Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

CHAPTER 17

Sheep and Goat Vaccines

OUTLINE

Although vaccines are available against many infectious diseases of small ruminants, they labor under the difficulty that individual animals may be of low value, and consequently, the cost of vaccines must also be very low to make economic sense. This severely limits vaccine choices for these species. Additionally, many small ruminant operations are traditionally managed and function at a low technological level. Nevertheless, small ruminants are the most significant livestock species in many countries, especially in less developed or arid regions. Conversely, some sheep and goat products such as wool and mohair are of significant value, and the highly efficient sheep producing systems in countries such as Australia and New Zealand are important contributors to their economies. Therefore it is not surprising that these countries are the sources of some of the most innovative and effective small ruminant vaccines.

Vaccine Administration

As in other food animals, the veterinarian should be aware of the potential of injected vaccines to induce injection site lesions including blemishes in show animals. Reaction sites that require trimming at slaughter may result in a significant financial penalty. In general, subcutaneous injection in the caudolateral neck region is preferred, with an injection behind the elbow over the ribs as a possible alternative. Do not administer vaccines over the loin or hindquarters where the valuable meat cuts are located. As always, animals must be properly restrained to minimize struggling and to ensure proper delivery of the full dose of vaccine. The use of excessively long needles over 0.5 inches long should be avoided and they should be changed often. Remember, the needle used to withdraw vaccine from the bottle should not be used for injection.

Antibacterial Vaccines

CLOSTRIDIAL DISEASES

The most important vaccines given routinely to sheep and lambs in North America are those used to protect against Clostridial diseases. Specifically, the preferred vaccine is CD-T toxoid. This protects against enterotoxemia caused by *Clostridium perfringens* types C and D and also tetanus caused by *Clostridium tetani*. These Clostridial organisms can grow rapidly in an animal and secrete a complex mixture of toxins and enzymes. Seven toxinotypes (A–E) have been identified. *Cl. perfringens* type C causes a hemorrhagic enteritis ("bloody scours") in suckling lambs during the first few weeks of life. It may be triggered by changes in feed or receiving too much

milk. Vaccination of the ewe in late pregnancy, four weeks before lambing, offers protection. *Cl. perfringens* type D causes enterotoxemia (overeating disease) and pulpy kidney disease. It usually affects lambs over one month of age and is often precipitated by a change of feed. This results in abrupt changes in the intestinal microbiota and clostridial proliferation. This leads to sudden death in weaned lambs on a high carbohydrate diet. Like type C, the type D *Cl. perfringens* vaccine should be administered to pregnant ewes in late pregnancy to ensure adequate levels of antibodies in colostrum and protection of lambs for four to six weeks.

Polyvalent clostridial vaccines contain a complex mixture of toxoids and bacterins from up to eight different species. They are normally administered in two doses and elicit responses that are protective for at least a year. Studies however suggest that antibody levels peak about 36 days after vaccination and are maintained up to 90 days before declining rapidly. They may be undetectable by 6 months. Factors other than antibodies must be responsible for the prolonged immunity seen in practice. As might be expected, large individual variations in response occur between animals. Additionally, some antigenic competition occurs in these complex mixtures. *Cl. tetani* and *Clostridium novyi* type B are immunodominant and induce the highest antibody levels whereas *Clostridium septicum* the lowest.

Clostridial vaccines are available in 3-, 7-, and 8-way combinations, each containing a mixture of toxoids and bacterins. In addition to *Cl. perfringens* types -B, -C and -D, they may contain *Clostridium sordellii, Cl. septicum, Cl. novyi, Clostridium haemolyticum,* and *Cl. tetani* (Table 17.1). The 7- and 8-way vaccines are combination vaccines used to protect against other clostridial diseases such as malignant edema, "big head", and blackleg caused by wound infections. These should only be used if these other clostridia are known to be present in a flock.

