermediate hosts is impor-tant in sheep and goat pastures. In a laboratory setting, animals may be procured that are already harboring the disease. Infected animals can be treated with anthelmintics such as ivermectin or levamisole. *Muellerius* tends to be resistant to levamisole. There is no anthelmintic currently approved for goats, but fenbenda-zole, administered 2 weeks apart, has been effective for all three nematodes. Treating *D. viviparus* depends on the type and stage of life of the cattle; label directions must be followed. There is no vaccine for *D. viviparus* in the United States. Even if infec-tions are not severe and do resolve with treatment, permanent lesions may be inflicted on the lung tissue.

c. Cestodes (Tapeworms)

i. Moniezia expansa and Thysanosoma actinoides infections. Tapeworms are rarely of clinical or economic importance. In younger animals, heavy infections result in potbellies, constipa-tion or mild diarrhea, poor growth, rough coat, and anemia. *Moniezia expansa,* and less commonly *Moniezia benedini,* in-habit the small intestines of grazing ruminants. *Moniezia ex-pansa* has the widest distribution of the tapeworm species in North America. Soil mites (*Galumna* spp. and *Oribatula* spp.) contribute to the life cycle as intermediate hosts, a period that lasts up to 16 weeks. Cysticercoids released from the mites are grazed, pass into the small intestines, and mature. No clinical or pathological sign is usually observed with *Moniezia* infection; diagnosis is made by observing the characteristic triangular-shaped eggs in fecal flotation examinations. Infection is treated with cestocides.

Thysanosoma actinoides, or the fringed tapeworm, is a ces-tode that resides in the duodenum, bile duct, and pancreatic duct of sheep and cattle raised primarily west of the Mississippi River in the United States. *Thysanosoma* is of the family Anoplocephalidae. The life cycle is indirect, and the inter-mediate host is the psocid louse. Larval forms, or cysticercoids, are ingested by grazing animals, and the prepatent period is sev-eral months. Typically, no clinical signs are observed with *Thysanosoma* infection; nonetheless, liver damage, resulting in liver condemnation at slaughter, occurs. Necropsy lesions in-clude bile and/or ductal hyperplasia and fibrosis. *Thysanosoma* is diagnosed premortem by identifying the gravid segments in the feces.

ii. Abdominal or visceral cysticercosis. Abdominal or visceral cysticercosis is an occasional finding at slaughter. The so-called bladder worms typically affect the liver or peritoneal cavity and are the larval form of *Taenia hydatigena,* the common tapeworm of the dog family. *Taenia hydatigena* resides in the small intestines of canids, and its gravid segments, oncospheres, contaminate feed and water sources. After ingestion, the larvae penetrate the intestinal mucosa, are transported via the bloodstream to the liver, and cause migration tracts throughout the liver parenchyma. The larvae may leave the liver and migrate into the peritoneal cavity, where they attach and develop over the next 1–9 months into small fluid-filled bladders. The life cycle is completed only after these bladders are ingested by a carnivore, thus completing the maturation of the adult tapeworms. Although larval migration may cause nonspecific signs such as anorexia, hyperthermia, and weight loss, affected animals are usually asymptomatic. At necropsy, the bladder worms will be observed attached to the peritoneal or organ surfaces. Migration tracts may result in fibrosis and inflammation. Diagnosis is usually made at necropsy. Because of the migration through the liver, *Fasciola hepatica* is a differential diagnosis. Minimizing exposure to canine feces–contaminated feeds and water effectively interrupts the life cycle. Research animals may have been exposed prior to purchase.

iii. Echinococcosis (hydatidosis, hydatid cyst disease). Echinococcosis, like cysticercosis, is an occasional finding at slaughter or necropsy. The hydatid cyst is the larval intermediate of the adult tapeworm *Echinococcus granulosus,* which resides in the small intestines of dogs and wild canids. Embryonated ova are expelled in the feces of the primary host and are ingested by herbivores, swine, and potentially humans. The eggs hatch in the gastrointestinal tract, and the oncospheres penetrate the mucosal lining, enter the bloodstream, and are transported to various organs such as the liver and lungs. The cystic structure develops and potentially ruptures, forming new cystic structures. Clinically, echinococcosis presents minimal clinical signs; unthriftiness or pneumonic lesions may be associated with infected organs. Cysts are typically observed at necropsy. Prevention should be aimed at decreasing fecal contamination of feed and water by canids. Additionally, tapeworm-infected dogs can be treated with standard tapeworm therapies. Treatment of infected ruminants is uncommon.

iv. Gid. *Coenuris cerebralis,* the larval form of the canid tapeworm *Taenia (Multiceps) multiceps,* is the causative agent of the rare condition called gid. The disease occurs in ruminants as well as many other mammalian species. The larval parasite, ingested from fecal-contaminated food and water, invades the brain and spinal cord and develops as a bladder worm that causes pressure necrosis of the nervous tissues. The resultant signs of hyperesthesia, meningitis, paresis, paralysis, ataxia,

and convulsions are observed. Diagnosis is usually made at necropsy. Eliminating transfer from the canid hosts prevents the disease.

d. Trematodes

i. Fascioliasis (liver fluke disease). Liver flukes are an important cause of acute and chronic disease in grazing sheep and cattle. There are three common species of flukes in ruminants of the continental United States: *Fasciola hepatica, Fascioloides magna,* and *Dicrocoelium dendriticum. Fasciola hepatica* infections are primarily seen in Gulf Coast and western states. *Fascioloides magna* infections are typically seen in Gulf, Great Lake, and northwestern states, where ruminants share pasture with deer, elk, and moose. *Dicrocoelium dendriticum* infections occur only in New York State. Liver fluke eggs are passed in the bile and feces and hatch in 2–3 weeks to form the free-swimming miracidia. It is important to note that each fluke egg represents the source of eventually thousands of cercariae or metacercariae. The miracidia penetrate the body of an intermediate host (usually freshwater snails) and develop through sporocyst and redia stages, finally forming cercariae. (*Dicrocoelium* is unique because it utilizes a land snail that expels slime balls, each containing several hundred cercariae. These are eaten by a second intermediate host, the ant *Formica fusca.*) The cercariae leave the intermediate host, swim to grassy vegetation, lose their tail, and become a cystlike metacercaria. The metacercariae may remain in a dormant stage on the grass for 6 months or longer until ingested by a ruminant. The ingested metacercariae penetrate the small-intestinal wall and migrate through the abdominal cavity to the liver. There they locate in a bile duct, mature, and remain for up to 4 years.

Acute liver fluke disease is related to the damage caused by the migration of immature flukes. Migratory flukes may lead to liver inflammation, hemorrhage, necrosis, and fibrosis. *Fascioloides magna* infections in sheep and goats can be fatal as the result of just one fluke tunneling through hepatic tissue. In cattle, infections are often asymptomatic because of the host's encapsulation of the parasite. Liver fluke damage may predispose to invasion by anaerobic *Clostridium* species such as *C. novyi* that could lead to fatal black disease or bacillary hemoglobinuria. Chronic disease may result from fluke-induced physical damage to the bile ducts and cholangiohepatitis. Blood loss into the bile may lead to anemia and hypoproteinemia. Liver damage also is evidenced by increases in liver enzymes such as γ-glutamyl transpeptidase (GGT). Persistent eosinophilia is also seen with liver fluke disease. Other clinical signs of liver fluke disease include anorexia, weight loss, unthriftiness, edema, and ascites. At necropsy, livers will be pale and friable and may have distinct migration tunnels along the serosal surfaces. Bile ducts will be enlarged, and areas of fibrosis will be evident.

Diagnosis can be made from clinical signs and postmortem

analyses. Blood chemistries suggestive of liver disease and eosinophilia support the diagnosis. Liver fluke control involves removal of the intermediate hosts. In a laboratory setting, liver fluke infection is unlikely. Nonetheless, incoming animals from pasture environments may be infected. Liver flukes can be treated by using the anthelmintic albendazole.

ii. Rumen fluke infections (paramphistomosis). Paramphistomosis is an uncommon disease found in sheep and cattle in southern states. *Paramphistomum microbothrioides* and *P. cervi* inhabit the duodenum and rumen of affected sheep. Eggs are passed in the feces and hatch in approximately 1 month, and the miracidia penetrate the intermediate snail hosts. Cercariae develop in the snail over the next month, emerge, and encyst on grasses as metacercariae. When eaten, the metacercariae develop into adult flukes and attach to the mucosal lining. The life cycle is complete in approximately 100 days. The flukes cause localized injury to the mucosa and, by interfering with digestive processes, cause diarrhea and protein loss. Clinically, animals may experience anorexia, dehydration, weight loss, and diarrhea with or without blood. Mortality may reach 25%. Diagnosis is based on clinical findings as well as the identification of flukes or eggs in the feces. Animals can be treated with flukicides. Eliminating the intermediate host prevents the disease.

e. Mites (Mange)

Mites cause a chronic dermatitis. The principal symptom of these infections is intense pruritus. In addition, papules, crusts, alopecia, and secondary dermatitis are seen. Anemia, disruption of reproductive cycles, and increased susceptibility to other diseases may also occur. Mites are rare in ruminants in the United States, but infections of *Sarcoptes* and *Psorergates* mange must be reported to animal health officials. Ruminants in poorly managed facilities are generally the most susceptible to infection, and infections are more frequent during winter months. Diagnosis is based on signs, examination of skin scrapings, and response to therapy. No effective treatment for demodectic mange in large animals has been found. The differential for mite infestations is pediculosis.

Several genera of mites may affect sheep. These have been eradicated from flocks in the United States or are very rare and include *Psoroptes ovis* (common scabies), *Sarcoptes scabiei* (head scabies, barn itch), *Psorergates ovis* (sheep itch mite), *Chorioptes ovis* (foot scabies, tail mange), and *Demodex ovis* (follicular mange).

Goats can also be infected by sarcoptic, chorioptic, and psoroptic mange. The scabies mite *Sarcoptes rupicaprae* invades epidermal tissue and causes focal pruritic areas around the head and neck. The chorioptic mite, either *Chorioptes bovis* or *C. caprae,* does not invade epidermal tissue but rather feeds on dead skin tissue. The chorioptic mite prefers distal limbs, the udder, and the scrotum and can be a significant cause of pruri-

tus. The psoroptic mite *Psoroptes cuniculi* commonly occurs in the ear canal and causes head shaking and scratching. Repeated treatments of lime sulfur, amitraz, or ivermectin may be effective (Smith and Sherman, 1994). Goats are also susceptible to demodectic mange caused by *Demodex caprae.* Adult mites invade hair follicles and sebaceous glands. Pustules may develop with secondary bacterial infection.

