

Diagnoses of Primary Cause of Mortality in Domestic Sheep in the North American Intermountain West

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Abstract

Causes of death of 246 domestic sheep (*Ovis aries*) necropsied from 2009-2016 at the Utah Veterinary Diagnostic Laboratory were summarized. Sheep originated from Utah (93%), Idaho (6%) or Wyoming (0.4%). There were 54 fetuses, 21 4 week lambs (1-28 d old), 69 young lambs (29-180 d), 28 older lambs (181-365 d), and 74 adult sheep (>365 d). If no age was provided, age was estimated from body weight based on literature and expert opinion. Of the 45% of sheep with age provided, 90% matched with the body weight estimates. Primary cause of mortality was diagnosed in 228 cases (93%); 6 diseases accounted for 136 (60%) of the diagnoses: abortion 50 (22%), parasitism 29 (13%) (most from *H. contortus*), pneumonia 19 (8%) (95% bacterial), enteritis/enterotoxemia 17 (7%), bloat 13 (6%), and selenium deficiency 8 (4%). No cause of death was evident in 18 sheep (7%). The most common cause of fetal death was abortion 50 (93%). In 4 week lambs, most common causes were 4 pneumonia (19%), and 3 parasitism (14%). In young lambs, 15 parasitism (22%) (10 *Haemonchus contortus*), and 10 pneumonia (15%) (9 bacterial pneumonia) predominated. In older lambs, 7 parasitism (25%) (4 *H. contortus*, 3 *Fasciola hepatica*), 3 bacterial pneumonia (11%) and 3 clostridial enterotoxemia (11%) were most common. Most common causes of adult sheep death were 5 bloat (7%), 4 *H. contortus* (5%), 4 peritonitis (5%), 4 bacterial pneumonia (5%), and 4 urolithiasis (5%), a cause of death only found in adult sheep. Control measures for the most common causes of domestic sheep mortality include vaccination and clean lambing environment to reduce abortions, enterotoxemia and other infectious disease, control of parasite infestation, prevention and treatment of pneumonia and bloat, and adequate mineral supplementation.

Keywords: Sheep; Mortality; Pathology; Pathogens

Introduction

The Intermountain West region (Utah, Idaho, and Nevada, sometimes defined as including western Wyoming, northern Arizona, western Colorado, and northwestern New Mexico) has the greatest proportion of the 5.2 million domestic sheep in the United States [1]. Utah is the fifth-ranked state (275,000 sheep, 5.3%) and Idaho is seventh (250,000, 4.8%) [1]. According to data from 2012 (most recent data available) there were 1,755 sheep farms in Utah and 1,241 in Idaho [2]. Sheep are produced primarily for meat and secondarily for wool. Sheep industry sales totaled approximately \$360 million in the U.S. during 2016 [3]. The objective of this descriptive study was to identify and summarize the causes of mortality as diagnosed from postmortem examination of 246 sheep from the Intermountain West over a 7-year period.

Materials and Methods

Domestic sheep included in this descriptive case series were necropsied from January 2009 through April 2016 at the Utah Veterinary Diagnostic Laboratory (UVDL). Sheep submitted with advanced postmortem degradation were disposed of rather than necropsied. No age was provided for more than half of the necropsied sheep. Therefore, except for fetuses, age was estimated from body weight based on the literature and expert opinion. Definitions of age categories and body weights for each category other than fetuses: 4 week lamb 1-28 d old, <8 kg; young lamb 29-180 d old, 8-35 kg; older lamb 181-365 d old, 35.1 - 54 kg; adult >365 d, >54 kg.

Specimen collection

Tissues and fluids routinely collected differed among fetuses and other age groups. From all fetuses, samples of liver, lung, kidney, spleen and abomasal fluid were collected and stored at -20°C. Also from all

fetuses, lung, rumen, abomasum, liver, heart, kidney, spleen, thymus, adrenal glands, thyroid, brain and placenta (if submitted) were collected and placed in 10% neutral buffered formalin (NBF).