Tetanus is a potential risk at docking and castration time. If their ewes were vaccinated when pregnant then revaccination of lambs is unnecessary. Vaccination at the time of docking or castration of lambs may not be protective because it takes about 7 to 10 days for antitoxic immunity to develop. Tetanus antitoxin should be used to provide immediate protection in such cases. Maternal antibodies will probably protect lambs and kids for about two months depending on their titer.

FOOTROT

Footrot is a common, complex, and important disease in the sheep industry. It is a painful and debilitating infection of the interdigital skin and is the most important cause of lameness in sheep. Footrot is primarily caused by a complex mixture of bacteria of which the most important is an anaerobic gram-negative bacterium, *Dichelobacter nodosus*. Infection by *D. nodosus* is preceded and accompanied by maceration and colonization of the interdigital skin by *Fusobacterium necrophorum*. Footrot causes significant losses because animals must be treated and/or culled. Based on the antigenicity of their fimbriae there are 10 major serogroups of *D. nodosus* (A-I and M), and within these serogroups there are additional serotypes. (Other classification systems have identified as many as 21 serotypes). Immunity is serogroup specific and multiple different serogroups may be found within a single sheep flock.

Sheep and goats can be immunized against footrot using vaccines against *D. nodosus* containing either whole cell antigens or fimbrial antigens. Whole cell vaccines are rarely protective against heterologous subgroups. The fimbriae provide the major antigenic determinants (also called epitopes) and as such are the major protective antigens. These fimbriae are composed of repeating protein subunits called pilins. Pilin monomers, although antigenic are not protective. Denatured fimbriae are not protective either. However, fimbriae containing pilin polymers are as effective as whole cell vaccines. These fimbrial antigens may be derived by physicochemical methods or produced in recombinant organisms.

Ideally footrot vaccines should contain antigens representing all the serogroups. A multivalent recombinant fimbrial vaccine containing ten serogroups (A, B1, B2, and C to M) is currently used in Australia and other countries. It is not ideal, and protection lasts for less than 10 weeks. Specific monovalent or bivalent vaccines, in contrast, can provide protection for up to 16 weeks

TABLE 17.1 ■ **A Suggested Vaccination Schedule for Lambs and Kids**

Disease/Vaccine	Vaccine Timing	Comments
Bacterial Diseases		
Clostridial diseases—C, D, and T (CORE)	Vaccinate at 6–8 weeks, and revaccinate 3–4 weeks later. If ewes were not vaccinated for *Cl. perfringens*, their lambs may be vaccinated at 2–3 days of age and revaccinated 2–3 weeks later. Feeder lambs should be vaccinated at time of purchase, and 2–4 weeks later.	If not previously vaccinated, ewes must be vaccinated twice at 6–4 weeks before lambing, with the last dose 4 weeks before lambing. If previously vaccinated a single dose is sufficient. Revaccinate annually. Withdrawal time 21 days.
Footrot *Dichelobacter nodosus*	Vaccinate before the anticipated problem. Revaccinate between 6 weeks and 6 months later,	Revaccinate every 6 months. Withdrawal time 60 days.
Caseous lymphadenitis *Corynebacterium pseudotuberculosis*	Vaccinate sheep and goats over 3 months of age. Revaccinate 4 weeks later on the opposite side of the animal.	May be combined with clostridia. Annual revaccination. Withdrawal time 21 days. Do not use in known infected animals because a severe reaction may result.
Campylobacter fetus-jejuni bacterin	Vaccinate before breeding and revaccinate in 60–90 days.	Annual revaccination. Withdrawal time 21 days.
Bacterial pneumonia (*M. haemolytica* and *P. multocida*)	Vaccinate breeding ewes and revaccinate 2–4 weeks apart. Revaccinate again 2–4 weeks before lambing. Lambs vaccinated under 3 months should be revaccinated at 4–6 months.	Revaccinate ewes annually before breeding or during pregnancy according to the label recommendations. May be combined with clostridia. Withdrawal time 21 days.
Chlamydia	Vaccinate 60 days before breeding and revaccinate 30 days later.	Administered with Campylobacter bacterins. Annual revaccination. Withdrawal time 60 days.
Anthrax	In known problem areas vaccinate twice at a 2–3 week interval.	Withdrawal time 42 days. Annual revaccination.
Viral Diseases		
Soremouth	Vaccinate lambs at 1 month. Revaccinate 2–3 months later. Range lambs entering a feedlot should be vaccinated at least 10 days previously.	Use this vaccine well ahead of lambing or showing. Do not use within 24 hours of dipping or spraying. Withdrawal time 21 days.
Bluetongue	Vaccinate lambs over 3 months of age and revaccinate 3 weeks before the breeding season or after lambing.	Do not vaccinate pregnant animals. Vaccine is strain specific so select it carefully. Withdrawal time 21 days.
Rabies	Vaccinate lambs over 3 months of age.	Revaccinate annually or 3 yearly depending on the vaccine. Withdrawal time 21 days.