Psoroptes bovis continues to be present in cattle in the United States, although it has been eradicated from sheep. *Chorioptes bovis* typically infects lower hindlimbs, perineum, tail, and scrotum but can become generalized. The sarcoptic mange mite *S. scabei* can survive off the host, so fomite transmission is a factor. The mange usually begins around the head but then spreads. This parasite can be transmitted to humans. *Demodex bovis* infects cattle; nodules on the face and neck are typical. *Demodex bovis* infections may resolve without treatment. Lindane, coumaphos, malathion, and lime sulfur are used to treat *Psoroptes* and *Psorergates.* Ivermectin is effective against *Sarcoptes* and is approved for use in cattle.

f. Lice (Pediculosis)

Lice that infect ruminants are of the orders Mallophaga, biting or chewing lice, and Anoplura, sucking lice. These are wingless insects. Members of the Mallophaga are colored yellow to red; members of the Anoplura are blue gray. Lice produce a seasonal (winter-to-spring), chronic dermatitis. In sheep, biting lice include *Damalinia (Bovicola) ovis* (sheep body louse). Sucking lice that infect sheep include *Linognathus ovillus* (blue body louse) and *L. pedalis* (sheep foot louse). In goats, biting lice infection are caused by *D. caprae* (goat biting louse), *D. limbatus* (Angora goat biting louse), and *D. crassipes.* Sucking louse infections in goats are caused by *L. stenopis* and *L. africanus. Damalinia bovis* is the cattle biting louse. Sucking lice include *L. vituli, Solenopotes capillatus, Haematopinus eurysternus,* and *H. quadripertusus.*

Pruritus is the most common sign and often results in alopecia and excoriation. The host's rubbing and grooming may not correlate with the extent of infestation. Hairballs can result from overgrooming in cattle. In severe cases, the organisms can lead to anemia, weight loss, and damaged wool in sheep and damaged pelts in other ruminants. Young animals with severe infestations of sucking lice may become anemic or even die. Pregnant animals with heavy infestations may abort. In sheep infected with the foot louse, lameness may result.

Lice are generally species-specific. Those infecting ruminants are usually smaller than 5 mm. Goats may serve as a source of infection for sheep by harboring *Damalinia ovis.* Transmission is primarily by direct contact between animals. Transmission can also occur by attachment to flies or by fomites. Some animals are identified as carriers and seem to be particularly susceptible to infestations.

Biting or chewing lice inhabit the host's face, lower legs, and

flanks and feed on epidermal debris and sebaceous secretions. Sucking lice inhabit the host's neck, back, and body region and feed on blood. Lice eggs or nits are attached to hairs near the skin. Three nymphal stages, or instars, occur between egg and adult, and the growth cycle takes about 1 month for all species. Lice cannot survive for more than a few days off the host. All ruminant mite infestations are differentials for the clinical signs seen with pediculosis.

Animals that are carriers should be culled, because these individuals may perpetuate the infection in the group. Lice are effectively treated with a variety of insecticides, including coumaphos, dichlorvos, crotoxyphos, avermectin, and pyrethroids. Label directions should be read and adhered to, including withdrawal times. Products should not be used on female dairy animals. Treatments must be repeated at least twice at intervals appropriate for nit hatches (about every 16 days) because nits will not be killed. Fall treatments are useful in managing the infections. Systemic treatments in cattle are contraindicated when there may be concurrent larvae of cattle grubs (*Hypoderma lineatum* and *H. bovis*). Back rubbers with insecticides, capitalizing on self-treatment, are useful for cattle. Sustained-release insecticide-containing ear tags are approved for use in cattle.

g. Ticks

Etiology. Ruminants are susceptible to many species of Ixodidae (hard-shell ticks) and Argasidae (softshell ticks). Many diseases, including anaplasmosis, babesiosis, and Q fever are transmitted by ticks.

Clinical signs and diagnosis. Tick infestations are associated with decreased productivity, loss of blood and blood proteins, transmission of diseases, debilitation, and even death. Feeding sites on the host vary with the tick species. Ticks are associated with an acute paralytic syndrome called tick paralysis. This disease is characterized by ascending paralysis and may lead to death if the tick is not removed before the paralysis reaches the respiratory muscles. Diagnosis is based on identification of the species.

Epizootiology and transmission. Ticks are not as host-specific as lice. Ticks are classified as one-host, two-host, or three-host; this refers to whether they drop off the host between larval and nymphal stages to molt.

Pathogenesis of tick infestations. Patterns of feeding on the host differ between Argasidae and Ixodidae. The former feed repeatedly, whereas the latter feed once during each life stage.

Pathogenesis of tick paralysis. Following a tick-feeding period of 4–6 days, the tick salivary toxin travels hematogenously to the myoneural junctions and spinal cord and inhibits nerve

transmission. Removal of the ticks reverses the syndrome unless paralysis has migrated anteriorly to the respiratory centers of the medulla. In these cases, death due to respiratory failure occurs.

Treatment. Ticks can be treated using systemic or topical insecticides.

h. Other Parasites

i. Nasal bots (nasal myiasis, head grubs). Nasal myiasis causes a chronic rhinitis and sinusitis. The disease is caused by the larval forms of the botfly *Oestrus ovis*. The botfly deposits eggs around the nostrils of sheep. The ova hatch, and the larvae migrate throughout the nasal cavity and sinuses, feeding on mucus and debris. In 2–10 months, the larvae complete their growing phase, migrate back to the nasal cavity, and are sneezed out. The mature larvae penetrate the soil and pupate for 1–1.5 months and emerge as botflies. Clinically, early in the disease course, animals display unique behaviors such as stamping, snorting, sneezing, and rubbing their noses against each other or objects. Hypersensitivity to the larvae occurs (Dorchies *et al.*, 1998). Later, mucopurulent nasal discharges associated with the larval-induced inflammation of mucosal linings will be observed. At necropsy, larvae will be observed in the nasal cavity or sinuses. Mild inflammatory reactions, mucosal thickening, and exudates will accompany the larvae. The disease is diagnosed by observing the behaviors or identifying organisms at necropsy. Up to 80% of a flock will potentially be infected; treatment should be employed on the rest of the flock. Ivermectins and other insecticides will eliminate the larvae; but treatment should be done in the early fall, when larvae are small. Fly repellents may be helpful at preventing additional infections.

ii. Screwworm flies. *Cochliomyia hominivorax* (*Callitroga americana*) is the the screwworm that causes occasional disease in the southwestern United States along the Mexico border. Eradication programs have been pursued, and the disease is reportable. Large greenish flies lay large numbers of white eggs as shinglelike layers at the edges of open wounds (including docking and castration sites), soiled skin, or abrasions. Eggs hatch within 24 hr. Larvae are obligate parasites of living tissue, and the cycle is perpetuated because the increasingly large wound continues to be attractive to the next generation of flies. Larvae eventually drop off, pupate best in hot climates, and hatch in 3 weeks. Large cavities in parasitized tissue are formed, and lesions are characterized by malodor, large volumes of brown exudate, and necrosis. Single animals or entire herds may be affected. Treatment is intensive, with dressings and larvicidal applications. If there is no intervention, the host succumbs to secondary infections and fluid loss. Effective current control regimens include subcutaneous injection of ivermectin and programs that release sterile male flies.

iii. Sheep keds ("sheep ticks"). In sheep and goats, sheep keds produce a chronic irritation and dermatitis with associated pruritus. The disease is caused by *Melophagus ovinus,* which is a flat, brown, blood-sucking, wingless fly; the term *sheep tick* is incorrectly used. The adult fly lives entirely on the skin of sheep. Females mate and produce 10–15 larvae following a gestation of about 10–12 days. The larvae attach to the wool or hair and then pupate for about 3 weeks. The adult female feeds on blood and lives for 4–5 months; the life cycle is completed in about 5–6 weeks. Infection is highest in fall and winter. Pruritus develops around the neck, sides, abdomen, and rump. In severe cases, anemia may occur. Keds can transmit bluetongue virus. Keds are diagnosed by gross or microscopic identification. Ivermectin or other insecticides are useful treatment agents.

5. Fungal Disease: Dermatophytes (Ringworm)

Etiology. Dermatophytosis, or infection of the keratinized layers of skin, is caused mostly by species of the genera *Trichophyton* and *Microsporum.* The primary causes in sheep are *T. mentagrophytes* and *T. verrucosum.* In goats, the agents are *T. mentagrophytes, M. canis, M. gypseum, T. verrucosum, T. schoenleinii,* and *Epidermophyton floccosum.* In cattle, *T. verrucosum* is the primary causative agent. Dermatophytosis is a common fungal infection of the epidermis of cattle and is less common in sheep and goats.

Clinical signs and diagnosis. Multiple, gray, crusty, circumscribed, hyperkeratotic lesions are characteristic of infection. Lesions will vary in size. In all ruminants, lesions will be around the head, neck, and ears. In goats and cattle, lesions will extend down the neck, and in cattle, lesions develop particularly around the eyes and on the thorax. Cattle lesions are unique in the marked crustiness, which progressively appears wartlike. Hair shafts become brittle and break off. Intense pruritus is often associated with the alopecic lesions.

The disease can be diagnosed by microscopic identification of hyphae and conidia on the hairs following skin scraping and 20% potassium hydroxide digestion. Dermatophyte test media (DTM) cultures are the most reliable means to diagnose the fungus. Broken hairs from the periphery of the lesion are the best sources of the fungus.

Epizootiology and transmission. Younger animals are more susceptible, and factors such as crowding, indoor housing, warm and humid conditions, and poor nutrition are also important. Transmission is by direct contact or by contact with contaminated fomites, such as equipment, fencing, or feed bunks.

Pathogenesis. Incubation can be as long as 6 weeks. The organisms invade and multiply in hair shafts.

Treatment. Spontaneous recovery occurs in all species in 1–4 months. Although cell-mediated immunity is considered important, other immune mechanisms are not well understood. Immunity may not be of long duration. Recovery is enhanced by correcting nutritional deficiencies and improving housing and ventilation problems. A number of topical treatments, such as 2–5% lime–sulfur solution, 3% captan, iodophors, thiabendazole, and 0.5% sodium hypochlorite, can be used. In severe cases, systemic therapy with griseofulvin may be successful.

Prevention and control. The animals' environment and overall physical condition should be reassessed with particular attention to ventilation, crowding, sanitation, and nutrition. Pens should be thoroughly cleaned and disinfected.

Research complications. Ringworm is a zoonotic disease.