From all adults, samples of liver, lung, kidney, and spleen were collected and stored at -20°C. Samples of esophagus, trachea, lung, rumen, reticulum, omasum, abomasum, intestine (multiple levels), pancreas, liver, heart, kidney, skeletal muscle, urinary bladder, reproductive organs (ovaries, uterus, testes), lymph node, spleen, thymus (juveniles), adrenal glands, thyroid, and brain were collected and placed in NBF. Collection of additional tissues and/or organs depended on reported clinical signs and gross findings at postmortem examination. After fixation, tissues were subsampled, processed, sectioned, and stained by routine methods. Tissues stained with hematoxylin and eosin were examined microscopically. Special stained replicate sections, including tissue Gram stains, periodic acid-Schiff, and Masson's trichrome, were prepared and examined on a case-by-case basis.

Ancillary tests

Bacterial isolation was done by sampling tissues or body fluids and

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plating directly on trypticase soy agar with 5% sheep blood, chocolate blood agar, Columbia nutrient agar, and MacConkey agar (all agars from Hardy Diagnostics, Santa Maria, CA). Resulting colonies were identified to genus level using either API (bioMérieux Inc., Durham, NC) or BBL Crystal (Becton Dickinson and Co., Franklin Lakes, NJ) test kits. Parasitism was detected by fecal flotation and identification of oocytes; direct visualization of gastrointestinal parasites occurred occasionally (e.g., large numbers of grossly visible *H. contortus*). Copper and selenium were quantified using inductively coupled plasma-mass spectroscopy. Vitamin E testing was performed at the California Animal Health and Food Safety Laboratory System (Davis, California).

Determination of cause of death

Cause of death was established based on reported clinical signs, pathology, and results of ancillary tests. Where multiple diseases or conditions were diagnosed, death was attributed to the disease that caused the most pathology in critical organs and/or tissues.

Electronic capture of data

All diagnostic findings were entered into a laboratory information management system (Vetstar animal disease diagnostic system [VADDS], Advanced Technology Corp., Ramsey, NJ). The system recorded owner and animal data, postmortem examination and laboratory test results, and allowed for the composition of text to summarize case findings. Data was summarized by review of diagnostic reports and entered into data fields using a commercial spreadsheet (Excel, Microsoft Corp., Redmond, WA). The following data fields were populated: accession number, state of origin, age (estimated from body weight if not provided), weight, breed, sex, diagnosis of cause of death, and agent isolated (where applicable). Totals by category were calculated.

Results

Postmortem examinations were performed on 246 domestic sheep during the 7-year period of study. Sheep were presented in groups of 1 to 7 animals with a mean of 1.2 animals per submission (there were 209 submissions). The sheep originated from farming operations or range flocks in Utah-229 sheep (93%) from 199 submissions, Idaho-16 sheep (6%) from 9 submissions, or Wyoming-1 sheep (0.4%) from one submission. No age was provided for 135 (55%) of necropsied sheep. Of the 111 (45%) sheep with an age provided, 100 (90%) matched with the body weight-based estimates. The breed of most sheep was not reported and could not be determined (174, 71%), unless the sheep was a Suffolk because of that breed's distinctive appearance. Breeds identified were: Suffolk 45 (18%), Rambouillet 9 (4%), Hampshire 3 (1%), other breeds (1-2 sheep per breed) 15 (6%).

Descriptive data by age group

There were 54 fetuses, 21 4 week lambs, 69 young lambs, 28 older

lambs, and 74 adult sheep. Descriptive data are shown in Table 1.

Overall causes of sheep mortality

Diagnosis of primary cause of mortality was made in 228 cases (93%); no cause of death was evident in 18 sheep (7%). Of the 228 sheep where cause of death were established, 6 diseases accounted for 136 (60%) of the diagnoses: abortion 50 (22%), parasitism 29 (13%) (66% of parasitism deaths were from *H. contortus*), pneumonia 19 (8%) (95% were bacterial pneumonia), enteritis/enterotoxemia 17 (7%), bloat 13 (6%), and selenium deficiency 8 (4%). Diagnoses of primary cause of death for all sheep are provided in Table 2. Approximately two-thirds of deaths with a diagnosis (145, 64%) were attributed to infectious disease, while the remaining one-third (83, 36%) were noninfectious (Table 2).