This table is an example of a consensus vaccination program. Individual programs are variable and will reflect animal health, local environmental and housing conditions, severity of challenge, and disease prevalence in addition to professional judgment. Be sure to follow the manufacturer's recommendations on the label.

or longer against homologous challenge. The reduced immunogenicity of multivalent vaccines appears to be caused by competition between their antigens. Attempts to produce a universal footrot vaccine have been unsuccessful.

Autogenous, outbreak-specific footrot vaccines have also been used successfully. In flocks infected with just one or two serogroups, serogroup-specific fimbrial or whole cell vaccines may be effective and permit eradication of the disease. If flocks are infected by more than one serogroup then sequential vaccination cycles using monovalent vaccines given at three-monthly intervals over several years may also prove effective.

Footrot is a seasonal disease because it results from animals standing in water and mud for prolonged periods. The vaccine should be given four months before the start of the "wet" season. Because duration of immunity is so short, sheep may require boosting every three to six months.

Vaccination for footrot is simply another tool that should be used in conjunction with other procedures, such as regular foot trimming and foot soaking in disinfectant baths in an effort to eliminate the infection.

CASEOUS LYMPHADENITIS

This disease of sheep is caused by *Corynebacterium pseudotuberculosis*. It causes abscess formation in lymph nodes. If the organism becomes systemic it can cause a chronic wasting disease. *C. pseudotuberculosis* also causes an acute disease of buffalo called edematous skin disease. Caseous lymphadenitis results from wound infections and may be associated with poor hygiene during shearing. It is a robust organism and can persist in the environment for up to a year. A formalin-inactivated bacterin using biovar 1 is used in healthy sheep and goats over three months of age. Adverse reactions have occurred in goats given the sheep vaccine. Once the prevalence of infection is reduced to a low level then infected animals should be culled rather than vaccinated.

CAMPYLOBACTER FETUS

Campylobacter fetus is one of the most common causes of abortion, late fetal loss in ewes, and the birth of dead or weak lambs. It is rarely a problem in goats. It may be prevented by vaccination given shortly before breeding. Two inactivated vaccines are available in the United States. They contain both *C. fetus* and *Campylobacter jejuni*. A third vaccine is available in Australia and New Zealand. This may contain multiple *C. fetus* strains (DL42, 6/1, 134) in addition to *C. jejuni*. Immunity develops in about 21 days. Do not use the vaccine licensed for cattle in sheep.

BACTERIAL PNEUMONIA

Bronchopneumonia caused by *Pasteurella multocida, Bibersteinia trehalosi,* and *Mannheimia haemolytica* is common in sheep and goats of all ages. It may be especially important in young lambs that have received insufficient colostrum. These organisms are normal inhabitants of the sheep nasopharynx. In times of stress caused by shipping, weather extremes, or overcrowding they can invade the lungs and cause pneumonia. Several types of vaccine are available to control these infections. These include whole cell bacterins, leukotoxin-toxoids, and cell surface iron binding proteins. The whole cell bacterins rely on outer membrane protein antigens specific for each serotype. *M. haemolytica* has 12 serotypes of which A2 is the most prevalent. Unfortunately, A2 is poorly immunogenic in sheep. As expected, these bacterins work reasonably well against homologous serotypes, but are less effective in protecting against unrelated serotypes.