B. Genetic, Metabolic, Nutritional, and Management-Related Diseases

1. Genetic Diseases

a. Entropion

Inverted eyelids are a common inherited disorder of lambs and kids of most breeds. Generally, the lower eyelid is affected and turns inward, causing various degrees of trauma to the conjunctiva and cornea. Young animals will display tearing, blepharospasm, and photophobia initially. If the disorder is left uncorrected, corneal ulcers, perforating ulcers, uveitis, and blindness may occur. Placing a suture or a surgical staple in the lower eyelid and the cheek, effectively anchoring the lid in an everted position, successfully treats the condition. The procedure likely results in the formation of some degree of scar tissue within the lower lid, because when the suture eventually is removed, the condition rarely returns. Other treatments include the injection of a "bleb" of penicillin in the lid, regular manual correction over a 2-day period early in the animal's life, and application of ophthalmic ointments, powders, and solutions. Boric acid or 10% Argyrol solutions have been used as treatments. Because of the genetic predisposition, prevention of the condition requires removal of maternal or paternal carriers.

b. β-Mannosidosis of Goats

β-Mannosidosis is an autosomal recessive lysosomal storage disease of goats. The disease affects kids of the Nubian breed and is identified by intention tremors and difficulty or inability of newborns to stand. Cells of affected animals are vacuolated because of a lack of lysosomal hydroxylase, which results in accumulation of oligosaccharides. Newborn kids are unable to rise, and they have characteristic flexion of the carpal joint and hyperextension of the pastern joint. Kids are born deaf and with musculoskeletal deformities such as domed skull, small narrow muzzle, small palpebral fissures, enophthalmos, and depressed

nasal bridge (Smith and Sherman, 1994). Carrier adults can be identified by plasma measurements of β-mannosidase activity.

c. Congenital Myotonia of Goats

Caprine congenital myotonia is an inherited autosomal dominant disease that affects voluntary striated skeletal muscles. Goats with this disease are commonly known as fainting goats. "Fainting" is actually transient spasms of skeletal musculature brought about by visual, tactile, or auditory stimuli (Smith and Sherman, 1994). Muscle fiber membranes appear to have fewer chloride channels than normal, resulting in decreased chloride conduction across the membrane, with subsequent increased membrane excitability and repetitive firing (Smith and Sherman, 1994). Contractions of skeletal muscle are sustained for up to 1 min. Kids exhibit the condition by 6 weeks of age, and males appear to exhibit more severe clinical signs than females (Smith and Sherman, 1994). Electromyographic studies produce an audible "dive-bomber" sound characteristic of hyperexcitable cell membranes (Smith and Sherman, 1994).

d. Inherited Conditions of Cattle

i. Congenital erythropoietic porphyria. Congenital erythropoietic porphyria (CEP) is an autosomal recessive disease of cattle seen primarily in Holsteins, Herefords, and Shorthorns. The disease also occurs in Limousin cattle, humans, and some other species. In the homozygous recessive animal, symptoms of the disease may vary from mild to severe and occur at different times of the year and in different ages of animals. A reddish brown discoloration of teeth and bones is a characteristic of the disease, as is discolored urine, general weakness and failure to thrive, photosensitization, and photophobia. Bones are more fragile compared with bones of normal animals. A regenerative anemia occurs as the result of the shortened life span of erythrocytes, due to accumulations of porphyrins. The genetic defect is associated with low activity of an essential enzyme, uroporphyrinogen III synthase, in the porphyrin–heme synthesis pathway in erythrocytic tissue. The ranges in the presentation of the disease are believed to be related to varying cycles of porphyrin synthesis. Porphyrins are excreted in varying amounts in the urine and the discoloration fluoresces under a Wood's lamp. Diagnosis is based on these clinical and visible signs of porphyria; skin biopsy provides definitive diagnosis. Heterozygotes may have milder symptoms.

Many other genetic defects, in all major organ systems, have been described in numerous breeds of cattle and are described in detail elsewhere ("Large Animal Internal Medicine," 1996). In many cases, the genetic basis has been clarified, and associated defects also noted. Many defects are reported in particular breeds, but as crossbreeding increases and new breeds are developed, these traits are appearing in these animals. The bovine genome continues to be further characterized, and more linkage maps and gene locations are forthcoming (Womack, 1998).

Some bovine genetic defects are also regarded as models of genetic disease, such as leukocyte adhesion deficiency of Holstein cattle. Some of the more commonly reported defects include syndactyly in Holsteins and other breeds and polydactyly in Simmentals; lysosomal storage diseases such as α-mannosidosis in some beef breeds; enzyme deficiencies such as citrullinemia in Holsteins; and progressive degenerative myeloencephalopathy ("weaver") in Brown Swiss.

ii. Goiter of sheep. A defect in the synthesis of thyroid hormone has been identified in Merino sheep (Radostits *et al.,* 1994). Lambs born with the defect have enlargement of the thyroid gland, a silky appearance to the wool, and a high degree of mortality. Edema, bowing of the legs, and facial abnormalities have also been noted in animals with this disorder. Immaturity of the lungs at birth causes neonatal respiratory distress and results in dyspnea and respiratory failure.

iii. Spider lamb syndrome (hereditary chondrodysplasia). Spider lamb syndrome is an inherited, often lethal, musculoskeletal disorder primarily occurring in Suffolk and Hampshire breeds. Severely affected lambs die shortly after birth. Animals that survive the perinatal period develop angular limb deformities, scoliosis, and facial deformities. With time, affected animals become debilitated, exhibit joint pain, and develop neurological problems associated with the spinal abnormalities. Radiologically, secondary ossification centers—especially the physis, subchondral areas, and cuboidal bones—are affected. Abnormal endochondral ossification leads to excess cartilage formation, notably apparent in the elbows. Lambs will typically display abnormally long limbs, medial deviation of the carpus and tarsus, flattening of the sternum, scoliosis/kyphosis of the vertebrae, and a rounded nose. Muscle atrophy is common. Diagnosis can be based on typical clinical signs, which are similar to those seen with Marfan syndrome in humans (Rook *et al.,* 1986). Long-term survival is rare; treatment is unsuccessful.

2. Metabolic Diseases

a. Abomasal Disorders

i. Abomasal and duodenal ulcers. Abomasal and duodenal ulcers occur more frequently in calves and adult cattle than in sheep and goats. Like rumenitis, abomasal and duodenal ulcers may be associated with lactic acidosis. Concurrent disease, such as salmonellosis, bluetongue, or overuse of anti-inflammatory drugs, or recent shipping or environmental stresses may also lead to ulcer formation. Copper deficiency, dietary changes, mycotic infections, *Clostridium perfringens* abomasitis, and abomasal bezoars are associated with this disease in calves. In older adult cattle, abomasal lymphosarcoma may be the underlying condition. Gastric acid hypersecretion in conjunction with insufficient gastric mucous secretion will physically destroy the gastric epithelium. Deep ulceration may cause serious hemorrhage and/or perforation with peritonitis. Chronic hemorrhage

may lead to anemia. Although ulcers are often asymptomatic in calves, perforation with peritonitis is more common than hemorrhage. Dark feces or melena and abdominal pain may be observed. Arched back, restlessness, kicking at the abdomen, bruxism, and anorexia are common signs of abdominal pain. Fecal occult blood is as an easy diagnostic test. Treatment includes gastrointestinal protectants and histamine antagonists. Anemia may be symptomatically treated with parenteral iron injections and anabolic steroids. Preventive measures in cattle herds include ensuring optimal passive immunity for calves, minimizing stress to calves, and striving for a herd free of bovine leukosis virus.

ii. Abomasal emptying defect. Abomasal emptying defect of sheep is a sporadic syndrome associated with abomasal distension and weight loss. Suffolks tend to be especially predisposed, although the disease has been diagnosed in Hampshires, Columbias, and Corriedales. The mechanism of the disease is unknown. Affected animals will exhibit a gradual weight loss with a history of normal appetites. Feces will continue to be normal. Ventral abdominal distension associated with abomasal accumulation of feedstuffs will be apparent in many of the animals. Diagnosis is primarily based on history and clinical signs. Elevations in rumen chloride concentrations (>15 mEq/liter) are commonly found. Radiography or ultrasonography may be helpful at identifying the distended abomasum. Abomasal emptying defect is usually eventually fatal. Medical treatment with metoclopramide and mineral oil may be helpful in early disease.

iii. Abomasal displacement. Displaced abomasum (DA) is a sporadic disorder usually associated with multiparous 4- to 7-year-old dairy cows in early lactation, but the condition can occur even in young calves. Displacement to the right (RDA) may be further complicated by torsion (RTA), a surgical emergency. Left displacement (LDA) is more common than RDA. Clinical signs include anorexia, lack of cud chewing, decreased frequency of ruminal contractions, shallow respirations, increased heart rate, treading, and decreased milk production. Diagnosis is based on characteristic areas of tympanic resonance during auscultation-percussion of the lateral to lateral–ventral abdomen ("pings"), ruminal displacement palpated per rectum, and clinical signs. Cow-side clinical chemistry findings include hypoglycemia and ketonuria; more extensive evaluations will often indicate moderate to severe electrolyte and acid–base abnormalities. DA occurs because of gas accumulation within the viscus, and the abomasum "floats" up from its normal ventral location to the lateral abdominal wall. No exact cause of DA has been identified, but it is commonly associated with stress; high levels of concentrate in the diet, leading to forestomach atony; and many disorders, including lack of regular exercise, mastitis, hypocalcemia, retained placenta, metritis, or twins. Factors such as body size and conformation indicate the possibility of genetic predisposition. Treatments include surgical and nonsurgical techniques for LDA; the former has a better chance of per-

manent correction. Emergency surgery is necessary for RTA; the disorder is fatal within 72 hr. Recurrence is rare after surgical correction. Electrolyte and acid–base imbalances are likely in severe cases and especially with RTA. Prevention includes reducing stress, taking greater care in the introduction and feeding of concentrates, and reducing incidence of predisposing diseases noted above (Rohrbach *et al.*, 1999).

b. Fat Cow Syndrome, Hepatic Lipidosis

Fat cow syndrome is seen in peri- or postparturient overconditioned or obese multiparous dairy cows. Factors in the development of the condition include negative energy balance related to the normal decreased dry matter intake as parturition approaches; hormonal changes associated with parturition; and concurrent diseases of parturition that decrease feed intake and increase energy needs. The possible concurrent diseases include metritis, retained fetal membranes, mastitis, parturient paresis, and displaced abomasum. Signs are nonspecific and include depression, anorexia, and weakness. Prognosis is usually guarded. Diagnosis is based on herd management, the animal's condition, ketonuria, and clinical signs. In prepartum cattle and in lactating cows, blood levels of nonesterified fatty acids (NEFA) greater than 1000 µEq/liter and 325–400 µEq/liter, respectively, are abnormal (Gerloff and Herdt, 1999). Triglyceride analysis of liver biposy specimens are useful. In affected cows, body fat is mobilized, in the form of NEFA in response to the energy demands. Hepatic lipidosis occurs rapidly as the NEFA are converted into hepatic triglycerides. The ability of the liver to extract the albumin-bound NEFA from the blood is better than that of other tissues that need and can also use NEFA as an energy source. Treatment for any concurrent diseases must be pursued aggressively, as well as measures to increase and stabilize blood glucose, decrease NEFA production, and increase forestomach digestion to improve production of normally metabolized volatile fatty acids. Therapeutic measures include intravenous glucose drips, insulin (NPH or Lente) injections every 12 hr, and transfaunation of ruminal fluid from a normal cow. Prevention includes minimizing stress to late-gestation cows. Dry and lactating cows should be maintained separately; their energy, protein, and dry matter requirements are very different. Cows with prolonged lactation or delayed breeding should be managed to prevent weight gain.