Causes of mortality in fetuses

Of 54 fetuses submitted for necropsy, abortion (50 cases, 93%) was the most common cause of death, and 4 (7%) died from dystocia (Table 3). Bacterial abortion (other than chlamydial) was the most common cause among abortions, with 29 (54%) cases. In 21 of those cases, bacteria were observed histopathologically, but microbiology was not performed. For 8 cases, a specific bacterial cause was determined: 3 *Campylobacter jejuni*, 2 *Campylobacter fetus*, 1 *Escherichia coli*, 1 *Streptococcus sanguinius*, and 1 *Streptococcus dysgalactiae*. There were 12 (22%) idiopathic abortions, including 1 mummified fetus. The third most common cause of fetal death was abortion caused by *Chlamydia abortus* (8 cases, 15%) and there was 1 case (2%) of nutritional myopathy from selenium deficiency.

Causes of mortality in 4 week lambs

Diagnoses of cause of mortality for 4 week lambs (n=21) are shown in Table 4. The most common cause was pneumonia, with 4 cases (19%), 2 caused by *Mannheimia haemolytica*, and 2 by aspiration. Three lambs (14%) died from parasitism (coccidiosis, cryptosporidiosis and haemonchosis), and 3 cases (14%) had no diagnosis. Dystocia (2 cases, 10%) was the next most common cause of death. There were 9 other diseases (43%) with a single case of each: bacterial enteritis, esophagitis with rumenitis, omphalophlebitis, polioencephalomalacia, pulmonary congestion with edema, renal failure, rumenitis, selenium deficiency, and spider lamb syndrome (hereditary chondrodysplasia, including disproportionately long, spider like legs, and spinal curvature, often with other deformities) [4].

Causes of mortality in young lambs

Of 69 young lambs necropsied, 15 (22%) died from parasitism (67% *H. contortus*) and 10 (15%) from pneumonia (90% bacterial) (Table 5). Specific causes of pneumonia were 3 *M. haemolytica*, 2 *Pseudomonas aeruginosa*, 2 diagnosed as bacterial in origin but with no pathogens isolated at culture, 1 *Pasteurella multocida*, 1 *Bibersteinia trehalosi*, and

Table 1: Sex, age and weight data for 246 sheep necropsied from 2009-2016.

Age Group	No.	M	F	Sex NR [‡]	Age Mean	Age Median	Age Range	Weight Mean [£]	Weight Median	Weight Range
Fetus	54	29	11	14	NA [‡]	NA	NA	3.2	3.2	0.3-7.3
4 Week Lamb	21	9	9	3	12 d	10 d	1-28 d	5.7	5.3	3.2-11.0
Young Lamb	69	35	32	2	121 d	120 d	32-180 d	22.0	20.5	8.6-42.5
Older Lamb	28	15	11	2	309 d	333 d	210-365 d	45.4	46.7	33.4-58.1
Adult	74	51	23	0	3.6 yr	3 yr	1-13 yr	80.3	75.7	33.0-150.0

‡: Sex not reported; £: Body weights in kg; †: Not applicable

Table 2: Diagnoses of cause of death in 246 domestic sheep.