Leukotoxins are critical virulence factors for *M. haemolytica* because they kill white blood cells. Addition of a leukotoxoid to these vaccines thus increases their efficacy. Like the outer membrane proteins, however, there is a great diversity in leukotoxin types.

M. haemolytica needs iron for growth. It expresses iron-binding proteins (siderophores) on its surface. Antibodies against these siderophores will effectively reduce its growth. Like the outer membrane proteins and leukotoxoids these proteins differ between different bacterial strains. However, when used in a vaccine against the appropriate strain they can be very effective.

The prevalence of respiratory disease in lambs increases beginning around three weeks of age. Maternal antibodies to these organisms appear to interfere minimally with vaccination of lambs so they can be vaccinated as early as 10 days of age. They should then be boosted three to four weeks later. A third booster may be needed around 12 to 14 weeks of age. If sheep are intensively housed and at high risk of respiratory disease then they may be revaccinated semiannually or annually.

OVINE ENZOOTIC ABORTION

The gram-negative intracellular bacterium, *Chlamydia abortus,* causes enzootic abortion in sheep and goats worldwide. Infected animals shed large amounts of the agent in the diseased placenta and uterine fluids. Killed vaccines are widely available. A temperature-sensitive mutant (strain 1B) has been generated by inducing mutations in a wild type strain (AB7) using the mutagen, N-methyl-N'-nitro-N-nitrosoguanidine. This organism has a reduced growth rate at 39.5°C. It is used in some European countries. Unfortunately, strain 1B has been implicated in cases of vaccine breakdown. Genomic sequencing has indicated that its genomic sequence is identical to its parent strain. As a result, it is not attenuated and can cause serious disease outbreaks. Vaccine-identical strains have been isolated from cases of disease.

Antiviral Vaccines

SOREMOUTH

Contagious ecthyma (orf, soremouth, or scabby mouth) is a skin disease of sheep and goats. The virus infects wounds around the mouth (often caused by abrasions or thorns such as from prickly pear cactus). As a result of these large painful lesions, the lamb or kid is unable to suckle. The infection may then spread to the ewe and cause mastitis.

Soremouth vaccine is unique because it contains virulent virus obtained from the scabs of affected animals. Lambs should be vaccinated when around one month of age. A booster may be administered two to three months later. The vaccine is brushed on to scarified, woolless skin at a time and place chosen by the sheep producer. It is commonly administered by a scratch to the inner thigh or foreleg of a lamb. The vaccine may be available in a container with the needle attached and a dye to ensure a successful take. Otherwise the vaccine may simply be brushed over the scratches. Ewes are vaccinated inside the ear or under the tail. The site should be checked 7 to 10 days after vaccination to ensure vaccine "take." If positive, the scratch will be raised and inflamed (Fig. 17.1). It produces an uncomfortable lesion, but after 12 to 14 days the scab falls off, the lesions heal, and the young animal is immune. They should be revaccinated annually. Ewes and does should be vaccinated well ahead of lambing. Animals should not be vaccinated immediately before a show. Vaccinated animals should be segregated from unprotected animals until the scabs have fallen off.

Soremouth is a zoonosis and will cause disease in humans. Vaccinators must therefore wear appropriate protection, including gloves and goggles. Flocks that are free of soremouth must not use this vaccine because it introduces the virus into a flock.