c. Rumen and Reticulum Disorders

i. Bloat. Bloat or tympanites refers to an excessive accumulation of gas in the rumen. The condition most frequently occurs in animals that have been recently fed abundant quantities of succulent forages or grains. Bloat is classified into two broad categories: frothy bloat and free-gas bloat. Frothy bloat is associated with ingestion of feeds that produce a stable froth that is not easily expelled from the rumen. Fermentation gases such as CO_2, CH_4, and minor gases such as N_2, O_2, H_2, and H_2S incorporate into the froth, overdistend the rumen, and eventu-

ally compromise respiration by limiting diaphragm movement. The froth is often derived from a combination of salivary muco-proteins, protozoal or bacterial proteins, and proteins, pectins, saponins, or hemicellulose associated with ingested leaves or grain. Typical foodstuffs that cause frothy bloat include green legumes, leguminous hay (alfalfa, clover), or grain (especially barley, corn, and soybean meal). Free-gas bloat is less related to feeds ingested; rather, it is caused by rumen atony or by physical or pathological problems that prevent normal gas eructation. Some examples of causes of free-gas bloat are esophageal obstructions (foreign bodies, tumors, abscesses, and enlarged cervical or thoracic lymph nodes), vagal nerve paralysis or injury, and central nervous system conditions that affect eructation reflexes. Clinically, the animal will exhibit rumen distension, and tympany will be observed in the left paralumbar fossa. Additional signs may include colic-like pain of the abdomen and dyspnea. Passage of a stomach tube helps to differentiate between free-gas bloat and frothy bloat; and with free-gas bloat, expulsion of gas through the stomach tube aids in treatment of the disorder. Once rumen distension is alleviated with free-gas bloat, the underlying cause must be investigated to prevent recurrence. Frothy bloat is more difficult to treat, because the foam blocks the stomach tube. Addition of mineral oil, household detergents, or antifermentative compounds via the tube may help break down the surface tension, allowing the gas to be expelled. In acute, life-threatening cases of bloat, treatment should be aimed at alleviating rumen distension by placing a trocar or surgical rumenotomy into the rumen via the paralumbar fossa. Limiting the consumption of feedstuffs prone to induce bloat can prevent the disease. Additionally, poloxalene or monensin will decrease the incidence of frothy bloat.

ii. Lactic acidosis. Lactic acidosis, or rumen acidosis, is an acute metabolic disease caused by engorgement of grains or other highly fermentable carbohydrate sources. The disease is most frequently related to a rapid change in diet from one containing high roughage to one containing excessive carbohydrates. Diet components that predispose to acidosis include common feed grains; feedstuffs such as sugar beets, molasses, and potatoes; by-products such as brewer's grains; and bakery products. Biochemically, ingestion of large amounts of the carbohydrate-rich diet causes the normally gram-negative rumen bacterial populations to shift to gram-positive *Streptococcus* and *Lactobacillus* species. The gram-positive organisms efficiently convert the starches to lactic acid. The lactic acid acidifies the rumen contents, leading to rumen mucosal inflammation, and increases the osmolality of rumen fluids, leading to sequestration of fluids and osmotic attraction of plasma and tissue fluid to the rumen. Lactic acid–induced rumenitis predisposes the animal to ulcers, to liver abscesses from "absorbed" bacterial pathogens, to laminitis from absorbed toxins, and to polioencephalomalacia from the inability of the new rumen bacterial populations to produce sufficient thiamine needed to maintain normal nervous system function. Clinically, animals

will become anorexic, depressed, and weak within 1–3 days after the initial insult. Incoordination, ataxia, dehydration, hemoconcentration, rapid pulse and respiration, diarrhea, abdominal pain, and lameness will also be noted. Rumen distension and an acetone-like odor to the breath, milk, or urine may also be observed. Diagnosis is based on history and clinical signs. Blood, urine, or milk ketones can be detected (Moore and Ishler, 1997). Additionally, rumen pH, which is normally above 6.0, will drop to less than 5.0 and in severe cases may achieve levels as low as 3.8. Similarly, urine pH will become acidic, blood pH will drop below 7.4, and hematocrit will appear to increase due to the relative hemoconcentration. Necropsy findings will be determined by secondary conditions. The primary lactic acidosis will cause swelling and necrosis of rumen papillae and abomasal hemorrhages and ulcers. Treatment must be applied early in the syndrome. In early hours of severe carbohydrate engorgement, rumenotomy and evacuation of the contents are appropriate. The patient should be given mineral oil and antifermentatives to prevent the continued conversion of starches to acids and the absorption of metabolic products. Bicarbonate or other antacids like magnesium carbonate or magnesium hydroxide introduced into the rumen will aid in adjusting rumen pH. Furthermore, animals can be given oral tetracycline or penicillin, which will decrease the gram-positive bacterial population.

iii. Rumen parakeratosis. Parakeratosis is a degenerative condition of the rumen mucosa that leads to keratinization of the papillary epithelium. Excessive and continuous feeding of diets low in roughage causes the mucosal changes. Generally, this condition is seen in feedlot lambs and steers that are fed an all-grain diet. Clinically, animals may exhibit only poor rates of gain, due to changes in the absorptive capacity of the injured mucosa. At necropsy, papillae will be thickened and rough. They will frequently be dark in color, and multiple papillae will clump together. Abscessation may be observed. Histopathologically, papilla surfaces will have hyperkeratinization of the squamous epithelium. Chronic laminitis may be observed. However, diagnosis of parakeratosis is generally made at necropsy. Feeding adequate roughage, such as stemmy hay, will prevent the disease. Antibiotics may be administered to prevent secondary liver abscess formation.

iv. Rumenitis. Rumenitis is an acute or chronic inflammation of the rumen, which occurs most commonly as a sequela to lactic acidosis. In addition to concentrate feeding, inadequate roughage in the diet is also associated with this disorder. Rumenitis may occur with contagious ecthyma infection or following ingestion of poisons or other irritants. Because rumenitis is often associated with lactic acidosis, it tends to occur in feedlot animals. The inflamed ruminal epithelium becomes necrotic and sloughs, creating ulcers. Endogenous rumen bacteria such as *Fusobacterium necrophorum* may invade the ulcers, penetrate the circulatory system, and induce abscesses of the liver. Clinically, the animals will appear depressed and

anorexic. Rumen motility will be decreased, and animals will lose weight. The disease may resolve in a week to 10 days; mortality may reach 20%. Necropsy lesions include rumen inflammation and ulcers in the anteroventral sac. Granulation tissue and scarring may be observed following healing. Rumenitis is not typically diagnosed clinically; thus, specific treatment is not commonly done. The disease can be prevented by minimizing the incidence of lactic acidosis.

d. Traumatic Reticulitis–Reticuloperitonitis (Hardware Disease)

Etiology.   Traumatic reticulitis–reticuloperitonitis is a disease of cattle related to their exploratory tendencies and ingestion of many different, nonvegetative materials. The disease is rarely seen in smaller ruminants.

Clinical signs.   Clinical signs range from asymptomatic to severe, depending on the penetration and damage by the foreign object after settling in the animal's forestomach. Many signs during the early, acute stages will be nonspecific, ranging from arched back, listlessness, anorexia, fever, decrease in production, ketosis, regurgitation, decrease or cessation of ruminal contractions, bloat, tachypnea, tachycardia, and grunts when urinating, defecating, or being forced to move. The prognosis is poor when peritonitis becomes diffuse. Sudden death can occur if the heart, coronary vessels, or other large vessels are punctured by the migrating object.

Epizootiology and transmission.   This is a noncontagious disease. The occurrence is directly related to sharp or metallic indigestible items in the feed or environment that the cattle mouth and swallow.

Necropsy findings.   In severe cases, necropsy findings include extensive inflammation throughout the cranial abdomen, malodorous peritoneal fluid accumulations, and lesions at the reticular sites of migration of the foreign objects. Cardiac puncture will be present in those animals succumbing to sudden death.

Pathogenesis.   Consumed objects initially settle in the rumen but are dumped into the reticulum during the digestive process, and normal contraction may eventually lead to puncture of the reticular wall. This sets off a localized inflammation or a localized or more generalized peritonitis. The inflammation may also temporarily or permanently affect innervation of local tissues and organs. Further damage may result from migration and penetration of the diaphragm, pericardium, and heart. Diagnosis is based on clinical signs, knowledge of herd management techniques in terms of placement of forestomach magnets, and reflection of acute or chronic infection on the hemogram. Radiographs and abdominocentesis may be useful.

Differential diagnosis.   Differentials include abomasal ulcers, hepatic ulcers, neoplasia (such as lymphosarcoma, usually in older animals, or intestinal carcinoma), laminitis, and cor pulmonale. Infectious diseases that are differentials include systemic leptospirosis and internal parasitism. Diseases causing sudden death may need to be considered.

Prevention and control.   This problem can be prevented entirely by elimination of sharp objects in cattle feed and in the housing and pasture environments. Adequately sized magnets placed in feed handling equipment and forestomach magnets (placed *per os* with a balling gun in young stock at 6–8 months of age) are also significant prevention measures.

Treatment.   Provision of a forestomach magnet, confinement, and nursing care, including antibiotics, are the initial treatments. In severe cases, rumenotomy may be considered.

e. Pregnancy Toxemia (Ketosis), Protein Energy Malnutrition

Etiology.   Pregnancy toxemia is a primary metabolic disease of ewes and does in advanced pregnancy. Beef heifers are susceptible to protein energy malnutrition (PEM) syndrome, which is also referred to as pregnancy toxemia.

Clinical signs.   In sheep, this disease is characterized by hypoglycemia, ketonemia, ketonuria, weakness, and blindness. Hypoglycemic and ketotic ewes begin to wander aimlessly and to move away from the flock. They become anorexic and act uncoordinated, frequently leaning against objects. Advanced signs may include blindness, muscle tremors, teeth grinding, convulsions, and coma. Body temperature, heart rate, respiratory rate, and rumen motility continue normally. Up to 80% of infected ewes may die from the disease. The course of the disease may last up to a week.