Disease or condition	No. affected*
Abortion	50 (20.3)
Parasitism	29 (11.8)
Pneumonia	19 (7.7)
No diagnosis	18 (7.3)
Enteritis/enterotoxemia	17 (6.9)
Bloat	13 (5.3)
Selenium deficiency	8 (3.3)
Peritonitis	7 (2.8)
Dystocia	6 (2.4)
Polioencephalomalacia	5 (2.0)
Lymphoma/Lymphosarcoma	4 (1.6)
Pulmonary edema	4 (1.6)
Septicemia	4 (1.6)
Urolithiasis	4 (1.6)
Copper toxicity	3 (1.2)
Mastitis	3 (1.2)
Metritis	3 (1.2)
Abomasal impaction	2 (0.8)
Abomasitis	2 (0.8)
Copper deficiency	2 (0.8)
Emaciation	2 (0.8)
Encephalitis (listeriosis)	2 (0.8)
Myocarditis	2 (0.8)
Neonatal atelectasis	2 (0.8)
Omphalophlebitis	2 (0.8)
Plant toxicosis	2 (0.8)
Pregnancy toxemia	2 (0.8)
Pulmonary abscesses	2 (0.8)
Rumen acidosis	2 (0.8)
Rumenitis	2 (0.8)
Acidophil adenoma	1 (0.4)
Ascites	1 (0.4)
Cecal and colonic impaction	1 (0.4)
Esophageal choke	1 (0.4)
Esophagitis	1 (0.4)
Hepatotoxicity	1 (0.4)
Hypomyelinogenesis	1 (0.4)
Jejunal entrapment and infarction (post-surgical)	1 (0.4)
Meningitis	1 (0.4)
Myocardial degeneration	1 (0.4)
Myodegeneration	1 (0.4)
Pancreatitis	1 (0.4)
Paravertebral abscess	1 (0.4)
Pleuritis/pericarditis	1 (0.4)
Pyelonephritis	1 (0.4)
Pyrrrolizidine alkaloid toxicity	1 (0.4)
Rectal perforation	1 (0.4)
Renal failure	1 (0.4)
Retained placenta and metritis	1 (0.4)
Spider lamb syndrome	1 (0.4)
Starvation, hypothermia	1 (0.4)
Trauma (subdural hematoma)	1 (0.4)
Urethral squamous metaplasia	1 (0.4)
Total	246 (100)

*Numbers in parentheses are percentages

Table 3: Causes of death in 54 fetal sheep.

Disease or condition	No. affected*
Abortion, bacterial (other than chlamydial)	29 (53.7)
Abortion, idiopathic (1 mummified)	12 (22.2)
Abortion, chlamydial	8 (14.8)
Dystocia (3 with fluid and meconium in lungs)	4 (7.4)
Abortion, nutritional myopathy	1 (1.9)

*Numbers in parentheses are percentages

Table 4: Causes of death in 21 four week lambs (1-28 d old).

Disease or condition	No. affected*
Pneumonia (2 <i>M. haemolytica</i> , 2 aspiration)	4 (19.0)
Parasitism	3 (14.3)
No diagnosis	3 (14.3)
Dystocia (born alive, died soon after)	2 (9.5)
Other (9 diseases, a single case of each; see text)	9 (42.9)

*Numbers in parentheses are percentages

Table 5: Causes of death in 69 young lambs (29 - 180 d old).

Disease or condition	No. affected*
Parasitism (10 <i>H. contortus</i>)	15 (21.7)
Pneumonia (9 bacterial, 1 aspiration)	10 (14.5)
Enteritis	7 (10.1)
Bloat (5 frothy)	6 (8.7)
Peritonitis (all with perforated abomasal ulcers)	3 (4.3)
Selenium deficiency	3 (4.3)
Septicemia (castration, tail dock, unknown origin)	3 (4.3)
No diagnosis	3 (4.3)
Abomasitis	2 (2.9)
Clostridial enterotoxemia	2 (2.9)
Polioencephalomalacia	2 (2.9)
Other (13 diseases, a single case of each; see text)	13 (18.8)

*Numbers in parentheses are percentages

1 aspiration. Next most common causes of death were 7 enteritis cases (10%) and 6 bloat (9%) (83% frothy bloat). There were 3 (4%) cases of peritonitis secondary to perforated abomasal ulcers, 3 (4%) cases of selenium deficiency, 3 (4%) cases of septicemia including 2 that were sequelae of surgery, and 3 cases (4%) with no diagnosis. Other causes of death included 2 abomasitis (3%), 2 clostridial enterotoxemia (3%), and 2 polioencephalomalacia (3%). There were 13 other diseases (19%) with a single case of each: ascites, copper deficiency, encephalitis (listeriosis), hypomyelinogenesis, myocarditis, myodegeneration, omphalophlebitis, paravertebral abscess, pericarditis, pulmonary abscesses, rumenitis, suppurative meningitis and urethral squamous metaplasia.