BLUETONGUE

Bluetongue virus (BTV) is a member of the Orbivirus genus in the *Reoviridae* family. Currently the BTV species contains 26 recognized serotypes, including Toggenburg virus (BTV 25) and

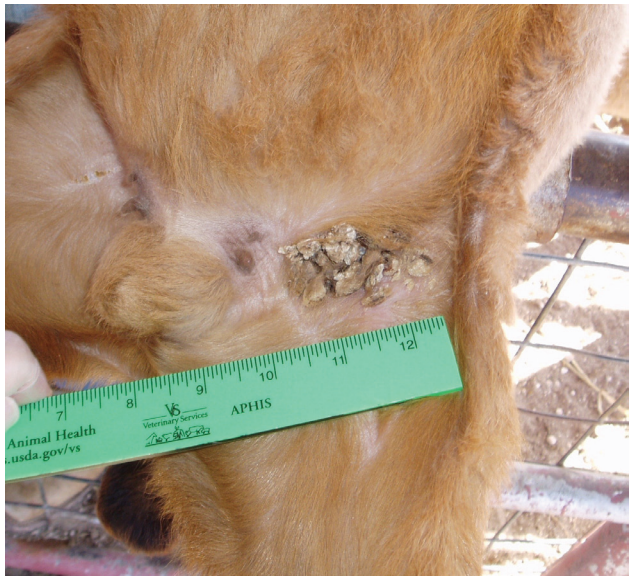

Fig. 17.1 A lesion produced on the inner thigh of a kid as a result of vaccination against soremouth (orf). (Courtesy of Dr. Jeffrey Musser.)

serotype 26 found in Kuwait. Serotypes 1, 2, 11, 13, and 17 are present in the United States. Serotype 8 is present in Northern Europe. It is transmitted by the bite of infected midges (*Culicoides*) and as a result it has a seasonal occurrence.

BTV can infect wild and domestic ruminants including sheep, goats, cattle, buffalo, deer, and antelope. Bluetongue infection is inapparent in most infected animals. Nevertheless, it can result in lethal disease in infected sheep and wild ruminants. BTV usually does not cause clinical disease in cattle except for serotype 8 in Europe.

Vaccination is used to minimize virus spread and allow the safe movement of animals. Both live attenuated and inactivated BTV vaccines are available for use in sheep or sheep and cattle. Studies suggest that they both provide protection for at least a year. Recombinant BTV vaccines have been investigated but none have been licensed.

Viruses for inactivated vaccines are grown in large-scale suspension cell systems under controlled conditions. When the culture reaches its maximum titer the cells are disrupted, the supernatant clarified and filtered. The virus is then inactivated by the addition of binary ethyleneimine or other inactivants. The inactivated virus is then concentrated and stored. Antibodies appear in response to vaccination by seven days but the duration of immunity is unclear.

Live attenuated vaccines have been produced by adapting field isolates to growth in tissue culture or embryonated chicken eggs. These modified live virus-bluetongue virus (MLV-BTV) strains retain the ability to replicate in the vaccinated animal and as a result can stimulate a strong antibody response after a single dose of vaccine. Antibodies appear by 10 days postvaccination, reach a maximum 4 weeks later, and persist for over a year. However, these vaccines, if underattenuated, may also depress milk production in lactating ewes. They also cause abortions and nervous system malformations in lambs especially if ewes were vaccinated during the first half of gestation. MLV-BTVs also cause a viremia and, as a result, may be spread by their vectors to other unvaccinated animals. Transmission of vaccine strains by the *Culicoides* vector midge has been documented in Europe and the United States.

A monovalent tissue culture derived, MLV-BTV type 10 vaccine, is available in the United States. It may be used in goats. A monovalent inactivated BTV-8 vaccine is available in the

United Kingdom and Northern Europe to fight an outbreak of BTV that began in 2006. The vaccine is given to sheep and cattle over 2.5 months of age. Animals require two doses of vaccine, 20 days (sheep) and 31 days (cattle) after the second dose, to develop protective immunity and prevent viremia. Nevertheless, blanket vaccination of cattle, sheep, and goats has brought the disease largely under control although occasional outbreaks continue to occur in France and Germany. Interestingly, cattle still had antibodies six years after receiving the BTV-8 vaccine.