In goats, the disease usually occurs in the last 6 weeks of gestation, especially in does carrying triplets. Pregnancy toxemia should be considered with any goat showing signs of illness in late gestation. The doe may separate herself from the herd, stagger, or circle and may appear blind. Appetite is poor, and tremors may be evident. A rapid metabolic acidosis results in subsequent recumbency. Urinalysis will readily reveal ketonuria. If fetal death occurs, acute toxemia and death of the doe may result.

In beef heifers, weight loss and thin body condition, weakness and inability to stand, and depression are clinical signs. Some cows develop diarrhea. Because the catabolic state is often so advanced, most affected heifers die even if treated.

Pregnancy toxemia is diagnosed by evidence of typical clinical signs. Sodium nitroprusside tablets or ketosis dipsticks may be used to identify ketones in the urine or plasma of ewes and does. Blood glucose levels found to be below 25 mg/dl and

ketonuria are good diagnostic indicators. In cattle, ketonuria is not a typical finding; hypocalcemia and anemia may be present.

Epizootiology. Pregnancy toxemia occurs primarily in ewes that are obese or bearing twins or triplets. The disease develops during the last 6 weeks of pregnancy. PEM most frequently occurs in heifers during the final trimester of pregnancy.

Necropsy findings. At necropsy, affected ewes will often have multiple fetuses, which may have died and decomposed. The liver will be enlarged, yellow, and friable, with fatty degeneration. The adrenal gland may also be enlarged. In cattle, heifers will be very thin, and in addition to a fatty liver, signs of concurrent diseases may be present.

Pathogenesis. Rapid fetal growth, a decline in maternal nutrition, and a voluntary decrease in food intake in overfat ewes result in an inadequate supply of glucose needed for both maternal and fetal tissues. The ewe develops a severe hypoglycemia in early stages of the disease. The ruminant absorbs little dietary glucose; rather, it produces and absorbs volatile fatty acids (acetic, propionic, and butyric acids) from consumed feedstuffs. Propionic acid is absorbed and selectively converted to glucose through gluconeogenesis. When the animal is in a state of negative energy balance, it hydrolyzes fats to glycerol and fatty acids. Glycerol is converted to glucose while the fatty acids are metabolized for energy. The oxidation of fatty acids in the face of declining oxaloacetate levels (required for normal Krebs cycle function) results in the formation of ketone bodies (acetone, acetoacetic acid, and β-hydroxybutyric acid), thus causing the condition ketoacidosis.

Heifer cattle have high energy requirements for completing normal body growth and supporting a pregnancy. Additional energy requirements are needed during pregnancy for winter conditions and during concurrent diseases. Marginal diets and poor-quality forage will place the cows in a negative energy balance.

Differential diagnosis. Hypocalcemia is a common differential diagnosis. In cattle, differentials include chronic or untreated diseases such as Johne's disease, lymphosarcoma, parasitism, and chronic respiratory diseases.

Prevention and control. Pregnancy toxemia can be prevented by providing adequate nutrition during late gestation and by maintaining animals in appropriate nonfat condition during pregnancy. In late pregnancy, the dietary energy and protein should be increased 1.5–2 times the maintenance level. PEM can be prevented by maintaining appropriate body condition earlier in pregnancy and supplying good-quality forage for the last trimester.

Treatment. In sheep, because the morbidity may be as high as 20%, treatment should be directed at the flock rather than the individual. Treating the individual is usually unsuccessful. Oral administration of 200 ml of propylene glycol or 50% glucose twice a day, anabolic steroids, and high doses of adrenocorticosteroids may be helpful. If ewes are still responsive and not severely acidotic or in renal failure, cesarean section may be successful by rapidly removing the fetus, which is the dietary drain for the ewe. In goats, pregnancy toxemia is best treated by removal of the fetuses either by cesarean section or induction of parturition. Parturition can be induced in does by either dexamethasone (10 mg) or PGF_{2a} (10 µg). In addition, goats may be treated with 10% dextrose (100 to 200 ml iv) or propylene glycol (60 ml *per os* 2 or 3 times a day). Adjunctive therapy includes normalizing acid base and hydration status, administration of vitamin B_{12} and transfaunation. Heifers may be force-fed alfalfa gruels, given propylene glycol *per os*, placed on IV 50% glucose drips, and treated for concurrent disease.

Research complications. In research requiring pregnant ewes in late stages of gestation, for example, this disease should be considered if the animals are likely to bear twins and will be transported or stressed in other ways during that time.

f. Hypocalcemia (Parturient Paresis, Milk Fever)

Etiology. Hypocalcemia is an acute metabolic disease of ruminants that requires emergency treatment; the presentation is slightly different in ewes, does, and cows.

Clinical signs and diagnosis. In sheep, the disease is seen in ewes during the last 6 weeks of pregnancy and is characterized by muscle tetany, incoordination, paralysis, and finally coma. As calcium levels drop, ewes begin to show early signs such as stiffness and incoordination of movements, especially in the hindlimbs. Later, muscular tremors, muscular weakness, and recumbency will ensue. Animals will frequently be found breathing rapidly despite a normal body temperature. Morbidity may approach 30%, and mortality may reach as high as 90% in untreated animals. Affected does become bloated, weak, unsteady, and eventually recumbent. Cows are affected within 24–48 hr before or after parturition. Cows initially are weak and show evidence of muscle tremors, then deteriorate to sternal recumbency, with the head usually tucked to the abdomen, and an inability to stand. Tachycardia, dilated pupils, anorexia, hypothermia, depression, ruminal stasis, bloat, uterine inertia, and loss of anal tone are also seen at this stage. The terminal stage of disease is a rapid progression from coma to death. Heart rates will be high, but pulse may not be detectable.

Hypocalcemia is diagnosed based on the pregnancy stage of the female and on clinical signs. It is later confirmed by laboratory findings of low serum calcium. With hypocalcemia in ewes, the plasma concentrations of calcium drop from normal values of 8–12 mg/dl to values of 3–6 mg/dl. In cattle, plasma

levels below 7.5 mg/dl are hypocalcemic; at the terminal stages levels may be 2 mg/dl.

Epizootiology. Hypocalcemia occurs primarily in overweight ewes during the last 6 weeks of pregnancy or during the first few weeks of lactation. The disease is not as common in the dairy goat as in the dairy cow. High-producing, older, multiparous dairy cows are the most susceptible, and the Jersey breed is considered susceptible. Cows that have survived one episode are prone to recurrence. In addition, dry cows must be managed carefully regarding limiting dietary calcium. The disease is not common in beef cattle unless there is an overall poor nutrition program.

Necropsy findings. There is no pathognomonic or typical finding at necropsy.

Pathogenesis. During the periparturient period, calcium requirements for fetal skeletal growth exceed calcium absorbed from the diet and from bone metabolism. Additionally, dietary calcium intake is thought to be compromised because, in advanced pregnancy, animals may not be able to eat enough to sustain adequate nutrient levels, and intestinal absorption capabilities do not respond as quickly as needed. After parturition, calcium needs increase dramatically because of calcium levels in colostrum and milk. Recent information suggests that legume and grass forages, high in potassium and low in magnesium, create a slight physiological alkalosis (at least in cattle), which antagonizes normal calcium regulation (Rings *et al.,* 1997). Thus, bone resorption, renal resorption, and gastrointestinal absorption of calcium are less than maximal.

Prevention and control. Maintaining appropriate nutrition during the last trimester is helpful in preventing the disease. In cows and does, for example, limiting calcium intake by removing alfalfa from the diet is helpful.

Treatment. Hypocalcemia must be treated quickly based on clinical signs; pretreatment blood samples can be saved for later confirmation. Twenty percent calcium borogluconate solution should be administered by slow intravenous infusion. Response will often be rapid, with the resolution of the animal's dull mentation. Less severely affected animals will often try to stand in a short time. Relapses are common, however, in sheep and cattle. Hypermagnesemia and hypophosphatemia often coincide with hypocalcemia. These imbalances should be considered when animals appear to be unresponsive to treatment. Hypocalcemia in the goat can be treated with 50–100 ml of calcium borogluconate. Heart rate should be monitored closely throughout calcium administration. If an irregular or rapid heart rate is detected, then calcium treatment should be slowed or discontinued. Calcium gels and boluses are also available for treatment (Rings *et al.,* 1997). Prognosis is generally good if the

animal is treated early in the disease, but the prognosis will often be poor when treatment is initiated in later stages of the disease.

g. Urinary Calculi (Obstructive Urolithiasis, Water Belly)

Etiology. Urolithiasis is a metabolic disease of intact and castrated male sheep, goats, and cattle that is characterized by the formation of bladder and urethral crystals, urethral blockage, and anuria (Murray, 1985). The disease occurs rarely in female ruminants.

Clinical signs and diagnosis. Affected animals will vocalize and begin to show signs of uneasiness, such as treading, straining postures, arched backs, raised tails, and squatting while attempting to urinate. These postures may be mistaken for tenesmus. Male cattle may develop swelling along the ventral perineal area. Affected animals will not stay with the herd or flock. Small amounts of urine may be discharged, and crystal deposits may be visible attached to the preputial hairs.

Additionally, in smaller ruminants, the filiform urethral appendage (pizzle) often becomes dark purple to black in color. The pulsing pelvic urethra may be detected by manual or digital rectal palpation, and bladder distention may be noticeable in cattle by the same means. As the disease progresses to complete urethral blockage, the animal will become anorexic and show signs of abdominal pain, such as kicking at the belly. The abdomen will swell as the bladder enlarges, and rupture can occur within 36 hr after development of clinical signs. Bladder or urethral rupture may cause a short-lived period of apparent pain relief; subsequent development of uremia will eventually lead to death. The disease may progress over a period of 1–2 weeks, and the mortality is high unless the blockages are reversed.

Diagnosis is made by the typical clinical signs. Abdominal taps may yield urine. Calculi are usually composed of calcium phosphate or ammonium phosphate matrices.

Epizootiology and transmission. Clinical disease is usually seen in growing intact or castrated males. The disease may be sporadic or there may be clusters of cases in the flock or herd.

Necropsy findings. Necropsy findings include urine in the abdomen with or without bladder or urethral rupture. Renal hydronephrosis may be evident. Calculi or struvite crystal sediment will be observed in the bladder and urethra. Histologically, trauma to the urethra and ureters will be present.

Pathogenesis. Urolithiasis is multifactorial and involves dietary, anatomical, hormonal, and environmental factors. Male sheep and goats have a urethral process that predisposes them to entrapment of calculi. In cattle, the urethra narrows at the sigmoid flexure, and calculi lodge there most frequently. Additionally, the removal of testosterone by early castration is thought to

result in hypoplasia of the urethra and penis. This physical reduction in the size of the excretory tube may predispose to the precipitation of and blockage by the struvite minerals. Grains fed to growing animals tend to be high in phosphorus and magnesium content. These calculogenic diets lead to the formation of struvite (magnesium ammonium phosphate) crystals. Other minerals associated with urolithiasis include silica (range grasses), carbonates (some grasses and clover pastures), calcium (exclusively alfalfa hay), and oxalates (fescue grasses).