Causes of mortality in older lambs

The most common causes of mortality for older lambs (n=28) were 7 cases of parasitism (25%; 57% *H. contortus*, 43% *F. hepatica*), bacterial pneumonia 3 (11%), and clostridial enterotoxemia 3 (11%) (Table 6). Specific causes of pneumonia were *P. multocida*, *Streptococcus bovis* and aspiration, and *Trueperella pyogenes*. Next most common were 2 cases (7%) of frothy bloat, 2 (7%) of plant toxicosis, 2 (7%) of selenium deficiency, and 2 cases (7%) had no diagnosis. Other causes of death included single cases of 7 (25%) diseases: copper toxicity, enteritis, jejunal entrapment and infarction (post-surgical), lymphosarcoma

Table 6: Causes of death in 28 older lambs (181 - 365 d old).

Disease or condition	No. affected*
Parasitism (4 <i>H. contortus</i> , 3 <i>F. hepatica</i>)	7 (25.0)
Pneumonia (all bacterial)	3 (10.7)
Clostridial enterotoxemia	3 (10.7)
Bloat, frothy	2 (7.1)
Plant toxicosis	2 (7.1)
Selenium deficiency	2 (7.1)
No diagnosis	2 (7.1)
Other (7 diseases, a single case of each; see text)	7 (25.0)

*Numbers in parentheses are percentages

Table 7: Principal causes of death in 74 adult (1-13 yr old) sheep.

Disease or condition	No. affected*
No diagnosis	10 (13.5)
Bloat (3 gas, 1 abomasal, 1 frothy)	5 (6.8)
Parasitism (all <i>H. contortus</i>)	4 (5.4)
Peritonitis (1 post-surgical dehiscence)	4 (5.4)
Pneumonia (all bacterial)	4 (5.4)
Urolithiasis	4 (5.4)
Clostridial enterotoxemia	3 (4.1)
Mastitis	3 (4.1)
Metritis	3 (4.1)
Pulmonary edema	3 (4.1)
Abomasal impaction	2 (2.7)
Copper toxicity	2 (2.7)
Emaciation	2 (2.7)
Lymphosarcoma	2 (2.7)
Polioencephalomalacia	2 (2.7)
Selenium deficiency	2 (2.7)
Other (19 diseases, a single case of each; see text)	19 (25.7)

*Numbers in parentheses are percentages

with spinal cord involvement, pregnancy toxemia, retained placenta with metritis, and rumen acidosis.

Causes of mortality in adult sheep

Of 74 adult sheep necropsied, the most common causes of death were 5 (7%) bloat cases, 4 (5%) *H. contortus* infestation, 4 (5%) peritonitis, 4 (5%) bacterial pneumonia, and 4 (5%) urolithiasis, a cause of death only found in adult sheep (Table 7). Specific causes of pneumonia were *M. haemolytica*, *P. multocida*, and *T. pyogenes* (the remaining case was not cultured due to tissue autolysis). Next most common causes of death were 3 (4%) clostridial enterotoxemia, 3 (4%) mastitis which only caused death in adult sheep, 3 (4%) metritis, 3 (4%) pulmonary edema, 2 (3%) abomasal impaction, 2 (3%) copper toxicity, 2 (3%) emaciation (no clear underlying cause), 2 (3%) lymphosarcoma, 2 (3%) polioencephalomalacia and 2 (3%) selenium deficiency. There were 19 other diseases (26%) with a single case of each: pituitary (acidophil) adenoma, cecal and colonic impaction, copper deficiency, encephalitis (listeriosis), esophageal choke, hepatotoxicity, lymphoma (tracheal pressure at thoracic inlet), myocardial degeneration, myocarditis, pancreatitis, pregnancy toxemia, pulmonary abscesses, pyelonephritis, pyrrolizidine alkaloid toxicity, rectal perforation, rumen acidosis, septicemia, starvation, and trauma with subdural hematoma. Ten (14%) adult sheep had no diagnosis of cause of death.