Because many BTV serotypes may be circulating within a geographic area, polyvalent vaccines are often required. Thus in South Africa, 15 serotypes are administered sequentially in three formulations each containing five different serotypes attenuated by passage in embryonated chicken eggs and baby hamster kidney cells. Not all these serotypes induce a strong response so the animals are revaccinated annually.

RABIES

In rabies endemic areas, sheep and goats may be required to be vaccinated against rabies. This should be administered to lambs and kids over three months of age and repeated annually. Sheep grazing public lands and attending livestock shows may also be required to be vaccinated.

Other Vaccines

Q FEVER

Coxiella burnetii causes Q (query) fever in humans and coxiellosis in animals. It is a significant zoonosis. In small ruminants and cattle, it is associated with sporadic abortions, and dead or weak lambs and kids. It may cause infertility in cattle. An inactivated vaccine that contains phase 1 *C. burnetii* (Coxevac vaccine; Ceva) is available in parts of Europe. It is used in goats to prevent abortions and minimize bacterial shedding. The vaccine is given in two doses at least three weeks before breeding. Annual revaccination is required in affected areas.

In 2007, a massive Q fever outbreak occurred in the Netherlands. Many goat farmers used the inactivated *C. burnetii* vaccine. The Dutch government tested bulk milk from these dairy farms for the presence of Coxiella DNA. In 2010, several goat farmers claimed that their milk had tested positive for this DNA despite using the killed vaccine. Analysis showed however that the DNA did indeed originate in the killed vaccine. Thus the vaccine-derived DNA appeared in goat's milk two hours after vaccination and could persist for as long as nine days. It represented more than a million-fold dilution of the vaccine dose—an example of the extreme sensitivity of polymerase chain reaction (PCR) assays. The problem was "solved" by requiring a two-week interval between vaccination and bulk milk testing.

SHEEP AND GOAT POX

These two infections are endemic to northern Africa, the Middle East, and Asia. Some European countries have also experienced outbreaks. They cause skin and lung lesions leading to death in small ruminants. They are related to the poxvirus that causes lumpy skin disease and are collectively designated as capripox viruses. Both live and inactivated vaccines have been developed for these diseases. All strains of capripox, irrespective of their species of origin, share a major neutralizing epitope so that there is cross-protection among all three species. Inactivated vaccines generally give short-term protection. They contain only antigens from the intracellular virus and lack the major antigenic components from the virus envelope. It is important to determine virus strain identity and their degree of attenuation before a product is licensed because the protective dose required for prevention varies between strains. These capripox vaccines provide protection for 12 to 30 months depending on the strain employed.

BRUCELLOSIS

Brucellosis is a significant cause of abortion in sheep and goats. As in cattle, killed vaccines cannot prevent brucellosis in these species. As a result, the attenuated strain of *Brucella melitensis*, Rev.1 is widely used for the prevention of brucellosis in sheep and goats. Rev.1 was generated by the use of streptomycin as a selective agent from a virulent field strain of *B. melitensis*. It is injected subcutaneously or dropped into the conjunctiva of lambs and kids between three and five months of age. Conjunctival vaccination is considered safer than subcutaneous injection. Generally, the entire flock should be vaccinated at one time during the late lambing season or lactation, especially when they are managed under extensive conditions. Attempts to control the disease by vaccinating only young replacement females have been unsuccessful. The immunizing dose is from 0.5 to 2×10^9 viable organisms (cfu). *Brucella melitensis* strain Rev.1 vaccine like *B. abortus* S19, can infect humans so appropriate precautions should be taken against needlestick injury (Chapter 10). It should not be given to pregnant animals because a full standard dose may cause abortion. Reducing the vaccine dose may minimize abortions, but result in unsatisfactory immunity. Also, like S19, it has a smooth lipopolysaccharide that is detected by serologic assays and is thus incompatible with conventional test-and-slaughter programs.