Differential diagnosis. Grain engorgement colic, gastrointestinal blockage, and causes of tenemus, such as enteritis or trauma, are differentials. Trauma to the urethral process should be considered. Urinary tract infections are uncommon in ruminants.

Prevention and control. One case often is indicative of a potential problem in the group. Urolithiasis can be minimized by monitoring the calcium:phosphorus ratio in the diet. The normal ratio should be 2:1. Additionally, increasing the amount of dietary roughage will help balance the mineral intake. Increasing the amount of salt (sodium chloride, 2–4%) in the diet to increase water consumption, or adding ammonium chloride to the diet, at 10 gm/head/day or 2% of the ration, to acidify the urine, will aid in the prevention of this disease. Palatability of and accessibility to water should be assessed as well as functioning of automatic watering equipment.

Treatment. Treatment is primarily surgical (Van Metre et al. 1996). Initially, amputation of the filiform urethral appendage may alleviate the disease since urethral blockage often begins here. As the disease progresses, urethral blockage in the sigmoid flexure as well as throughout the urethra may occur. In more advanced stages, perineal urethrostomy may yield good results. The prognosis is poor when the condition becomes chronic, reoccurs, or surgery is required.

Research complications. Young castrated and intact male ruminants used in the laboratory setting will be the susceptible age group for this disorder.

h. Rickets

Rickets is a disease of young, growing animals but rarely occurs in goats. It is a metabolic disease characterized by a failure of bone matrix mineralization at the epiphysis of long bones due to lack of phosphorus. The condition can occur as an absolute deficiency in vitamin D_2, an inadequate dietary supply of phosphorus, or a long-term dietary imbalance of calcium and phosphorus. The syndrome must be differentiated from epiphisitis (unequal growth of the epiphyses of long bones in young, rapidly growing kids fed diets with excess calcium). Clinical signs include poor growth, enlarged costochondral

junctions, narrow chests, painful joints, and reluctance to move. Spontaneous fractures of long bones may occur. Animals will recover when dietary phosphorus is provided and if joint damage is not severe.

3. Nutritional Diseases

a. Copper Deficiency (Enzootic Ataxia, Swayback)

Etiology. Chronic copper deficiency in pregnant ewes and does may produce a metabolic disorder in their lambs and kids called enzootic ataxia. In goats, this deficiency also causes swayback in the fetuses.

Clinical signs and diagnosis. This disease results in a progressive hindlimb ataxia and apparent blindness in lambs up to about 3 months of age. Additionally, because copper is essential for osteogenesis, hematopoiesis, myelination, and pigmentation of wool and hair, ewes may appear unthrifty, may be anemic, and may have poor, depigmented wool with a decrease in wool crimp. Affected kids are born weak, tremble, and have a characteristic concavity to the spinal cord, leading to the name *swayback.* When the deficiency occurs later during gestation, demyelination is limited to the spinal cord and brain stem. Kids are born normally but develop a progressive ataxia, leading to paralysis, muscle atrophy, and depressed spinal reflexes with lower motor neuron signs. Diagnosis is based on low copper levels found in feedstuffs and tissues at necropsy. Diagnosis is based on clinical signs, feed analysis, and pathological findings.

Epizootiology and transmission. Enzootic ataxia is rarely seen in western states; most North American diets have sufficient copper levels to prevent this disease. Copper antagonists in the feed or forage at sufficient levels, such as molybdenum, sulfate, and cadmium, however, may predispose to copper deficiencies.

Pathogenesis. The maternal copper deficiency leads to a disturbance early in the embryonic development of myelination in the central nervous system and the spinal cord. Copper is part of the cytochrome oxidase system and other enzyme complexes and is important in myelination, osteogenesis, hematopoiesis (iron absorption and hemoglobin formation), immune system development, and maintenance and normal growth (Smith and Sherman, 1994).

Differential diagnosis. The differential diagnosis for newborns includes β-mannosidosis, hypoglycemia, and hypothermia. For older animals the differential should include caprine arthritis encephalitis (goats), enzootic muscular dystrophy, listeriosis, spinal trauma or abscessation, and cerebrospinal nematodiasis.

Prevention and control. Copper deficiency can be prevented by providing balanced nutrition for pregnant animals.

Necropsy findings. Gross encephalomalacia has been noted. Histopathologically, white matter of the brain and spinal cord displays gelatinization and cavitation. Extensive nerve demyelination and necrosis are evident. Postmortem lesions include extensive demyelination and neuronal degeneration.

Treatment. Because the condition is developmental, supplemental copper may improve clinical signs but not eliminate them.

b. Copper Toxicosis

Etiology: Acute or chronic copper ingestion or liver injury often causes a severe, acute hemolytic anemia in weanling to adult sheep and in calves and adult dairy cattle. Growing lambs may be the most susceptible. Copper toxicosis is rare in goats.

Clinical signs and diagnosis. The clinical course in sheep can be as short as 1–4 days, and mortality may reach 75%. Hemolysis, anemia, hemoglobinuria, and icterus characterize the acute hemolytic crisis, associated with copper released from the overloaded liver. Some clinical signs are related to direct irritation to the gastrointestinal tract mucosa. Weakness, vomiting, abdominal pain, bruxism, diarrhea, respiratory difficulty, and circulatory collapse are followed by recumbency and death.

Hepatic biopsy is currently considered the best diagnostic approach; serum or plasma levels of copper and hepatic enzymes such as aspartate aminotransferase (AST) and γ-glutamyltransferase (GGT) may provide some information, but it is generally believed that these will not accurately reflect total copper load or hepatic damage.

Epizootiology and transmission. A single toxic dose for sheep and goats is the range of 20–100 mg/kg, and for cattle it is 220–880 mg/kg. Chronic poisoning in sheep may occur when 3.5 mg/kg is ingested. Copper-containing pesticides, soil additives, therapeutics, and improperly formulated feeds may potentially lead to copper toxicity. Phytogenous sources include certain pastures such as subterranean clover. Feed low in molybdenum, zinc, or calcium may lead to increased uptake of copper from properly balanced rations. A common cause of the disease in sheep is feeding concentrates balanced for cattle; cattle feeds and mineral blocks contain much higher quantities of copper than are required for sheep. Chronic ingestion of these feedstuffs leads to copper accumulation and toxicity. Copper toxicosis has been reported in calves given regular oral or parenteral copper supplements, and in adult dairy cattle given copper supplements to compensate for copper-deficient pasture. Pregnant dairy cattle may be more susceptible to copper toxicity. Rare sources of copper ingestion may include copper sulfate footbaths.

Necropsy findings. Common findings at necropsy include icterus; a soft, dark, friable, enlarged spleen; an enlarged, yellow-brown friable liver; and "gun-barrel" black kidneys. Hemoglobin-stained urine will be visible in the bladder. Copper accumulations in the liver reaching 1000–3000 ppm are toxic.

Pathogenesis. Hemolysis occurs when sufficient amounts of copper are ingested or released suddenly from the liver and is believed to be due direct interaction of the copper with red-cell surface molecules. Stresses such as transportation, lactation, and poor nutrition or exercise may precipitate the hemolysis.

Differential diagnosis. Other causes of hemolytic disease include babesiosis, trypanosomiasis, and plant poisonings such as kale. Arsenic ingestion, organophosphate toxicity, and cyanide or nitrate poisoning should also be considered as the source of poisoning. Urethral obstruction and gastrointestinal emergencies should be considered for the abdominal pain.

Control and prevention. The disease is prevented by carefully monitoring copper access in sheep and copper supplementation in cattle. Sheep and goats should not be fed feedstuffs formulated for cattle, and dairy calf milk replacer should not be used for lambs and kids. Molybdenum may be administered to animals considered at high risk. Molybdenum-deficient pastures may be treated with molybdenum superphosphate. Herd copper supplementation should be undertaken with the knowledge of existing hepatic copper levels, and existing copper and molybdenum levels, in the feedstuffs.

Treatment. Oral treatment for sheep consists of ammonium or sodium molybdenate (50–100 mg/day), and sodium thiosulfate (0.5–1.0 mg/day) for 3 weeks aids in excretion of copper. Oral D-penicillamine daily for 6 days (50 mg/kg) has also been shown to increase copper excretion in sheep. Ammonium molybdenate has been administered intravenously to goats at 1.7 mg/kg for 3 treatments on alternate days. Cattle have been treated orally with sodium molybdenate (3 gm/day) or sodium thiosulfate (5 gm/day). Treatment for anemia and nephrosis may be necessary in severe cases.

Research complications. Some breeds of sheep, such as Merino crosses and the British breeds, may be more susceptible to copper toxicosis caused by phytogenous sources.

c. Selenium/Vitamin E Deficiency (Nutritional Muscular Dystrophy, Nutritional Myodegeneration, White Muscle Disease, Stiff Lamb Disease)

Etiology. White muscle disease, also known as stiff lamb disease, is a nutritional muscular dystrophy caused by a deficiency of selenium or vitamin E.

Clinical signs and diagnosis. Clinically two forms of the disease have been identified: cardiac and skeletal. The cardiac form occurs most commonly in neonates. In these, respiratory difficulty will be a manifestation of damage to cardiac, diaphragmatic, and intercostal muscles. Young will be able to nurse when assisted. In slightly older animals, the disease is characterized by locomotor disturbances and/or circulatory failure. Clinically, animals may display paresis, stiffness or inability to stand, rapid but weak pulse, and acute death. Mortality may reach 70% (Jensen and Swift, 1982). Paresis and sudden death in neonates with associated pathological signs are frequently diagnostic. With the skeletal form, affected animals are stiff and reluctant to move, and muscles of affected animals are painful. Young will be reluctant to get up but will readily nurse when assisted. Peracute to acute myocardial degeneration may occur in the cardiac form, and animals may simply be found dead. Serum selenium levels are usually below 50 ppb (normal is 158–160 ppb) (Nelson, 1983).

Diagnosis may also include determination of antemortem whole blood levels of selenium and plasma levels of vitamin E. Glutathione peroxidase levels in red blood cells can be measured as an indirect test. Clinical biochemistry findings of significant elevations of aspartate aminotransferase (AST) in creatinine kinase (CK) are also supportive of the diagnosis.

Epizootiology and transmission. Selenium deficiency has been associated with formulated diets deficient in selenium, forages grown on selenium-deficient soils in certain geographic regions, and forages such as alfalfa and clover that have an inability to efficiently extract available selenium from the soils. Rumen bacterial reduction of selenium compounds to unavailable elemental selenium may also contribute to the disease.