Discussion

As expected, most common causes of mortality observed in domestic sheep varied with age. In fetuses, over 90% of deaths were abortions and bacterial infection was detected in more than half of these, most commonly *Chlamydia abortus* followed by *Campylobacter jejuni* and *Campylobacter fetus* when a specific pathogen was identified. However, most abortions where bacteria were observed histologically were not cultured because despite being in sufficient preservation for necropsy, bacterial overgrowth or contamination was considered likely because of the condition of the tissues. These agents reported here have often been described in this order as the most common causes of ovine abortion worldwide, including the U.S., even though most of the data comes from the United Kingdom or elsewhere [5,6]. No summary reports of diagnostic results of causes of ovine abortion in the U.S. have been published for over 20 years, when *C. fetus* was isolated more frequently than *C. jejuni* and *C. abortus* [7]. No diagnosis could be made in one-fifth of the fetuses in the present study, including one that was mummified, while in the 1993 report, 56% of abortions, 6% of which were mummified, could not be diagnosed [7]. Other results in this report are similar to the 1993 findings.

A variety of parasitic, infectious, and metabolic diseases caused death in lambs during the first month of life. Spider lamb syndrome and parasitism have been previously described [4,8], but there are no refereed publications summarizing causes of lamb deaths during the first month of life in North America.

Lambs from 1 to 6 months old died primarily from *H. contortus* infestation, bacterial pneumonia, enteritis, and frothy bloat. These diseases have been reported as major causes of sheep losses, but not specifically by age [9-12].

Six-months to 1-year-old lambs died of similar causes to the above age group, but nearly half of the deaths from parasites were attributed to liver flukes (*F. hepatica*). The pre-patent period for this parasite is at least 3 months, which partly accounts for why it was not observed at necropsy in younger animals. Fascioliasis is recognized as an important cause of sheep mortality and its prevalence is increasing in many parts of the world in association with warmer temperatures [12,13].

Adult sheep exhibited the greatest variety of fatal diseases. Some were similar to those that killed younger sheep such as parasitism, pneumonia and bloat. However, causes of adult mortality also included obstructive urolithiasis, mastitis, metritis, neoplasia and trauma. Urolithiasis, mastitis, and metritis are recognized as important and common diseases in sheep, including as causes of mortality [6,14,15]. One sheep had a pituitary acidophil adenoma while another had pancreatitis. The only previous report of acidophil adenoma in a sheep was in an adult ewe being treated experimentally with reproductive hormones [16]. Pancreatitis was reported at necropsy of sheep in 1960 and suggested to be associated with chronic copper toxicity, but the mechanism or origin of pancreatitis in sheep was not definitively identified [17].

This observational study is a report of diagnoses of mortality in domestic sheep from a partly state-funded laboratory. A potential limitation of the study is that in a diagnostic service for clientele, primarily livestock owners or submitting veterinarians, this setting does not always allow for complete, exhaustive diagnostic procedures. Financial considerations often preclude additional testing (e.g., PCR, virus isolation, toxicological testing, etc.) outside of routine necropsy procedures. Nevertheless, these results reflect diagnoses of the main

causes of death in farmed or range flock sheep presented for necropsy from the Intermountain West region of the U.S.

Control measures for the most common causes of domestic sheep mortality include vaccination and clean lambing environment to reduce infectious abortions and enterotoxemia, control of parasite infestation including *H. contortus* and *F. hepatica*, prevention and treatment of bloat, pneumonia, mastitis and metritis, and adequate mineral supplementation, particularly copper and selenium levels and prevention of urolithiasis [18].

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