Brucella ovis is a significant cause of epididymitis and infertility in rams. It is associated with abortions and perinatal mortality but its main impact is on males. There is no current vaccine specific for *B. ovis* but vaccination with *B. melitensis* Rev.1 is protective. Unfortunately, this also interferes with surveillance and eradication programs.

In China, *Brucella suis* strain 2 is the preferred attenuated vaccine to prevent ovine and caprine brucellosis. It is administered orally. It retains some virulence when injected parenterally and should not be used in pregnant animals.

CONTAGIOUS AGALACTIA

Caused by *Mycoplasma agalactiae,* this is a significant disease in Africa, Asia, and in the Mediterranean region. In addition to agalactia and mammary lesions, affected animals develop arthritis, conjunctivitis, respiratory disease, and abortion. Both inactivated and modified live vaccines are widely employed to prevent the disease. The major limitation is however strain specificity. Immunity is short so animals must be revaccinated every six months. The inactivated vaccines do not prevent infection but simply reduce disease severity.

LEPTOSPIROSIS

Leptospirosis may be a significant disease affecting some sheep and goat flocks where it can cause abortions, renal damage, and lamb deaths. The primary causes are *Leptospira interrogans* serovar Pomona and *Leptospira borgpetersenii* serovar Hardjo. Currently available combined bacterins provide protection for several months but the duration of immunity is unclear.

PESTE DES PETITS RUMINANTS

Peste des petits ruminants (PPR) is one of the most important and dangerous diseases affecting small ruminants in Africa, the Middle East, and in Central and Southeast Asia. PPR is caused by small ruminant morbillivirus (PPRV) closely related to rinderpest and distemper. (It is also called ovine rinderpest.) PPRVs have been grouped into four genetic lineages. All four lineages occur in Africa while lineage 4 also occurs in Asia. Cross-protection occurs among viruses of all four lineages. In December 2016, the disease reached Mongolia and in June 2018 it reached Bulgaria.

PPRV is highly lethal for goats with up to 100% mortality. It is less lethal for sheep who may be subclinically infected. Not only does PPRV infect sheep and goats, but occasionally also

camels, cattle, and buffalo. It has caused massive mortalities in wild ungulates such as saiga antelope (*Saiga tatarica*). The animals develop a fever with the development of vesicular lesions on the oral mucosa, ocular and nasal discharge, leukopenia, diarrhea, and dyspnea. Death occurs as a result of bronchopneumonia, diarrhea, and dehydration. PPRV causes profound immunosuppression so affected animals may also die as a result of secondary bacterial and mycoplasma infections.

In 1989, an attenuated PPRV vaccine was developed by serial passage of a Nigerian strain in Vero cells. This vaccine was highly successful. Vaccinated sheep and goats were protected and the vaccine virus was not transmitted to contact animals. Subsequently attenuated vaccines against Indian goat and sheep strains have been developed using a similar technique and have also proved highly effective. These vaccines protect animals for at least four years.

One problem with live attenuated vaccines used in the tropics is maintaining the cold chain. Live attenuated PPRV strains are thermolabile, but have a shelf life of around one year at 4°C. Many efforts have been made to improve freeze-drying techniques and develop new stabilizers. Likewise, extensive efforts have been made to develop recombinant vectored vaccines involving capripox, fowlpox, or adenoviruses as vectors (Chapter 5). Some recombinant PPRV vaccines may therefore also protect against goat and sheep pox.

The major limitation of currently available vaccines is the absence of a DIVA capability that would enable vaccinated animals to be differentiated from naturally infected animals.

The global eradication of the related morbillivirus, rinderpest has had an interesting consequence in that PPR is spreading throughout Africa south of the Sahara and also the Middle East, Morocco, China, and Bhutan. Likewise, the Asian genotype 4 has now become established in the Sudan. A plan to globally eradicate PPR by 2030 was initiated by the World Organization for Animal Health (OIE) and Food and Agriculture Organization (FAO) in 2015. The virus has an estimated R_0 of 4.0 to 6.9 and the herd immunity threshold is 75% to 86%. Mass vaccination campaigns seek a minimum of 70% coverage.