Necropsy findings. Necropsy lesions include petechial hemorrhages and muscle edema. Hallmarks are pale white streaking of affected skeletal and cardiac muscle. These are due to coagulation necrosis. Pale striated muscles of the limb, diaphragm, and tongue are also seen.

Pathogenesis. Selenium and vitamin E function together as antioxidants that protect lipid membranes from oxidative destruction. Selenium is a cofactor for glutathione peroxidase, which converts hydrogen peroxide to water and other nontoxic compounds. Lack of one or both results in loss of membrane integrity.

Differential diagnosis. In neonatal ruminants presenting with respiratory and cardiac dysfunction, differentials include congenital cardiac anomalies. Differentials generally for weak neonates or sudden or peracute neonatal deaths should include septicemia, pneumonia, toxicity, diarrhea, and dehydration.

Prevention and control. Awareness of regional selenium deficiencies is important. Control involves providing good-quality roughage, vitamin E and selenium supplementation, and parenteral injections prior to parturition and weaning.

Treatment. Affected animals may be treated by administering vitamin E or selenium injections. Administering vitamin E or selenium to ewes in late pregnancy can prevent white muscle disease (Kott et al., 1998). The label dose for selenium is 2.5–3 mg/45 kg of body weight. Combination products are available and can be used in goats at the sheep dose (Smith and Sherman, 1994). Proper mineral balance in the diet is critical.

d. Selenium Toxicity

Selenium toxicity occurs most frequently as the result of excessive dosing to prevent or correct selenium deficiency or as the result of ingestion of selenium-converting plants. The main preventive measure for the former is the use of the appropriate product for the species. Secondarily, the concentration of the available product should be double-checked. In the United States, ruminants in the Midwest and western areas may be subject to selenium toxicity when pastured in areas containing selenium-converting plants. Signs of overdosing include weakness, dyspnea, bloating, and diarrhea. Shock, paresis, and death may occur. Initial clinical signs of excessive selenium intake from plants are observed in the distal limb, with cracked hoof walls and subsequent infection and irregular hoof growth.

e. Thiamin Deficiency (Polioencephalomalacia)

Etiology. Polioencephalomalacia (PEM) is a noninfectious, noncontagious disease characterized by neurological signs. Growing and adult ruminants on high-concentrate diets are typically affected. Animals exposed to toxic plants or moldy feed containing thiaminases, feed high in sulfates, or unusually high doses of some medications are also at risk.

Clinical signs and diagnosis. An early sign may be mild diarrhea. Acute clinical signs include bruxism, hyperesthesia, involuntary muscle contractions, depression, partial or complete opisthotonus, nystagmus, dorsomedial strabismus, seizures, and death. In subacute cases of the disease, animals may appear to walk aimlessly as if blind or may display head-pressing postures. Hypersalivation may be present, but body temperatures and ocular reflexes are normal. Morbidity and mortality may be high, especially in younger animals. Diagnosis is suggestive from clinical signs and from response to intensive parental thiamine hydrochloride.

Epizootiology and transmission. PEM is caused by a thiamin deficiency. The disease tends to be seen more frequently in cattle and sheep feedlots where the concentrates fed are high in fermentable carbohydrates. Pastured animals are also vulnerable if grain is feed. Thiaminase-containing plants, such as bracken fern, are often unpalatable so will less likely be a contributing factor. Recent studies have also indicated that high

levels of sulfate in the diet, such as in the fermentable, low-fiber concentrates, may play an important role. Medications such as as amprolium, levamisole, and thiabendazole have thiamin-antagonizing activity when given in excessive doses.

Necropsy signs. Cerebral lesions characterized by softening and discoloration are grossly observed in the gray matter. Microscopically, neurons will exhibit edema, chromatolysis, and shrinkage. Gliosis and cerebral capillary proliferation may be observed.

Pathogenesis. A lack of thiamin results in inappropriate carbohydrate metabolism and accumulation of pyruvate and other intermediaries that lead to cerebral edema and neuronal degeneration.

Differential diagnosis. Several important differentials include acute lead poisoning, nitrofuran toxicity, hypomagnesemia, vitamin A deficiency, listeriosis, pregnancy toxemia, infectious thromboembolic meningoencephalitis, and type D clostridial enterotoxemia.

Prevention and control. The disease can be prevented by monitoring the diet and by providing adequate roughage necessary to prevent overgrowth of thiaminase-producing ruminal flora and to maximize ruminal production of B vitamins. If excess sulfur is the primary factor, immediate removal of the source is critical.

Treatment. Early aggressive treatment is essential to save animals. The disease is treated by frequent parenteral administration of thiamine hydrochloride, the first dose being administered intravenously. Dexamethasone, B vitamins, and diazepam may also be required. Treatment is less successful when sulfur plays a prominent role in the etiology.

Research complications. This disease is preventable. Although the disease is less likely to occur in smaller groups of confined ruminants, the risks of feeding concentrates or moldy feed, for example, with minimal good-quality roughage, should be kept in mind.

f. Vitamin D Toxicity

Vitamin D toxicity can result either from iatrogenic overadministration or ingestion of the plant *Trisetum flavescens*. Serum calcium levels may be high enough that blood in EDTA tubes will clot.

g. Nutritional Deficiencies

In goats, nutritional deficiencies often manifest as a generalized poor coat that is dry, scaly, thin, and erectile. Zinc-responsive dermatitis has been reported in goats (Smith and

Sherman, 1994). Vitamin A deficiencies associated with hyperkeratosis have been reported, as well as vitamin E–responsive and selenium-responsive dermatitis.

4. Management-Related Diseases

a. Failure of Passive Transfer

Neonatal ruminants are born without immunoglobulins and must receive colostrum by 24 hr after birth. The morbidity and mortality associated with failure of or inadequate passive transfer, such as enteric and respiratory illnesses, can be severe. Measures to assure passive immunity for neonatal ruminants are covered in Section II,B,5, and clinical signs of illness associated with lack of immunity are addressed in the discussions of bacterial diseases (e.g., *Escherichia coli* infections) and, of viral diseases (e.g., diarrheas) in Section III,A,1 and III,A,2. Generally, transfer of less than 600 mg/dl of immunoglobulins in the serum is classified as failure of transfer, 600–1600 mg/dl is partial, and above 1600 mg/dl is complete transfer. Methods to determine success of transfer should be performed within a week of birth and include single radial immunodiffusion (quantitates immunogloblin classes); zinc sulfate turbidity (semi-quantitative); sodium sulfite precipitation (semiquantitative); glutaraldehyde coagulation (coagulates above specific level); and, γ-glutamyltransferase (assays enzyme in high concentration in colostrum and absorbed simultaneously with colostrum).

b. Laminitis

Laminitis is common in ruminants and can be caused by sudden changes in diet, excess dietary energy, and grain overload (or overeating). Laminitis is also associated with mastitis and metritis. Facility conditions, such as concrete flooring, poor manure management, and inadequate resting areas may also contribute to the pathogenesis of the disease. The complete pathogenesis of laminitis is poorly understood; however, it is thought that changes in the diet cause changes in rumen microbial populations, resulting in acidosis and endotoxemia. Dramatic changes in the vascular endothelium result in chronic inflammation of the sensitive laminae of the hoof, separation of corium and hoof wall, and rotation of the third phalanx. Affected animals may be reluctant to get up or walk, will shift their weight frequently, and will grind teeth or walk on carpi. Chronically, the hoof wall takes on a "slipper" appearance. Treatment consists of identifying the underlying cause, administering anti-inflammatories (phenylbutazone, flunixin meglumin), feeding good-quality forages only, and regular foot trimming.

c. Nutritional Diarrhea

Otherwise normal, well-managed lambs, kids, and calves can develop loose, pasty feces due to a nutritional imbalance caused by overfeeding and/or improper mixing of milk replacers. Only

milk replacer formulated for the particular species should be used. Once nutritional imbalances are corrected, the feces readily return to normal. Sudden changes in diet can also result in loose feces.

d. Photosensitization (Bighead)

Photosensitization is an acute dermatitis associated with an interaction between photosensitive chemicals and sunlight. The photosensitive chemicals are usually ingested, but in some cases exposure may be by contact. Animals with a lack of pigment are more susceptible to the disease. Three types of photosensitization occur: primary; secondary, or hepatogenous; and aberrant. Primary photosensitization is related to uncommon plant pigments or to drugs such as phenothiazine, sulfonamides, or tetracyclines. Secondary photosensitization is more common in large animals and is specifically related to the plant pigment phylloerythrin. Phylloerythrin, a porphyrin compound, is a degradation product of chlorophyll released by rumen microbial digestion. Liver disease or injury, which prevents normal conjugation of phylloerythrin and excretion through the biliary system, predisposes to photosensitization. The only example of aberrant photosensitization is congenital porphyria of cattle (see Section III,B,1). Pathologically, the photosensitive chemical is deposited in the skin and is activated by absorbed sunlight. The activated pigments transfer their energy to local proteins and amino acids, which, in the presence of oxygen, are converted to vasoactive substances. The vasoactive substances increase the permeability of capillaries, leading to fluid and plasma protein losses and eventually to local tissue necrosis. Photosensitization can occur within hours to days after sun exposure and produces lesions of the face, vulva, and coronary bands; lesions are most likely to occur on white-haired areas. Initially, edema of the lips, corneas, eyelids, nasal planum, face, vulva, or coronary bands occurs. The facial edema, nostril constriction, and swollen lips potentially lead to difficulty in breathing. With secondary photosensitization, icterus is also common. Necrosis and gangrene may occur. Diagnosis is based on clinical lesions and exposure to the photosensitive chemi-cals and sunlight. Treatment is symptomatic. The prognosis for hepatogenous type may be guarded if hepatic disease is severe.

e. Reproductive Prolapses (Vaginal, Uterine)

Vaginal and uterine prolapses occur in ewes, does, and cows. The conditions are not common in does. Vaginal prolapses usually occur during late gestation and may be related to relaxation of the pelvic ligaments in response to hormone levels. In sheep, these are most common in overconditioned ewes that are also carrying twins or triplets. Overconsumption of roughages, which distends the rumen, and lack of exercise leading to intra-abdominal fat may predispose an animal to vaginal prolapse by increasing intra-abdominal pressure. The condition may result from excessive straining associated with dysuria from the pressure of the fetuses and/or abdominal contents on the bladder. If the prolapse obstructs subsequent urination, rupture of the bladder may occur. The vaginal prolapse can be reduced and repaired if discovered early, and techniques in small and large ruminants are comparable. The animal should be restrained, and the prolapsed tissue should be cleansed with disinfectants. Best done under epidural anesthesia, the vagina is replaced into the pelvic canal and the vulvar or vestibular opening is sutured closed (Buhner suture). Alternatively, a commercial device called a bearing retainer (or truss) can be placed into the reduced vagina and tied to the wool, thereby holding the vagina in proper orientation without interfering with subsequent lambing.

Vaginal prolapses may have a hereditary basis in ewes and cows and may prolapse the following year. These animals should be culled. Vaginal prolapses may occur in nonpregnant animals that graze estrogenic plants or as a sequela to docking the tail too close to the body (Ross, 1989).

Uterine prolapses occur sporadically in postpartum ewes and cattle. The gravid horn invaginates after delivery and protrudes from the vulva. The cause is unknown, but excessive traction utilized to correct dystocia or retained placenta, uterine atony, hypocalcemia, and overconditioning or lack of exercise have been implicated. In cattle, the uterine prolapses usually develop within 1 week of calving, are more common in dairy cows than in beef cows, and are often associated with dystocia or hypocalcemia. Cows may also have concurrent parturient paresis. Initially, the tissue will appear normal, but edema and environmental contamination or injuries of the tissue develop quickly. Clinical signs will include increased pulse and respiratory rates, straining, restlessness, and anorexia. If identified early, the uterus can be replaced as for vaginal prolapses. Electrolyte imbalances should be corrected if present. Additional supportive therapy, including the use of antibiotics should always be considered. Tetanus prophylaxis should be included. Oxytocin should be administered to induce uterine reduction. Vaginal closures are less successful at retaining uterine prolapses. Preventive and control measures include regular exercise for breeding animals, and management of prepartum nutrition and body condition.

f. Rectal Prolapse

Rectal prolapse is common in growing, weaned lambs and in cattle from 6 months to 2 years old. The physical eversion of the rectum through the anal sphincter is usually secondary to other diseases or management-related circumstances. Rectal prolapses may occur secondary to gastrointestinal infection or inflammation, especially when the colon is involved. Diseases that cause tenesmus, such as coccidiosis, salmonellosis, and intestinal worms, may result in prolapse. Urolithiasis may result in prolapses as the animal strains to urinate. Any form of cystitis or urethritis, vaginal irritation, or vaginal prolapse and some

forms of hepatic disease may lead to rectal prolapse. Abdominal enlargement related to advanced stages of pregnancy, excessive rumen filling or bloat, and overconditioning may cause prolapse. Finally, excessive coughing during respiratory tract infections, improper tail docking (too short), growth implants, prolonged recumbency, or overcrowded housing with animal piling may lead to prolapses.

Diagnosis is based on clinical signs. Early prolapses may be corrected by holding the animal with the head down, while a colleague places a pursestring suture around the anus. The mucosa and underlying tissue of prolapses that have been present for longer periods of time will often become necrotic, dry, friable, and devitalized and will require surgical amputation or the placement of prolapse rings to remove the tissue. Rectal prolapse may also be accompanied by intestinal intussusceptions that will further complicate the treatment and increase mortality. Occasionally, acute rectal prolapse with evisceration will result in shock and prompt death of the animal. Prognosis depends on the cause and extent of the prolapse as well as the timeliness of intervention. In all cases of treatment, determination and elimination of the underlying cause are essential.

g.   Trichobezoars

Gastrointestinal accumulations or obstructions of hair (and/ or sometimes very coarse roughage, forming bezoars) occur in cattle and sheep. Cattle that are maintained on a low-roughage diet, that lick their coats frequently, that have long hair coats from outdoor housing, or that have heavy lice or mite infestations and associated pruritus will often develop bezoars. In addition, younger calves with abomasal ulcers have been found to be more likely to have abomasal trichobezoars as well. Clinical signs may be mild or severe according to size, number, and location. Ruminal trichobezoars rarely result in clinical signs. Obstruction will be accompanied by signs of pain, development of bloat, and decreased fecal production. Serum profiles will show hypochloridemia; other imbalances depend on the duration of the problem. Diagnosis is also based on abdominal auscultation, rectal palpation, and ultrasound (useful in calves and smaller ruminants). Treatment is surgical, such as paracostal laparotomy (for abomasal), paralumbar celiotomy with manual breakdown, or enterotomy. Supportive care should be administered as necessary to correct electrolyte imbalances and to prevent inflammation and sepsis. Prognosis is generally good if the condition is diagnosed and treated before dehydration and imbalances become severe and peritonitis develops. Prevention includes providing good-quality roughage and treating lice and mange infestations.

C.   Traumatic Disorders (Wounds, Bites, and Entrapped Foreign Bodies)

Wounds may be sustained from poorly constructed pens or fences, or from skirmishes among animals. Predators will usu-

ally be sources of bite wounds. Standard veterinary wound assessment and care are essential for wounds or bites. Tetanus antitoxin may be indicated. Use of approved antibiotics may be appropriate. The lesion should be cleaned with disinfectants and repaired with primary closure if it is clean and uncontaminated. Thorough cleaning, regular monitoring, and healing by second intention are recommended for older wounds. Abscesses may also occur in the soft tissues of the hooves (sole abscesses; see Section III,C,3) because of entrapped foreign bodies or hoof cracks that fill with dirt. Preventive measures include improvement of housing facilities, pens, and pastures; monitoring hierarchies among animals penned together; and implementing predator control measures, such as sound fencing, flock guard dogs, or donkeys, in pasture situations.

D.   Iatrogenic Diseases

1.   Anaphylactic Reactions

Acute anaphylatic reactions in sheep, goats, and cattle are often clinically referable to the respiratory system. Anaphylactic vaccine reactions cause acute lung edema; lungs are the primary site of lesions if collapse and death are sequelae. The animals will also be anxious and shivering and will become hyperthermic. Salivation, diarrhea, and bloat also occur. Immediate therapy must include epinephrine by intravenous infusion at (1 ml of 1:1000 per 50 kg of body weight for goats and 1:10,000 (0.1 mg/ml) or 0.01 mg/kg (about 5 ml) for adult cows.) Furosemide (5 mg/kg) may be beneficial to reduce edema. Prognosis is usually guarded. Recovery can occur within 2 hr.

2.   Catheter Sites and Experimental Surgeries

In a research environment, catheter sites or experimental surgeries may be sources of iatrogenic infection. Traumatic injuries to peripheral nerves can cause acute lameness. Improper administration of therapeutics can easily cause this type of lameness. Injections given in gluteals or between the semimembranosus and semitendinosus can cause irritation to the sciatic nerve and subsequent lameness. Contraction of the quadriceps results in the limb being pulled forward. Injections in the caudal thigh can damage the peroneal nerve and cause knuckling at the fetlock. Traumatic injury to the radial nerve can result in a "dropped elbow" (Nelson, 1983). Husbandry procedures such as tail docking, castration, dehorning, dosing with a balling gun, and shearing may result in superficial lesions, dermal infections, or cases of tetanus. Balling-gun injuries to the pharynx may lead to cellulitis with coughing, decreased appetite, and sensitivity to palpation.

Standard veterinary assessment and care are essential for these cases. Local and systemic antibiotics with supportive care may be indicated. Swelling around peripheral nerves caused by inoculations may be reduced by diuretics and anti-inflammato-

ries. Mild cases of peripheral nerve damage may recover in 7–14 days. Personnel training, including review of relevant anatomy, preprocedure preparation, appropriate technique, careful surgical site preparation, rigorous instrument sanitation, and sterile technique will minimize the incidence of potential complications from surgical procedures.

E. Neoplastic Diseases

Neoplasia and tumors are relatively rare in ruminants. Lymphosarcoma/leukemia in sheep has been shown to result from infection by a virus related (or identical) to the bovine leukemia virus. Pulmonary carcinoma (pulmonary adenomatosis) and hepatic tumors are found in sheep. Virus-induced papillomatosis (warts), discussed in Section III,A,2,s, and squamous cell carcinomas have also been reported in sheep.

In goats, thymoma is one of the two most common neoplasias reported, although no distinct clinical syndrome has been described. Cutaneous papillomas are the most common skin and udder tumor of goats, and although outbreaks involve multiple animals, no wart virus has been identified. Persistent udder papillomas may progress to squamous cell carcinoma. Lymphosarcoma is reported rarely in goats. Although adrenocortical adenomas have been reported frequently and almost exclusively in older wethers, no clinical condition has been described.

Lymphosarcoma of various organ systems and "cancer eye" (bovine ocular squamous cell carcinoma, or OSCC) are the most commonly reported cancers in cattle. Lymphosarcoma is described in Section III,A,2,c. Lack of periocular pigmentation and the amount and intensity of exposure to solar ultraviolet light are considered important factors in OSCC. Genetic factors may also play a role. Many cases occur in Herefords. This is a disease of older cattle; no case has been reported in animals less than 4 years of age. The cancer metastasizes through the lymph system to major organs. Treatment in either lymphosarcoma or OSCC is recommended only as a palliative measure. The extent of ocular neoplastic involvement is a significant criterion for carcass condemnation. Papillomatosis (warts) are common in cattle (see Section III,A,2,s).

F. Miscellaneous

1. Amyloidosis

Amyloidosis in adult cattle is due to accumulations of amyloid protein in the kidney, liver, adrenal glands, and gastrointestinal tract. The disease has been classified as AA type, or associated with chronic inflammatory disease, although other unknown factors are believed to be involved in some cases. Clinical signs include chronic diarrhea, weight loss, decreased production, nonpainful renomegaly, and generalized edema. The loss of protein in the urine contributes to abnormal plasma albumin values and foaming urine. The proteinuria also distinguishes amyloidosis (and glomerulonephritis) from other causes of weight loss and diarrhea in cattle such as Johne's disease, parasitism, copper deficiency, salmonellosis, and bovine viral diarrhea virus infection. Prognosis is poor, and no treatment is reported.

2. Dental Wear

Dental wear is seen most commonly in sheep. As sheep age, excessive dental wear may lead to an inability to properly masticate feed, manifesting as weight loss and unthriftiness. Several factors predisposing to dental wear should be considered. The diet should be properly balanced for minerals, especially calcium and phosphorus, because primary or secondary calcium deficiency during teeth development results in softening of the enamel and dentin. Dietary contamination with silica (i.e., hays and grains harvested in sandy regions) will lead to mechanical wear on the teeth. Likewise, animals grazing or being fed in sandy environments will have excessive tooth wear. Sheep older than about 5 years of age are especially prone to tooth wear and should be checked frequently, especially if signs of weight loss or malnutrition are evident. Managing the content and consistency of the diets can best prevent the disease.

3. Sole abscesses

Of the ruminants, cows are the most frequently affected by subsolar abcesses. Dirt becomes packed into cracks in the horny layer of the sole of the hoof, and contamination eventually extends into the sensitive areas of the hoof, with lameness and infection resulting. Animals maintained in very soiled or muddy conditions, combined with poor hoof care, are more likely affected. *Fusobacterium necrophorum* is often the pathogen involved. Separation of the animal, supportive care, surgical drainage, and antibiotic treatment are indicated.

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