PRODUCTION ENHANCING VACCINES

Sheep immunized with polyandroalbumin (androstenedione-7-carboxyethyl thioester linked to human serum albumin) produce about 23% more lambs than untreated sheep. These vaccines are marketed under the names Androvax, Fecundin, and Ovastim. Ewes are given two doses of this vaccine before mating. It is believed that the vaccine induces autoantibodies that reduce serum androstenedione levels. This temporarily blocks ovulation so that when the effect wears off, the ewe responds by producing more mature ova. Therefore if bred at this time the number of multiple births will be increased. The vaccine is used in young healthy ewes of breeds that can feed the increased number of lambs. Ewes that are in poor condition may not benefit from this vaccine. Adequate nutrition, parasite control, and shelter must be provided to take advantage of this increased productivity. The priming dose is given six to nine weeks before mating and the booster three to four weeks before breeding. A minimum of three weeks should elapse between boosting and breeding. Vaccinated ewes may be revaccinated annually three to four weeks before mating.

Adverse Events

In sheep, pulmonary signs predominate in anaphylaxis as a result of constriction of the bronchi and pulmonary vessels. Smooth muscle contraction also occurs in the bladder and intestine with predictable results. The major mediators of type I hypersensitivity in sheep are histamine, serotonin, leukotrienes, and kinins. Clostridial vaccines do tend to induce adverse reactions ranging from local swelling and stiffness to fever, pulmonary edema, abortion, and bloating. Aluminum adjuvants may cause injection site granulomas.

Related Species

GOATS

The most important "core" vaccine that should be used in goats is CD-T, the combined vaccine for *Clostridium perfringens* types C and D, plus tetanus. Pregnant does should receive the vaccine 30 days before birth. Kids should be vaccinated at five to six weeks of age, given a booster three to four weeks later, and boosted annually. It has been suggested that the duration of immunity against clostridia in goats is shorter than that in sheep so allowance may have to be made for this. Rabies vaccination should be considered in rabies endemic areas. Optional goat vaccines may include, caseous lymphadenitis, soremouth, rabies, footrot, Chlamydia, Leptospirosis, *Mannheimia haemolytica,* and *Pasteurella multocida*. As always, it is essential to keep a record of vaccinations given.

LLAMAS AND OTHER CAMELIDS

All vaccines used in llamas and related species have to be used in an extra-label fashion having been specifically developed primarily in cattle and small ruminants. Thus if a veterinarian uses a vaccine in a species not specified on the label or on the insert, then they assume full responsibility for product failure or any adverse consequences. A product licensed for use in another species may be used if there is a demonstrated need for it and if there is reasonable evidence that it can be expected to be efficacious.

As with sheep and goats, the most important llama vaccine is the triple clostridial vaccine CD-T. Although developed for small ruminants it would almost certainly be effective in llamas and alpacas. A typical vaccination schedule for llamas is similar to that described in goats above. Other optional llama vaccines may include other Clostridial vaccines, West Nile Virus, leptospirosis, rabies, and coronavirus.

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Abstract: The relatively low economic value of small ruminants places constraints upon vaccination in these species. In general, vaccination against clostridial diseases such as enterotoxemia and tetanus are most important. Enzootic pneumonia is a major cause of losses in intensively housed sheep. Footrot is a difficult disease to control because of the extreme antigenic diversity of its causal agent. In some areas soremouth vaccination is important. Bluetongue vaccination, even though complex, is also essential in some areas. Peste de petits ruminants is a growing cause for concern over much of Africa. Goats and llamas generally require the same vaccines as sheep.

Keywords: Enterotoxemia, Clostridia, bluetongue, footrot, soremouth, bacterial pneumonia, Peste de petits ruminants, goats, llamas.